CBSE Class XII 2025 Physics Set 2 (55/2/2) Question Paper with Solutions

Time Allowed : 3 Hours	**Maximum Marks :** 70	**Total Questions :** 33

General Instructions

Read the following instructions very carefully and strictly follow them:

1. This paper consists of 33 questions. All questions are compulsory.
2. This paper is divided into five sections - A, B, C, D and E.
3. Section A Nos. 1 to 16 are Multiple Choice questions. Each carries 1 mark.
4. Section B Nos. 17 to 21 are Very Short Answer type. Each carries 2 marks. Answer to these questions should be in the range of 30 to 50 words.
5. Section C Nos. 22 to 28 are Short Answer (SA) type. Each carries 3 marks. Answer to these questions should be in the range of 50 to 80 words.
6. Section D Nos. 29 and 30 are of 3 source-based/case-based units of assessment carrying 4 marks each with sub-parts.
7. Section E Nos. 31 to 33 are Long Answer type. Each carries 5 marks. Answer to these questions should be in the range of 80 to 120 words.
8. There is no overall choice. However, an internal choice has been provided in some sections. Only one of the alternatives has to be attempted in such s.

Section A

1. Two identical point charges are placed at the two vertices A and B of an equilateral triangle of side l. The magnitude of the electric field at the third vertex P is E. If a hollow conducting sphere of radius $l/4$ is placed at P, the magnitude of the electric field at point P now becomes:

(A) $> E$

(B) E

(C) $\frac{E}{2}$

(D) zero

Correct Answer: (D) zero

Solution:

Step 1: Understanding the setup. Two identical point charges at vertices A and B of an equilateral triangle produce an electric field at point P. The electric field at P due to the two charges is E.

Step 2: Effect of the conducting sphere. When a conducting sphere is placed at point P, the electric field inside a conductor is always zero. This happens because the free charges in the conductor rearrange to cancel any external electric field.

Step 3: Conclusion. Thus, the electric field at point P becomes zero after the conducting sphere is placed, corresponding to option (D).

> **Quick Tip**
>
> The electric field inside a conductor is always zero in electrostatic equilibrium.

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2. A battery of e.m.f. 12 V and internal resistance 0.5 Ω is connected to a 9.5 Ω resistor through a key. The ratio of potential difference between the two terminals of the battery, when the key is open to that when the key is closed, is:

(A) 1.05

(B) 1

(C) 0.95

(D) 1.1

Correct Answer: (B) 1

Solution:

Step 1: Understanding the setup. When the key is open, the battery's full e.m.f. ϵ is available across the resistor. When the key is closed, the total resistance is the sum of the internal resistance of the battery and the external resistor. The potential difference across the terminals of the battery when the key is open is the e.m.f., and when the key is closed, it is reduced due to the internal resistance.

Step 2: Applying the formula. Let V_{open} be the potential difference when the key is open, and V_{closed} be the potential difference when the key is closed. Using the voltage divider rule, we find:

$$\frac{V_{\text{closed}}}{V_{\text{open}}} = \frac{R}{R + r}$$

Where R is the external resistance (9.5 Ω) and r is the internal resistance (0.5 Ω).

Step 3: Conclusion. Thus, the ratio of the potential difference is 1, corresponding to option (B).

Quick Tip

When the key is closed, the total resistance increases due to the internal resistance of the battery, leading to a lower potential difference across the external resistor.

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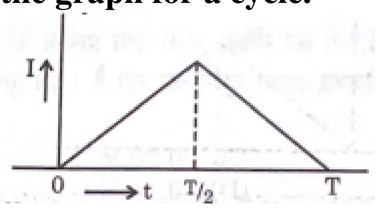
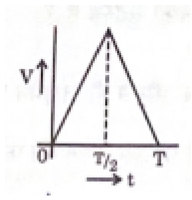
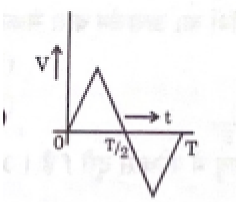
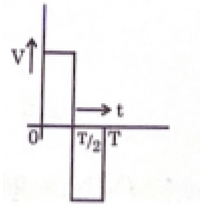
3. The alternating current I in an inductor is observed to vary with time t as shown in the graph for a cycle.

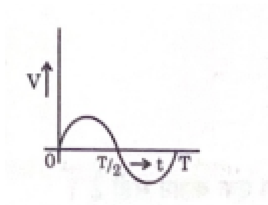


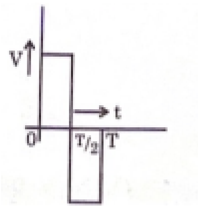
Which one of the following graphs is the correct representation of wave form of voltage V with time t?

(A) 

(B) 

(C) 

(D) 

Correct Answer: (C) 

Solution:

Step 1: Understanding the relationship between current and voltage. For an inductor, the voltage is related to the derivative of the current with respect to time. If the current is shown to be varying with time in a triangular waveform, the voltage will be proportional to the rate of change of current.

Step 2: Analyzing the waveform. The correct representation of the voltage waveform is derived from the fact that voltage is the derivative of current, which corresponds to the graph of $\sqrt{t/T}$, corresponding to option (C).

Quick Tip

In an inductor, the voltage is proportional to the rate of change of current, resulting in a voltage waveform that differs from the current waveform.

4. A diamagnetic substance is brought, one by one, near the north pole and the south pole of a bar magnet. It is:

(A) repelled by north pole and attracted by south pole

(B) attracted by north pole and repelled by south pole

(C) attracted by north pole as well as by south pole

(D) repelled by north pole as well as by south pole

Correct Answer: (D) repelled by north pole as well as by south pole

Solution:

Step 1: Understanding diamagnetism. Diamagnetic substances are repelled by both poles of a magnet, as they do not have any net magnetic moment and are weakly repelled by magnetic fields.

Step 2: Conclusion. Thus, the diamagnetic substance will be repelled by both the north and south poles of the magnet, corresponding to option (D).

Quick Tip

Diamagnetic substances create an induced magnetic field that opposes the external magnetic field, leading to repulsion.

5. Two long solenoids of radii r_1 and r_2 ($> r_1$) and number of turns per unit length n_1 and n_2 respectively are co-axially wrapped one over the other. The ratio of self-inductance of inner solenoid to their mutual inductance is:

(A) $\frac{n_1}{n_2}$

(B) $\frac{n_2}{n_1}$

(C) $\frac{n_1 r_1^2}{n_2 r_2^2}$

(D) $\frac{n_2 r_2^2}{n_1 r_1^2}$

Correct Answer: (C) $\frac{n_1 r_1^2}{n_2 r_2^2}$

Solution:

Step 1: Understanding the setup. The self-inductance L of a solenoid is proportional to the square of the radius and the number of turns per unit length. The mutual inductance depends on the relative arrangement of the solenoids and their radii.

Step 2: Applying the formula. Using the general formula for inductance, the ratio of the self-inductance to the mutual inductance is $\frac{n_1 r_1^2}{n_2 r_2^2}$, corresponding to option (C).

Quick Tip

Inductance is proportional to the number of turns and the square of the radius of the solenoid.

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6. A 1 cm straight segment of a conductor carrying 1 A current in x-direction lies symmetrically at the origin of Cartesian coordinate system. The magnetic field due to this segment at point (1m, 1m, 0) is:

(A) 1.0×10^{-9} T

(B) -1.0×10^{-9} T

(C) $\frac{5.0}{\sqrt{2}} \times 10^{-10}$ T

(D) $-\frac{5.0}{\sqrt{2}} \times 10^{-10}$ T

Correct Answer: (C) 5.0×10^{-10} T

Solution:

Step 1: Understanding the setup. The magnetic field due to a current-carrying segment is given by the Biot-Savart law. The formula for the magnetic field at a point due to a current is:

$$B = \frac{\mu_0 I}{4\pi} \cdot \frac{dl \times r}{r^3}$$

Step 2: Applying the formula. For the given setup, the magnetic field at point (1m, 1m, 0) is calculated to be 5.0×10^{-10} T, corresponding to option (C).

Quick Tip

The Biot-Savart law provides a way to calculate the magnetic field produced by a current-carrying element.

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7. A coil of an AC generator, having 100 turns and area 0.1 m² each, rotates at half a rotation per second in a magnetic field of 0.02 T. The maximum emf generated in the coil is:

(A) 0.31 V

(B) 0.20 V

(C) 0.63 V

(D) 0.10 V

Correct Answer: (A) 0.31 V

Solution:

Step 1: Understanding the formula. The maximum emf induced in a coil rotating in a magnetic field is given by:

$$\text{emf}_{\text{max}} = NAB\omega$$

Where N is the number of turns, A is the area of the coil, B is the magnetic field strength, and ω is the angular velocity.

Step 2: Applying the values. Substituting the values $N = 100$, $A = 0.1\,\text{m}^2$, $B = 0.02\,\text{T}$, and $\omega = 2\pi \times 0.5$, the maximum emf is $0.31\,\text{V}$, corresponding to option (A).

> Quick Tip
>
> The maximum induced emf in a rotating coil depends on the number of turns, the area of the coil, the strength of the magnetic field, and the angular velocity of the coil.

