



PHYSICS

NUMERICAL PROBLEMS & SOLUTIONS

PART 1

An initiative by
**ASSOCIATION OF PHYSICS TEACHERS
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Chapter 1

ELECTRIC CHARGES AND FIELDS

1. The number of electrons are present in 1 C of electric charge is

- a. 6.25×10^{-20} b. 6.25×10^{18} c. 6.225×10^{-18}
d. 6.25×10^{20}

Solution:

$$Q = ne$$

$$n = \frac{Q}{e} = \frac{1}{1.6 \times 10^{-19}} = 6.25^{18}$$

2. A polythene piece rubbed with wool is found to have a negative charge of $32 \times 10^{-17} \text{C}$. Estimate the number of electrons transferred from wool to polythene.

Solution:

$$n = \frac{Q}{e} = \frac{-32 \times 10^{-17}}{1.6 \times 10^{-19}} = 2000$$

3. What are the nature and the magnitude of the force between a proton and an electron separated by 0.8fermi.

Solution:

$$q_1 = q_2 = 1.6 \times 10^{-19} \text{C}$$

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \quad r = 0.8 \text{ fermi} = 0.8 \times 10^{-15} \text{m}$$

$$= 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{(0.8 \times 10^{-15})^2} = 360 \text{N}$$

4. How many electrons make a charge of 3.2C

Solution:

$$Q = ne \quad Q = 3.2 \text{C}$$

$$n = \frac{Q}{e}$$

$$= \frac{3.2}{1.6 \times 10^{-19}} = 2 \times 10^{19}$$

5. A body has 10^7 extra electrons .Find the total charge on it

Solution:

$$Q = ne \quad n = 10^7$$

$$Q = 10^7 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-12} \text{C}$$

6. Two identical spheres have charge of +6e and -2e. They are brought into contact and then separated, What will be the final charge on each sphere

Solution:

$$Q_1 = +6e \quad Q_2 = -2e$$

$$\text{Total charge} = +6e - 2e = +4e$$

Since spheres are identical total charge will be equally distributed

$$\text{Final charge on each sphere} = \frac{+4e}{2} = +2e$$

7. Two charges of -1C and 2C are 3m apart. Find the force between them

Solution:

$$q_1 = -1\text{C} \quad q_2 = 2\text{C} \quad r = 3\text{m}$$

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{1 \times 2}{3^2}$$

$$= 9 \times 10^9 \times \frac{1 \times 2}{3^2}$$

$$= 2 \times 10^9 \text{ N attractive in nature}$$

8. A point charge of $-8\mu\text{C}$ is placed at the origin. Find the electric field at a point 2m away from the charge

Solution:

$$Q = -8\mu\text{C} \quad r = 2\text{m}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

$$= 9 \times 10^9 \times \frac{8 \times 10^{-6}}{2^2}$$

$$= 18 \times 10^3 \text{ NC}^{-1}, \text{ towards the charge}$$

9. A dipole is placed in a uniform electric field at an angle θ . The torque acting on it is $3 \times 10^{-4} \text{ Nm}$ and the electric field is $6 \times 10^4 \text{ NC}^{-1}$. Find the angle if the dipole moment is $10 \times 10^{-9} \text{ Cm}$.

Solution:

$$\tau = 3 \times 10^{-4} \text{ Nm} \quad E = 6 \times 10^4 \text{ NC}^{-1} \quad p = 10 \times 10^{-9} \text{ Cm}.$$

$$\tau = pE \sin \theta$$

$$3 \times 10^{-4} = 10 \times 10^{-9} \times 6 \times 10^4 \times \sin \theta$$

$$\text{or, } \sin \theta = \frac{1}{2} \text{ or, } \theta = 30^\circ$$

10. An electric dipole is formed by $+5 \times 10^{-6} \text{ C}$ and $-5 \times 10^{-6} \text{ C}$ charges at 4 mm apart. What is the strength of electric dipole and give it direction.

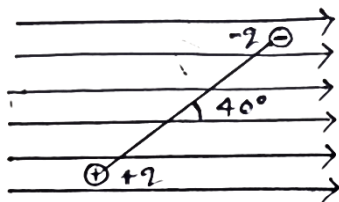
Solution:

$$\text{Electric dipole moment, } p = q2a$$

$$= 5 \times 10^{-6} \times 4 \times 10^{-3}$$

$$= 2 \times 10^{-8} \text{ Cm, direction is from negative charge to positive charge}$$

11. Figure shows an electric dipole situated in a uniform electric field of 10^4 N/C . The strength of the dipole is $p = 1.8 \times 10^{-19} \text{ Cm}$, what is the value of torque acting on the dipole.



Solution:

$$\tau = pE \sin \theta$$

$$= 1.8 \times 10^{-19} \times 10^4 \times \sin 140$$

(The angle between p and E is $180 - 40 = 140$,
Since the direction of dipole moment is from -q to +q)

$$= 1.16 \times 10^{-15} \text{ Nm.}$$

12. A uniformly charged conducting shell has a total charge of $5 \mu\text{C}$ and radius 0.1m .What is the electric field

(i) at a point 0.2m from the centre

(ii) on the surface of the shell

(iii) inside the shell

Solution:

$$(i) E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{5 \times 10^{-6}}{0.2^2}$$

$$= 1125 \times 10^{-6} \text{ NC}^{-1} \text{ outwards}$$

$$(ii) E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

$$= \frac{1}{4\pi\epsilon_0} \frac{5 \times 10^{-6}}{0.1^2}$$

$$= 4500 \times 10^{-6} \text{ NC}^{-1} \text{ outwards}$$

(iii) $E=0$

13. A long straight wire has a linear charge density $2 \times 10^{-6} \text{ C m}^{-1}$. Calculate the electric field 50 cm away

from the wire

Solution:

$$E = \frac{1}{2\pi\epsilon_0} \frac{\lambda}{r}$$

$$= \frac{1}{2\pi\epsilon_0} \frac{2 \times 10^{-6}}{0.5} = 7.19 \times 10^4 \text{ NC}^{-1}$$

14. A body has 10^8 protons and 10^7 electrons, What is the net charge

Solution:

$$\text{Charge of } 10^8 \text{ protons} = +10^8 \times 1.6 \times 10^{-19}$$

$$= +1.6 \times 10^{-11} \text{ C}$$

$$\text{Charge of } 10^7 \text{ electrons} = -10^7 \times 1.6 \times 10^{-19}$$

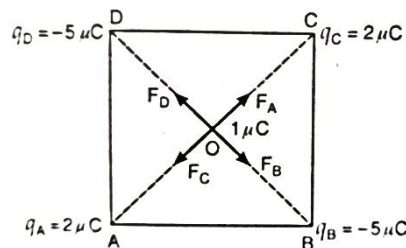
$$= -1.6 \times 10^{-12} \text{ C}$$

$$\text{Net charge} = (+1.6 \times 10^{-11} \text{ C}) + (-1.6 \times 10^{-12} \text{ C})$$

$$= +1.44 \times 10^{-11} \text{ C}$$

15. Four point charges $q_A = 2 \mu\text{C}$, $q_B = -5 \mu\text{C}$, $q_C = 2 \mu\text{C}$ and $q_D = -5 \mu\text{C}$ are located at the corners of a square ABCD of side 10 cm . What is the force on charge $q_0 = 1 \mu\text{C}$ placed at the centre of the square.

Solution:



$$\vec{F} = \vec{F}_A + \vec{F}_C + \vec{F}_D + \vec{F}_B$$

$$F_A = \frac{1}{4\pi\epsilon_0} \frac{q_A q_O}{\sqrt{50}^2} = 9 \times 10^9 \times \frac{2 \times 10^{-6} \times 1 \times 10^{-6}}{50} = 3.6 \times 10^{-4}$$

N along $\vec{OC}$

$$F_C = \frac{1}{4\pi\epsilon_0} \frac{q_C q_O}{\sqrt{50}^2} = 9 \times 10^9 \times \frac{2 \times 10^{-6} \times 1 \times 10^{-6}}{50} = 3.6 \times 10^{-4}$$

N along $\vec{OA}$

$$F_D = \frac{1}{4\pi\epsilon_0} \frac{q_D q_O}{\sqrt{50}^2} = 9 \times 10^9 \times \frac{-5 \times 10^{-6} \times 1 \times 10^{-6}}{50} = -9 \times 10^{-4} \text{ N along } \overrightarrow{OD}$$

$$F_B = \frac{1}{4\pi\epsilon_0} \frac{q_B q_O}{\sqrt{50}^2} = 9 \times 10^9 \times \frac{-5 \times 10^{-6} \times 1 \times 10^{-6}}{50} = -9 \times 10^{-4} \text{ N along } \overrightarrow{OB}$$

The pairs, $\overrightarrow{OA}$ and $\overrightarrow{OC}$, $\overrightarrow{OD}$ and $\overrightarrow{OB}$ are opposite directions. Hence net $F = 0N$

16. Two charges exert a force of .36N on each other when 0.3m apart .What will be the force if the distance is reduce to 0.1m

Solution:

$$r_1 = 0.3m \quad r_2 = 0.1m \quad F_1 = 0.36N \quad F_2 = ?$$

$$\frac{F_1}{F_2} \propto \frac{\frac{1}{r_1^2}}{\frac{1}{r_2^2}}$$

$$\frac{F_1}{F_2} = \frac{r_2^2}{r_1^2} = \frac{0.01}{0.09}$$

$$\frac{F_2}{F_1} = 9$$

$$F_2 = 9F_1 = 3.24N$$

17. Three charges are placed as follows

$$q_1 = 2\mu C \text{ at } x = 0$$

$$q_2 = 3\mu C \text{ at } x = 40cm$$

$$q_3 = -2\mu C \text{ at } x = 120cm$$

17. Find the net force on q_2

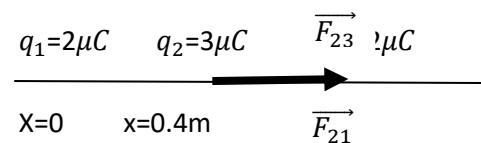
Solution:

Let net force on q_2 be $\overrightarrow{F_2}$

$$\overrightarrow{F_2} = \overrightarrow{F_{21}} + \overrightarrow{F_{23}}$$

$$= \left(\frac{1}{4\pi\epsilon_0} \frac{3 \times 10^{-6} \times 2 \times 10^{-6}}{(0.4)^2} \right) + \left(\frac{1}{4\pi\epsilon_0} \frac{3 \times 10^{-6} \times 2 \times 10^{-6}}{(0.8)^2} \right)$$

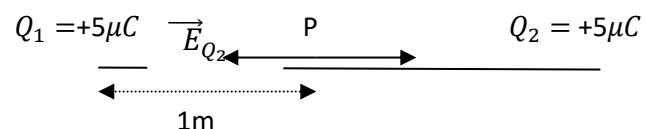
$$= 0.422 \text{ N}$$



18. Two charges $Q_1 = +5\mu C$ is at the origin and $Q_2 = +5\mu C$ is placed 2m away from Q_1 . Find the electric field at a point 1m away from Q_1 (along the line connecting the charges)

Solution:

$$\vec{E}_{Q_1} = \frac{1}{4\pi\epsilon_0} \frac{5 \times 10^{-6}}{1^2} \vec{E}_{Q_1}$$



$$\vec{E}_{Q_2} = \frac{-1}{4\pi\epsilon_0} \frac{5 \times 10^{-6}}{1^2}$$

$$\vec{E}_{net} = 0$$

19. Two charges are placed on a straight line. $Q_1 = 4\mu C$ at position 0m and $Q_2 = -2\mu C$ at position 4m. Find the net electric field at a point 2m between them

Solution:

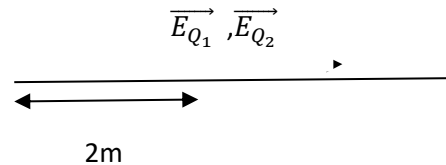
$$Q_1 = 4\mu C \quad Q_2 = -2\mu C$$

$$\vec{E}_{Q_1} = \frac{1}{4\pi\epsilon_0} \frac{4 \times 10^{-6}}{2^2}$$

$$\vec{E}_{Q_2} = \frac{1}{4\pi\epsilon_0} \frac{2 \times 10^{-6}}{2^2}$$

$$\vec{E}_{net} = \frac{1}{4\pi\epsilon_0} \frac{4 \times 10^{-6}}{2^2} + \frac{1}{4\pi\epsilon_0} \frac{2 \times 10^{-6}}{2^2}$$

$$= 9 \times 10^9 \left[\frac{4 \times 10^{-6}}{2^2} + \frac{2 \times 10^{-6}}{2^2} \right] = 27 \times 10^{-6} \text{ NC}^{-1}$$



20. A $+3\mu C$ charge is placed at $x=0$ and a $+12\mu C$ is placed at $x = 60\text{cm}$. At what point on the axis is the net electric field is zero.

Solution:

Let the point where electric field is zero be at a distance x from $+3\mu C$.

$$|\vec{E}_{+3\mu C}| = |\vec{E}_{+12\mu C}|$$

$$\frac{1}{4\pi\epsilon_0} \frac{3 \times 10^{-6}}{x^2} = \frac{1}{4\pi\epsilon_0} \frac{12 \times 10^{-6}}{(60-x)^2}$$

$$X = 20\text{cm from } +3\mu C$$

21. Calculate the field due to an electric dipole of length 5 cm and consisting of charges of $\pm 1000\mu C$ at a point 20 cm from each charge.

Solution:

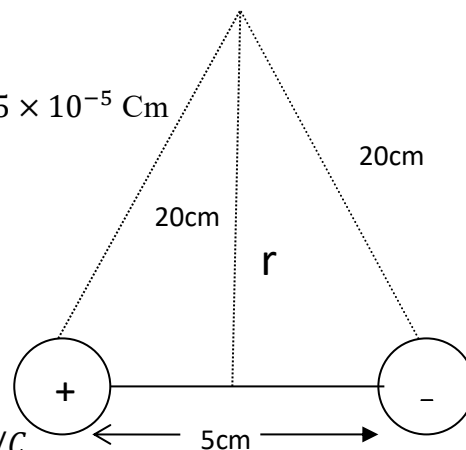
$$p = q \times 2a = 1000 \times 10^{-6} \times 5 \times 10^{-2} = 5 \times 10^{-5} \text{ Cm}$$

$$(r^2 + a^2)^{\frac{1}{2}} = 20 \times 10^{-2}$$

$$\text{or } (r^2 + a^2)^{\frac{3}{2}} = (20 \times 10^{-2})^3$$

$$\text{Or } E = \frac{1}{4\pi\epsilon_0} \frac{p}{(r^2 + a^2)^{\frac{3}{2}}}$$

$$= 9 \times 10^9 \times \frac{5 \times 10^{-5}}{(20 \times 10^{-2})^3} = 56.3 \times 10^6 \text{ N/C}$$



22. A rectangular frame of wire $25\text{ cm} \times 15\text{ cm}$ is placed in a uniform electric field of strength $2 \times 10^4\text{ N/C}$ such that the plane of the coil is normal to field. Find the electric flux linked with the rectangular frame.

