CBSE Class 12 Physics 2025 Question Paper (55/2/3) With Solutions

Time Allowed :3 Hour	**Maximum Marks :**70	**Total questions :**33

General Instructions

Read the following instructions very carefully and strictly follow them:

1. This question paper contains 33 questions. All questions are compulsory.
2. This question paper is divided into five sections Sections A, B, C, D and E.
3. In Section A Questions no. 1 to 16 are Multiple Choice type questions. Each question carries 1 mark.
4. In Section B Questions no. 17 to 21 are Very Short Answer type questions.Each question carries 2 marks.
5. In Section C Questions no. 22 to 28 are Short Answer type questions. Each question carries 3 marks.
6. In Section D Questions no. 29 and 30 are case study based questions. Each question carries 4 marks.
7. In Section E Questions no. 31 to 33 are Long Answer type questions. Each question carries 5 marks.
8. There is no overall choice given in the question paper. However, an internal choice has been provided in few questions in all the Sections except Section A.
9. Kindly note that there is a separate question paper for Visually Impaired candidates.
10. Use of calculators is not allowed.

Section-A

1. Consider two identical dipoles D_1 and D_2. Charges $-q$ and q of dipole D_1 are located at $(0,0)$ and $(a,0)$, and that of dipole D_2 at $(0,a)$ and $(0,2a)$ in the x-y plane, respectively. The net dipole moment of the system is:

(A) $qa(\hat{i}+\hat{j})$

(B) $-qa(\hat{i}+\hat{j})$

(C) $qa(\hat{i}-\hat{j})$

(D) $-qa(\hat{i}-\hat{j})$

Correct Answer: (A) $qa(\hat{i}+\hat{j})$

Solution: Step 1: Dipole moment of D_1

For D_1, the displacement vector is $a\hat{i}$, so:

$$\mathbf{p_1} = q \times a\hat{i} = qa\hat{i}$$

Step 2: Dipole moment of D_2

For D_2, the displacement vector is $a\hat{j}$, so:

$$\mathbf{p_2} = q \times a\hat{j} = qa\hat{j}$$

Step 3: Net dipole moment

The net dipole moment is:

$$\mathbf{p_{net}} = \mathbf{p_1} + \mathbf{p_2} = qa\hat{i} + qa\hat{j}$$

Thus, the net dipole moment is $qa(\hat{i}+\hat{j})$.

Quick Tip

For dipoles, calculate the dipole moment by multiplying the charge by the displacement vector. If multiple dipoles are involved, sum the individual dipole moments.

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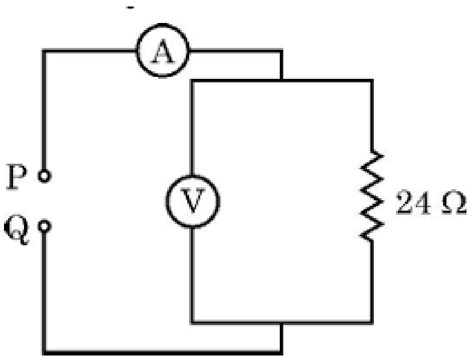
2. Which pair of readings of ideal voltmeter and ideal ammeter in the given circuit is possible when a suitable power source of 3 Ω internal resistance is connected between P and Q?



(A) 12.0 V, 2.0 A

(B) 2.0 V, 0.5 A

(C) 6.0 V, 2.0 A

(D) 12 V, 0.5 A

Correct Answer: (D) 12 V, 0.5 A

Solution: From the given circuit, the total resistance is the sum of the internal resistance of the power source (3 Ω) and the resistance of the resistor (24 Ω).

Thus, the total resistance $R_{total} = 3\Omega + 24\Omega = 27\Omega$.

Using Ohm's law, $V = IR$, we can calculate the current:

$$I = \frac{V}{R} = \frac{12\,\text{V}}{27\,\Omega} = 0.444\,\text{A}$$

Now, considering the power source of 12 V, the closest possible value for current and voltage matching the available options would be $12\,\text{V}$ and $0.5\,\text{A}$.

Quick Tip

When solving circuit problems, use Ohm's law $V = IR$ to find the current or voltage. Check the options carefully, especially when considering the effect of internal resistance.

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3. 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) conservative and field lines form closed loops.

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

(D) non-conservative and field lines form closed loops.

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

Solution:

Step 1: Nature of electric field due to static charges

Electric field $\vec{E}$ due to static charges is a conservative field. That means:

$$\oint \vec{E} \cdot d\vec{l} = 0$$

i.e., the work done in moving a test charge in a closed path in such a field is zero.

Step 2: Nature of field lines

Field lines start from positive charges and end at negative charges.

Electrostatic field lines do not form closed loops.

Step 3: Evaluate the options

Option (A): Correct. Conservative + field lines don't form closed loops.

Option (B): Incorrect. Electrostatic field lines never form closed loops.

Option (C): Incorrect. The field is conservative.

Option (D): Incorrect. Neither conservative nor closed loops.

Hence, the correct option is (A).

Quick Tip

Electrostatic fields are conservative and field lines start and end on charges, not forming closed loops. This is unlike magnetic field lines.

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4. A material is pushed out when placed in a uniform magnetic field. The material is

(A) non-magnetic

(B) diamagnetic

(C) paramagnetic

(D) ferromagnetic

Correct Answer: (B) diamagnetic

Solution: When a material is placed in a uniform magnetic field and is pushed out (repelled), it is exhibiting properties of a **diamagnetic** material.