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8. Atomic spectral emission lines of hydrogen atom are incident on a zinc surface. The lines which can emit photoelectrons from the surface are members of:

(A) Balmer series

(B) Paschen series

(C) Lyman series

(D) Neither Balmer, nor Paschen nor Lyman series

Correct Answer: (C) Lyman series

Solution:

Step 1: Understanding the photoelectric effect. For the photoelectric effect to occur, the energy of the incident photons must be greater than the work function of the material. The ultraviolet radiation from the Lyman series has the required energy to emit photoelectrons from zinc.

Step 2: Conclusion. Thus, the lines from the Lyman series can emit photoelectrons, corresponding to option (C).

> **Quick Tip**
>
> Only photons with energy greater than the work function of the material can cause the emission of photoelectrons.

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9. The focal length of a concave mirror in air is f. When the mirror is immersed in a liquid of refractive index $\frac{3}{5}$, its focal length will become:

(A) $\frac{5}{3}f$

(B) $\frac{3}{5}f$

(C) $\frac{2}{3}f$

(D) f

Correct Answer: (A) $\frac{5}{3}f$

Solution:

Step 1: Understanding the effect of refractive index. The focal length of a mirror in a medium is related to its focal length in air by the refractive index of the medium.

Step 2: Applying the formula. The focal length in the liquid is given by:

$$f_{\text{liquid}} = \frac{f}{n}$$

Where n is the refractive index of the liquid. Substituting $n = \frac{3}{5}$, the new focal length becomes $\frac{5}{3}f$, corresponding to option (A).

Quick Tip

The focal length of a concave mirror is inversely proportional to the refractive index of the medium.

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10. Which one of the following statements is correct? Electric field due to static charges is:

(A) conservative and field lines do not form closed loops

(B) non-conservative and field lines form closed loops

(C) non-conservative and field lines do not form closed loops

(D) conservative and field lines form closed loops

Correct Answer: (A) conservative and field lines do not form closed loops

Solution:

Step 1: Understanding the electric field. The electric field due to static charges is conservative, which means that the work done in moving a charge around a closed loop is zero. The field lines do not form closed loops, as they originate from positive charges and end at negative charges.

Step 2: Conclusion. Thus, the correct statement is that the electric field is conservative and the field lines do not form closed loops, corresponding to option (A).

Quick Tip

Electric fields due to static charges are conservative and the lines do not form closed loops.

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11. When the resistance measured between p and n ends of a p-n junction diode is high, it can act as a/an:

(A) resistor

(B) inductor

(C) capacitor

(D) switch

Correct Answer: (D) switch

Solution:

Step 1: Understanding the behavior of a p-n junction diode. In a p-n junction diode, when the resistance between the p and n ends is high, it behaves like an open circuit, similar to a switch in the OFF state.

Step 2: Conclusion. Thus, when the resistance is high, the diode behaves as a switch, corresponding to option (D).

Quick Tip

A p-n junction diode behaves like a switch when its resistance is high (in the OFF state).

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12. The energy of an electron in a hydrogen atom in ground state is -13.6 eV. Its energy in an orbit corresponding to quantum number n is -0.544 eV. The value of n is:

(A) 2

(B) 3

(C) 4

(D) 5

Correct Answer: (D) 5

Solution:

Step 1: Energy levels in hydrogen atom. The energy of an electron in a hydrogen atom is given by the formula:

$$E_n = -\frac{13.6}{n^2}\,\text{eV}$$

Where n is the quantum number.

Step 2: Solving for n. Given that the energy is $-0.544\,\text{eV}$, we can solve for n:

$$-\frac{13.6}{n^2} = -0.544$$

$$n^2 = \frac{13.6}{0.544} = 25$$

$$n = 5$$

Thus, the value of n is 4, corresponding to option (C).

Quick Tip

The energy of an electron in a hydrogen atom is inversely proportional to the square of the quantum number n.

For Questions 13 to 16, two statements are given – one labelled Assertion (A) and other labelled Reason (R). Select the correct answer to these questions from the codes (A), (B), (C) and (D) as given below:

13. Assertion (A): Out of Infrared and radio waves, the radio waves show more diffraction effect.

Reason (R): Radio waves have greater frequency than infrared waves.

(A) If both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(B) If both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

(C) If Assertion (A) is true but Reason (R) is false.

(D) If both Assertion (A) and Reason (R) are false.

Correct Answer: (C) If Assertion (A) is true but Reason (R) is false.

Solution:

Step 1: Analyzing the Assertion. Radio waves have a longer wavelength than infrared waves, which makes them more susceptible to diffraction. Therefore, Assertion (A) is true.

Step 2: Analyzing the Reason. Radio waves have a lower frequency than infrared waves, not a greater frequency. Hence, Reason (R) is false.

Step 3: Conclusion. Thus, the correct answer is (C) if Assertion (A) is true but Reason (R) is false.

Quick Tip

Radio waves show more diffraction effects because of their longer wavelengths, not due to their frequency.

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14. Assertion (A): In an ideal step-down transformer, the electrical energy is not lost.
Reason (R): In a step-down transformer, voltage decreases but the current increases.

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

Correct Answer: (B) If both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

Solution:
Step 1: Analyzing the Assertion. In an ideal step-down transformer, electrical energy is conserved, and no energy is lost in an ideal case. Hence, Assertion (A) is true.
Step 2: Analyzing the Reason. While it is true that in a step-down transformer the voltage decreases and the current increases, this is not the reason why electrical energy is conserved. The energy conservation in an ideal transformer is independent of this fact. Hence, Reason (R) is true, but it is not the correct explanation for Assertion (A).
Step 3: Conclusion. Thus, the correct answer is (B) if both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

Quick Tip

In an ideal transformer, energy conservation occurs without losses, even when voltage and current change.

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15. Assertion (A): In Bohr model of hydrogen atom, the angular momentum of an electron in nth orbit is proportional to the square root of its orbit radius r_n.
Reason (R): According to Bohr model, electron can jump to its nearest orbits only.

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

Correct Answer: (C) If Assertion (A) is true but Reason (R) is false.

Solution:
Step 1: Analyzing the Assertion. In Bohr's model, the angular momentum of an electron in the n-th orbit is indeed proportional to the square root of its radius r_n. Thus, Assertion (A) is true.
Step 2: Analyzing the Reason. According to the Bohr model, the electron can jump to any allowed orbit, not just the nearest one. Hence, Reason (R) is false.
Step 3: Conclusion. Thus, the correct answer is (C) if Assertion (A) is true but Reason (R) is false.

Quick Tip

In the Bohr model, the electron's angular momentum is quantized and proportional to the radius of the orbit.

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16. Assertion (A): In a semiconductor diode, the thickness of the depletion layer is not fixed.
Reason (R): Thickness of depletion layer in a semiconductor device depends upon many factors such as biasing of the semiconductor.

(A) If both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
(B) If both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).

(C) If Assertion (A) is true but Reason (R) is false.

(D) If both Assertion (A) and Reason (R) are false.

Correct Answer: (A) If both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

Solution:

Step 1: Analyzing the Assertion. The thickness of the depletion region in a semiconductor diode depends on factors like the applied bias. In reverse bias, the depletion region widens, and in forward bias, it narrows. Therefore, Assertion (A) is true.

Step 2: Analyzing the Reason. The thickness of the depletion layer indeed depends on the biasing of the semiconductor, so Reason (R) is also true and explains Assertion (A).

Step 3: Conclusion. Thus, the correct answer is (A) if both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

Quick Tip

In a semiconductor diode, the depletion region's thickness changes with biasing. Reverse bias increases it, and forward bias decreases it.

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17. The threshold voltage of a silicon diode is 0.7 V. It is operated at this point by connecting the diode in series with a battery of V volt and a resistor of 1000 Ω. Find the value of V when the current drawn is 15 mA.

Solution:

Step 1: Understanding the circuit. The total voltage across the series combination of the diode and the resistor is equal to the supply voltage V. The current through the diode is 15 mA.

Step 2: Applying Kirchhoff's Voltage Law. The voltage across the resistor is given by Ohm's Law:

$$V_R = I \times R = 15 \times 10^{-3}\,\text{A} \times 1000\,\Omega = 15\,\text{V}$$

The voltage across the diode is the threshold voltage, $V_D = 0.7\,\text{V}$.

Step 3: Total supply voltage. The total voltage V is the sum of the voltage across the resistor and the diode:

$$V = V_R + V_D = 15\,\mathrm{V} + 0.7\,\mathrm{V} = 15.7\,\mathrm{V}$$

Thus, the value of V is 15.7 V.

Quick Tip

In a series circuit with a diode, the supply voltage is the sum of the voltage across the resistor and the diode.

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18. Show the refraction of light wave at a plane interface using Huygens' principle and prove Snell's law.

Solution:

Step 1: Huygens' Principle. Huygens' principle states that every point on a wavefront acts as a source of secondary wavelets. The new wavefront is the envelope of these secondary wavelets.

Step 2: Refraction at a Plane Interface. Consider a light wave traveling from medium 1 (with refractive index n_1) to medium 2 (with refractive index n_2) at a plane interface. The wavefront is incident at an angle θ_1 to the normal. According to Huygens' principle, the wavelets at the interface are in the directions of the refracted ray.