Solution:

$$A = 25\text{cm} \times 15\text{cm} = 375\text{cm}^2$$

$$E = 2 \times 10^4\text{ N/C}$$

$$\phi = EA \cos \theta$$

$$= 2 \times 10^4 \times 375 \times 10^{-4} \cos 0$$

$$= 750\text{ Nm}^2\text{C}^{-1}$$

23. Two very long lines of charge are parallel to each other, separated by a distance x . They each have the same linear charge density. One is positive and the other is negative.

a) What is the magnitude of the E-field at a point half-way between the lines of charge?

b) How does the E-field at a point $x/3$ from the positive charge line (and $2x/3$ from the negative charge line) compare to the E-field $x/3$ from the negative charge line (and $2x/3$ from the positive charge line).

Solution:

a) Each line would contribute to the E-field

equally and in the same direction.

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

$$= 2 \frac{\lambda}{2\pi\epsilon_0 \frac{x}{2}}$$

$$= 2 \frac{\lambda}{2\pi\epsilon_0 x}$$

b) Each point will have the same magnitude

and direction for the E-field.

$$\vec{E} = \vec{E}_+ + \vec{E}_- = \frac{\lambda}{2\pi\epsilon_0 \frac{x}{3}} + \frac{\lambda}{2\pi\epsilon_0 \frac{2x}{3}}$$

$$E = \frac{9\lambda}{4\pi\epsilon_0 x}$$

24. Can a body have a charge of $4.8 \times 10^{-19}\text{C}$. Justify your answer

Solution:

$$Q = ne \quad Q = 4.8 \times 10^{-19}\text{C}$$

$$n = \frac{Q}{e}$$

$$= \frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}} = 3, \text{ yes it is possible because}$$

charge is quantised

25. If charge on each of the two particle is doubled and distance is also doubled, how does force change

Solution:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$F' = \frac{1}{4\pi\epsilon_0} \frac{2q_1 2q_2}{(2r)^2}$$

= F , force remains same

26. Force of attraction between two point electric charges placed at a distance d in a medium is F. What distance apart should these be kept in the same medium, so that force between them becomes $\frac{F}{3}$.

Solution:

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{d^2}$$

$$\frac{F}{3} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{x^2} \dots\dots\dots \text{If } d=x, F=\frac{F}{3}$$

$$\frac{\frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{d^2}}{3} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{x^2}$$

$$3d^2 = x^2 \text{ or, } x = \sqrt{3} d$$

27. Two point charges of $2 \times 10^{-7} \text{ C}$ and $1 \times 10^{-7} \text{ C}$ are 1 cm apart. What is the magnitude of the field produced by either charge at the site of the other.

Solution:

$$q_1 = 2 \times 10^{-7} \text{ C}$$

$$q_2 = 1 \times 10^{-7} \text{ C}$$

$$r = 1 \text{ cm} = 1 \times 10^{-2} \text{ m}$$

$$E_1 = \frac{1}{4\pi\epsilon_0} \frac{q_1}{r^2} \dots\dots\dots \text{electric field at the site of } q_2 \text{ due to } q_1$$

$$E_1 = 9 \times 10^9 \times \frac{2 \times 10^{-7}}{(1 \times 10^{-2})^2} = 1.8 \times 10^7 \text{ NC}^{-1}$$

$$E_2 = \frac{1}{4\pi\epsilon_0} \frac{q_2}{r^2} \dots\dots\dots \text{electric field at the site of } q_1 \text{ due to } q_2$$

$$E_2 = 9 \times 10^9 \times \frac{1 \times 10^{-7}}{(1 \times 10^{-2})^2} = 9 \times 10^6 \text{ NC}^{-1}$$

28. Calculate the electric flux from a cubical surface if an electric dipole is placed inside the cube

Solution:

$$\phi = \frac{q_{\text{enclosed}}}{\epsilon_0}$$

=0, as total charge inside the cube=0

29. Consider two hollow concentric spheres S_1 and

S_2 enclosing charges 20 and 40 respectively, as shown in the figure,

- Find out the ratio of the electric flux through them,
- How will the electric flux through the spheres S_1 change if a medium of dielectric constant ϵ_r is introduced in the space inside S_1 in place of air? Deduce the necessary

expression.

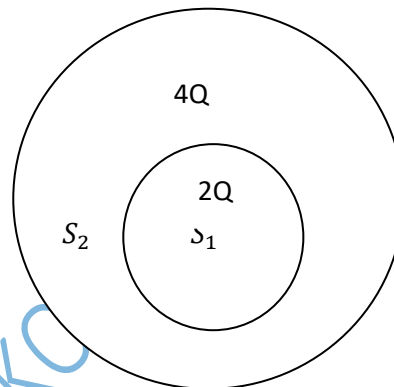
Solution:

$$(i) \phi = \frac{q_{\text{enclosed}}}{\epsilon_0}$$

$$\frac{\phi_1}{\phi_2} = \frac{2Q}{6Q} = \frac{1}{3}$$

$$(ii) \phi = \frac{q_{\text{enclosed}}}{\epsilon_0 \epsilon_r}$$

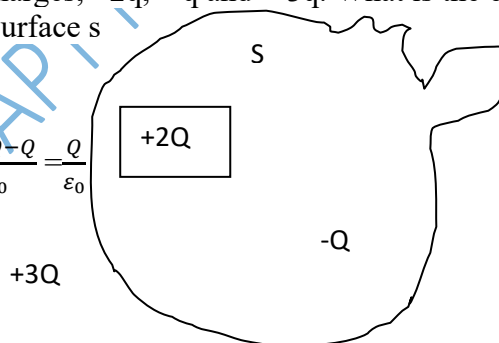
$$= \frac{2Q}{\epsilon_0 \epsilon_r}$$



30. Figure shows three point charges, +2q, -q and +3q. What is the electric flux due to this configuration through the surface s

Solution:

$$\phi = \frac{q_{\text{enclosed}}}{\epsilon_0} = \frac{+2Q - Q}{\epsilon_0} = \frac{Q}{\epsilon_0}$$



Since +3Q is outside the closed surface, it would not be taken into consideration while applying Gauss's law

31. If the radius of the Gaussian surface enclosing a charge is halved, how does the electric flux through the Gaussian surface change?

Solution:

Total charge enclosed by the Gaussian surface

remains the same, even when the radius is halved.

Therefore electric flux remains the same. There

will be no change in the electric flux through the

Gaussian surface

32. Calculate the electric field strength required to just support a water drop of mass 10^{-7} Kg and having a charge 1.6×10^{-19} C.

Solution:

$$\text{Weight} = mg$$

force required to support this weight is $F = Ee$

$$eE = mg$$

$$E = \frac{mg}{e} = \frac{10^{-7} \times 9.8}{1.6 \times 10^{-19}} = 6.13 \times 10^{12} \text{ NC}^{-1}$$

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CHAPTER 2

ELECTROSTATIC POTENTIAL AND CAPACITANCE

- 5J work is done in moving a positive charge of 0.5 C between two points. What is the potential difference between these points ?

Solution:

$$\begin{aligned}
 V_B - V_A &= \frac{W_{AB}}{q_0} = \frac{5}{0.5} = 10 \text{ V} \\
 &= \frac{kq_1q_2}{r} + \frac{kq_1q_3}{r} + \frac{kq_2q_3}{r} = \frac{k[q_1q_2 + q_1q_3 + q_2q_3]}{r} \\
 &= \frac{9 \times 10^9 [(1 \times 10^{-6} \times 2 \times 10^{-6}) + (1 \times 10^{-6} \times 3 \times 10^{-6}) + (2 \times 10^{-6} \times 3 \times 10^{-6})]}{0.1} \\
 &= 0.99 \text{ J}
 \end{aligned}$$

- When electrons equal to Avogadro number are transferred from one conductor to another, a potential difference of 10^6 V appears between them. Calculate the capacitance of the system of two conductors.

Solution:

$$q = ne = 6.02 \times 10^{23} \times 1.6 \times 10^{-19} = 96320 \text{ C}$$

$$C = \frac{q}{V} = \frac{96320}{10^6} = 96.32 \times 10^{-3} \text{ F}$$

- An electric dipole consists of two opposite charges each of $1 \mu\text{C}$ separated by 2 cm. The dipole is placed in an external uniform field of 10^5 N/C intensity. Find (a) maximum torque exerted by the field on the dipole and (b) the work done in rotating the dipole through 180° starting from the position $\theta=0^\circ$.

Solution:

$$q = 1 \times 10^{-6} \text{ C}, E = 10^5 \text{ N/C} \quad 2a = 0.02 \text{ m} \quad p = q \times 2a = 1 \times 10^{-6} \times 0.02 = 2 \times 10^{-8} \text{ Cm},$$

a) Torque acting on the dipole, $T = pE \sin \theta$ Torque is maximum when $\theta = 90^\circ$

$$T_{\max} = pE \sin 90 = 2 \times 10^{-8} \times 10^5 \times 1 = 0.002 \text{ Nm}$$

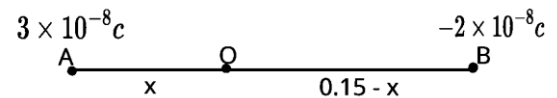
(b) The work done in rotating the dipole from 0° to 180° is $W = pE [\cos 0 - \cos 180]$

$$\text{ie, } W = 2 \times 10^{-8} \times 10^5 \times [1 - (-1)] = 0.004 \text{ J}$$

- Two charges $3 \times 10^{-8} \text{ C}$ and $-2 \times 10^{-8} \text{ C}$ are located 15 cm apart. At what point on the line joining the two charges is the electrical potential zero? Take the potential at infinity to be zero.

Solution:

Let 'O' be the point where the electric potential is zero.



$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

$$V_A = 9 \times 10^9 \times \frac{3 \times 10^{-8}}{x}$$

$$V_B = 9 \times 10^9 \times \frac{-2 \times 10^{-8}}{0.15 - x}$$

$$\text{At O, } V_A + V_B = 0, \text{ ie, } 9 \times 10^9 \times \left[\frac{3 \times 10^{-8}}{x} - \frac{2 \times 10^{-8}}{0.15 - x} \right] = 0$$

$$\left[\frac{3}{x} - \frac{2}{0.15 - x} \right] = 0$$

$$3(0.15 - x) = 2x$$

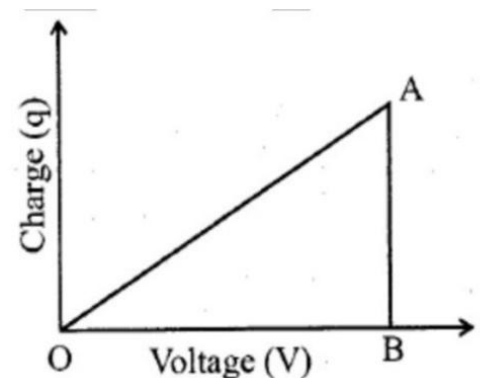
$$\text{Hence } x = 0.09 \text{ m}$$

9. The variation of electric charge with electric potential in a device is given below

- Identify the device.
- What does the slope of the graph represents?
- The area under the graph gives -----

Solution:

- Capacitor.
- Capacitance.
- Energy stored in the capacitor



10. A parallel plate capacitor with air between the plates has a capacitance of 8pF. What will be the capacitance if the distance between the plates is reduced by half and space between them is filled with a substance of dielectric constant 6.

Solution:

$$C = \frac{\epsilon_0 A}{d}$$

$$C' = \frac{K \epsilon_0 A}{d/2} = 2KC$$

$$= 2 \times 6 \times 8 \text{ pF} = 96 \text{ pF}$$

11. Three capacitors of equal capacitance when connected in series have a net capacitance C_1 and when connected in parallel have a net capacitance C_2 . What will be the ratio C_1/C_2 .

Solution:

Effective capacitance when equal capacitors are connected in series.

$$C_1 = C/n = C/3$$

Effective capacitance when capacitors are connected in parallel ,

$$C_2 = nC = 3C$$

$$\text{Then } \frac{C_1}{C_2} = \frac{C/3}{3C} = \frac{1}{9}$$

12. Obtain the equivalent capacitance of the network in Figure. For a 300 V supply, determine the charge and voltage across each capacitor.

Solution:

The capacitors C_2 and C_3 are connected in series. The equivalent capacitance C'

$$\frac{1}{C'} = \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{200} + \frac{1}{200} = \frac{2}{200}$$

$$C' = 100 \text{ pF}$$

The capacitors C' and C_1 are parallel. The equivalent capacitance is $C'' = C' + C_1$

$$C'' = 100 + 100 = 200 \text{ pF}$$

C'' and C_4 are connected in series. Let the equivalent capacitance be C

$$\frac{1}{C} = \frac{1}{C''} + \frac{1}{C_4} = \frac{1}{200} + \frac{1}{100} = \frac{3}{200}$$

$$C = 200/3 \text{ pF}$$

Hence, the equivalent capacitance of the circuit is $200/3 \text{ pF}$

$$\text{Total charge, } Q = CV = \frac{200}{3} \times 10^{-12} \times 300 = 2 \times 10^{-8} \text{ C}$$

$$Q = Q_4 = 2 \times 10^{-8} \text{ C}$$

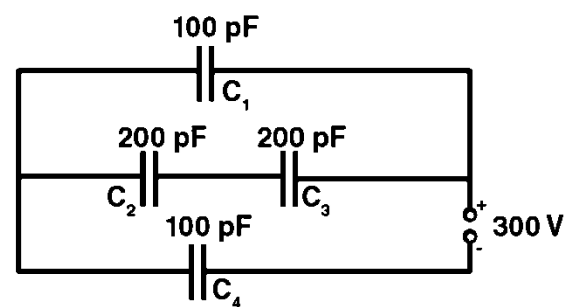
$$\text{Potential difference across } C_4, V_4 = \frac{Q}{C_4}$$

$$= \frac{(2 \times 10^{-8})}{(100 \times 10^{-12})} = 200 \text{ V}$$

$$\text{Potential difference across } C'', V'' = 300 \text{ V} - 200 \text{ V} = 100 \text{ V}$$

$$\text{Potential difference across } C_1, V_1 = V'' = 100 \text{ V}$$

$$\text{Charge across } C_1, Q_1 = C_1 V_1 = (100 \times 10^{-12}) \times 100 = 10^{-8} \text{ C}$$



The charge across C_2 and C_3 , $Q_2 = Q - Q_1 = 2 \times 10^{-8} - 10^{-8} = 10^{-8}$

$$\text{Potential across } C_2, V_2 = \frac{Q_2}{C_2} = \frac{10^{-8}}{200 \times 10^{-12}} = 50 \text{ V}$$

$$\text{Potential across } C_3, V_3 = \frac{Q_2}{C_3} = \frac{10^{-8}}{200 \times 10^{-12}} = 50 \text{ V}$$

Therefore,

$$Q_1 = 10^{-8} \text{ C}, V_1 = 100 \text{ V}$$

$$Q_2 = 10^{-8} \text{ C}, V_2 = 50 \text{ V}$$

$$Q_2 = Q_3 = 10^{-8} \text{ C}, V_3 = 50 \text{ V}$$

$$Q_4 = 2 \times 10^{-8} \text{ C}, V_4 = 200 \text{ V}$$

13. A $4\mu\text{F}$ capacitor is charged to 400 V. It is then disconnected from the source and connected in parallel to an uncharged $2\mu\text{F}$ capacitor. Find the common potential attained by the two capacitors.