Diamagnetic materials have a weak, negative susceptibility to magnetic fields, meaning they create an induced magnetic field in the opposite direction to that of the applied magnetic field. As a result, these materials are repelled by the magnetic field.

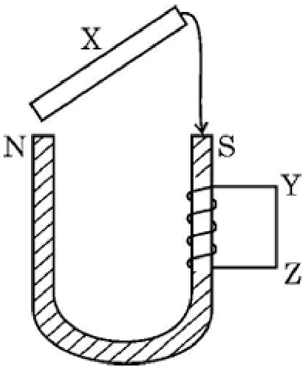
The behavior can be explained by the fact that the electron motion in diamagnetic materials generates a small opposing magnetic field, which leads to the repulsion observed when the material is placed in a magnetic field. This repulsion is weak compared to other types of magnetic materials, but it is sufficient to push the material out of the magnetic field.

Examples of diamagnetic materials include bismuth, copper, and graphite.

Quick Tip

For diamagnetic materials, the magnetic moment is opposite to the applied field, leading to a repulsive effect. The repulsion is weak but detectable.

5. A soft iron rod X is allowed to fall on the two poles of a U-shaped permanent magnet as shown in the figure. A coil is wrapped over one arm of the U-shaped magnet. During the fall of the rod, the current in the coil will be



(A) clockwise current

(B) anticlockwise current

(C) alternating current

(D) zero

Correct Answer: (B) anticlockwise current

Solution: As the soft iron rod X falls through the magnetic field of the U-shaped permanent magnet, it cuts through the magnetic lines of flux, inducing an emf (electromotive force) in the coil according to Faraday's Law of Electromagnetic Induction. Here's the step-by-step reasoning:

Magnetic flux change: As the rod moves, it causes a change in the magnetic flux through the coil, which is the key for inducing an emf.

Direction of the current: When the soft iron rod X falls, it initially increases the magnetic flux through the coil. According to Lenz's Law, the induced current will flow in such a direction as to oppose this change. Therefore, the current in the coil will flow in an anticlockwise direction to generate a magnetic field that opposes the increase in flux.

Motion of the rod: As the rod falls, the increasing flux through the coil induces the current in the anticlockwise direction.

Thus, the current in the coil will be anticlockwise as the rod falls, in accordance with the laws of electromagnetic induction and Lenz's Law.

Quick Tip

When a conductor moves through a magnetic field, the direction of the induced current is such that it opposes the change in magnetic flux, as per Lenz's Law. In this case, the current is anticlockwise.

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

(A) $1.0 \times 10^{-9}\,\hat{k}\,\mathrm{T}$

(B) $-1.0 \times 10^{-9}\,\hat{k}\,\mathrm{T}$

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

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

Correct Answer: (C) $\frac{5.0}{\sqrt{2}} \times 10^{-10}\,\hat{k}\,\mathrm{T}$

Solution:

Step 1: Use Biot–Savart Law for a small straight wire segment Biot–Savart Law:

$$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{I\,\vec{l} \times \hat{r}}{r^2}$$

Step 2: Given

- $I = 1\,\mathrm{A}$
- $\vec{l} = 0.01\,\hat{\imath}\,\mathrm{m}$
- Observation point: $\vec{r} = \langle 1, 1, 0 \rangle$, so $r = \sqrt{1^2 + 1^2} = \sqrt{2}$
- Unit vector: $\hat{r} = \frac{\vec{r}}{r} = \frac{1}{\sqrt{2}}(\hat{\imath} + \hat{\jmath})$

Step 3: Cross product calculation

$$\vec{l} \times \hat{r} = 0.01\hat{i} \times \left(\frac{1}{\sqrt{2}}(\hat{\imath} + \hat{\jmath}) \right) = 0.01 \cdot \left(\frac{1}{\sqrt{2}}\hat{\imath} \times \hat{\imath} + \frac{1}{\sqrt{2}}\hat{\imath} \times \hat{\jmath} \right) = 0 + 0.01 \cdot \frac{1}{\sqrt{2}}\hat{k} = \frac{0.01}{\sqrt{2}}\hat{k}$$

Step 4: Plug into Biot–Savart Law

$$\vec{B} = \frac{10^{-7}}{1} \cdot \frac{1 \cdot \frac{0.01}{\sqrt{2}}}{2}\hat{k} = \frac{10^{-7} \cdot 0.01}{2\sqrt{2}}\hat{k} = \frac{10^{-9}}{2\sqrt{2}}\hat{k} = \frac{5 \times 10^{-10}}{\sqrt{2}}\hat{k}$$

$$\Rightarrow \vec{B} = \frac{5.0}{\sqrt{2}} \times 10^{-10}\hat{k}\,\mathrm{T}$$

Quick Tip

For short wire segments, use the Biot–Savart law directly using vector cross products and approximate the wire as a vector $\vec{l}$.

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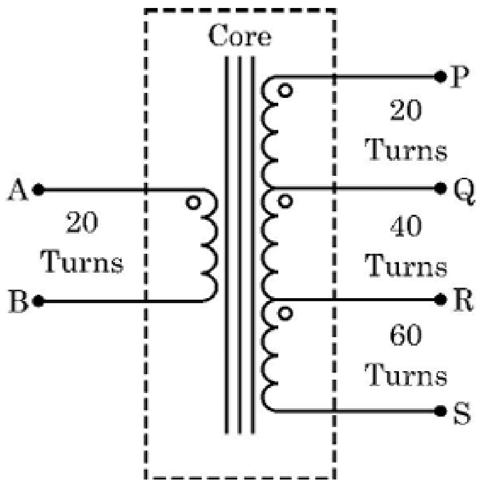
7. The number of turns between different pairs of output terminals are shown for a step-up transformer.