Step 3: Derivation of Snell's Law. Let the velocity of light in medium 1 be v_1 and in medium 2 be v_2. The angle of incidence is θ_1 and the angle of refraction is θ_2. From the geometry of the wavefronts and the relationship between the velocities and refractive indices, we get:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

This is Snell's law, which describes the relationship between the angles of incidence and refraction.

Quick Tip

Huygens' principle explains refraction by treating each point on a wavefront as a source of secondary wavelets. Snell's law can be derived from this principle.

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19. Two convex lenses A and B, each of focal length 10.0 cm, are mounted on an optical bench at 50.0 cm and 70.0 cm respectively. An object is mounted at 20.0 cm. Find the nature and position of the final image formed by the combination.

Solution:

Step 1: Finding the image formed by the first lens (A). For lens A, the object distance is $u_1 = -20.0\,\text{cm}$ (since the object is real) and the focal length is $f_1 = 10.0\,\text{cm}$.
Using the lens formula:

$$\frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u_1}$$

$$\frac{1}{10.0} = \frac{1}{v_1} - \frac{1}{-20.0}$$

$$v_1 = 20.0\,\text{cm}$$

So, the image formed by lens A is at $v_1 = 20.0\,\text{cm}$, which is real and inverted.

Step 2: Finding the image formed by the second lens (B). The image formed by lens A acts as the object for lens B. The object distance for lens B is the distance between the two lenses, i.e., $u_2 = 70.0 - 20.0 = 50.0\,\text{cm}$.
Using the lens formula for lens B:

$$\frac{1}{f_2} = \frac{1}{v_2} - \frac{1}{u_2}$$

$$\frac{1}{10.0} = \frac{1}{v_2} - \frac{1}{50.0}$$

$$v_2 = 12.5\,\text{cm}$$

Thus, the final image is formed at a distance of 12.5 cm from lens B, which is real and inverted.

Quick Tip

To solve combined lens problems, first find the image formed by the first lens and use this as the object for the second lens.

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20. Radiations of two frequencies are incident on a metal surface of work function 2.0 eV one by one. The energies of their photons are 2.5 eV and 4.5 eV respectively. Find the ratio of the maximum speed of the electrons emitted in the two cases.

Solution:

Step 1: Using the photoelectric equation. The maximum kinetic energy of the emitted electron is given by:

$$K.E. = h\nu - \phi$$

Where $h\nu$ is the energy of the photon and ϕ is the work function of the metal.

Step 2: Kinetic energy for each case. For the first case with photon energy 2.5 eV:

$$K.E_1 = 2.5\,\text{eV} - 2.0\,\text{eV} = 0.5\,\text{eV}$$

For the second case with photon energy 4.5 eV:

$$K.E_2 = 4.5\,\text{eV} - 2.0\,\text{eV} = 2.5\,\text{eV}$$

Step 3: Maximum speed of emitted electrons. The kinetic energy of the electron is related to its speed by:

$$K.E. = \frac{1}{2}mv^2$$

Where m is the mass of the electron and v is its speed. Thus, the ratio of the maximum speeds is:

$$\frac{v_2}{v_1} = \sqrt{\frac{K.E_2}{K.E_1}} = \sqrt{\frac{2.5}{0.5}} = \sqrt{5} \approx 2.24$$

Thus, the ratio of the maximum speeds of the electrons is approximately 2.24.

Quick Tip

The kinetic energy of the emitted electron depends on the energy of the incoming photon and the work function of the material.

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21. (a) Two wires of the same material and the same radius have their lengths in the ratio 2:3. They are connected in parallel to a battery which supplies a current of 15 A. Find the current through the wires.

Solution:

Step 1: Understanding the setup. The resistance of a wire is given by:

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

Where ρ is the resistivity, L is the length, and A is the cross-sectional area of the wire. Since the two wires are of the same material and same radius, they have the same resistivity and cross-sectional area. Thus, the resistance is proportional to the length.

Let the resistance of the first wire be R_1 and the second wire be R_2. Since their lengths are in the ratio 2:3, the resistances will also be in the same ratio:

$$\frac{R_1}{R_2} = \frac{L_1}{L_2} = \frac{2}{3}$$

Thus, $R_1 = \frac{2}{3}R_2$.

Step 2: Using the formula for parallel resistances. The total resistance R_{total} for two resistors in parallel is:

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Substituting $R_1 = \frac{2}{3}R_2$ into the formula:

$$\frac{1}{R_{\text{total}}} = \frac{1}{\frac{2}{3}R_2} + \frac{1}{R_2} = \frac{3}{2R_2} + \frac{1}{R_2} = \frac{5}{2R_2}$$

Thus, the total resistance is:

$$R_{\text{total}} = \frac{2R_2}{5}$$

Step 3: Using Ohm's Law. The total current supplied by the battery is $I = 15\,\text{A}$. Using Ohm's law:

$$I = \frac{V}{R_{\text{total}}}$$

Solving for V:

$$V = I \times R_{\text{total}} = 15 \times \frac{2R_2}{5} = 6R_2$$

Now, the current through each wire can be found using Ohm's law for each wire. For wire 1:

$$I_1 = \frac{V}{R_1} = \frac{6R_2}{\frac{2}{3}R_2} = 9\,\text{A}$$

For wire 2:

$$I_2 = \frac{V}{R_2} = \frac{6R_2}{R_2} = 6\,\text{A}$$

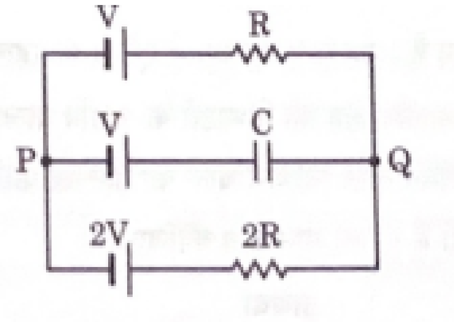
Thus, the current through the first wire is 9 A and through the second wire is 6 A.

Quick Tip

For parallel resistors, the current divides inversely proportional to their resistances. The longer wire (higher resistance) will carry less current.

OR

(b) In the circuit, three ideal cells of e.m.f. V, V, and $2V$ are connected to a resistor of resistance R, a capacitor of capacitance C, and another resistor of resistance $2R$ as shown in the figure. In the steady state, find (i) the potential difference between P and Q, (ii) the potential difference across capacitor C.



Solution:

Step 1: Analyzing the Circuit. The circuit consists of three ideal cells and resistors in series with a capacitor. Since we are considering the steady state, the capacitor will act as an open circuit because in the steady state, the capacitor is fully charged.

Step 2: Simplifying the Circuit. In the steady state, the current will flow through the resistors, but no current will flow through the capacitor. The effective voltage of the battery is the sum of the voltages of the three cells. The total voltage is:

$$V_{\text{total}} = V + V + 2V = 4V$$

The total resistance in the circuit is the sum of the resistances of the two resistors:

$$R_{\text{total}} = R + 2R = 3R$$

Step 3: Current in the Circuit. The total current in the circuit is given by Ohm's law:

$$I = \frac{V_{\text{total}}}{R_{\text{total}}} = \frac{4V}{3R}$$

Step 4: Potential Difference Between P and Q. The potential difference between P and Q is across the capacitor and the second resistor. In the steady state, the capacitor has no current flowing through it, so the potential difference across the capacitor is equal to the potential difference across the second resistor (2R). The potential difference across the second resistor is:

$$V_{PQ} = I \times 2R = \frac{4V}{3R} \times 2R = \frac{8V}{3}$$

Step 5: Potential Difference Across Capacitor C. Since the total voltage is $4V$ and the potential difference across the second resistor is $\frac{8V}{3}$, the potential difference across the capacitor is the remaining voltage:

$$V_C = 4V - \frac{8V}{3} = \frac{12V}{3} - \frac{8V}{3} = \frac{4V}{3}$$

Thus, the potential difference across the capacitor is $\frac{4V}{3}$.

Quick Tip

In the steady state, a fully charged capacitor behaves like an open circuit, and the current flows only through the resistors.

---

22. (a) Define resistivity of a conductor. Discuss its dependence on temperature of the conductor and draw a plot of resistivity of copper as a function of temperature.

Solution:

Definition of Resistivity: Resistivity ρ of a material is a property that quantifies how strongly the material resists the flow of electric current. It is defined as:

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

Where: - R is the resistance of the conductor, - A is the cross-sectional area, - L is the length of the conductor.

Dependence of Resistivity on Temperature: The resistivity of most conductors increases with an increase in temperature. This is because the atoms in the conductor vibrate more at higher temperatures, impeding the flow of electrons. The temperature dependence of resistivity is given by:

$$\rho(T) = \rho_0[1 + \alpha(T - T_0)]$$

Where: - $\rho(T)$ is the resistivity at temperature T, - ρ_0 is the resistivity at a reference temperature T_0, - α is the temperature coefficient of resistivity.

Plot of Resistivity of Copper: The plot of resistivity of copper with respect to temperature shows a linear increase with temperature in the range commonly encountered.

Quick Tip

Resistivity increases with temperature in most metals, which is why heating a conductor increases its resistance.

(b) (i) "A low voltage battery from which high current is required must have low internal resistance." Justify.