Solution:

$$\text{Charge on the capacitor, } Q_1 = C_1 V_1 = 4 \times 10^{-6} \times 400 = 16 \times 10^{-4} \text{ C}$$

$$\text{Total capacitance, } C = C_1 + C_2 = 4 + 2 = 6 \mu\text{F}$$

$$\text{Common potential} = \frac{\text{Total charge}}{\text{Total capacitance}} = \frac{16 \times 10^{-4}}{6 \times 10^{-6}}$$

$$= 266.67 \text{ V}$$

14. In a parallel plate capacitor, the capacitance increases from $4\mu\text{F}$ to $80\mu\text{F}$ on introducing a dielectric medium between the plates. What is the dielectric constant of the medium.

Solution:

$$\text{Given that } C = \frac{\epsilon_0 A}{d} = 4 \mu\text{F}; C' = \frac{\epsilon_0 K A}{d} = 80 \mu\text{F}$$

$$K = \frac{C'}{C} = \frac{80 \mu\text{F}}{4 \mu\text{F}} = 20$$

15. A 600 pF capacitor is charged by a 200 V supply. How much electrostatic energy is stored by the capacitor. It is then disconnected from the supply and is connected to another uncharged 600 pF capacitor. How much electrostatic energy is lost in the process.

Solution:

Initial energy stored in the charged capacitor,

$$U_1 = \frac{1}{2} C V^2 = \frac{1}{2} \times 600 \times 10^{-12} \times 200^2 = 12 \times 10^{-6} \text{ J}$$

$$\text{Charge on the capacitor, } Q = C V = 600 \times 10^{-12} \times 200 = 12 \times 10^{-8} \text{ C}$$

When connected to an uncharged capacitor , the charge on each capacitor becomes

$$Q' = \frac{Q}{2} = \frac{12 \times 10^{-8}}{2} = 6 \times 10^{-8}$$

$$\text{Energy of each capacitor , } U = \frac{Q'^2}{2C} = \frac{(6 \times 10^{-8})^2}{2 \times 600 \times 10^{-6}} = 3 \times 10^{-6} \text{ J}$$

$$\text{Total energy in the system } U_2 = 2 \times 3 \times 10^{-6} = 6 \times 10^{-6} \text{ J}$$

$$\text{Loss of energy} = U_1 - U_2 = 12 \times 10^{-6} - 6 \times 10^{-6} = 6 \times 10^{-6} \text{ J}$$

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Chapter 3

CURRENT ELECTRICITY

1. Current flowing through a wire varies with time t in second as

$$I = (2t + 4) A$$

How much charge passes through a cross-section of the wire in 2s?

Solution:

$$\text{Given } I = (2t + 4)A$$

$$\text{As we know } dq = Idt$$

$$q = \int (2t + 4)dt$$

$$\text{Integrating we get } q = t^2 + 4t$$

$$\text{At } t = 2s \quad q = 12C$$

2. Ten million electrons pass from point P to point Q in one micro second. The current and its direction is



Solution:

$$I = \frac{ne}{t}$$

$$I = \frac{10^7 \times 1.6 \times 10^{-19}}{10^{-6}}$$

$$= 1.6 \times 10^{-6} A \quad (\text{From Q to P})$$

3. In an atom electrons revolves around the nucleus along a path of radius 0.72 angstrom making 9.4×10^{18} revolution per second . The equivalent current is

Solution:

$$I = \frac{e}{T} = fe$$

$$I = 9.4 \times 10^{18} \times 1.6 \times 10^{-19}$$

$$I = 1.504 A$$

4. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $1.0 \times 10^{-7} m^2$ carrying a current of 1.5A . Assume the density of conduction electrons to be $9 \times 10^{28} m^{-3}$.

Solution: $I = nA v_d e$

$$\therefore v_d = \frac{I}{nAe} = 1.041 \times 10^{-3} m/s$$

5. The current flowing through a conductor is 2mA at 50 V and 3mA at 60V. Is it an ohmic or non-ohmic conductor? Give reason

Solution

$$R_1 = \frac{V_1}{I_1} = \frac{50}{2 \times 10^{-3}} = 25 \times 10^3 \Omega$$

$$\text{And } R_2 = \frac{V_2}{I_2} = \frac{60}{3 \times 10^{-3}} = 20 \times 10^3 \Omega$$

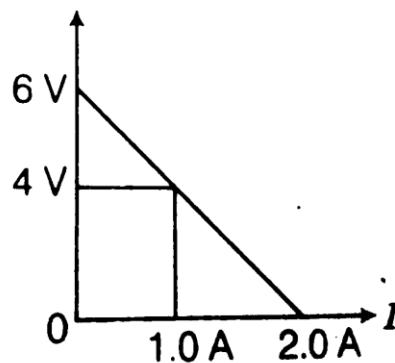
It is clear that $R_1 \neq R_2$

Hence, the given conductor is non-ohmic.

6. The figure shows a plot of terminal voltage V versus the current I of a given cell. Calculate from the graph

(a) emf of the cell.

(b) Internal resistance of the cell.



Solution:

$$V = E - Ir$$

(a) When $I = 0$, then $V = E$

When $I = 0$, then $V = 6V$, from the graph

$$\therefore E = 6V$$

(b) When $I = 2A$, then $V = 0$ (from the graph)

$$\therefore E = Ir$$

$$r = \frac{E}{I} = \frac{6}{2} = 3\Omega$$

7. A heating element is marked 210V ,630W. What is the value of current drawn by the element when connected to a 210 V dc source?

Solution:

$$P = VI$$

$$I = \frac{P}{V} = \frac{630}{210} = 3A$$

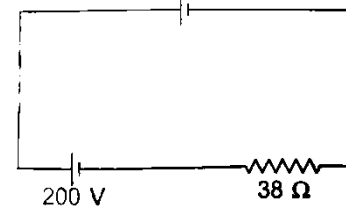
8. A 10 V cell of negligible internal resistance is connected in parallel across a battery of emf 200V and internal resistance 38Ω as shown in the figure. Find the value of current in the circuit.

Solution:

$$\text{Equivalent emf } \epsilon = 200 - 10 = 190V$$

$$\text{Internal resistance } r = 38\Omega$$

$$\text{Current in the given circuit } I = \frac{\epsilon}{r} = \frac{190}{38} = 5A$$



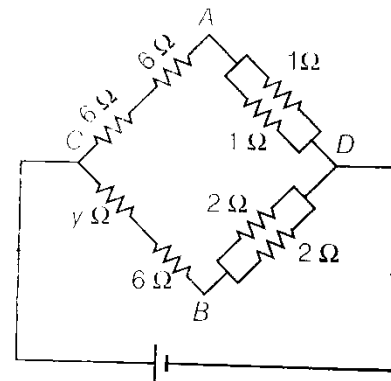
9. For what value of unknown resistance y , the potential difference between A and B is zero in the arrangement as shown in figure below?

Solution:

$$\text{As, } V_A - V_B = 0$$

Thus it is a balanced Wheatstone bridge.

$$\text{Ans. } 18\Omega$$



10. Six lead-acid type of secondary cells each of emf 2.0 V and internal resistance 0.015Ω are joined in series to provide supply to a resistance of 8.5Ω . What is the current drawn from the supply and its terminal voltage?

Solution:

$$\text{Given emf of each cell} = 2.0V$$

$$\text{Total emf of six cells} = 2 \times 6 = 12V$$

$$\text{Total internal resistance} = 6 \times 0.015\Omega = 0.090\Omega$$

$$\text{Load resistance} = 8.5\Omega$$

$$\text{Current in the circuit } I = \frac{E_q}{R + r_{eq}}$$

$$\text{i.e., } I = \frac{12}{8.5 + 0.09} = 1.4A$$

$$\text{The terminal voltage of the battery} = V = IR$$

$$\text{i.e., } V = 1.4 \times 8.5V = 11.9V$$

11. A wire of 15Ω resistance is gradually stretched to double its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 3.0 V battery. Find the current drawn from the battery.

Solution:

When a resistance wire of initial resistance R is stretched to n times, new resistance is,
 $R' = n^2 R$

So new resistance $R' = 2^2 \times 15 = 60\Omega$

After dividing into two parts ,resistance of each part $= 30\Omega$

$\therefore$ Effective resistance after connecting them into parallel combination,

$$R_{eff} = 15\Omega$$

Applied potential difference , $V = 3V$

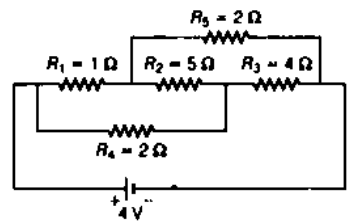
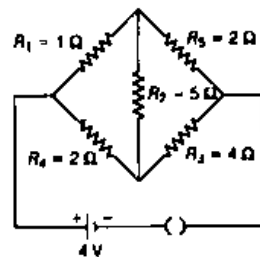
$\therefore$ Current drawn from the battery, $I = \frac{V}{R}$

$$I = \frac{3}{15} = \frac{1}{5} A$$

12. Calculate the current drawn from the battery in the given network

Solution:

The given circuit can be redrawn as given below,



Here $\frac{R_1}{R_5} = \frac{R_4}{R_3}$ ie., $\frac{1}{2} = \frac{2}{4}$

Wheatstone bridge is balanced. So there will be no current in the diagonal resistance R_2 or it can be withdrawn from the circuit.

The equivalent resistance would be equivalent to a parallel combination of two rows which consists of series combination of R_1 and R_4 and R_5 and R_3 , respectively.

$$\frac{1}{R} = \frac{1}{1+2} + \frac{1}{2+4}$$

$$R = 2\Omega$$

$$\therefore I = \frac{V}{R} = \frac{18}{2} = 2 A$$

13. Calculate the conductivity of a conductor of resistance 0.05 ohm ,area of cross section $10^{-4}m^2$ and length 50cm.

Solution:

$$\text{Resistance , } R = \rho \frac{l}{A}$$

$$\text{Resistivity , } \rho = \frac{RA}{l}$$

$$\text{Conductivity } \sigma = \frac{1}{\rho} = \frac{l}{RA} = \frac{0.5}{0.05 \times 10^{-4}} = 10^5 Sm^{-1}$$

14. A 10Ω thick wire is stretched so that its length becomes 3 times .Assuming that there is no change in its density on stretching ,calculate the resistance of the new wire.

Solution:

Since the volume remains constant, when the length becomes three times, the area of cross section becomes one third of the original value.

$$\text{Initial resistance } R = \rho \frac{l}{A}$$

$$\begin{aligned} \text{Resistance after stretching } R' &= \frac{\rho l'}{A'} = \frac{\rho(3l)}{\left(\frac{A}{3}\right)} = 9\left(\frac{\rho l}{A}\right) \\ &= 9 \times 10 \text{ ohm} \\ &= 90 \Omega \end{aligned}$$

15. A silver wire has a resistance of 2.1Ω at 27.5°C and a resistance of 2.7Ω at 100°C . Determine the temperature coefficient of resistance of silver.

Solution:

We know that the temperature coefficient of resistance is

$$\alpha = \frac{R_2 - R_1}{R_1 (T_2 - T_1)} = \frac{2.7 - 2.1}{2.1 \times 72.5} = 0.00394 \text{ } ^\circ\text{C}^{-1}$$

16. A current of 3A is flowing in an aluminium wire of cross section $2 \times 10^{-6} \text{ m}^2$. Find the current density in the wire.

Solution:

$$\text{Current density, } j = \frac{I}{A} = \frac{3}{2 \times 10^{-6}} = 1.5 \times 10^6 \text{ Am}^{-2}$$

17. Two cells of emfs E_1 and E_2 ($E_1 > E_2$) produce a current of 3A through a resistance when they are in opposition. The current through the same wire is 5A when they are in series. Find the ratio of emfs of the two cells.

Solution:

When the cells are in opposition, the net emf of the circuit is $(E_1 - E_2)$, So

$$I = \frac{E_1 - E_2}{R}$$

$$3 = \frac{E_1 - E_2}{R}$$

When the cells are in series the net emf is $(E_1 + E_2)$

So we have

$$5 = \frac{E_1 + E_2}{R}$$

Dividing the above two equations and solving,

$$\frac{E_1}{E_2} = \frac{1}{4}$$

Chapter 4

MOVING CHARGES AND MAGNETISM

1. A proton enters a magnetic field of flux density 2.5 T with a velocity of $1.5 \times 10^7 \text{ ms}^{-1}$ at an angle of 30° with the field. Find the force on the proton.

Solution:

Given:

$$q = 1.6 \times 10^{-19} \text{ C}$$

$$v = 1.5 \times 10^7 \text{ m/s}$$

$$B = 2.5 \text{ T}$$

$$\theta = 30^\circ$$

$$F = qvB \sin \theta$$

$$F = 1.6 \times 10^{-19} \times 1.5 \times 10^7 \times 2.5 \times \sin 30 = 1.6 \times 10^{-19} \times 1.5 \times 10^7 \times 2.5 \times 0.5$$

$$F = 3 \times 10^{-12} \text{ N}$$

2. A particle of charge q moves with along positive y - direction in velocity $\vec{v}$ a magnetic field $\vec{B}$. Compute the Lorentz force experienced by the particle.
 - (a) when magnetic field is along positive y-direction
 - (b) when magnetic field points in positive z - direction

Solution:

- (a) Magnetic field is along positive y - direction, this implies, $\vec{B} = B.\hat{j}$
Velocity $\vec{v} = v.\hat{j}$

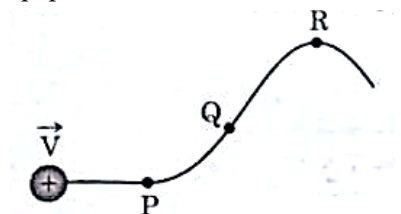
$$\begin{aligned}\vec{F} &= q(\vec{v} \times \vec{B}) \\ &= q(v.\hat{j} \times B.\hat{j}) = 0\end{aligned}$$

- (b) Magnetic field points in positive z - direction, this implies, $\vec{B} = B.\hat{k}$

$$\begin{aligned}\vec{F} &= q(\vec{v} \times \vec{B}) \\ &= q(v.\hat{j} \times B.\hat{k}) = qvB\hat{i}\end{aligned}$$

3. (i) A proton moving with velocity $\vec{V}$ in a non-uniform magnetic field traces a path as shown in the figure. The path followed by the proton is always in the plane of the paper. What is the direction of the magnetic field in the region near points P, Q and R? What can you say about relative magnitude of magnetic fields at these points?