(A) P and Q

(B) Q and S

(C) P and R

(D) P and S

Correct Answer: (D) P and S

Solution:

We are given a step-up transformer, and the input voltage is 20 V. We need to find the pair of terminals between which the output voltage will be 120 V. The voltage ratio in a transformer is related to the turns ratio by the following formula:

$$\frac{V_{out}}{V_{in}} = \frac{N_{secondary}}{N_{primary}}$$

Where:

V_{out} is the output voltage

V_{in} is the input voltage

$N_{secondary}$ is the number of turns in the secondary coil

$N_{primary}$ is the number of turns in the primary coil

Now, the number of turns between different pairs of terminals are: Between A and P: 20 turns

Between A and Q: 40 turns

Between A and R: 60 turns

Between A and S: 80 turns

We need to determine which pair will give an output of 120 V, given that the input voltage is 20 V.

The voltage ratio is $\frac{V_{out}}{V_{in}} = \frac{N_{secondary}}{N_{primary}}$.

For **P and S**, the turns ratio is:

$$\frac{N_S}{N_A} = \frac{80}{20} = 4$$

Using the voltage ratio formula:

$$\frac{V_{out}}{20} = 4 \quad \Rightarrow \quad V_{out} = 20 \times 4 = 120 \text{ V}$$

Thus, the correct pair is **P and S**.

Quick Tip

In a step-up transformer, the output voltage increases based on the turns ratio. Ensure that the turns ratio is calculated correctly to determine the correct output voltage.

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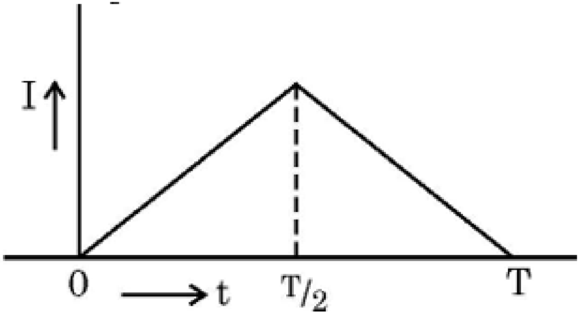
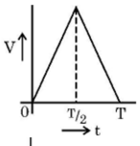
9. The alternating current I in an inductor is observed to vary with time t as shown in the graph for a cycle.

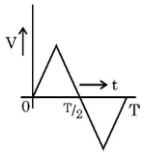


Which one of the following graphs is the correct representation of wave form of voltage V with time t?

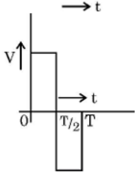
(A)



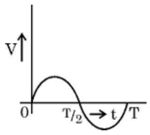
(B)



(C)



(D)



Correct Answer: (C)

Solution:

Step 1: Use the relation between voltage and current for an inductor:

$$V = L\frac{dI}{dt}$$

where V is the voltage across the inductor, L is the inductance, and $\frac{dI}{dt}$ is the rate of change of current with respect to time.

Step 2: Analyze the graph of $I(t)$:

The current graph is a triangular waveform:

- From 0 to $\frac{T}{2}$, I increases linearly $\Rightarrow \frac{dI}{dt} =$ constant positive
- From $\frac{T}{2}$ to T, I decreases linearly $\Rightarrow \frac{dI}{dt} =$ constant negative

Step 3: Apply the derivative:

$$V(t) = \begin{cases} +\text{constant}, & \text{for } 0 < t < T/2 \\ -\text{constant}, & \text{for } T/2 < t < T \end{cases}$$

So, the voltage is a square wave alternating between positive and negative constant values.

Step 4: Match with the options:

Option (C) shows a square wave for voltage, positive for 0 to $T/2$, and negative for $T/2$ to T, which is correct.

Quick Tip

For an inductor, voltage is proportional to the slope of the current graph: $V = L\frac{dI}{dt}$. So if current varies linearly, voltage is constant.

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9. The plane face of a planoconvex lens is silvered. The refractive index of material and radius of curvature of the curved surface of the lens are n and R respectively. This lens will behave as a concave mirror of focal length.

(A) $\dfrac{R}{n}$

(B) $\dfrac{R}{(n-1)}$

(C) nR

(D) $\dfrac{R}{2(n-1)}$

Correct Answer: (D) $\dfrac{R}{2(n-1)}$

Solution: When the plane face of a planoconvex lens is silvered, the lens behaves as a concave mirror. The focal length f of a concave mirror is related to the radius of curvature R by the equation:

$$f = \frac{R}{2}$$

For a planoconvex lens, the effective focal length when silvered also depends on the refractive index n of the material. The focal length of the lens behaves like a concave mirror and is given by:

$$f = \frac{R}{2(n-1)}$$

Therefore, the correct expression for the focal length is $\frac{R}{2(n-1)}$.

Quick Tip

When the plane face of a planoconvex lens is silvered, the lens behaves like a concave mirror. The focal length is given by $\frac{R}{2(n-1)}$, taking the refractive index of the lens into account.

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10. 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: (A) resistor and (C) capacitor

Solution:

Step 1: High resistance indicates reverse bias.

When a p-n junction diode is reverse biased, it offers very high resistance and does not conduct current appreciably. This behavior is similar to a resistor (with high resistance).

Step 2: Depletion layer acts as a dielectric.

In reverse bias, the depletion region widens, and no current flows across the junction, but charge separation occurs across this region. This is similar to how a capacitor works (two plates separated by a dielectric).