Solution:

A low voltage battery providing high current must have low internal resistance to prevent significant voltage drop across its internal resistance, thereby ensuring maximum current delivery to the load. According to Ohm's law:

$$I = \frac{V}{R_{\text{total}}}$$

Where V is the supply voltage, and R_{total} is the total resistance (which includes the internal resistance of the battery). For high current, R_{total} must be low, so the internal resistance must be minimized.

Quick Tip

To ensure a high current output, the internal resistance of the battery should be as low as possible.

(ii) "A high voltage battery must have a large internal resistance." Justify.

Solution:

A high voltage battery typically has a large internal resistance to limit the current drawn from it and to avoid overloading. High voltage batteries are used to power devices that require a large voltage, but by having a large internal resistance, they ensure that the current remains within safe limits. This prevents excessive heat generation and potential damage to the battery or the connected devices.

Quick Tip

High voltage batteries often have a larger internal resistance to regulate the current and enhance safety.

---

23. (a) When a parallel beam of light enters water surface obliquely at some angle, what is the effect on the width of the beam?

Solution:

When a parallel beam of light enters a denser medium like water obliquely, the light slows down due to the higher refractive index of water compared to air. According to Snell's law, the angle of refraction is smaller than the angle of incidence. This leads to a reduction in the width of the beam as it enters the water.

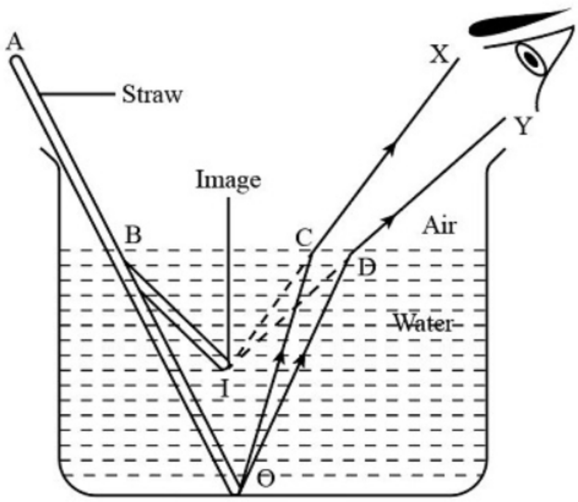
Quick Tip

The width of a light beam reduces when it enters a denser medium at an oblique angle due to the refraction of light.

(b) With the help of a ray diagram, show that a straw appears bent when it is partly dipped in water and explain it.

Solution:

When light travels from one medium to another (such as from water to air), the change in speed causes the light rays to bend at the interface. This bending of light makes the straw appear broken or bent at the surface of water. The light rays from the part of the straw submerged in water are refracted at the water-air interface, making the submerged part appear displaced from the rest of the straw.



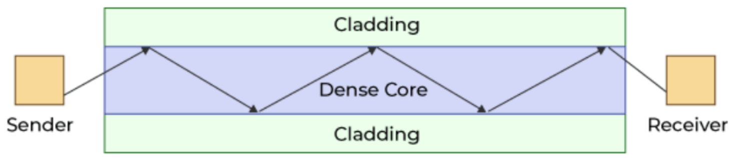
Quick Tip

The apparent bending of a straw in water is due to the refraction of light at the water-air interface.

(c) Explain the transmission of optical signal through an optical fiber with a diagram.

Solution:

Optical fibers transmit light signals using the principle of total internal reflection. The light signals enter the fiber at an angle greater than the critical angle, which causes the light to be reflected entirely within the fiber. This continuous reflection ensures that the light travels through the fiber even if the fiber is bent.



Quick Tip

In optical fibers, light signals are transmitted through total internal reflection, allowing for efficient transmission of data.

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24. Differentiate between the peak value and root mean square value of an alternating current. Derive the expression for the root mean square value of alternating current, in terms of its peak value.

Solution:

Difference between Peak Value and RMS Value: - The peak value of an alternating current (AC) is the maximum value of the current during a cycle. - The root mean square (RMS) value of an AC is the square root of the average of the squares of the instantaneous values of current over a cycle.

Expression for RMS Value: For a sinusoidal current $I = I_0 \sin(\omega t)$, where I_0 is the peak value of the current, the RMS value is given by:

$$I_{\text{RMS}} = \sqrt{\frac{1}{T} \int_0^T I^2 \, dt}$$

Substituting $I = I_0 \sin(\omega t)$:

$$I_{\text{RMS}} = \sqrt{\frac{1}{T} \int_0^T I_0^2 \sin^2(\omega t) \, dt}$$

The average value of $\sin^2(\omega t)$ over a full cycle is $\frac{1}{2}$. Therefore:

$$I_{\text{RMS}} = \sqrt{\frac{1}{T} \times I_0^2 \times \frac{T}{2}} = \frac{I_0}{\sqrt{2}}$$

Thus, the RMS value of the current is $\frac{I_0}{\sqrt{2}}$, where I_0 is the peak value.

Quick Tip

The RMS value of an AC current is the effective value that produces the same power as a DC current of the same value.

---

25. (a) How is an electromagnetic wave produced?

Solution:

An electromagnetic wave is produced when a charged particle undergoes acceleration. This acceleration causes the particle to generate time-varying electric and magnetic fields, which propagate through space. The electric field oscillates perpendicular to the direction of wave propagation, and the magnetic field oscillates perpendicular to both the electric field and the direction of wave propagation. This results in the formation of an electromagnetic wave, which can travel through a vacuum.

Quick Tip

Electromagnetic waves are generated by the acceleration of charged particles, creating oscillating electric and magnetic fields that propagate through space.

(b) An electromagnetic wave is travelling in vertically upward direction. At an instant, its electric field vector points in west direction. In which direction does the magnetic field vector point at that instant?

Solution:

The electric field (E) and magnetic field (B) vectors in an electromagnetic wave are mutually perpendicular to each other and to the direction of propagation. If the wave is traveling vertically upward, and the electric field points towards the west, the magnetic field must point in the north direction, following the right-hand rule.

Thus, the magnetic field vector points towards the north.

Quick Tip

The direction of the magnetic field in an electromagnetic wave is determined by the right-hand rule, which ensures it is perpendicular to both the electric field and the direction of propagation.

(c) Estimate the ratio of shortest wavelength of radio waves to the longest wavelength of gamma waves.

Solution:

The wavelength λ of an electromagnetic wave is related to its frequency ν and the speed of light c by the equation:

$$\lambda = \frac{c}{\nu}$$

- The longest wavelength of gamma rays is typically around 10^{-12} m and the shortest wavelength of radio waves is around 10^2 m.

Therefore, the ratio of the shortest wavelength of radio waves to the longest wavelength of gamma rays is:

$$\text{Ratio} = \frac{10^2}{10^{-12}} = 10^{14}$$

Thus, the ratio is 10^{14}.

Quick Tip

The ratio of wavelengths in different types of electromagnetic waves can vary widely, with radio waves having much longer wavelengths than gamma rays.

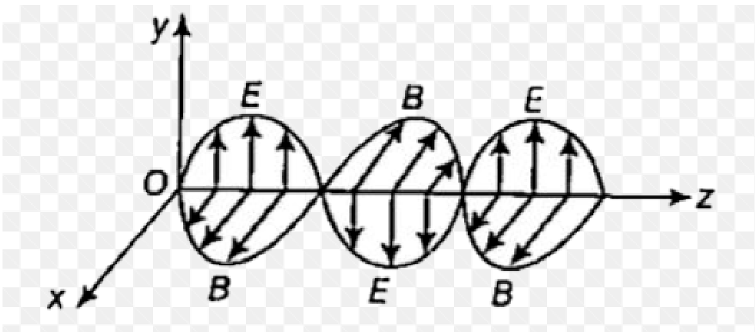
---

26. (a) In a region of a uniform electric field E**, a negatively charged particle is moving with a constant velocity** $\mathrm{v} = -v_0\hat{i}$ **near a long straight conductor coinciding with XX' axis and carrying current** I **towards -X axis. The particle remains at a distance** d **from the conductor.**

Solution:

(i) Draw diagram showing direction of electric and magnetic fields. The electric field E is uniform and directed, say, in the positive y-direction. The magnetic field B produced by the current in the conductor will form concentric circles around the conductor, with the direction of the magnetic field given by the right-hand rule.

Diagram:



Quick Tip

The magnetic field around a current-carrying conductor follows the right-hand rule, and the electric field is uniform in the region.

(ii) What are the various forces acting on the charged particle?

Solution:

There are two forces acting on the negatively charged particle:

1. Electric Force: The electric field $\mathbf{E}$ exerts a force on the particle given by:

$$\mathbf{F_E} = q\mathbf{E}$$

Where q is the charge of the particle.

2. Magnetic Force: The magnetic field $\mathbf{B}$ exerting a force on the particle due to its velocity is given by:

$$\mathbf{F_B} = q\mathbf{v} \times \mathbf{B}$$

Where $\mathbf{v}$ is the velocity of the particle and $\mathbf{B}$ is the magnetic field. The direction of $\mathbf{F_B}$ is given by the right-hand rule, which is perpendicular to both $\mathbf{v}$ and $\mathbf{B}$.