- (ii) A current carrying circular loop of area A produces a magnetic field B at its centre.



Show that the magnetic moment of the loop is $\frac{2BA}{\mu_0} \sqrt{\frac{A}{\pi}}$

Solution:

i) By right hand thumb rule magnetic field points *into* the plane of the paper.

by equation

$$r = \frac{mv}{qB}$$

$$B = \frac{mv}{qr}$$

If r is small B is large

From figure radius of curvature at **P < Q < R**

So, $B_P > B_Q > B_R$

ii) the magnetic field at the center of a current-carrying circular loop of radius r is

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

area of the circular loop $A = \pi r^2$

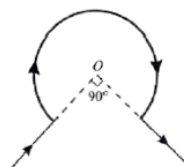
$$r = \sqrt{\frac{A}{\pi}}$$

Substituting in above equation

$$B = \frac{\mu_0 I}{2\sqrt{\frac{A}{\pi}}}$$

$$B = \frac{\mu_0 I}{2} \sqrt{\frac{\pi}{A}}$$

4. The wire shown below carries a current I. Determine magnetic field at the centre. Radius of the circular section is R



Solution:

The Magnetic field at the centre of a circular loop is given by

$$B = \frac{\mu_0 I}{2R}$$

But here only $\frac{3}{4}th$ of the loop is given.

Thus Magnetic field will be $\frac{3}{4}th$ of the above Magnetic field due to circular loop.

$$\text{ie, } B = \frac{3}{4} \times \frac{\mu_0 I}{2R} = \frac{3\mu_0 I}{8R}$$

5. The magnetic field due to a current-carrying circular loop of radius 12 cm at its centre is $0.05 \times 10^{-4} \text{ T}$. Find the magnetic field due to this loop at a point on the axis at a distance of 5.0 cm from the centre.

Solution:

$$\text{Given, } R = 12 \times 10^{-2} \text{ m}$$

$$x = 5 \times 10^{-2} \text{ m}$$

$$B_{\text{centre}} = 0.05 \times 10^{-4} \text{ T}$$

$$B_{\text{axial}} = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}$$

$$B_{\text{centre}} = \frac{\mu_0 I}{2R}$$

$$\therefore \frac{B_{\text{axial}}}{B_{\text{centre}}} = \frac{R^3}{2(R^2 + x^2)^{3/2}}$$

$$B_{\text{axial}} = \frac{(12 \times 10^{-2})^3}{2(144 \times 10^{-4} + 25 \times 10^{-4})^{3/2}} \times 0.05 \times 10^{-4} = 3.9 \times 10^{-5} \text{ T}$$

6. A current of 10 A is flowing east to west in a long wire kept horizontally in the east-west direction. Find the magnitude and direction of magnetic field in a horizontal plane at a distance of

(i) 10 cm north

(ii) 20 cm south from the wire;

Solution:

(i) magnetic field in a horizontal plane at a distance of 10 cm north of the wire is

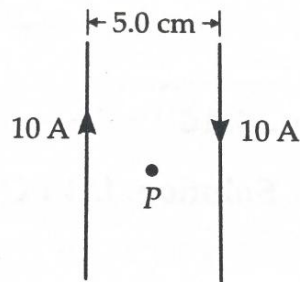
$$B_N = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 10}{2\pi \times 0.10} = 2 \times 10^{-5} \text{ T}$$

According to right hand thumb rule, the direction of the magnetic field will be directing downwards.

$$(ii) B_S = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 10}{2\pi \times 0.20} = 1 \times 10^{-5} \text{ T}$$

According to right hand thumb rule, the direction of the magnetic field will be directing upwards.

7. shows two long straight wires carrying electric currents of 10 A each in opposite directions. The separation between the wires is 5 cm. Find the magnetic field at a point P, midway between the wires.



Solution:

According to right hand thumb rule, the direction of the magnetic field due to current in each wire is perpendicular to and pointing into the plane of the paper. Hence the total magnetic field at point P is

$$B = 2 \times \frac{\mu_0 I}{2\pi r} = 2 \times \frac{4 \times \pi \times 10^{-7} \times 10}{2\pi \times 2.5 \times 10^{-2}}$$

$$B = 1.6 \times 10^{-6} \text{ T} \quad \left(r = \frac{5}{2} \text{ cm}\right)$$

8. A current of 5.0 A flows through each of two parallel long wires. The wires are 2.5 cm apart. Calculate the force acting per unit length of each wire. Use the standard value of constant required. What will be the nature of the force, if both currents flow in the same direction?

Solution:

Given:

$$I_1 = I_2 = 5.0 \text{ A}$$

$$\text{Distance between wires: } d = 2.5 \text{ cm} = 0.025 \text{ m}$$

The force per unit length between two long, straight, parallel wires carrying current

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

$$F = \frac{4\pi \times 10^{-7} \times 5 \times 5}{2\pi \times 0.025} = 2 \times 10^{-4} \text{ N}$$

Since both currents flow in the same direction, the force between the wires is attractive.

9. A solenoid of length 0.5 m has a radius of 1 cm and is made up of 500 turns. It carries a current of 5 A. What is the magnitude of the magnetic field inside the solenoid?

Solution:

Given

$$\begin{aligned} \text{Length, } l &= 0.5 \text{ m} \\ \text{Radius, } r &= 1 \times 10^{-2} \\ \text{Current, } I &= 5 \text{ A} \\ \text{Total turns, } N &= 500 \end{aligned}$$

Magnetic field inside a long solenoid, $B = \mu_0 nI$

But, $n = N/l$

$$B = \mu_0 \frac{N}{l} I = 4\pi \times 10^{-7} \times \frac{500}{0.5} \times 5 = 6.28 \times 10^{-3}$$

10. A 0.5 m long solenoid has 500 turns and has a flux density of 2.52×10^{-3} T at its centre. Find the current in the solenoid. Given: $\mu_0 = 4\pi \times 10^{-7}$ H m⁻¹.

Solution:

Given

Length, $l = 0.5$ m

Flux density, $B = 2.52 \times 10^{-3}$

Total turns, $N = 500$

Magnetic field inside a long solenoid, $B = \mu_0 nI$

$$I = \frac{Bl}{\mu_0 N} = \frac{2.52 \times 10^{-3} \times 0.5}{4\pi \times 10^{-7} \times 500} = 2 \text{ A}$$

11. Calculate the torque on a 100 turn rectangular coil of length 40 cm and breadth 20 cm, carrying a current of 10 A, when placed making an angle of 60° with a magnetic field of 3 T.

Solution:

Given,

Number of turns, $N=100$

Current, $I=10$ A

Magnetic field, $B=3$ T

Length = 40 cm = 0.40 m

Breadth = 20 cm = 0.20 m

the torque on a rectangular coil placed in a magnetic field

$$\tau = NIAB \sin \theta$$

$$\tau = 100 \times 10 \times (0.40 \times 0.20) \times 3 \times \sin 60$$

$$\tau = 100 \times 10 \times (0.40 \times 0.20) \times 3 \times 0.866$$

$$\tau = 207.84 \text{ Nm}$$

12. A galvanometer gives deflection of 10 divisions per mA. The resistance of galvanometer is 60Ω . If a shunt of 2.5Ω is connected to the galvanometer and there are 50 divisions on the galvanometer scale, what maximum current can this galvanometer read?

Solution:

Given that galvanometer has 10 divisions per mA

$$\therefore \text{Current per Division} = \frac{1}{10} \text{mA}$$

Current Required for full scale deflection = $I_g \text{Current for One division} \times$
Total No of Divisions

$$= \frac{1}{10} \times 50 = 5 \text{mA}$$

If I is the maximum current that the galvanometer can read, then

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

S=Shunt Resistance, G= Galvanometer Resistance

$$\text{Or, } I = \frac{(G + S)I_g}{S}$$

$$= \frac{(60 + 2.5) \times 5 \text{m}}{2.5} = 125 \text{mA}$$

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Chapter 5

Magnetism And Matter

1. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.4 Tesla experiences a torque of magnitude $2 \times 10^{-2} \text{ J}$. What is the magnitude of the magnetic moment of the magnet?

Solution:

$$\tau = mB \sin \theta$$

$$m = \frac{\tau}{B \sin \theta} = \frac{2 \times 10^{-2}}{0.4 \times \sin 30} = \frac{2 \times 10^{-2}}{0.4 \times (1/2)} = 0.1 \text{ J/T}$$

2. A solenoid has a core of a material with relative permeability 500 and its windings carry a current of 1 A. The number of turns of the solenoid is 500/m. Find magnetisation of the material.

Solution:

$$\mu_r = 500$$

$$I = 1 \text{ A}$$

$$n = 500$$

$$\chi = \mu_r - 1 = 500 - 1 = 499$$

$$H = nI = 500 \times 1 = 500 \text{ A/m}$$

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

$$M = \chi H = 499 \times 500 = 2.5 \times 10^5 \text{ Am}^{-1}$$

3. A magnetic needle suspended parallel to a magnetic field requires $\sqrt{5} \text{ J}$ of work to turn it through 60° . Calculate the torque needed to maintain the needle in the position.

Solution:

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

$$\theta_1 = 0^\circ \quad \theta_2 = 60^\circ$$

$$W = -mB(\cos 60 - \cos 0)$$

$$= -mB(1/2 - 1) = \sqrt{5}$$

$$mB = 2\sqrt{5}$$

$$\tau = mB \sin \theta$$

$$= 2\sqrt{5} \sin 60 = 2\sqrt{5} \times \frac{\sqrt{3}}{2} = \sqrt{15} \text{ Nm}$$

4. A short bar magnet of magnetic moment 0.36 J/T is placed in a uniform magnetic field of 0.25 T . If the bar magnet is free to rotate in the plane of the field, which orientation would correspond to its
 a) Stable equilibrium b) Unstable equilibrium
 What is the potential energy of the magnet in each case?

Solution:

- a) Stable equilibrium

$\theta = 0^\circ$ (bar magnet is aligned along the magnetic field)

$$PE = -mB \cos \theta$$

$$PE = -mB \cos 0 = -mB$$

$$= -0.36 \times 0.25 = -9 \times 10^{-2} \text{ J}$$

- b) Unstable equilibrium

$\theta = 180^\circ$ (bar magnet is aligned opposite to the magnetic field)

$$PE = -mB \cos 180 = mB$$

$$= 9 \times 10^{-2} \text{ J}$$

5. A closely wound solenoid of 500 turns and area of cross section $2 \times 10^{-4} \text{ m}^2$ carries a current of 2A. What is the magnetic moment associated with the solenoid?

Solution:

$$n = 500$$

$$A = 2 \times 10^{-4} \text{ m}^2$$

$$I = 2 \text{ A}$$

$$m = nIA = 500 \times 2 \times 2 \times 10^{-4} = 2 \times 10^{-1} = 0.2 \text{ J/T}$$

6. A closely wound solenoid of magnetic moment 0.6 J/T is placed in a uniform external magnetic field of 0.25 T . What is the magnitude of the torque on the solenoid, when its axis makes an angle 30° with the direction of the field

Solution:

$$\tau = mB \sin \theta$$

$$= 0.6 \times 0.25 \times \sin 30$$

$$= 0.6 \times 0.25 \times \frac{1}{2} = 7.5 \times 10^{-2} \text{ J}$$

7. A short bar magnet has a magnetic moment 0.36J/T . Give the magnitude and direction of the magnetic field produced by the magnet at a distance 10cm from the centre of the magnet on a) the axis b) the equatorial lines on the magnet

Solution:

a. Magnetic field at a point on the axis

$$\begin{aligned} B &= \frac{\mu_0}{4\pi} \frac{2M}{d^3} \\ &= \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2 \times 0.36}{(10 \times 10^{-2})^3} \\ &= \frac{10^{-7} \times 2 \times 0.36}{10^{-3}} = 0.72 \times 10^{-4} \text{T} \end{aligned}$$

The magnetic field is along the South-North direction

b. Magnetic field at a point on the equatorial line

$$\begin{aligned} B &= \frac{\mu_0}{4\pi} \frac{M}{d^3} \\ &= \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{0.36}{(10 \times 10^{-2})^3} \\ &= 0.36 \times 10^{-4} \text{T} \end{aligned}$$

The magnetic field is along the North-South direction

8. A solenoid has a core of a material with relative permeability 500. The windings of the solenoid are insulated from the core and carry a current of 1A . If the number of turns is 2000 per meter, Calculate
1. Magnetic Intensity H
 2. Magnetic Field B
 3. Magnetisation M

Solution:

$$1. H = nI = 2000 \times 1 = 2 \times 10^3 \text{A/m}$$

$$2. B = \mu H = \mu_r \mu_0 H = 500 \times 4\pi \times 10^{-7} \times 2 \times 10^3 = 4\pi \times 10^{-7} \times 10^6 = 1.256 \text{T}$$

$$3. \text{Susceptibility, } \chi = \frac{M}{H}$$

$$\begin{aligned} M = \chi H &= (\mu_r - 1)H = 499 \times 2 \times 10^3 \\ &= 9.98 \times 10^5 \text{A/m} \end{aligned}$$

9. A bar magnet of magnetic moment 0.48J/T lies aligned with the direction of a uniform magnetic field 0.1T .
- What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment
 - Normal to the field direction
 - Opposite to the field direction
 - What is the torque on the magnet in cases (i) and (ii)

Solution:

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

$$(i) m = 0.48\text{J/T} \quad \theta_1 = 0^\circ \quad \theta_2 = 90^\circ$$

$$W = -mB(\cos 90^\circ - \cos 0^\circ) = 0.48 \times 0.1(0 - 1) = 0.048\text{J}$$

$$(ii) \theta_1 = 0^\circ \quad \theta_2 = 180^\circ$$

$$W = -mB(\cos 180^\circ - \cos 0^\circ) = 0.48 \times 0.1(-1 - 1) = 0.096\text{J}$$

- For case (i) $\theta = 90^\circ$

$$\text{Torque } \tau = mB \sin\theta$$

$$= 0.48 \times 0.1 \times \sin 90^\circ = 0.048\text{J}$$

$$\text{For case (ii) } \theta = 180^\circ$$

$$\text{Torque } \tau = mB \sin\theta$$

$$= 0.48 \times 0.1 \times \sin 180^\circ = 0\text{J}$$

10. A solenoid has a core of a substance with relative permeability 600. Find the magnetic permeability of the given substance.