Thus, under high resistance (reverse bias) conditions:

It resists current flow like a resistor.

It stores electric charge like a capacitor.

Quick Tip

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

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11. 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: 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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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:

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

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

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

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

13. 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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14. 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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15. 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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14. 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.

Section-B

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.

Correct Answer: The value of V is $15.7\,\text{V}$.

Solution:

First, apply Kirchhoff's voltage law (KVL) to the circuit. The total voltage across the resistor and diode should be equal to the battery voltage.

The current through the resistor and diode is the same, so we can write the equation:

$$V = I \cdot R + V_{\text{diode}}$$

Where:

$I = 15\,\text{mA} = 0.015\,\text{A}$ (current through the circuit)

$R = 1000\,\Omega$ (resistance)

$V_{\text{diode}} = 0.7\,\text{V}$ (threshold voltage of the diode)

Substitute the known values:

$$V = (0.015)(1000) + 0.7 = 15 + 0.7 = 15.7\,\text{V}$$

Thus, the value of V is $\boxed{15.7\,\text{V}}$.

Quick Tip

Use Ohm's law and Kirchhoff's voltage law to relate the total voltage to the current, resistance, and threshold voltage of the diode in series circuits.

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18 In a double slit experiment, it is observed that the angular width of one fringe formed on the screen is 0.2°. The wavelength of light used in the experiment is 500 nm. Calculate the separation of the two slits.

Solution:

To solve this problem, we apply the formula for the angular fringe separation in a double-slit experiment:

$$\theta = \frac{\lambda}{d}$$

Where:

θ is the angular fringe separation,

λ is the wavelength of light used,

d is the separation of the two slits.

Given Values:

Wavelength of light, $\lambda = 500\,\text{nm} = 500 \times 10^{-9}\,\text{m}$,

Angular width of one fringe, $\theta = 0.2^\circ$.

Converting Angle to Radians:

First, we convert the angle from degrees to radians:

$$\text{angle in radians} = \theta \times \frac{\pi}{180}$$

Thus,

$$\theta = 0.2^\circ \times \frac{\pi}{180} \approx 0.00349\,\text{radians}$$

Rearranging the Formula:

Rearranging the formula to find the separation of the slits d:

$$d = \frac{\lambda}{\theta}$$

Calculating the Separation of Slits:

Substituting the values:

$$d = \frac{500 \times 10^{-9}\,\text{m}}{0.00349\,\text{radians}} \approx 1.43 \times 10^{-4}\,\text{m}$$

$$d \approx 0.143\,\text{mm}$$

Quick Tip

To calculate the separation of the slits, always remember that the angular fringe separation formula is derived from the basic principles of wave interference. Ensure to convert angle units correctly when applying the formula.

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19. A light beam converges at a point O. In the path of this beam, a concave lens of focal length 15 cm is placed at a distance of 10 cm before point O. The beam now converges at a point O'. Find the magnitude and the direction of shift OO'.

Solution:

Step 1: Understand the setup and identify the nature of the object.

- A light beam *converges* at point O. This means if no lens were present, the rays would meet at O.
- When a lens is placed *before* the convergence point, the point O acts as a **virtual object** for the lens. A virtual object is always located on the right side of the lens (in the direction of light propagation) and its distance is taken as positive.

- The concave lens is placed 10 cm *before* point O.

Step 2: List the given parameters and apply sign conventions.

- **Focal length of the concave lens,** $f = -15$ **cm** (Focal length of a concave (diverging) lens is always negative).
- **Object distance,** $u = +10$ **cm** (Since the light rays are converging towards point O which is to the right of the lens, O is a virtual object. For a virtual object, the object distance is taken as positive).

Step 3: Use the lens formula to find the position of the final image (O').

The lens formula is: $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

Substitute the known values into the formula:

$\frac{1}{-15} = \frac{1}{v} - \frac{1}{+10}$

$\frac{1}{v} = \frac{1}{-15} + \frac{1}{10}$

$\frac{1}{v} = -\frac{1}{15} + \frac{1}{10}$

To add the fractions, find a common denominator, which is 30:

$\frac{1}{v} = -\frac{2}{30} + \frac{3}{30}$

$\frac{1}{v} = \frac{-2+3}{30}$

$\frac{1}{v} = \frac{1}{30}$

$v = +30$ cm

Step 4: Interpret the result for the image position (O').

- The positive sign for v indicates that the final image O' is formed on the right side of the lens (real image).
- So, the new convergence point O' is 30 cm from the lens, on the right side.

Step 5: Calculate the magnitude and direction of the shift OO'.

- The original convergence point O was 10 cm to the right of the lens.
- The new convergence point O' is 30 cm to the right of the lens.

The shift is the distance between the original point O and the new point O'.

Magnitude of shift OO' = Position of O' - Position of O (all measured from the lens)

Magnitude of shift OO' = 30 cm $-$ 10 cm

Magnitude of shift OO' = 20 cm

Direction of shift: Since the new convergence point O' (30 cm) is further to the right than the original convergence point O (10 cm), the shift is **away from the lens** (or in the direction of light propagation).

$$\boxed{\text{Magnitude of shift OO' = 20 cm, Direction: Away from the lens}}$$

Quick Tip

For problems involving concave lenses, remember that the focal length is negative, and the object distance is also negative when the object is on the same side as the incoming light. Always ensure to use the correct sign conventions when applying the lens formula.

---

20. The threshold wavelength of a metal is 450 nm. Calculate (i) the work function of the metal in eV and (ii) the maximum energy of the ejected photoelectrons in eV by incident radiation of 250 nm.