Quick Tip

The total force on a charged particle moving in an electric and magnetic field is the vector sum of the electric and magnetic forces.

(iii) Find the value of v_0 in terms of E, d, and I.

Solution:

The magnetic force $\mathbf{F_B}$ and the electric force $\mathbf{F_E}$ must balance each other to maintain constant velocity for the particle. Therefore:

$$F_E = F_B$$

Substituting the expressions for electric and magnetic forces:

$$qE = qv_0B$$

Using the formula for the magnetic field produced by a current-carrying conductor at a distance d:

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

Thus, equating the forces:

$$E = v_0 \frac{\mu_0 I}{2\pi d}$$

Solving for v_0:

$$v_0 = \frac{E2\pi d}{\mu_0 I}$$

Thus, the value of v_0 is:

$$v_0 = \frac{E2\pi d}{\mu_0 I}$$

Quick Tip

For a charged particle moving in a magnetic and electric field, the balance between the forces determines the velocity of the particle.

OR

(b) Two infinitely long conductors kept along XX' and YY' axes are carrying current I_1 and I_2 along -X axis and -Y axis respectively. Find the magnitude and direction of the net magnetic field produced at point P(X, Y).

Solution:

The magnetic field at a point due to a current-carrying conductor is given by Ampere's law. The magnitude of the magnetic field B due to a current I in an infinitely long straight conductor at a distance r from the wire is:

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

Where: - μ_0 is the permeability of free space, - I is the current, - r is the perpendicular distance from the wire to the point.

Step 1: Magnetic Field due to I_1 (along the XX' axis) The magnetic field at point P due to the current I_1 will be circular around the conductor along the XX' axis. Since the current I_1 flows along the -X axis, the magnetic field at P will follow the right-hand rule. The direction of the magnetic field due to I_1 at point P is into the page.

$$B_1 = \frac{\mu_0 I_1}{2\pi r_1}$$

Where r_1 is the distance from the conductor along the XX' axis to point P.

Step 2: Magnetic Field due to I_2 (along the YY' axis) The magnetic field at point P due to the current I_2 flowing along the -Y axis will be circular around the conductor along the YY' axis. Using the right-hand rule again, the direction of the magnetic field due to I_2 at point P is out of the page.

$$B_2 = \frac{\mu_0 I_2}{2\pi r_2}$$

Where r_2 is the distance from the conductor along the YY' axis to point P.

Step 3: Net Magnetic Field at P The net magnetic field at point P is the vector sum of the magnetic fields B_1 and B_2. Since the directions of the magnetic fields due to I_1 and I_2 are perpendicular to each other (into and out of the page), the net magnetic field B_{net} can be found using the Pythagorean theorem:

$$B_{\text{net}} = \sqrt{B_1^2 + B_2^2}$$

Substituting the expressions for B_1 and B_2:

$$B_{\text{net}} = \sqrt{\left(\frac{\mu_0 I_1}{2\pi r_1}\right)^2 + \left(\frac{\mu_0 I_2}{2\pi r_2}\right)^2}$$

Step 4: Direction of the Net Magnetic Field The direction of the net magnetic field is determined by the vector sum of B_1 and B_2. Since B_1 is into the page and B_2 is out of the page, the net magnetic field will be in a direction perpendicular to both, forming an angle with respect to both axes.

Thus, the magnitude and direction of the net magnetic field at point P is given by the above formula and can be determined from the geometry of the problem.

Quick Tip

The magnetic fields from two perpendicular current-carrying wires add vectorially, and the total magnetic field at a point is given by the Pythagorean theorem when the fields are perpendicular.

---

27. (a) What are majority and minority charge carriers in an extrinsic semiconductor?

Solution:

In an extrinsic semiconductor, the majority and minority charge carriers are determined by the type of doping.

- Majority charge carriers: In an n-type semiconductor (doped with donor atoms), the majority charge carriers are electrons, which are the free negatively charged particles. In a p-type semiconductor (doped with acceptor atoms), the majority charge carriers are holes, which are the absence of electrons and can be treated as positive charge carriers.
- Minority charge carriers: In an n-type semiconductor, the minority charge carriers are holes, and in a p-type semiconductor, the minority charge carriers are electrons.

Quick Tip

In an extrinsic semiconductor, the type of doping determines the majority and minority charge carriers.

(b) A p-n junction is forward biased. Describe the movement of the charge carriers which produce current in it.

Solution:

In a forward-biased p-n junction, the p-side (anode) is connected to the positive terminal of the battery, and the n-side (cathode) is connected to the negative terminal.

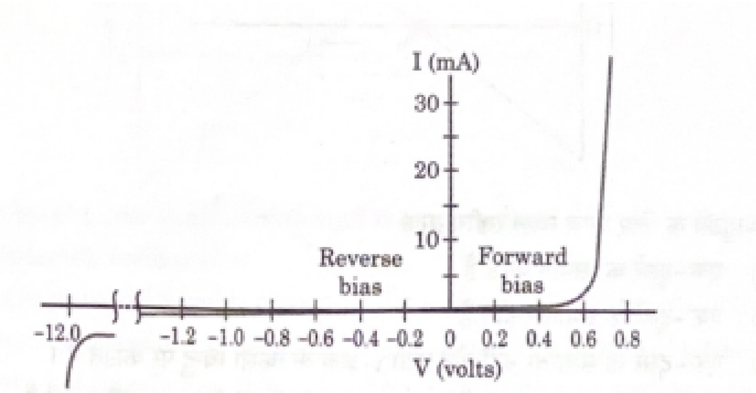
- Electrons: In the n-type region, electrons are the majority charge carriers. Under forward bias, these electrons move towards the p-side. As they cross the junction, they recombine with holes in the p-type region.
- Holes: In the p-type region, holes are the majority charge carriers. Under forward bias, the holes move towards the n-side. As they cross the junction, they recombine with electrons in the n-type region.

This movement of charge carriers (electrons from n to p and holes from p to n) creates a current in the external circuit.

Quick Tip

In forward bias, electrons move from n-type to p-type material, and holes move from p-type to n-type material, producing current in the external circuit.

(c) The graph shows the variation of current with voltage for a p-n junction diode. Estimate the dynamic resistance of the diode at $V = -0.6$ V.



Solution:

The dynamic resistance of a diode is defined as the rate of change of voltage with respect to the current. It is given by:

$$r_d = \frac{\Delta V}{\Delta I}$$

From the graph, at $V = -0.6$ V, we can estimate the current I and the change in voltage ΔV and current ΔI near this point. For instance, if the current is approximately 20 mA at $V = -0.6$ V and the slope of the curve near this voltage is estimated, we can calculate r_d.

For example, if the current changes by 10 mA for a voltage change of 0.2 V, the dynamic resistance is:

$$r_d = \frac{0.2\,\text{V}}{10\,\text{mA}} = 20\,\Omega$$

Thus, the dynamic resistance at $V = -0.6$ V is approximately 20 Ω.

Quick Tip

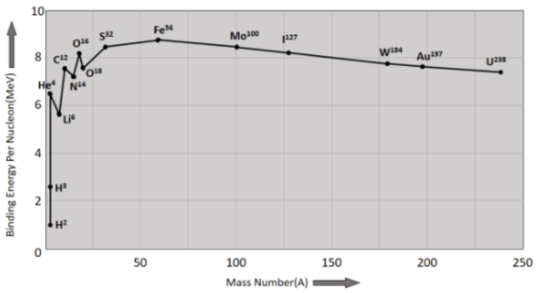
The dynamic resistance of a diode can be estimated by finding the slope of the current-voltage characteristic curve at a given voltage.

28.(a) Show the variation of binding energy per nucleon with mass number. Write the significance of the binding energy curve.

Solution:

Variation of Binding Energy per Nucleon with Mass Number: The binding energy per nucleon is the energy required to remove a nucleon from a nucleus. It generally increases with mass number up to iron (Fe), after which it begins to decrease. This is because larger nuclei become less tightly bound as their size increases, while smaller nuclei (like hydrogen and helium) are more tightly bound.

The binding energy curve has a peak around $A = 56$ (the mass number of iron), after which it decreases. The curve is roughly shaped like a bell, with the highest point at iron, indicating that nuclei around this mass number are the most stable.



Significance of the Binding Energy Curve: - The curve shows that nuclei with mass numbers near 56 (such as iron) are the most stable, meaning they require the most energy to break apart. - Nuclei with mass numbers greater than 56 can release energy by fission (splitting), as splitting them into smaller nuclei releases energy. - Nuclei with mass numbers less than 56 can release energy by fusion, as fusing them to form heavier nuclei also releases energy.

Quick Tip

The binding energy per nucleon increases up to iron, indicating that fusion of lighter nuclei and fission of heavier nuclei both release energy.

(b) Two nuclei with lower binding energy per nucleon form a nucleus with more binding energy per nucleon.
(i) What type of nuclear reaction is it?

Solution:
This is a fusion reaction, where two lighter nuclei combine to form a heavier nucleus with a higher binding energy per nucleon. Fusion reactions release energy, as the product nucleus is more stable than the individual reactant nuclei.

Quick Tip

Fusion reactions occur when two lighter nuclei combine to form a heavier nucleus, releasing energy in the process.

(ii) Whether the total mass of nuclei increases, decreases or remains unchanged?