Solution:

$$\mu = \mu_0 \mu_r, \quad \mu = 4\pi \times 10^{-7} \times 600 = 7.54 \times 10^{-4}\text{H/m}$$

Chapter 6

Electromagnetic Induction

1. If N is the number of turns in a coil, the value of self inductance varies as:

- (a) N_0 (b) N (c) N^2 (d) $N^{(-2)}$

Solution:

$$L = \mu_0 N^2 A / L$$

L is proportional to N^2

2. What is the energy stored in a coil of self inductance $2H$, when a current of $10A$ is set up through it?
(a) $10J$ (b) $50J$ (c) $100J$ (d) $500J$

Solution:

$$U = LI^2 / 2 = 2 \times (10)^2 / 2 = 100J$$

3. A bicycle wheel of radius $0.5m$ has 32 spokes. It is rotating at the rate of 120 revolutions per minute, perpendicular to the horizontal component of earth's magnetic field $B_H = 4 \times 10^{-5}T$. The emf induced between the rim and the centre of the wheel will be:
(a) $6.28 \times 10^{-5}V$ (b) $6.0 \times 10^{-5}V$ (c) $4.8 \times 10^{-5}V$ (d) $1.6 \times 10^{-5}V$

Solution:

For each spoke the induced emf between the centre and the rim will be the same,

$$\mathcal{E} = (1/2) B \omega L^2 = B \times 3.14 \times L^2 f \quad (\text{since } \omega = 2 \times 3.14 \times f)$$

Further for all spokes, the centre will be positive while rim will be negative. Thus all emf's are parallel hence total emf independent of the number of spokes.

$$\mathcal{E} = B \times 3.14 \times L^2 \times f$$

Substituting the values,

$$\mathcal{E} = 4 \times 10^{-5} \times 3.14 \times 0.5^2 \times 2 = 6.28 \times 10^{-5}V$$

4. A coil of area $0.2 m^2$ rotates at half a revolution per second in a uniform magnetic field of $0.2T$ perpendicular to the axis of rotation of coil. What is the maximum voltage generated in the coil ?

Solution:

$$\mathcal{E}_0 = NBA\omega = 1 \times 0.2 \times 0.2 \times 2 \times 3.14 \times 0.5 = 0.125 V$$

5. A ring rotates with angular velocity ω about an axis perpendicular to the plane of the ring passing through the centre of the ring. A constant magnetic field B exists parallel to the axis. Find the emf induced in the ring

Solution:

Flux passing through the ring $\Phi = B.A$ is a constant, therefore emf induced in the coil is zero

6. The flux linked with a ring at any time t is given by
 $\Phi = 5t^2 - 30t + 150$. What is the induced emf at $t = 2s$?

Solution:

$$5t^2 - 30t + 150$$

$$E = -d\Phi / dt = -(10t - 30) = -10t + 30$$

$$\text{At } t = 2s, \quad -10 \times 2 + 30 = 10V$$

7. A current in a circuit falls from $5A$ to $0A$ in $0.1s$ if an average emf of $200V$ induced, give an estimate of self inductance of the circuit.

Solution:

$$\mathcal{E} = -L dI / dt$$

$$200 = -L(0.5) / 0.1 = 50L$$

$$\text{Or } L = 200/50 = 4H$$

8. A train is running on meter gauge at a speed of 36 km/hr. what will be the emf generated between the railway lines if the vertical component of the earth field is $4 \times 10^{-5}T$

Solution:

$$B = 4 \times 10^{-5}T \quad L = 1m \quad V = 36km/hr = 10m/s$$

$$\mathcal{E} = BLV = 4 \times 10^{-5} \times 1 \times 10 = 4 \times 10^{-4}V$$

Radius of the wire is decreasing such that $dr/dt = 0.1cm/s$ in a region of normal magnetic field of $2T$. Find the induced emf at an instant when $r = 0.1m$

Solution:

$$\mathcal{E} = -d\Phi/dt = -dB\pi r^2/dt = -B\pi dr^2/dt = -B\pi 2rdr/dt = 4\pi \times 10^{-4}V$$

9. A step down transformer converts transmission line voltage from 2200 V to 220V. Primary coil is having 5000 turns. Efficiency of transformer is 90% and output power is 8Kw. Evaluate number of turns in secondary coil and input

Solution:

$$\text{Efficiency } \eta = P_o/P_i$$

$$P_i = P_o / \eta = 8kW / 0.90 = 8.88Kw$$

$$E_s/E_p = N_s/N_p$$

$$\text{So, } N_s = (E_s/E_p)N_p = 220 \times 5000 / 2200 = 500$$

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Chapter 7

Alternating Currents

1. A 100 ohm resistor is connected to a 220V, 50Hz AC supply.

- what is the rms value of current in the circuit
- What is the power consumed over a full cycle

Solution:

$$R = 100 \text{ ohm}, V_{\text{rms}} = 220\text{V}, f = 50\text{Hz}$$

$$\text{a) current in the circuit } I_{\text{rms}} = \frac{V_{\text{rms}}}{R} = \frac{220}{100} = 2.2\text{A}$$

$$\text{b) Net power consumed in full cycle } P = V_{\text{rms}} I_{\text{rms}} = 220 \times 2.2 = 484 \text{ W}$$

2. (a) The peak value of AC supply is 300V. What is the rms voltage.?

- (b) The rms value of current in an AC circuit is 10A. What

Is the peak current?

Solution:

$$V_0 = 300\text{V}, I_{\text{rms}} = 10\text{A}$$

$$\text{a) } V_{\text{rms}} = \frac{V_0}{\sqrt{2}} = \frac{300}{\sqrt{2}} = 212.1\text{V}$$

$$\text{b) } I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$I_0 = \sqrt{2} I_{\text{rms}} = \sqrt{2} \times 10 = 14.14\text{A}$$

3. A 44mH inductor is connected to 220V, 50Hz AC supply. Determine the rms value of current in the circuit

Solution:

$$L = 44\text{mH} = 44 \times 10^{-3}\text{H}, V_{\text{rms}} = 220\text{V}, f = 50\text{Hz}$$

$$X_L = 2\pi fL = 2 \times 3.14 \times 50 \times 44 \times 10^{-3} = 13.82 \text{ ohm}$$

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{X_L} = \frac{220}{13.82} = 15.92\text{A}$$

4. A 60μF capacitor is connected to a 110V, 60Hz AC supply. Determine the rms value of current in the circuit

Solution:

$$C = 60\mu\text{F} = 60 \times 10^{-6}\text{F}, V_{\text{rms}} = 110\text{V}, f = 60\text{Hz}$$

$$X_c = \frac{1}{2\pi f C} = \frac{1}{3 \times 3.14 \times 60 \times 60 \times 10^{-6}} = 44.23\Omega$$

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{X_c} = \frac{110}{44.23} = 2.49\text{ A}$$

5. A charged $30\mu\text{F}$ capacitor is connected to a 27mH inductor. What is the angular frequency of free oscillations of circuit.

Solution:

$$C = 30\mu\text{F} = 30 \times 10^{-6}\text{F}, L = 27\text{mH} = 27 \times 10^{-3}\text{H}$$

For free oscillations angular frequency should be resonant frequency

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{27 \times 10^{-3} \times 30 \times 10^{-6}}} = 1.1 \times 10^3 \text{ rad/s}$$

6. A series LCR circuit with $R = 20\Omega$, $L = 1.5\text{H}$, $C = 35\mu\text{F}$ is connected to a variable frequency of 200V AC supply. When the frequency of supply equals the natural frequency of the circuit, what is the average power transferred to the circuit in one complete cycle

Solution:

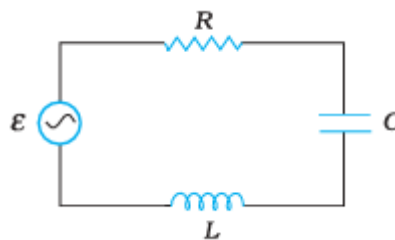
$$R = 20\Omega, L = 1.5\text{H}, C = 35\mu\text{F} = 35 \times 10^{-6}\text{F}, V_{\text{rms}} = 200\text{V}$$

At resonance $Z = R$

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{200}{20} = 10\text{A}, \Phi = 0$$

$$\text{Power, } P = V_{\text{rms}} I_{\text{rms}} \cos \Phi = 10 \times 200 \times \cos 0 = 2000\text{W}$$

7. Figure shows a series LCR circuit connected to a variable frequency of 230V . $L = 50\text{H}$, $C = 80\mu\text{F}$, $R = 40\Omega$



- (a) Determine the source frequency which drives the circuit in resonance.
 (b) Obtain the impedance of the circuit and the amplitude of current at the resonating frequency. (c) Determine the rms potential drops across the three elements of the circuit. Show that the potential drop across the LC combination is zero at the resonating frequency

Solution:

$$a) \omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5 \times 80 \times 10^{-6}}} = 50 \text{ rad/s}$$

$$\text{source frequency } \nu_0 = \frac{\omega_r}{2\pi} = 7.96 \text{ Hz}$$

b) At resonance, $X_L = X_C$ so $Z = R = 40 \text{ ohm}$

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{230}{40} = 5.75 \text{ A}$$

$$I_0 = \sqrt{2} I_{\text{rms}} = \sqrt{2} \times 5.75 = 8.13 \text{ A}$$

c) The rms potential drop across L

$$V_L = I_{\text{rms}} X_L = I_{\text{rms}} L \omega_r = 5.75 \times 50 \times 5 = 1437.5 \text{ V}$$

The rms potential drop across R

$$V_R = I_{\text{rms}} R = 5.75 \times 40 = 230 \text{ V}$$

The rms potential drop across C

$$V_C = I_{\text{rms}} X_C = I_{\text{rms}} \times \frac{1}{\omega_r C} = 5.75 \times \frac{1}{50 \times 80 \times 10^{-6}} = 1437.5 \text{ V}$$

Potential drop across LC combinations

$$V_{\text{rms}} = I_{\text{rms}} (X_L - X_C) = 0$$

Because At resonance $X_L = X_C$

8. A sinusoidal voltage of peak value 283V and frequency 50 Hz is applied to a series LCR circuit in which $R = 3 \text{ ohm}$, $L = 25.48 \text{ mH}$ and $C = 796 \mu\text{F}$. Find the impedance of the circuit

Solution:

$$R = 3 \text{ ohm}, L = 25.48 \text{ mH} = 25.48 \times 10^{-3} \text{ H and } C = 796 \mu\text{F} = 796 \times 10^{-6} \text{ F}$$

$$\nu = 50 \text{ Hz}$$

$$X_L = 2\pi\nu L = 2 \times 3.14 \times 50 \times 25.48 \times 10^{-3} = 8 \text{ ohm}$$

$$X_C = \frac{1}{2\pi\nu C} = X_C = \frac{1}{2 \times 3.14 \times 50 \times 796 \times 10^{-6}} = 4 \text{ ohm}$$

$$\text{Impedance } Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{3^2 + (8 - 4)^2} = \sqrt{25} = 5 \text{ ohm}$$

9. A power transmission line feeds input power at 3300V to a step down transformer with its primary windings having 6000 turns. What should be the number of turns in the secondary in order to get out put power at 220V

Solution:

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

$$V_p = 3300 \text{ V}, N_p = 6000, V_s = 220\text{V}, N_s = ?$$

$$N_s = \frac{V_s}{V_p} \times N_p = \frac{220}{3300} \times 6000 = 400$$

10. The equation of ac is given by

$$V = 200\sqrt{2} \sin(100\pi t) \text{ .Find rms value and frequency}$$

Solution:

$$V_0 = 200\sqrt{2} \text{ V}, \omega = 100\pi$$

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}} = \frac{200\sqrt{2}}{\sqrt{2}} = 200\text{V}$$

$$\omega = 2\pi\nu$$

$$\nu = \frac{\omega}{2\pi} = \frac{100\pi}{2\pi} = 50\text{Hz}$$

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Chapter 8

Electromagnetic Waves

1. A plane electromagnetic wave travels in freespace along the X-direction. At a particular point in space and time, $E_0 = 3.3 \hat{j} V/m$. what is B_0 at this point.

Solution:

$$B_0 = \frac{E_0}{c} = \frac{3.3}{3 \times 10^8} = 1.1 \times 10^{-8} T$$

B is along the Z-direction

$$B_0 = 1.1 \times 10^{-8} \hat{k} T$$

2. The electric field in a plane electromagnetic wave is given by $E_z = 60 \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t) V/m$.
 - a. What is the wavelength and frequency of the wave?
 - b. Write an expression for the magnetic field

Solution:

$$a. E_z = 60 \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t) V/m$$

Comparing with the equation $E_z = E_0 \sin(kx + \omega t)$

$$E_0 = 60, k = 0.5 \times 10^3, \omega = 1.5 \times 10^{11}$$

$$k = \frac{2\pi}{\lambda} = 500$$

$$\text{Wavelength } \lambda = \frac{2\pi}{500} = 1.26 \times 10^{-2} m$$

$$\omega = 2\pi\nu = 1.5 \times 10^{11}$$

$$\text{Frequency } \nu = \frac{1.5 \times 10^{11}}{2\pi} = 2.39 \times 10^{10} Hz$$

$$b. \frac{E_0}{B_0} = c$$

$$B_0 = \frac{E_0}{c} = \frac{60}{3 \times 10^8} = 2 \times 10^{-7} T$$

Magnetic field along the Y- direction

$$B_y = 2 \times 10^{-7} \sin(0.5 \times 10^3 x + 1.5 \times 10^{11} t) T$$

3. Light with an energy flux of $6W/m^2$ falls on a non reflecting surface at normal incidence. If the surface has an area of $12m^2$, find the average force exerted on the surface during a 30 minute time span.

Solution:

The total energy falling on the surface is

$$U = 6W/m^2 \times 12 \times 30 \times 60$$

$$= 1.3 \times 10^5 J$$

The total momentum delivered

$$P = \frac{U}{c} = \frac{1.3 \times 10^5}{3 \times 10^8} = 4.33 \times 10^{-4} Kgm/s$$

The average force exerted on the surface

$$F = \frac{P}{t} = \frac{4.33 \times 10^{-4}}{30 \times 60} = 2.4 \times 10^{-7} N$$

4. A parallel plate capacitor is made of circular plates each of radius 6cm and separated by 5cm. The capacitor is being charged by an external source. The charging current is 0.2A.
- Calculate the capacitance and the rate of change of potential difference between the plates
 - Obtain the displacement current across the plates

Solution:

$$a. r = 6cm = 6 \times 10^{-2} m$$

$$d = 5cm = 5 \times 10^{-2} m$$

$$Area = \pi r^2 = 3.14 \times (6 \times 10^{-2})^2 = 1.13 \times 10^{-2} m^2$$

$$Capacitance C = \frac{\epsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 1.13 \times 10^{-2}}{5 \times 10^{-2}} = 2 \times 10^{-12} F$$

$$q = CV$$

$$\frac{dq}{dt} = C \frac{dV}{dt}$$

$$I = C \frac{dV}{dt}$$

$$\therefore \text{rate of change of potential difference, } \frac{dV}{dt} = \frac{I}{C}$$

$$= \frac{0.2}{2 \times 10^{-12}} = 1 \times 10^{11} V/s$$

- b. Displacement current across the plates would be same as the conduction current,

$$\text{Displacement Current} = 0.2 A$$

5. In a plane EM wave, the electromagnetic field oscillates at a frequency of 25 MHz and amplitude 480V/m. Find the amplitude of the oscillating magnetic field.