Solution: We will use the photoelectric effect equation to solve this problem.

$$E = h\nu - W$$

where:

E is the maximum kinetic energy of the ejected photoelectron (in eV),

h is Planck's constant, 6.626×10^{-34} J·s,

ν is the frequency of the incident radiation,

W is the work function of the metal (in eV).

The frequency ν of light is related to its wavelength λ by the equation:

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

where:

c is the speed of light (3×10^8 m/s),

λ is the wavelength (in meters).

Part (i): Calculate the Work Function of the Metal

The work function W of the metal is related to its threshold wavelength λ_0 by the following equation:

$$W = \frac{hc}{\lambda_0}$$

Given:

$h = 6.626 \times 10^{-34}$ J·s,

$c = 3 \times 10^8$ m/s,

$\lambda_0 = 450\,\text{nm} = 450 \times 10^{-9}$ m.

Now, substitute the values into the formula:

$$W = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{450 \times 10^{-9}} = \frac{1.9878 \times 10^{-25}}{450 \times 10^{-9}} = 4.41 \times 10^{-19}\,\text{J}$$

Now, to convert the energy into eV, divide by the charge of an electron, 1.6×10^{-19} C:

$$W = \frac{4.41 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.75\,\text{eV}$$

Thus, the work function of the metal is $\boxed{2.75\,\text{eV}}$.

Part (ii): Calculate the Maximum Energy of the Ejected Photoelectrons

The energy of the incident radiation can be found using the frequency and the wavelength of the incident radiation $\lambda = 250\,\text{nm} = 250 \times 10^{-9}$ m.

First, calculate the frequency of the incident radiation:

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{250 \times 10^{-9}} = 1.2 \times 10^{15}\,\text{Hz}$$

Now, we calculate the energy of the incident photons:

$$E_{\text{photon}} = h\nu = 6.626 \times 10^{-34} \times 1.2 \times 10^{15} = 7.95 \times 10^{-19}\,\text{J}$$

Convert this energy to electron volts:

$$E_{\text{photon}} = \frac{7.95 \times 10^{-19}}{1.6 \times 10^{-19}} = 4.96\,\text{eV}$$

Now, calculate the maximum energy of the ejected photoelectrons using the photoelectric equation:

$$E = E_{\text{photon}} - W = 4.96 - 2.75 = 2.21\,\text{eV}$$

Thus, the maximum energy of the ejected photoelectrons is $\boxed{2.21\,\text{eV}}$.

Final Answer: (i) Work function of the metal: $\boxed{2.75\,\text{eV}}$

(ii) Maximum energy of the ejected photoelectrons: $\boxed{2.21\,\text{eV}}$

Quick Tip

Remember, the energy of the incident photon is the difference between the energy of the incoming radiation and the work function of the metal. If the photon energy is greater than the work function, photoemission occurs, and the excess energy becomes the kinetic energy of the ejected electron.

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: 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:

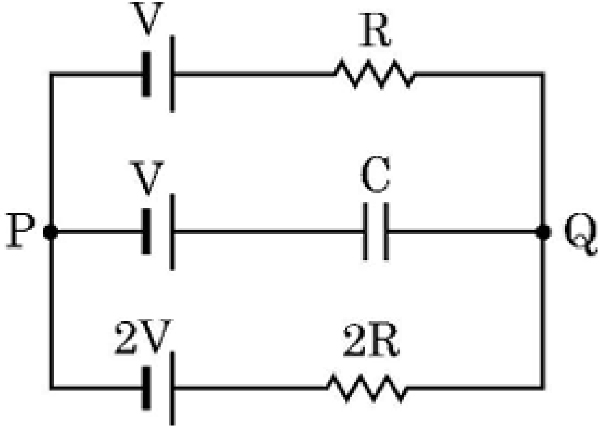
$$I_2 = \frac{V}{R_2} = \frac{6R_2}{R_2} = 6\,\text{A}$$

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.

21(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.

Section-C

22(a) Define Electrical conductivity. Obtain the expression of electrical conductivity of a conductor in terms of number density and relaxation time of free electrons.

Solution:

Electrical conductivity is a measure of a material's ability to conduct electric current. It is denoted by the symbol σ and is the inverse of electrical resistivity (ρ). The higher the conductivity, the easier it is for the material to conduct electricity.

The electrical conductivity σ of a conductor can be expressed in terms of the number density of free electrons (n) and the relaxation time (τ) of the free electrons. This expression is derived from Ohm's law in microscopic form, considering the movement of electrons under an electric field.

The expression for electrical conductivity is given by:

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

where:

n is the number density of free electrons (number of electrons per unit volume),

e is the charge of an electron,

τ is the relaxation time of the free electrons (the average time between collisions),

m is the mass of the electron.

This formula shows that electrical conductivity is proportional to the number density of free electrons and the relaxation time of these electrons.

Quick Tip

To calculate conductivity, focus on the properties of free electrons—more free electrons or a longer relaxation time leads to better conductivity.

22(b) Explain qualitative change in resistivity of a conductor with temperature using expression obtained in (a).

Solution:

The resistivity ρ of a material is inversely related to conductivity σ. The expression for resistivity is:

$$\rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau}$$

To explain how resistivity changes with temperature, we consider the effect of temperature on the number density of free electrons and the relaxation time of electrons. Generally:

1. Number Density n: For most conductors, the number density of free electrons does not change significantly with temperature.

2. Relaxation Time τ: The relaxation time decreases as temperature increases. This is because, at higher temperatures, the thermal vibrations of the atoms increase, causing more frequent collisions between the free electrons and the atoms in the conductor.