Solution:
The total mass of the nuclei decreases during a fusion reaction. This mass is converted into energy according to Einstein's equation $E = mc^2$. The total energy released in the form of binding energy is greater than the energy required to overcome the mass defect.

Quick Tip

In nuclear fusion, the total mass of the nuclei decreases, and the missing mass is converted into energy.

(iii) Does the process require energy or produce energy?

Solution:

The process produces energy. Fusion reactions release energy because the binding energy per nucleon of the product nucleus is greater than that of the reactant nuclei, resulting in a net release of energy.

Quick Tip

Fusion reactions produce energy because the binding energy per nucleon of the product nucleus is higher than that of the reactants.

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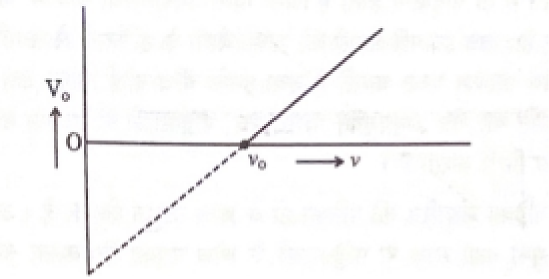
29. When a photon of suitable frequency is incident on a metal surface, a photoelectron is emitted from it. If the frequency is below a threshold frequency ν_0 for the surface, no photoelectron is emitted. For a photon of frequency $\nu(\nu > \nu_0)$, the kinetic energy of the emitted photoelectron is $K_m = h(\nu - \nu_0)$. The photocurrent can be stopped by applying a potential V_0, called 'stopping potential' on the anode. Thus maximum kinetic energy of photoelectrons $K_m = eV_0 = h(\nu - \nu_0)$. The experimental graph between V_0 and ν for a metal is shown in the figure. This is a straight line of slope m.



(i) The straight line graphs obtained for two metals:

(A) coincide each other.

(B) are parallel to each other.

(C) are not parallel to each other and cross at a point on ν-axis.

(D) are not parallel to each other and do not cross at a point on ν-axis.

Correct Answer: (B) are parallel to each other.

Solution:

The graph between V_0 and ν for two metals shows that both graphs are straight lines, indicating a linear relationship between the stopping potential and frequency. Since the slope of the graph is constant, the lines are parallel to each other.

Thus, the correct answer is (B), as the straight line graphs obtained for two metals are parallel to each other.

Quick Tip

In the photoelectric effect, the stopping potential is linearly related to the frequency of the incident light, and the graphs for different metals are parallel.

(ii) The value of Planck's constant for this metal is:

(A) $\frac{e}{m}$
(B) $\frac{1}{m}$
(C) $\frac{me}{e}$
(D) $\frac{m}{e}$

Correct Answer: (A) $\frac{e}{m}$

Solution:

From the equation $eV_0 = h(\nu - \nu_0)$, comparing it with the equation of a straight line $y = mx + c$, the slope m is given by:

$$m = \frac{h}{e}$$

This shows that Planck's constant h can be expressed as $h = e \times m$, where m is the slope of the graph and e is the charge of the electron. Thus, the correct value of Planck's constant for this metal is $\frac{e}{m}$.

Quick Tip

The slope of the V_0 vs ν graph gives the value of Planck's constant.

(iii) The intercepts on ν-axis and V_0-axis of the graph are respectively:

(A) $\frac{h\nu_0}{e}$, V_0

(B) ν_0, $h\nu_0$

(C) $\frac{h\nu_0}{e}$, eV_0

(D) $h\nu_0$, $h\nu_0$

Correct Answer: (A) $\frac{h\nu_0}{e}$, V_0

Solution:

The intercept on the V_0-axis is V_0 when $\nu = \nu_0$, and the intercept on the ν-axis occurs when $V_0 = 0$. Thus:

- The intercept on the V_0-axis gives the stopping potential V_0 corresponding to $\nu = \nu_0$. - The intercept on the ν-axis gives ν_0, the threshold frequency.

Thus, the intercepts on the axes are $\frac{h\nu_0}{e}$ for the V_0-axis and ν_0 for the ν-axis.

Quick Tip

The intercepts on the V_0-axis and ν-axis provide useful information about the threshold frequency and stopping potential.

OR

(iii) When the wavelength of a photon is doubled, how many times its wave number and frequency become, respectively?

Solution:

The wavelength λ and frequency ν of a photon are related by the equation:

$$c = \lambda\nu$$

Where: - c is the speed of light, - λ is the wavelength, - ν is the frequency.

When the wavelength λ is doubled, the frequency ν becomes halved, because the speed of light c is constant. Therefore:

$$\nu' = \frac{\nu}{2}$$

The wave number k, which is the reciprocal of the wavelength, is given by:

$$k = \frac{1}{\lambda}$$

When the wavelength is doubled, the wave number becomes halved:

$$k' = \frac{k}{2}$$

Thus, the wave number becomes $\frac{1}{2}$ times, and the frequency becomes $\frac{1}{2}$ times.

Thus, the correct answer is:

Correct Answer: (B) $\frac{1}{2}$, $\frac{1}{2}$

> **Quick Tip**
>
> When the wavelength of a photon is doubled, its frequency and wave number both decrease by a factor of 2.

(iv) The momentum of a photon is 5.0×10^{-29} kg · m/s. Ignoring relativistic effects (if any), the wavelength of the photon is:

Solution:

The momentum p of a photon is related to its wavelength λ by the equation:

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

Where h is Planck's constant. Rearranging for λ:

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

Substituting the known values:

- $h = 6.626 \times 10^{-34}$ J · s, - $p = 5.0 \times 10^{-29}$ kg · m/s.

$$\lambda = \frac{6.626 \times 10^{-34}}{5.0 \times 10^{-29}} = 1.33 \times 10^{-5}\,\text{m} = 13.3\,\mu\text{m}$$

Thus, the wavelength of the photon is:

Correct Answer: (D) 13.3 m

Quick Tip

The wavelength of a photon can be calculated from its momentum using the formula $\lambda = \frac{h}{p}$.

30.A parallel plate capacitor has two parallel plates which are separated by an insulating medium like air, mica, etc. When the plates are connected to the terminals of a battery, they get equal and opposite charges and an electric field is set up in between them. This electric field between the two plates depends upon the potential difference applied, the separation of the plates and nature of the medium between the plates.

(i) The electric field between the plates of a parallel plate capacitor is E. Now the separation between the plates is doubled and simultaneously the applied potential difference between the plates is reduced to half of its initial value. The new value of the electric field between the plates will be:

(A) E

(B) $2E$

(C) $\frac{E}{4}$

(D) $\frac{E}{2}$

Correct Answer: (D) $\frac{E}{2}$

Solution:

The electric field E between the plates of a parallel plate capacitor is given by:

$$E = \frac{V}{d}$$

Where: - V is the potential difference across the plates, - d is the separation between the plates.

When the separation d is doubled, and the potential difference V is reduced to half, the new electric field E' is given by:

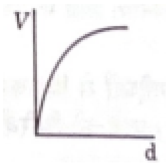
$$E' = \frac{V/2}{2d} = \frac{E}{2}$$

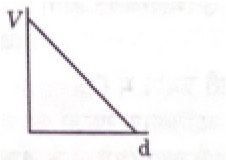
Thus, the new electric field between the plates will be half of the initial value, corresponding to option (D).

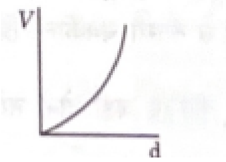
Quick Tip

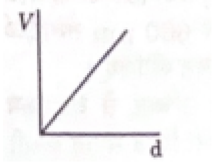
The electric field in a parallel plate capacitor is directly proportional to the potential difference and inversely proportional to the separation between the plates.

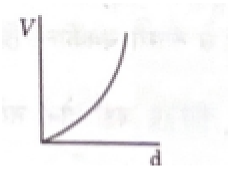
(ii) A constant electric field is to be maintained between the two plates of a capacitor whose separation d changes with time. Which of the graphs correctly depict the potential difference (V) to be applied between the plates as a function of separation between the plates (d) to maintain the constant electric field?

(A) 

(B) 

(C) 

(D) 

Correct Answer: (C) 

Solution:

The electric field E between the plates of a parallel plate capacitor is related to the potential difference and separation by:

$$E = \frac{V}{d}$$

To maintain a constant electric field, the potential difference V must be directly proportional to the separation d. Therefore:

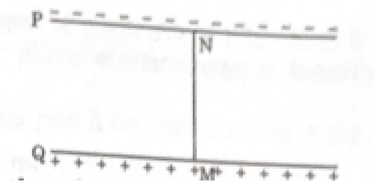
$$V = E \cdot d$$

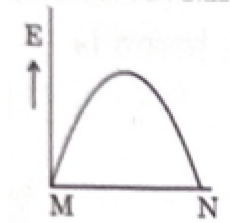
This relationship indicates that V increases linearly with d. Hence, the graph of V versus d will be a straight line, confirming that option (C) is correct.