Solution:

$$E_0 = 480V/m$$

$$B_0 = \frac{E_0}{c} = \frac{480}{3 \times 10^8} = 1.6 \times 10^{-6}T$$

6. A plane electromagnetic wave is travelling through space along the Z direction. If the electric field is along the X direction,
- a) What is the direction of the magnetic field? b) If the frequency of the wave is 50MHz, what is its wavelength?

Solution:

a. The magnetic field is along the Y-direction.

b. $C = v\lambda$

$$C = 3 \times 10^8 m/s$$

$$\nu = 50MHz = 50 \times 10^6 Hz$$

$$\lambda = \frac{C}{\nu} = \frac{3 \times 10^8}{5 \times 10^6} = 6m$$

7. A radio can tune into any station in the 5MHz to 12 MHz band. What is the corresponding wavelength band?

Solution:

Minimum frequency, $\nu_1 = 5MHz = 5 \times 10^6 Hz$

$$\text{Wavelength, } \lambda_1 = \frac{C}{\nu_1} = \frac{3 \times 10^8}{5 \times 10^6} = 60m$$

Maximum frequency, $\nu_2 = 12MHz$

$$\text{Wavelength, } \lambda_2 = \frac{C}{\nu_2} = \frac{3 \times 10^8}{12 \times 10^6} = 25m$$

The corresponding wavelength band would be between 60m and 25m.

8. A parallel plate capacitor made of circular plates each of radius 12cm has a capacitance 200PF. The capacitor is connected to a 230V ac supply with an angular frequency of 300rad/sec. What is the rms value of the conductor current?

Solution:

$$C = 200PF = 200 \times 10^{-12}F$$

$$\text{Rms value of the Conductor current, } I = \frac{V}{X_c}$$

$$\text{Capacitive reactance, } X_c = \frac{1}{C\omega}$$

$$\therefore I = \frac{V}{1/C\omega} = V \times C\omega$$

$$= 230 \times 200 \times 10^{-12} \times 300 = 1.38 \times 10^{-5}A$$

9. Suppose that the electric field amplitude of an electromagnetic wave is $E_0 = 100 \text{ N/C}$ and its frequency is $\nu = 50 \text{ MHz}$. Determine B_0 , ω , λ and K

Solution:

$$\frac{E_0}{B_0} = C$$

$$\therefore B_0 = \frac{E_0}{C} = \frac{100}{3 \times 10^8} = 3.33 \times 10^{-7}T$$

$$\omega = 2\pi\nu = 2\pi \times 50 \times 10^6 = 3.14 \times 10^8 \text{ rad/sec}$$

$$\lambda = \frac{C}{\nu} = \frac{3 \times 10^8}{50 \times 10^6} = 6m$$

$$K = \frac{2\pi}{\lambda} = \frac{2\pi}{6} = 1.05m^{-1}$$

10. The amplitude of the magnetic field part of a harmonic electromagnetic wave in vacuum is 1620 nT . What is the amplitude of the electric field part of the wave?

Solution:

$$B_0 = 1620 \text{ nT} = 1620 \times 10^{-9}T$$

$$\text{Amplitude of the electric field part } E_0 = B_0 \times C$$

$$= 1620 \times 10^{-9} \times 3 \times 10^8 = 486 \text{ V/m}$$

Chapter 9

Ray Optics and Optical Instruments

RAY OPTICS

1. In Youngs double slit experiment distance between slits is halved and distance between screen and slit is doubled . What will happen to the bandwidth produced?

a) No change b) Doubled c) Increases 4 times d) Decreases 4 times

Solution:

Increases 4 times

2. Velocity of light in a medium is 2.25×10^8 m/s . Refractive index of the medium is

Solution:

$$n = \frac{c}{v} = \frac{3 \times 10^8}{2.25 \times 10^8} = 1.33$$

3. The apparent depth of an object at the bottom of a tank filled with a liquid of refractive index 1.62 is 8.5 cm .What is the actual depth of the liquid in the tank?

Solution:

$$n = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$\text{Real depth} = n \times \text{Apparent depth} = 1.62 \times 8.5 = 13.77 \times 10^{-2} \text{ m}$$

4. An astronomical telescope of angular magnification 10 has a tube length of 44 cm.What is the focal length of the objective lens?

Solution:

$$\text{Angular magnification , } m = \frac{f_o}{f_e}, \quad 10 = \frac{f_o}{f_e}, \quad f_e = \frac{f_o}{10}$$

$$\text{Tube length} = f_o + f_e, \quad 44 = f_o + \frac{f_o}{10}, \quad \text{Focal length of objective lens, } f_o = 40 \text{ cm}$$

5. A telescope has an objective of focal length 1.44 m and an eyepiece of focal length .06 m .What is the separation between the objective and the eye piece?

Solution:

$$\text{Separation} = \text{length of the telescope} = f_o + f_e = 1.44 + .06 = 1.5 \text{ m}$$

6. Two thin convex lenses of focal lengths 10 cm and 20 cm are kept in contact with each other. Find the equivalent focal length and power of combination.

Solution:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{10} + \frac{1}{20} = \frac{3}{20}$$

$$f = 6.67 \text{ cm}$$

$$P = \frac{1}{f} = \frac{10^2}{6.67} = 14.9 \text{ dioptres}$$

7. A convex lens of refractive index 1.5 is immersed in a medium of refractive index 1.65. Will the lens now act as converging or diverging lens? Explain

Solution:

Refractive index of glass with respect to the refractive index of medium is less than 1. So focal length is negative according to the relation, $\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right) \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Hence the lens will act as diverging lens.

8. The refractive index of glass is 1.5 and that of water is 1.33. If the speed of light in water is $2.26 \times 10^8 \text{ m/s}$. what is the speed of light in glass?

Solution:

$$n_g = 1.5$$

$$n_w = 1.33$$

$$n_g = \frac{c}{v_g} = 1.5$$

$$n_w = \frac{c}{v_w} = 1.33$$

$$\frac{n_w}{n_g} = \frac{v_g}{v_w} = \frac{1.33}{1.5}$$

$$v_g = \frac{1.33}{1.5} v_w = \frac{1.33 \times 2.26 \times 10^8}{1.5} = 2.0 \times 10^8 \text{ m/s}$$

9. Two lens of power -15 D and +5 D are in contact with each other. Calculate the focal length of the combination.

Solution:

$$\text{Power of combination } P = P_1 + P_2 = -15 + 5 = -10 \text{ D}$$

$$\text{Focal length of combination } f = \frac{1}{P} = \frac{1}{-10} = -0.1 \text{ m}$$

10. Calculate the critical angle of a medium in which light travels with a speed of $2.12 \times 10^8 \text{ m/s}$

Solution:

$$n = \frac{c}{v} = \frac{3 \times 10^8}{2.12 \times 10^8} = 1.415$$

$$\text{Sinc} = \frac{1}{n}$$

$$\text{Critical angle } C = \sin^{-1}\left(\frac{1}{n}\right) = \sin^{-1}\left(\frac{1}{1.415}\right) = 45^\circ$$

11. In Youngs double slit experiment ,interference pattern is observed at 5 cm from the slits with a fringe width of 1mm.Calculate the separation between slits .($\lambda = 5000 \text{ \AA}$)

Solution:

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

$$d = \frac{\lambda D}{\beta} = \frac{5 \times 10^{-7}}{1 \times 10^{-3}} \times \frac{5 \times 10^{-2}}{1} = .025 \text{ mm}$$

12. A double convex lens of radii of curvatures 10 cm and 15 cm have a focal length of 12 cm . Find the refractive index of the material of the lens.

Solution:

$$R_1 = 10 \text{ cm} \quad R_2 = -15 \text{ cm} \quad f = 12 \text{ cm}$$

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

$$\frac{1}{12} = (n - 1) \left(\frac{1}{10} - \frac{1}{-15} \right) = (n - 1) \times \frac{1}{6}$$

$$n = 1.5$$

13. A small candle of size 3 cm is placed in front of a concave mirror with a focal length of 18 cm . A virtual image is formed at a distance of 10 cm from the mirror .Calculate the object distance .Also describe the nature and size of the image.

Solution:

$$h = 3 \text{ cm} , \quad f = -20 \text{ cm} , \quad v = 10 \text{ cm}$$

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

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

$$= \frac{1}{-20} - \frac{1}{10} = \frac{-30}{200}$$

$$\text{Object distance , } u = -6.6 \text{ cm}$$

$$\text{Magnification, } m = \frac{-v}{u} = \frac{-10}{-6.6} = 1.51$$

Image is virtual and large

14. How long will the light take in travelling a distance of 600 m in water ? Refractive index of water is 1.33.

Solution:

$$\text{Speed of light in water, } v_w = \frac{c}{n_w} = \frac{3 \times 10^8}{1.33} = 2.26 \times 10^8 \text{ m/s}$$

$$\text{Time taken to travel 600 m in water , } t = \frac{\text{distance}}{\text{speed}} = \frac{600}{2.26 \times 10^8} = 265 \times 10^{-8} \text{ s}$$

15. Find the position of an object which when placed in front of a concave mirror of focal length 20 cm produces a real image which is twice the size of the object.

Solution:

$$f = -20 \text{ cm}, \quad m = -2 \quad (\text{for real image magnification is negative}), \quad u = ?$$

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

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

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

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

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

$$\text{Magnification, } m = \frac{-v}{u} = \frac{-f}{u-f}$$

$$-2 = \frac{-(-20)}{u-(-20)}$$

$$-2 = \frac{20}{u+20}$$

$$-2u - 40 = 20$$

$$\text{Object distance} = U = -30 \text{ cm}$$

16. Data of some lenses are given below

LENS	POWER	APERTURE
L_1	6D	1 cm
L_2	3D	8 cm
L_3	10 D	1 cm

Choose any two lenses which are to be preferred as objective and eyepiece to construct a telescope. Give reasons for your selection.

Solution:

L_2 – Objective

L_3 - Eye piece

Power of eye piece should be greater than the power of objective

17. A small bulb is placed at the bottom of a tank containing water to a depth of 1 m.

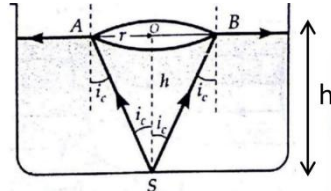
What is the area of the surface of water through which light from the bulb can emerge out? Refractive index of water is 1.33. (Consider the bulb to be a point source)

Solution:

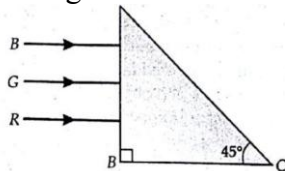
Given, $h = 1\text{ m}$, $n_w = 1.33$, From ΔSOB , $\sin i_c = \frac{1}{n_w}$, $\sin i_c = \frac{1}{1.33}$, $i_c = 48.75^\circ$

$\tan i_c = \frac{r}{h}$, $r = h \tan i_c$, $r = 1 \times \tan 48.75^\circ = 1.131\text{ m}$

Area of the surface of water, $A = \pi r^2 = 3.14 \times (1.131^2) = 4\text{ m}^2$



18. Three rays of light red, green and blue are incident on a right angled prism, as shown in figure. The refractive indices of the material of the prism for red, green and blue wavelengths is 1.39, 1.44 and 1.47 respectively. Out of the three which colour will emerge out of the face AC? Justify your answer. Trace the path of these rays after passing through face AB.



Solution:

For total internal reflection, angle of incidence should be greater than critical angle, $i > C$

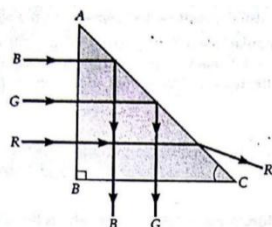
For all the colours, $i = 45^\circ$ and $C = \sin^{-1}\left(\frac{1}{n}\right)$

For blue, $C = \sin^{-1}\left(\frac{1}{1.47}\right) = 42.86^\circ$

For green, $C = \sin^{-1}\left(\frac{1}{1.44}\right) = 43.98^\circ$

For red, $C = \sin^{-1}\left(\frac{1}{1.39}\right) = 46^\circ$

So for red light alone, angle of incidence $<$ critical angle. So blue and green will undergo total internal reflection, while red will emerge out of the face AC.



19. The radii of curvature of both the surfaces of a lens are equal. How will the focal length and power of lens change if one of the surfaces is made plane?

Solution:

For original lens, by sign convention, $R_1 = R$ and $R_2 = -R$

Lens makers formula , $\frac{1}{f} = (n_{21} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$

$$\frac{1}{F} = (n_{21} - 1) \left(\frac{1}{R} + \frac{1}{R} \right) = (n_{21} - 1) \left(\frac{2}{R} \right)$$

When one of the surfaces is made plane $R_1 = R$ and $R_2 = \infty$

So

$$\frac{1}{f^1} = (n_{21} - 1) \left(\frac{1}{R} \right)$$

$$\frac{f^1}{f} = 2, \quad f^1 = 2f$$

So focal length becomes double and power becomes half

20. Radii of curvature of both the surfaces of a lens are equal. If it is immersed in water what will be its effect on the power of the lens ?

Solution:

Lens makers formula $\frac{1}{f} = (n_{21} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$

Power , $P = (n_{21} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$

Power of lens in air , $P_{GA} = (n_{GA} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$

Power of lens in water, $P_{GW} = (n_{GW} - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$

Since $n_{GW} < n_{GA}$, Power of lens will be decreased when it is immersed in water.

Chapter 10

Wave Optics

WAVE OPTICS

1. Wavelength of light in air is $6000\text{\AA}$. Calculate the wavelength in water and glass. Given refractive index of water is $4/3$ and glass is 1.5

Solution:

Frequency remains unchanged

$$\lambda = 6000\text{\AA} = 6000 \times 10^{-10} \text{ m} \quad \text{speed of light } C = 3 \times 10^8 \text{ m/s}$$

$$c = v\lambda$$

$$v = \frac{c}{\lambda} = \frac{3 \times 10^8}{6000 \times 10^{-10}} = 5 \times 10^{14} \text{ Hz}$$

wave length in water, $n = 4/3$

$$n = \frac{c}{v}$$

$$v = \frac{c}{n} = \frac{3 \times 10^8}{4/3} = 9/4 \times 10^8 \text{ m/s}$$

$$\text{wavelength } \lambda = \frac{v}{f} = \frac{9 \times 10^8}{5 \times 10^{14}} = 4500 \times 10^{-10} = 4500\text{\AA}$$

Wave length in glass $n = 1.5$

$$v = \frac{c}{n} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ m/s}$$

$$\lambda = \frac{v}{f} = \frac{2 \times 10^8}{5 \times 10^{14}} = 4000 \times 10^{-10} = 4000\text{\AA}$$

2. In an interference pattern, the ratio of maximum intensity to minimum intensity is $25:1$. Find the ratio of amplitude of intensities of two interfering waves.