Thus, with increasing temperature, the relaxation time τ decreases, leading to an increase in resistivity.

Therefore, resistivity increases with temperature for most conductors. This relationship can be expressed as:

$$\rho(T) = \rho_0(1 + \alpha T)$$

where:

ρ_0 is the resistivity at a reference temperature (usually 0°C),

α is the temperature coefficient of resistivity,

T is the temperature.

This equation shows that resistivity increases linearly with temperature for most metallic conductors.

Quick Tip

As temperature increases, electron collisions become more frequent, which results in higher resistivity for most metals.

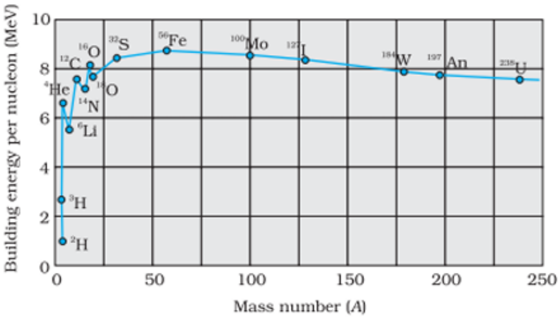
23(a). Show the variation of binding energy per nucleon with mass number. Write the significance of the binding energy curve.

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.

23(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.

24(a) ac voltage of frequency ω is applied across a series LCR circuit. Draw the phasor diagram and obtain the impedance of the circuit.

Solution:

We will calculate the impedance of a series LCR circuit step by step:

1. Impedance Formula for Series LCR Circuit:

The impedance Z of a series LCR circuit is given by:

$$Z = R + j\,(X_L - X_C)$$

Where:

R is the resistance,

$X_L = \omega L$ is the inductive reactance,

$X_C = \frac{1}{\omega C}$ is the capacitive reactance,

ω is the angular frequency of the AC supply.

2. Total Impedance Magnitude:

To find the magnitude of the impedance $|Z|$, we use the following formula:

$$|Z| = \sqrt{R^2 + (X_L - X_C)^2}$$

This gives us the total impedance in terms of the resistance and the difference between the inductive and capacitive reactances.

3. Phase Angle between Voltage and Current:

The phase angle ϕ between the applied voltage and the current is given by:

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

This phase angle indicates whether the current leads or lags the applied voltage.

4. Phasor Diagram:

The current vector is used as the reference vector.

The voltage across the resistor is in phase with the current.

The voltage across the inductor leads the current by $90°$.

The voltage across the capacitor lags the current by $90°$.

The resulting impedance vector is the sum of these components.

Quick Tip

In a series LCR circuit, the total impedance depends on the relative magnitudes of the inductive and capacitive reactances. The phasor diagram can help visualize the phase relationships and their effect on impedance.

24(b)

Discuss ’resonance’ in a series LCR circuit and write the expression for resonant frequency.

Solution:

1. Definition of Resonance:

In a series LCR circuit, resonance occurs when the inductive reactance (X_L) and capacitive reactance (X_C) are equal in magnitude but opposite in phase. At this point, the total reactance of the circuit becomes zero, and the impedance of the circuit is purely resistive ($Z = R$).

2. Condition for Resonance:

Resonance occurs when the inductive reactance is equal to the capacitive reactance:

$$X_L = X_C$$

Substituting the expressions for X_L and X_C:

$$\omega L = \frac{1}{\omega C}$$

3. Solving for Resonant Angular Frequency (ω_0):

Solving the above equation for ω, we get the angular frequency at resonance:

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

This is the angular frequency at which resonance occurs in the circuit.

4. Resonant Frequency (f_0):

The resonant frequency f_0 in hertz (Hz) is related to the angular frequency ω_0 by:

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$$

5. Current at Resonance:

At resonance, the impedance of the circuit is at its minimum value ($Z = R$), and the current reaches its maximum value. The voltage and current are in phase at resonance, meaning the phase angle ϕ is zero.

Quick Tip

At resonance, the impedance of the circuit is minimized, and the current reaches its maximum value. This is crucial for tuning circuits like radio receivers, where the desired frequency is selected to achieve resonance.

25(a) The amplitude of a light wave becomes n times. This results in intensity of the wave becoming m times. What is the relation between n and m?

Correct Answer: (B) $m = n^2$

Solution:

The intensity (I) of a light wave is directly proportional to the square of the amplitude (A) of the wave. This means that any change in the amplitude will result in a change in the intensity by the square of the amplitude's factor. Mathematically, this is expressed as:

$$I \propto A^2$$

When the amplitude of a wave increases by a factor of n, the new amplitude becomes $A' = nA$. The intensity, which is proportional to the square of the amplitude, will then become:

$$I' = (nA)^2 = n^2A^2$$

Since the original intensity is $I = A^2$, the new intensity is:

$$I' = n^2I$$

Thus, the intensity becomes n^2 times the original intensity. Therefore, $m = n^2$, which means the intensity increases by the square of the factor by which the amplitude increases.

This relationship between the amplitude and intensity is a fundamental concept in wave theory and is applicable to light waves, sound waves, and other types of mechanical waves.

Conclusion:

The intensity of the wave becomes n^2 times the original intensity when the amplitude increases by a factor of n. Thus, the correct answer is $m = n^2$.

Quick Tip

Remember, the intensity of a wave is always proportional to the square of its amplitude. So, if the amplitude increases by a factor of n, the intensity increases by a factor of n^2.