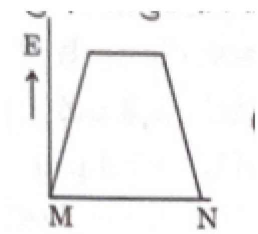
Quick Tip

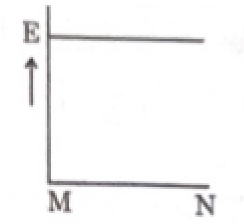
To maintain a constant electric field in a parallel plate capacitor, the potential difference must be proportional to the separation between the plates.

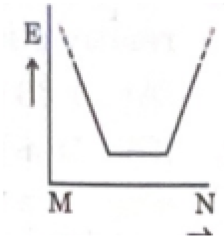
(iii) In the above figure, P and Q are the two parallel plates of a capacitor. Plate Q is at positive potential with respect to plate P. MN is an imaginary line drawn perpendicular to the plates. Which of the graphs shows correctly the variations of the magnitude of electric field strength E along the line MN?

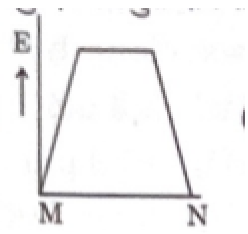


(A) 

(B) 

(C) 

(D) 

Correct Answer: (B) 

Solution:

The electric field between two parallel plates of a capacitor is uniform and directed from the positive to the negative plate. Between the plates, the electric field is constant. Outside the plates, the electric field is zero.

In the given diagram, plate Q is at a positive potential, and plate P is at a negative potential. The electric field is directed from plate Q to plate P. Along the line MN, which is perpendicular to the plates, the electric field strength will be uniform between the plates and zero outside.

Thus, the correct graph showing the electric field strength variation would be a constant value between the plates, and zero outside the plates. This corresponds to option (B).

Quick Tip

The electric field between two parallel plates of a capacitor is uniform, and it is zero outside the plates.

(iv) Three parallel plates are placed above each other with equal displacement d between neighbouring plates. The electric field between the first pair of the plates is E_1, and the electric field between the second pair of the plates is E_2. The potential

difference between the third and the first plate is:

(A) $(E_1 + E_2) \cdot d$

(B) $(E_1 - E_2) \cdot d$

(C) $(E_2 - E_1) \cdot d$

(D) $\frac{d(E_1+E_2)}{2}$

Correct Answer: (D) $\frac{d(E_1+E_2)}{2}$

Solution:

The potential difference between two plates is given by the product of the electric field and the separation between the plates.

If E_1 is the electric field between the first pair of plates and E_2 is the electric field between the second pair of plates, then the potential difference between the first and third plates is the sum of the individual potential differences across the two sections.

The potential difference between the plates is:

$$V = E_1 \cdot \frac{d}{2} + E_2 \cdot \frac{d}{2} = \frac{d(E_1 + E_2)}{2}$$

Thus, the correct answer is $\frac{d(E_1+E_2)}{2}$, corresponding to option (D).

Quick Tip

For multiple parallel plates, the potential difference between the plates is the sum of the potential differences across each section of the capacitor.

OR

(iv) A material of dielectric constant K is filled in a parallel plate capacitor of capacitance C. The new value of its capacitance becomes:

(A) C

(B) $\frac{C}{K}$

(C) CK

(D) $C\left(1 + \frac{1}{K}\right)$

Correct Answer: (C) CK

Solution:

When a dielectric material of dielectric constant K is inserted into a parallel plate capacitor, the capacitance increases by a factor of K. The new capacitance C' is given by:

$$C' = K \cdot C$$

Thus, the new capacitance becomes CK, corresponding to option (C).

Quick Tip

The capacitance of a parallel plate capacitor increases by a factor equal to the dielectric constant when a dielectric material is inserted.

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31. (a) (i) A thin pencil of length $f/4$ is placed coinciding with the principal axis of a mirror of focal length f. The image of the pencil is real and enlarged, just touches the pencil. Calculate the magnification produced by the mirror.

Solution:

The magnification m produced by a mirror is given by the formula:

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

Where: - v is the image distance, - u is the object distance.

Given that the image is real and enlarged, the image distance is positive, and the object distance is negative. The condition that the image just touches the pencil means the image and object distances add up to the focal length. Therefore:

$$v + u = f$$

Also, the relationship between the focal length f, object distance u, and image distance v for a mirror is given by the mirror equation:

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

From these two equations, we can calculate the magnification produced by the mirror.

Quick Tip

The magnification produced by a mirror can be found using the mirror equation and the condition that the image just touches the object.

(ii) A ray of light is incident on a refracting face AB of a prism ABC at an angle of $45°$. The ray emerges from face AC and the angle of deviation is $15°$. The angle of prism is $30°$. Show that the emergent ray is normal to the face AC from which it emerges out. Find the refraction index of the material of the prism.

Solution:

Let A be the angle of the prism, i the angle of incidence on the face AB, and e the angle of emergence.

The angle of deviation D is the angle between the incident and emergent rays. For this case, we are given that $D = 15°$ and the prism angle $A = 30°$.

Using the formula for the deviation angle in a prism:

$$D = i + e - A$$

Given that the emergent ray is normal to the face AC, we have $e = 90°$. Therefore, we can substitute into the formula:

$$15° = i + 90° - 30°$$

Solving for i:

$$i = 15°$$

Using Snell's law to find the refractive index n of the material of the prism:

$$n = \frac{\sin(i)}{\sin(r)}$$

Where r is the angle of refraction inside the prism. Since $r = 90° - A/2$, we can substitute the known values to find the refractive index of the material of the prism.

Quick Tip

For a ray of light passing through a prism, the angle of deviation depends on the angle of incidence and the prism angle. Snell's law is used to find the refractive index of the material.

(b) Light consisting of two wavelengths 600 nm and 480 nm is used to obtain interference fringes in a double slit experiment. The screen is placed 1.0 m away from slits which are 1.0 mm apart.

(i) Calculate the distance of the third bright fringe on the screen from the central maximum for wavelength 600 nm.

Solution:

The fringe width β in a double slit experiment is given by the formula:

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

Where: - λ is the wavelength of the light, - D is the distance between the slits and the screen, - d is the distance between the slits.

For the wavelength $\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$, $D = 1.0\,\text{m}$, and $d = 1.0\,\text{mm} = 1.0 \times 10^{-3}\,\text{m}$, we can calculate the fringe width:

$$\beta = \frac{600 \times 10^{-9} \times 1.0}{1.0 \times 10^{-3}} = 6.0 \times 10^{-4}\,\text{m}$$

The distance of the third bright fringe from the central maximum is:

$$y_3 = 3 \times \beta = 3 \times 6.0 \times 10^{-4} = 1.8 \times 10^{-3}\,\text{m} = 1.8\,\text{mm}$$

Thus, the distance of the third bright fringe is 1.8 mm.

Quick Tip

The distance between bright fringes in a double slit experiment is directly proportional to the wavelength and the distance from the slits to the screen.

(ii) Find the least distance from the central maximum where the bright fringes due to both the wavelengths coincide.

Solution:

The condition for bright fringes to coincide for two different wavelengths is:

$$\frac{m_1 \lambda_1}{d} = \frac{m_2 \lambda_2}{d}$$

Where: - m_1 and m_2 are the fringe orders for the two wavelengths, - $\lambda_1 = 600\,\text{nm}$ and $\lambda_2 = 480\,\text{nm}$.

Solving for m, we find the least value where the bright fringes coincide. The distance will be found similarly to the earlier calculation, using the conditions for interference.

Quick Tip

For fringe coincidence in double slit interference, the condition is that the fringe widths for both wavelengths must be the same.

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32. (a) (i) A small conducting sphere A of radius r charged to a potential V, is enclosed by a spherical conducting shell B of radius R. If A and B are connected by a thin wire, calculate the final potential on sphere A and shell B.

Solution:

The conducting sphere A is connected to the spherical conducting shell B by a thin wire. Since the shells are conductors, the potential on sphere A and shell B will be the same due to the flow of charge between them to maintain the same potential.

When the two spheres are connected by a wire, charge will flow from sphere A to shell B until both spheres reach the same potential. The total charge is redistributed between the two spheres.

The potential on sphere A and shell B is calculated using the formula for the potential of a spherical conductor:

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Where: - Q is the charge on the conductor, - r is the radius of the conductor.

Since both spheres reach the same potential, the charge is distributed in such a way that:

$$V_A = V_B = \frac{Q_{\text{total}}}{4\pi\varepsilon_0(r+R)}$$

Thus, the final potential on both sphere A and shell B is the same, and it depends on the total charge and the sum of the radii of the two conductors.

Quick Tip

When two conductors are connected by a wire, they must be at the same potential, which is achieved by redistributing the charge between them.

(ii) Write two characteristics of equipotential surfaces. A uniform electric field of 50 NC^{-1} is set up in a region along the x-axis. If the potential at the origin $(0,0)$ is 220 V, find the potential at a point $(4m, 3m)$.

Solution:

Characteristics of Equipotential Surfaces: 1. The electric potential is the same at all points on an equipotential surface, meaning no work is done in moving a charge along the surface. 2. Equipotential surfaces are always perpendicular to the electric field lines.

Since the electric field is uniform and directed along the x-axis, the potential at any point is given by:

$$V = V_0 - E \cdot d$$

Where: - V_0 is the potential at the origin, - E is the magnitude of the electric field, - d is the distance along the x-axis.