Solution:

$$\text{given, } \frac{I_{\max}}{I_{\min}} = \frac{25}{1}$$

$$\frac{a_1}{a_2} = ? , \quad \frac{I_1}{I_2} = ?$$

$$\frac{I_{\max}}{I_{\min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{25}{1}$$

$$\frac{(a_1 + a_2)}{(a_1 - a_2)} = \frac{5}{1}$$

$$4a_1 = 6a_2$$

$$\frac{a_1}{a_2} = 3/2$$

$$\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \left(\frac{3}{2}\right)^2 = 9/4$$

3. Two wavelengths λ_1 and λ_2 are used in young's double slit experiment $\lambda_1 = 430\text{nm}$. What is the value of λ_2 if 4th bright band of one coincides with 6th bright band of other.

Solution:

$$\text{Distance to } n^{\text{th}} \text{ bright band, } x_n = \frac{n\lambda D}{d}$$

$$x_4 = x_6$$

$$\frac{4\lambda_1 D}{d} = \frac{6\lambda_2 D}{d}$$

$$4\lambda_1 = 6\lambda_2$$

$$\lambda_2 = \frac{4\lambda_1}{6} = \frac{4 \times 430 \times 10^{-7}}{6}$$

$$= 286.7 \times 10^{-7} = 286.7\text{nm}$$

4. What is the effect on interference fringes in Young's double slit experiment when
- (a) distance between slit and screen(D) is increased
 - (b) wavelength λ of light is decreased
 - (c) separation between slit is increased
 - (d) Monochromatic source is replaced by white light

Solution:

$$\text{Distance to } n^{\text{th}} \text{ bright band, } x_n = \frac{n\lambda D}{d}$$

a) $x_n \propto D$, As D is increased x_n increases or fringe width increases

b) $x_n \propto \lambda$, As λ is decreased x_n decreases or fringe width decreases

c) $x_n \propto \frac{1}{d}$, d is increased x_n decreases

d) coloured pattern is seen with white at the centre

5. Plane wave of wavelength 600nm is incident normally on a slit of width 0.18mm .calculate the total angular width of central maximum in the diffraction pattern

Solution:

$$a\theta = n\lambda \quad n=1 \text{ for central maximum}$$

$$\theta = \frac{n\lambda}{a} = \frac{1 \times 600 \times 10^{-9}}{0.18 \times 10^{-3}} = 3.3 \times 10^{-3} \text{ on either side}$$

$$\text{total width} = 2\theta = 6.6 \times 10^{-3} \text{ rad}$$

Chapter 11

Dual Nature of Radiation and Matter

- Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W
 - What is the energy of a photon in the light beam?
 - How many photons per second on an average are emitted by the source?

Solution:

- Each photon has an energy: $E = h\nu = 6.63 \times 10^{-34} \text{ Js} \times 6.0 \times 10^{14} \text{ Hz} = 3.98 \times 10^{-19} \text{ J}$
- Number of photons emitted per second, the power p transmitted in the beam equals N times the energy per photon

$$P = NE \Rightarrow N = \frac{P}{E} = \frac{2.0 \times 10^{-3} \text{ W}}{3.98 \times 10^{-19} \text{ J}} = 5.0 \times 10^{15} \text{ photons per second}$$

- The work function of caesium is 2.14 eV. Find the threshold frequency for caesium and the wavelength of the incident light if the photocurrent is brought to zero by a stopping potential of 0.60 V.

Solution:

$$\text{Threshold Frequency } \nu_0 = \frac{\phi_0}{h} = \frac{2.14 \times 1.6 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ Js}} = 5.16 \times 10^{14} \text{ Hz}$$

$$\text{Wavelength : } \lambda = \frac{hc}{eV_0 + \phi_0} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{(0.60 \text{ eV} + 2.14 \text{ eV})} = \frac{19.89 \times 10^{-26} \text{ Jm}}{2.74 \times 1.6 \times 10^{-19} \text{ J}} = 454 \text{ nm}$$

- Calculate the de Broglie wavelength of a ball of mass 0.12 kg moving with a speed of 20 m/s.

Solution:

$$\text{Momentum } P = mv = 0.12 \text{ kg} \times 20 \text{ m/s} = 2.40 \text{ kg m/s}$$

$$\text{Wavelength : } \lambda = \frac{h}{P} = \frac{6.63 \times 10^{-34} \text{ Js}}{2.40 \text{ kg m/s}} = 2.76 \times 10^{-34} \text{ m}$$

- What is the de Broglie wavelength associated with:
 - an electron moving with the speed of $5.4 \times 10^6 \frac{\text{m}}{\text{s}}$
 - a ball of mass 150g travelling at 30.0 m/s

Solution:

$$\text{a) For electron: } \lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 5.4 \times 10^6} = 0.135 \text{ nm}$$

$$\text{b) For ball: } \lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{150 \times 10^{-3} \times 30} = 1.47 \times 10^{-34} \text{ m}$$

- Find the a) maximum frequency and b) minimum wavelength of X-rays produced by 30 kV electrons.

Solution:

Max Frequency

$$V = 30 \times 10^3 \text{ V}$$

$$\nu = \frac{eV}{h} = \frac{1.6 \times 10^{-19} \times 30 \times 10^3}{6.63 \times 10^{-34}} = 7.25 \times 10^{18} \text{ Hz}$$

$$\text{b) Min Wavelength : } \lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{7.25 \times 10^{18}} = 0.414 \times 10^{-10} \text{ m}$$

6. The work function of caesium metal is 2.14 eV. When light of frequency 6×10^{14} Hz is incident, find: a) Maximum kinetic energy of electrons b) Stopping potential c) Maximum speed of photo electrons

Solution:

$$\text{a) } K.E_{\max} = h\nu - \phi. K.E = (6.63 \times 10^{-34} \times 6 \times 10^{14}) - (2.14 \times 1.6 \times 10^{-19}) = 0.548 \times 10^{-19} \text{ J}$$

$$\text{b) } V_0 = \frac{K.E_{\max}}{e} : V_0 = \frac{0.548 \times 10^{-19}}{1.6 \times 10^{-19}} = 0.3425 \text{ V}$$

$$\text{c) } \frac{1}{2}mv_{\max}^2 = K.E_{\max} : v_{\max}^2 = \frac{2 \times 0.548 \times 10^{-19}}{9.1 \times 10^{-31}} = 0.1204 \times 10^{12} v_{\max} = 344 \times 10^3 \text{ m/s}$$

7. The photoelectric cut-off in a certain experiment is 1.5 V. What is the maximum Kinetic energy of photoelectrons?

Solution:

$$K.E_{\max} = eV_0 = 1.6 \times 10^{-19} \times 1.5 = 2.4 \times 10^{-19} \text{ J}$$

8. Helium-neon laser ($\lambda = 632.8 \text{ nm}$) with Power = 9.42 mW: a) Find energy and momentum of each photon b) Photons per second c) Velocity of Hydrogen atom with same momentum

Solution:

$$\text{a) Energy: } E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{632.8 \times 10^{-9}} = 3.14 \times 10^{-19} \text{ J}$$

$$\text{Momentum: } p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{632.8 \times 10^{-9}} = 1.044 \times 10^{-27} \text{ kg m/s}$$

$$\text{b) Photons: } N = \frac{P}{E} = \frac{9.42 \times 10^{-3} \text{ W}}{3.14 \times 10^{-19} \text{ J}} = 3 \times 10^{16} \text{ photons/s}$$

$$\text{c) Velocity: } v = \frac{p}{m} = \frac{1.044 \times 10^{-27}}{1.67 \times 10^{-27}} = 0.625 \text{ m/s}$$

9. Slope of cut-off voltage vs frequency is 4.12×10^{-15} Vs. Find Planck's constant.

Solution:

$$\text{Slope} = \frac{h}{e} \Rightarrow h = \text{Slope} \times e$$

$$h = 4.12 \times 10^{-15} \times 1.6 \times 10^{-19} = 6.6 \times 10^{-34} \text{ Js}$$

10. Threshold frequency = 3.3×10^{14} Hz. Incident frequency = 8.2×10^{14} Hz. Find cut-off voltage.

Solution:

$$eV_0 = h(\nu - \nu_0)$$

$$V_0 = \frac{6.6 \times 10^{-34} (8.2 \times 10^{14} - 3.3 \times 10^{14})}{1.6 \times 10^{-19}} \approx 2 \text{ V}$$

11. Metal work function = 4.2 eV. Incident $\lambda = 330 \text{ nm}$. Will emission occur?

Solution:

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{330 \times 10^{-9} \times 1.6 \times 10^{-19}} = 3.75 \text{ eV}$$

Since $\phi_0 > E$, emission is not possible.

12. Metal surface with $\nu = 7.21 \times 10^{14} \text{ Hz}$ and $v_{\max} = 6 \times 10^5 \text{ m/s}$. Find threshold frequency.

Solution:

$$\nu_0 = \nu - \frac{\frac{1}{2}mv_{\max}^2}{h}$$

$$\nu_0 = 7.21 \times 10^{14} - \frac{0.5 \times 9.1 \times 10^{-31} \times (6 \times 10^5)^2}{6.6 \times 10^{-34}} = 4.73 \times 10^{14} \text{ Hz}$$

13. Wavelength = 488 nm, stopping potential = 0.38 V. Find work function.

Solution:

$$\phi_0 = \frac{hc}{\lambda} - eV_0$$

$$\phi_0 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{488 \times 10^{-9}} - 0.38 \text{ eV} = 2.16 \text{ eV}$$

14. Find de Broglie wavelength of: a) Bullet (0.040 kg) at 1.0 km/s b) Ball (0.060 kg) at 1.0 m/s c) Dust particle ($1.0 \times 10^{-9} \text{ kg}$) at 2.2 m/s

Solution:

$$\text{a) } \lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{0.04 \times 1000} = 1.65 \times 10^{-35} \text{ m}$$

$$\text{b) } \lambda = \frac{6.6 \times 10^{-34}}{0.06 \times 1} = 1.1 \times 10^{-32} \text{ m}$$

$$\text{c) } \lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{1 \times 10^{-9} \times 2.2} = 3 \times 10^{-23} \text{ m}$$

15. Wavelength = 332 nm, work function = 1.07 eV. Find stopping potential.

Solution:

$$V_0 = \frac{hc}{e\lambda} - \frac{\phi_0}{e}$$

$$V_0 = 3.73 - 1.07 = 2.66 \text{ V}$$

Chapter 12

Atoms

1. In a Geiger-Marsden experiment, what is the distance of closest approach to the nucleus of a 7.7 MeV α -particle before it comes momentarily to rest and reverses its direction?

Solution:

$$\text{Kinetic Energy, } E_k = \frac{1}{4\pi\epsilon_0} \frac{2e \cdot Ze}{d}$$

$$\text{Distance, } d = \frac{2Ze^2}{4\pi\epsilon_0 E_k}$$

$$\text{Calculation: } d = \frac{2 \times 79 \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2}{7.7 \times 10^6 \times 1.6 \times 10^{-19} \text{ J}} = 2.95 \times 10^{-14} \text{ m}$$

2. It is found experimentally that 13.6 eV energy is required to separate a hydrogen atom into a proton and an electron. Compute the orbital radius and the velocity of the electron.

Solution:

$$\text{Total energy } E = -13.6 \text{ eV} = -2.2 \times 10^{-18} \text{ J}$$

$$\text{Radius } r = \frac{e^2}{8\pi\epsilon_0 E} = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{2 \times 2.2 \times 10^{-18}} = 5.3 \times 10^{-11} \text{ m}$$

$$\text{The velocity } v \text{ formula: } v = \frac{e}{\sqrt{4\pi\epsilon_0 mr}}$$

3. Calculate the initial frequency of the light emitted by the electron revolving around a proton in hydrogen atom.

Solution:

The frequency of electromagnetic waves is equal to the frequency of revolution.

$$\text{Given } r = 5.3 \times 10^{-11} \text{ m and } v = 2.2 \times 10^6 \text{ m/s}$$

$$\nu = \frac{v}{2\pi r} = \frac{2.2 \times 10^6}{2 \times 3.14 \times 5.3 \times 10^{-11}}$$

4. A difference of 2.3 eV separates two energy levels in an atom. What is the frequency of radiation emitted?

Solution:

$$E = h\nu$$

$$\nu = \frac{2.3 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = 5.56 \times 10^{14} \text{ Hz}$$

5. The ground state energy of hydrogen atom is -13.6 eV. What are the Kinetic and potential energies?

Solution:

$$\text{Total Energy (TE)} = -13.6 \text{ eV}$$

$$\text{Relation: } KE = -\frac{1}{2}PE$$

$$PE = -27.2 \text{ eV}$$

$$KE = 13.6 \text{ eV}$$

6. A hydrogen atom excites to the $n = 4$ level. Determine the wavelength and frequency.

Solution:

$$E_1 = -13.6 \text{ eV and } E_4 = -0.85 \text{ eV}$$

$$\Delta E = E_4 - E_1 = 12.75 \text{ eV}$$

$$\text{Frequency } \nu = \frac{\Delta E}{h} = 3.08 \times 10^{15} \text{ Hz}$$

$$\text{Wavelength } \lambda = \frac{c}{\nu} = 974 \text{ Å}$$

7. The radius of the innermost electron orbit of a hydrogen atom is $5.3 \times 10^{-11} \text{ m}$. What are the radii of the $n=2$ and $n=3$ orbits?

Solution:

$$r_n = 5.3 \times 10^{-11} \cdot n^2 \text{ m}$$

$$n = 2: r = 21.1 \times 10^{-11} \text{ m}$$

$$n = 3: r = 47.7 \times 10^{-11} \text{ m}$$

8. Find the quantum number that characterises the earth's revolution around the sun $r = 1.5 \times 10^{11} \text{ m}$, $v = 3 \times 10^4 \text{ m/s}$

Solution:

$$mvr = \frac{nh}{2\pi}$$

$$n = \frac{2\pi \times 6 \times 10^{24} \times 3 \times 10^4 \times 1.5 \times 10^{11}}{6.63 \times 10^{-34}} = 2.56 \times 10^{74}$$

9. Find the wavelength of the electron in the ground state of hydrogen atom $r = 0.53 \times 10^{-10} \text{ m}$

Solution:

$$2\pi r = n\lambda$$

$$\text{For } n = 1: \lambda = 2 \times 3.14 \times 0.53 \times 10^{-10} = 3.32 \text{ Å}$$

10. The total energy in the first excited state is -3.4 eV . Find KE and PE.

Solution:

$$KE = -E = +3.4 \text{ eV}$$

$$PE = -2KE = -6.8 \text{ eV}$$

Chapter 13

Nuclei

1. Obtain the binding energy of a nitrogen nucleus ${}^{14}_7\text{N}$, given mass of ${}^{14}_7\text{N} = 14.00307 \text{ u}$.