25(b)(i) White light is incident on three identical surfaces – a black surface, a yellow surface, and a white surface, one by one. For which surface, the pressure exerted on the surface by the incident light will be maximum?

Correct Answer: (A) Black surface

Solution: The pressure exerted by light on a surface is related to the amount of energy absorbed by the surface. A black surface absorbs the most light because it reflects very little, resulting in the maximum pressure. Therefore, the maximum pressure exerted by the light will be on the black surface.

Quick Tip

Darker surfaces like black absorb more light and exert higher pressure compared to lighter surfaces like white.

25(b)(ii) White light is incident on three identical surfaces – a black surface, a yellow surface, and a white surface, one by one. For which surface, the pressure exerted on the surface by the incident light will be minimum?

Correct Answer: (B) White surface

Solution: The white surface reflects most of the light and absorbs the least, meaning it exerts the minimum pressure. Thus, the minimum pressure exerted by the light will be on the white surface.

Quick Tip

Lighter surfaces like white reflect most of the light and absorb less, resulting in the minimum pressure compared to darker surfaces.

---

26. (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.

26(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.

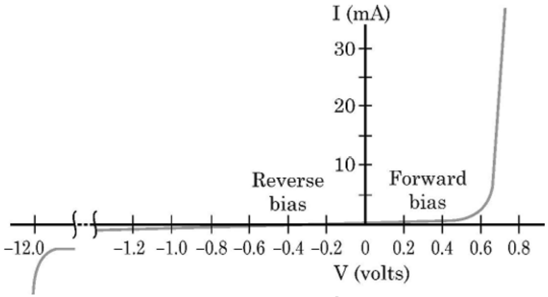
Holes: In the p-type region, holes are the majority charge carriers. Under forward bias, the holes move towards the n-side. As they cross the junction, they recombine with electrons in the n-type region.

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.

26(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.



Estimate the dynamic resistance of diode at V = –0.6 volt.

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.

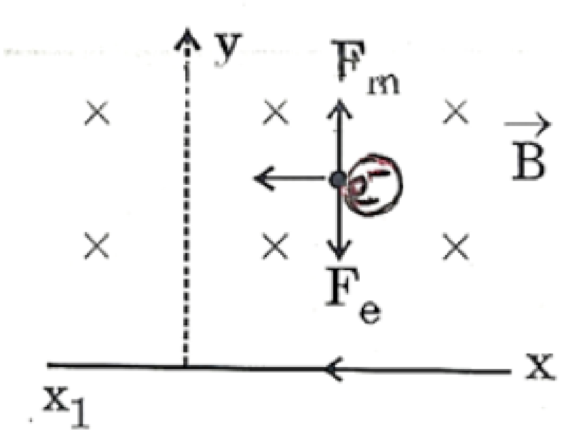
---

27. (a) In a region of a uniform electric field $\vec{E}$, a negatively charged particle is moving with a constant velocity 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.

(i) Draw diagram showing direction of electric and magnetic fields. Solution:

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.

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

27(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:

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

Thus, the value of v_0 is:

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

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

27(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.

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28. (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.

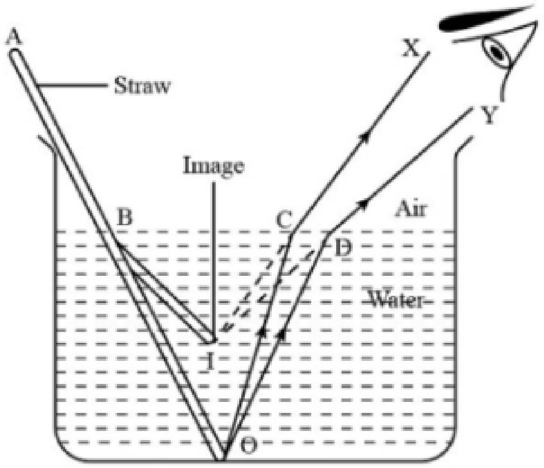
Quick Tip

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

28(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.



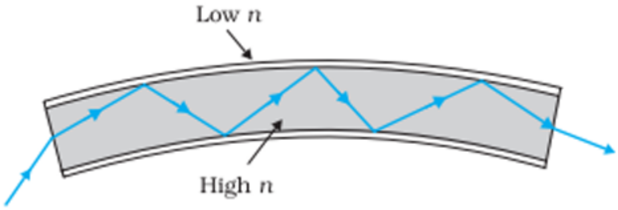
Quick Tip

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

28(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.



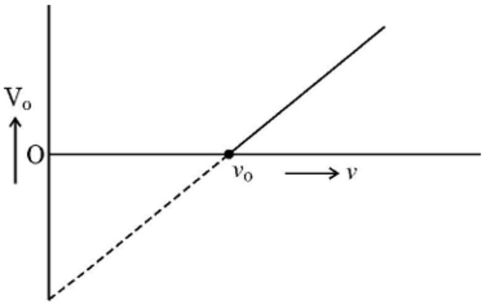
Quick Tip

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

Section-D

Question numbers 29 and 30 are case study based questions. Read the following paragraphs and answer the questions that follow.

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 $\cdot$ 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:

$h = 6.626 \times 10^{-34}\,\mathrm{J \cdot s}$,

$p = 5.0 \times 10^{-29}\,\text{kg} \cdot \text{m/s}$.

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

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:

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

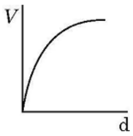
Thus, the new electric field between the plates will be half of the initial value, corresponding to option (D).

Quick Tip

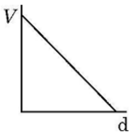
The electric field in a parallel plate capacitor is directly proportional to the potential difference and inversely proportional to the separation between the plates.