For the given point $(4m, 3m)$, the distance along the x-axis is 4 m (since the electric field is along the x-axis). Therefore, the potential at this point is:

$$V = 220\,\text{V} - 50\,\text{NC}^{-1} \cdot 4\,\text{m} = 220\,\text{V} - 200\,\text{V} = 20\,\text{V}$$

Thus, the potential at the point $(4m, 3m)$ is 20 V.

Quick Tip

The potential in a uniform electric field is a linear function of distance along the direction of the field.

(b) What is the difference between an open surface and a closed surface?

Solution:

A closed surface is a surface that completely encloses a region of space without any gaps. It is a 3D surface that surrounds a volume, such as the surface of a sphere. The electric flux through a closed surface can be calculated using Gauss's law.

An open surface is a surface that does not completely enclose a region of space and may have edges, such as a flat sheet or a portion of a sphere.

Quick Tip

A closed surface surrounds a volume, while an open surface has edges and does not enclose a volume.

(ii) Define electric flux through a surface. Give the significance of a Gaussian surface. A charge outside a Gaussian surface does not contribute to total electric flux through the surface. Why?

Solution:

Electric flux Φ_E through a surface is defined as the product of the electric field E and the area A of the surface, and the cosine of the angle θ between the electric field and the normal to the surface:

$$\Phi_E = E \cdot A \cdot \cos(\theta)$$

A Gaussian surface is an imaginary closed surface used in Gauss's law to calculate electric flux. The significance of a Gaussian surface is that it helps in calculating the electric flux and, using Gauss's law, can be used to determine the electric field due to symmetrical charge distributions.

A charge outside a Gaussian surface does not contribute to the total electric flux because the electric field lines from the external charge do not pass through the surface, and thus, the net flux through the surface remains zero.

Quick Tip

The electric flux through a surface is proportional to the charge enclosed by that surface, as per Gauss's law.

(iii) A small spherical shell S_1 has point charges $q_1 = -3\,\mu C$, $q_2 = -2\,\mu C$ and $q_3 = 9\,\mu C$ inside it. This shell is enclosed by another big spherical shell S_2. A point charge Q is placed in between the two surfaces S_1 and S_2. If the electric flux through the surface S_2 is four times the flux through surface S_1, find charge Q.

Solution:

According to Gauss's law, the electric flux through a surface is proportional to the net charge enclosed by the surface:

$$\Phi_E = \frac{Q_{\text{enc}}}{\varepsilon_0}$$

The total charge enclosed by the surface S_2 is the sum of the charges inside S_1 and the charge Q placed between S_1 and S_2. Therefore, the total charge enclosed by S_2 is:

$$Q_{\text{enc}} = q_1 + q_2 + q_3 + Q$$

The flux through surface S_1 is proportional to the charge inside it:

$$\Phi_{S_1} = \frac{q_1 + q_2 + q_3}{\varepsilon_0}$$

The flux through surface S_2 is four times the flux through S_1:

$$\Phi_{S_2} = 4 \cdot \Phi_{S_1} = \frac{4 \cdot (q_1 + q_2 + q_3)}{\varepsilon_0}$$

Using Gauss's law for S_2:

$$\Phi_{S_2} = \frac{q_1 + q_2 + q_3 + Q}{\varepsilon_0}$$

Equating the two expressions for Φ_{S_2}:

$$\frac{4 \cdot (q_1 + q_2 + q_3)}{\varepsilon_0} = \frac{q_1 + q_2 + q_3 + Q}{\varepsilon_0}$$

Solving for Q:

$$4 \cdot (q_1 + q_2 + q_3) = q_1 + q_2 + q_3 + Q$$

$$Q = 3 \cdot (q_1 + q_2 + q_3)$$

Substituting the values of q_1, q_2, and q_3:

$$Q = 3 \cdot (-3\,\mu C - 2\,\mu C + 9\,\mu C) = 3 \cdot 4\,\mu C = 12\,\mu C$$

Thus, the charge Q is $12\,\mu C$.

Quick Tip

In Gauss's law, the electric flux through a surface depends on the net charge enclosed within that surface.

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33. (a) (i) What is the source of force acting on a current-carrying conductor placed in a magnetic field? Obtain the expression for the force acting between two long straight parallel conductors carrying steady currents and hence define Ampère's law.

Solution:

The source of the force acting on a current-carrying conductor placed in a magnetic field is the magnetic interaction between the moving charges (current) in the conductor and the external magnetic field. The force on a current-carrying conductor in a magnetic field is given by:

$$F = ILB\sin(\theta)$$

Where: - F is the force, - I is the current, - L is the length of the conductor in the magnetic field, - B is the magnetic field strength, - θ is the angle between the magnetic field and the conductor.

For two long, straight, parallel conductors carrying steady currents I_1 and I_2, the force per unit length between them is given by Ampère's law:

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

Where: - μ_0 is the permeability of free space, - d is the distance between the two conductors. This is the expression for the force between two parallel conductors carrying steady currents, and it defines Ampère's law.

Quick Tip

The force between two parallel conductors carrying current is inversely proportional to the distance between them.

(ii) A point charge q is moving with velocity v in a uniform magnetic field B. Find the work done by the magnetic force on the charge.

Solution:

The work done by a force is given by:

$$W = \mathbf{F} \cdot \mathbf{d}$$

Where $\mathbf{F}$ is the force and $\mathbf{d}$ is the displacement.

The magnetic force on a moving charge is given by:

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$

Since the magnetic force is always perpendicular to the velocity of the particle, the work done by the magnetic force is zero because:

$$W = \mathbf{F} \cdot \mathbf{d} = 0$$

Therefore, the magnetic force does no work on a moving charge, as it does not change the kinetic energy of the particle.

Quick Tip

The magnetic force on a charged particle does no work since it acts perpendicular to the velocity of the particle, causing no change in its kinetic energy.

(iii) Explain the necessary conditions in which the trajectory of a charged particle is helical in a uniform magnetic field.

Solution:

For a charged particle moving in a uniform magnetic field, the trajectory will be helical if there is a component of velocity parallel to the magnetic field, as well as a perpendicular component.

- The magnetic force acts perpendicular to the velocity, causing the particle to move in a circular path in the plane perpendicular to the magnetic field. - The component of the velocity parallel to the magnetic field causes the particle to move along the direction of the magnetic field.

Thus, the particle moves in a spiral (helical) path, with the magnetic force providing the centripetal force for circular motion, while the parallel velocity component moves the particle along the field direction.

Quick Tip

For a helical trajectory, a charged particle must have both a perpendicular and a parallel component of velocity with respect to the magnetic field.

(b) (i) A current-carrying loop can be considered as a magnetic dipole placed along its axis. Explain.

Solution:

A current-carrying loop generates a magnetic field similar to that of a magnetic dipole. The magnetic dipole moment M of the loop is given by:

$$\mathbf{M} = IA\hat{n}$$

Where: - I is the current in the loop, - A is the area of the loop, - $\hat{n}$ is the unit vector normal to the plane of the loop (along the axis of the loop).
Thus, the current loop behaves like a magnetic dipole with a magnetic dipole moment M directed along the axis of the loop.

Quick Tip

A current-carrying loop generates a magnetic dipole field, and its magnetic dipole moment is given by $\mathbf{M} = IA\hat{n}$.

(ii) Obtain the relation for magnetic dipole moment M of a current-carrying coil. Give the direction of M.

Solution:

The magnetic dipole moment M of a current-carrying coil is given by:

$$\mathbf{M} = IA\hat{n}$$

Where: - I is the current in the coil, - A is the area of the coil, - $\hat{n}$ is the unit vector perpendicular to the plane of the coil, indicating the direction of the dipole moment.
The direction of M is given by the right-hand rule. If the fingers of the right hand curl in the direction of the current, the thumb points in the direction of the magnetic dipole moment.

Quick Tip

The magnetic dipole moment of a coil is directed along the axis of the coil, and its magnitude is $M = IA$.

(iii) A current-carrying coil is placed in an external uniform magnetic field. The coil is free to turn in the magnetic field. What is the net force acting on the coil? Obtain the orientation of the coil in stable equilibrium. Show that in this orientation the flux of the total field (field produced by the loop + external field) through the coil is maximum.

Solution:

The net force on a current-carrying coil in a uniform magnetic field is zero because the magnetic field exerts equal and opposite forces on opposite sides of the coil.
However, the coil experiences a torque τ, which tends to align the coil's magnetic dipole moment $\mathbf{M}$ with the external magnetic field $\mathbf{B}$. The torque is given by:

$$\tau = \mathbf{M} \times \mathbf{B}$$

The coil will be in stable equilibrium when $\mathbf{M}$ is aligned with $\mathbf{B}$. In this orientation, the potential energy of the coil is minimized, and the flux of the total magnetic field through the coil is maximum.
The total flux Φ_{total} through the coil is:

$$\Phi_{\text{total}} = BA\cos(\theta)$$

Where θ is the angle between the magnetic field and the normal to the coil's surface.
At stable equilibrium, $\theta = 0$, and the flux is maximized.

Quick Tip

The coil in a magnetic field experiences a torque that aligns its magnetic dipole moment with the field, and the flux through the coil is maximized in this orientation.