Solution:

Atomic mass of nitrogen (m): 14.00307 u .

Composition: A nucleus of ${}^{14}_7\text{N}$ contains 7 protons and 7 neutrons.

Mass defect (Δm): $\Delta m = 7m_H + 7m_n - m$

Mass of a proton $m_H = 1.007825 \text{ u}$.

Mass of a neutron $m_n = 1.008665 \text{ u}$.

$$\Delta m = 7 \times 1.007825 + 7 \times 1.008665 - 14.00307$$

$$\Delta m = 7.054775 + 7.060655 - 14.00307 = 0.11236 \text{ u}$$

Binding Energy (E_b):

Using $1 \text{ u} = 931.5 \text{ MeV}/c^2$.

$$E_b = \Delta m \times c^2$$

$$E_b = 0.11236 \times 931.5 \left(\frac{\text{MeV}}{c^2} \right) \times c^2 = 104.66334 \text{ MeV}.$$

The binding energy is 104.66334 MeV .

2. Obtain the binding energy of the nuclei ${}^{56}_{26}\text{Fe}$ and ${}^{209}_{83}\text{Bi}$ in units of MeV from the following data:

$$m({}^{56}_{26}\text{Fe}) = 55.934939 \text{ u}$$

$$m({}^{209}_{83}\text{Bi}) = 208.980388 \text{ u}.$$

Solution:

for ${}^{56}_{26}\text{Fe}$:

Composition: 26 protons and 30 neutrons ($56 - 26 = 30$).

Mass defect (Δm):

$$\Delta m = 26 \times 1.007825 + 30 \times 1.008665 - 55.934939$$

$$\Delta m = 26.20345 + 30.25995 - 55.934939 = 0.528461 \text{ u}.$$

Binding Energy (E_{b1}):

$$E_{b1} = 0.528461 \times 931.5 = 492.26 \text{ MeV}.$$

Average binding energy per nucleon: $\frac{492.26}{56} = 8.79 \text{ MeV}.$

A for ${}^{209}_{83}\text{Bi}$:

Composition: 83 protons and 126 neutrons ($209 - 83 = 126$).

Mass defect (Δm):

$$\Delta m = 83 \times 1.007825 + 126 \times 1.008665 - 208.980388$$

$$\Delta m = 83.649475 + 127.091790 - 208.980388 = 1.760877 \text{ u}.$$

Binding Energy (E_{b2}):

$$E_{b2} = 1.760877 \times 931.5 = 1640.26 \text{ MeV}.$$

Average binding energy per nucleon: $\frac{1640.26}{209} = 7.848 \text{ MeV}.$

3. A coin has a mass of 3.0g. Calculate the nuclear energy required to separate all neutrons and protons. Assume it is entirely made of ${}^{63}_{29}\text{Cu}$ atoms (mass 62.92960 u)

Solution:

Number of atoms (N):

$$N = \frac{\text{Avogadro's number} \times \text{mass}}{\text{Mass number}}.$$

$$N = \frac{6.023 \times 10^{23} \times 3}{63} = 2.868 \times 10^{22} \text{ atoms}.$$

Mass defect per nucleus (Δm°):

$$\Delta m = 29 \times 1.007825 + 34 \times 1.008665 - 62.9296 = 0.591935 \text{ u}.$$

Total mass defect of the coin (Δm):

$$\Delta m = 0.591935 \times 2.868 \times 10^{22} = 1.69766958 \times 10^{22} \text{ u}.$$

Total Binding Energy (E_b):

$$E_b = (1.69766958 \times 10^{22} \times 931.5) \text{ MeV} = 1.581 \times 10^{25} \text{ MeV}.$$

$$\text{Converted to Joules: } 1.581 \times 10^{25} \times 1.6 \times 10^{-13} = 2.5296 \times 10^{12} \text{ J}.$$

4. Obtain approximately the ratio of the nuclear radii of the gold isotope ${}^{197}_{79}\text{Au}$ and the silver isotope ${}^{107}_{47}\text{Ag}$.

Solution:

Mass numbers: $A_{Au} = 197, A_{Ag} = 107.$

Formula: Nuclear radius R is related to mass number A by $R = R_0 A^{1/3}.$

$$\text{Ratio: } \frac{R_{Au}}{R_{Ag}} = \left(\frac{197}{107} \right)^{1/3} = 1.2256.$$

Conclusion: The ratio is about **1.23**

5. Determine the Q-value for: (i) ${}^1_1\text{H} + {}^3_1\text{H} \rightarrow {}^2_1\text{H} + {}^2_1\text{H}$
 (ii) ${}^{12}_6\text{C} + {}^{12}_6\text{C} \rightarrow {}^{20}_{10}\text{Ne} + {}^4_2\text{He}$.

Solution:

$$(i): Q = [1.007825 + 3.016049 - 2 \times 2.014102] \times 931.5$$

$$Q = -0.00433 \times 931.5 = -4.0334 \text{ MeV.}$$

Negative Q-value means the reaction is **endothermic**.

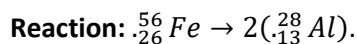
$$(ii): Q = [2 \times 12.0 - 19.992439 - 4.002603] \times 931.5$$

$$Q = 0.004958 \times 931.5 = 4.618377 \text{ eV}$$

Positive Q-value means the reaction is **exothermic**.

6. Is the fission of ${}^{56}_{26}\text{Fe}$ into two equal fragments of ${}^{28}_{13}\text{Al}$ energetically possible?.

Solution:



Q-value: $Q = [55.93494 - 2 \times 27.98191] \times 931.5$

$$Q = -0.02888 \times 931.5 = -26.902 \text{ MeV.}$$

Conclusion: Fission is **not possible** energetically because the Q-value is negative.

7. Show that nuclear matter density is nearly constant and independent of A.

Solution:

Formula: $\rho = \frac{\text{Mass}}{\text{Volume}}$.

Mass of nucleus: mA (where m is average mass of a nucleon).

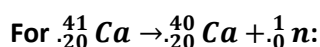
Volume: $\frac{4}{3}\pi R^3 = \frac{4}{3}\pi(R_0 A^{1/3})^3 = \frac{4}{3}\pi R_0^3 A$.

Density: $\rho = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$.

Result: Since m and R_0 are constants, density is independent of A.

8. Obtain the neutron separation energies for ${}^{41}_{20}\text{Ca}$ and ${}^{27}_{13}\text{Al}$.

Solution:



$$\Delta m = 39.962591 + 1.008665 - 40.962278 = 0.008978 \text{ u.}$$

$$E = 0.008978 \times 931.5 = 8.363007 \text{ MeV.}$$

For ${}_{13}^{27}\text{Al}$ Separation energy is **13.059 MeV**.

9. If India targets 200,000 MW electric power, 10% from nuclear, efficiency 25%, how much ${}^{235}\text{U}$ is needed per year?.

Solution:

Total nuclear power required: $10\% \times 2 \times 10^5 \text{ MW} = 2 \times 10^4 \text{ MW} = 2 \times 10^{10} \text{ J/s}$.

Total energy per year: $2 \times 10^{10} \times 365 \times 24 \times 3600 \text{ J/y}$

Energy per fission (25% efficiency): $200 \text{ MeV} \times 0.25 = 50 \text{ MeV}$

Mass needed per year: $3.076 \times 10^4 \text{ kg}$

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Chapter 14

Semiconductor Electronics: Materials, Devices and Simple Circuits

1. What is the order of band gap (E_g) in case intrinsic semiconductors Ge and Si?
 $5K\Omega$ (b) $10K\Omega$ (c) 10Ω (d) 5Ω

Solution:

The forbidden band (E_g) is about 0.72 eV for germanium and about 1.1 eV for silicon.

2. When the voltage drop across a p-n junction is increased from 0.65 V to 0.70 V, the change in the diode current is 5mA. What is the dynamical resistance of the diode?

Solution:

$$R = \frac{\Delta V}{\Delta I} = \frac{0.05}{5 \times 10^{-3}} = 10\Omega$$

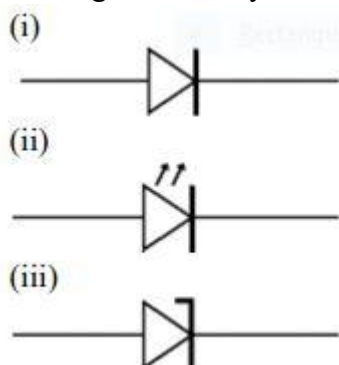
3. The intrinsic carrier concentration is given as $n_i = 1.5 \times 10^{16} \text{ m}^{-3}$ in a silicon crystal at room temperature if every millionth silicon atom is replaced by an atom of indium. If the concentration in Si-atoms is $5 \times 10^{28} \text{ m}^{-3}$, find out the electron concentration.

Solution:

$$\text{The number of indium atoms added to Si-crystal is} = \frac{5 \times 10^{28}}{10^6} = 5 \times 10^{22} \text{ m}^{-3}$$

$$n_i^2 = n_e n_h; n_e = \frac{n_i^2}{n_h} = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{22}} = 4.5 \times 10^9 \text{ m}^{-3}$$

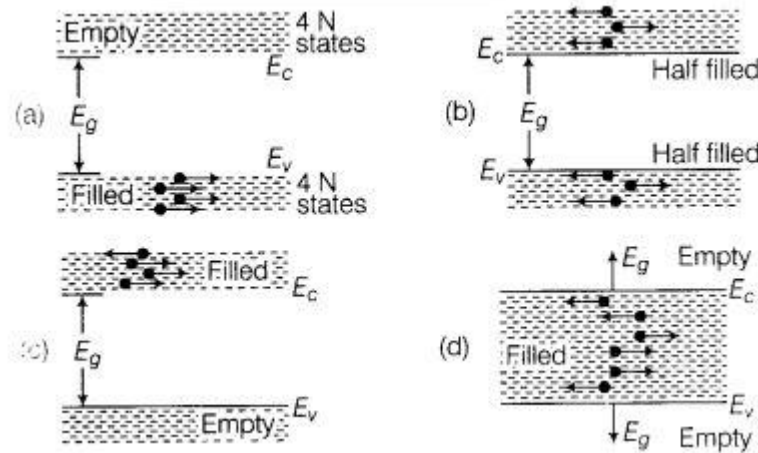
4. Diodes are one of the building elements of electronic circuits. Some types of diodes are shown in the figure, Identify the rectifier diode from the figure.



Solution:

Option (i)

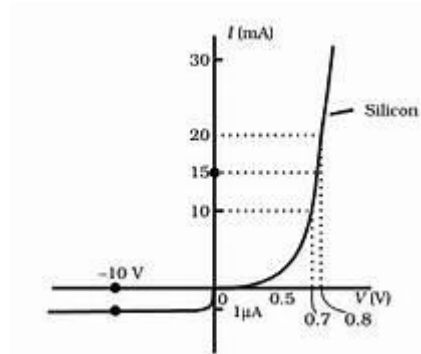
5. The following diagram shows energy bands in a semiconductor, which diagram shows energy band positions at 0K.



Solution:

Option (a)

6. The V-I characteristic of a silicon diode is shown in the figure below. Calculate the resistance of the diode at (a) $I_D = 15 \text{ mA}$ and (b) $V_D = -10 \text{ V}$.



Solution:

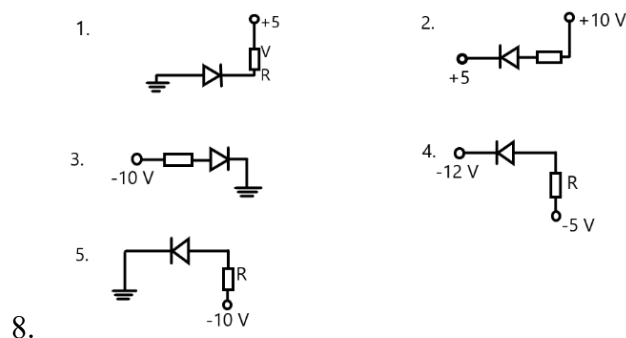
(a) Dynamic resistance in forward biased region

$$r_d = \frac{\Delta V}{\Delta I} = \frac{(0.8 - 0.7)V}{(20 - 10)mA} = \frac{0.1}{10 \times 10^{-3}} = 10\Omega$$

(b) The resistance in reverse biased region

$$r_d = \frac{10V}{1\mu A} = \frac{10V}{1 \times 10^{-6} A} = 1 \times 10^7 \Omega$$

7. In the following diagrams indicate which of the diodes are forward biased and reverse biased.



Solution:

Option (2) and (4)

In figure 1, the n-type is connected to +5V (positive terminal) and p-type is connected to earth (negative terminal). This means that the barrier potential of the n-terminal will be higher than the p-terminal. Therefore, it is reverse biased.

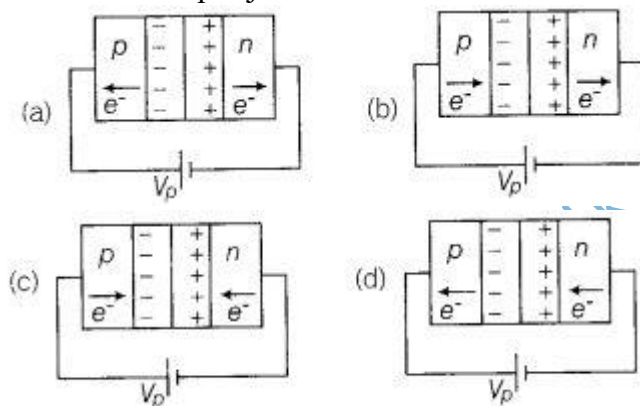
In figure 2, the p-type is connected to +10V and the n-type is connected to +5V. Therefore, it will be forward biased.

In figure 3 also, the barrier potential of n-terminal is greater than the p-terminal. Hence, it is reverse biased.

In figure 4, the n-type is connected to -12V and the p-type is connected to -5V. This means that the potential of p-terminal is higher than the n-terminal. Therefore, it is forward biased.

In figure 5, again the potential of n-terminal is greater than the p-terminal, hence, it is reverse biased.

9. Forward biased p-n junction diodes are shown in the figure.



Identify the figure, which shows the correct direction of flow of charges

Solution:

Option (d)

10. The depletion layer in a silicon diode is $1\mu\text{m}$ wide and its knee potential is 0.6 V, then the electric field in the depletion layer will be?

Solution:

$$\text{Electric field intensity, } E = \frac{\Delta V}{\Delta x} = \frac{0.6}{10^{-6}} = 6 \times 10^5 \text{ V/m}$$

i.

Credits

1. Shini C
2. Sitara V
3. Sabitha E
4. Muhammed Afsal
5. Bindu M
6. Sabira M
7. Sreeshyju K P
8. Seema P
9. Smitha A
10. Anooja M
11. Sujith. P

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