(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?

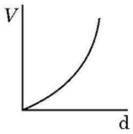
(A)



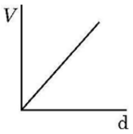
(B)



(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:

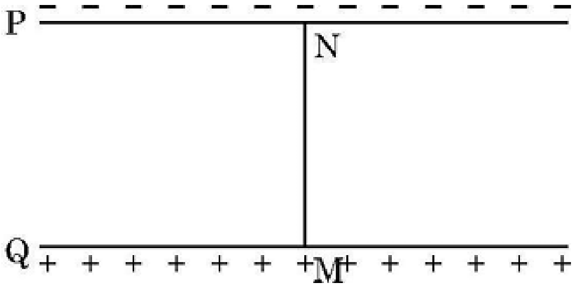
$$V = E \cdot d$$

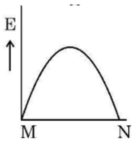
This relationship indicates that V increases linearly with d. Hence, the graph of V versus d will be a straight line, confirming that option (C) is correct.

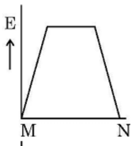
Quick Tip

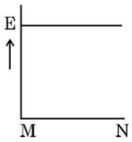
To maintain a constant electric field in a parallel plate capacitor, the potential difference must be proportional to the separation between the plates.

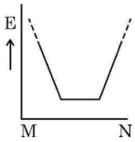
(iii) In the above figure, P and Q are the two parallel plates of a capacitor. Plate Q is at positive potential with respect to plate P. MN is an imaginary line drawn perpendicular to the plates. Which of the graphs shows correctly the variations of the magnitude of electric field strength E along the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

Section-E

31. (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.

---

31 (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 M with the external magnetic field B. The torque is given by:

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

The coil will be in stable equilibrium when M is aligned with 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.

---

32. (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 $e = 90^\circ$. Therefore, we can substitute into the formula:

$$15^\circ = i + 90^\circ - 30^\circ$$

Solving for i:

$$i = 15^\circ$$

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 $r = 90^\circ - A/2$, 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.

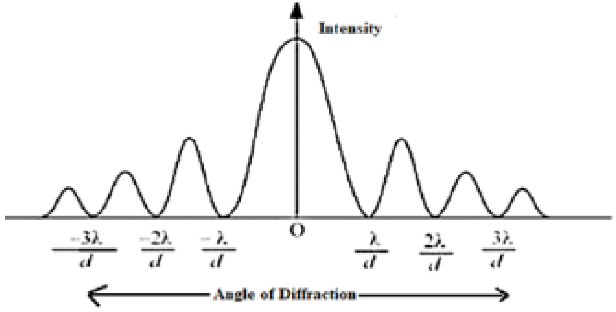
Quick Tip

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

32(b)(ii).1 Draw the variation of intensity with angle of diffraction in single slit diffraction pattern. Write the expression for value of angle corresponding to zero intensity locations.

Correct Answer: The intensity variation in a single slit diffraction pattern shows a central bright fringe, followed by alternating dark and bright fringes with decreasing intensity.

Solution:



Step 1: Understanding Single Slit Diffraction Pattern:

In a single slit diffraction pattern, the central maximum is the brightest, and the intensity decreases as we move away from the center. The minima (zero intensity) occur at specific angles where destructive interference happens between the light waves passing through the slit.

The condition for zero intensity (minima) in a single slit diffraction pattern is given by the equation:

$$a \sin\theta = m\lambda \quad \text{where} \quad m = \pm 1, \pm 2, \pm 3, \ldots$$

Here,

a is the width of the slit,

θ is the angle of diffraction,

λ is the wavelength of the light.

For the first minima (zero intensity), we substitute $m = \pm 1$ in the equation:

$$a \sin\theta = \pm\lambda$$

Thus, the angle corresponding to the first minima (zero intensity) is:

$$\theta = \sin^{-1}\left(\frac{\lambda}{a}\right)$$

This process repeats for higher-order minima with $m = \pm 2, \pm 3, \ldots$.

Quick Tip

In single slit diffraction, the central maximum is the brightest. The intensity decreases for higher-order minima, and the spacing between minima increases as the wavelength increases.

32(b)(ii).2 In what way diffraction of light waves differs from diffraction of sound waves?

Correct Answer: The diffraction of light and sound waves differs mainly in their wavelength and the extent of diffraction. Light waves, due to their much smaller wavelength, show diffraction only around very small obstacles or apertures, whereas sound waves, having a much larger wavelength, exhibit noticeable diffraction around larger objects and through wide openings.

Solution: Understanding Diffraction:

Diffraction is the bending of waves around obstacles or through small openings. It depends on the ratio of the wavelength of the wave to the size of the obstacle or aperture.

Diffraction of Light Waves:

Light waves have extremely small wavelengths (on the order of nanometers), so they only show significant diffraction when passing through very small apertures or around very small objects, typically on the scale of the wavelength of light.

Diffraction of Sound Waves:

Sound waves, on the other hand, have much larger wavelengths (on the order of meters), which means they can bend around larger obstacles and spread through larger openings. This makes sound diffraction much more noticeable in everyday situations, such as hearing sounds around corners.

Thus, the main difference lies in the relative size of the wavelength compared to the obstacle size, affecting the observable diffraction pattern.

Quick Tip

Sound waves, with their larger wavelengths, diffract more easily around everyday objects compared to light waves, which require much smaller apertures or obstacles to show significant diffraction.

---

33. (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.
