CBSE Class 12 Physics 2025 Question Paper (55/2/1) 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.

1. Two charges $-q$ each are placed at the vertices A and B of an equilateral triangle ABC. If M is the mid-point of AB, the net electric field at C will point along:

(A) CA

(B) CB

(C) MC

(D) CM

Correct Answer: (D) CM

Solution:

Step 1: Understanding the symmetry of the system.

The problem involves two charges of equal magnitude $-q$, placed at vertices A and B of an equilateral triangle ABC. The third vertex is C, and the midpoint M is located along line AB.

Step 2: Direction of electric field due to each charge.

Each of the charges $-q$ at vertices A and B will create an electric field at point C. Since both charges are negative, the electric fields will point towards each charge (because the electric field points towards negative charges).

Step 3: Superposition of electric fields.

The resultant electric field at point C will be the vector sum of the electric fields due to the charges at A and B. Due to the symmetry of the equilateral triangle, the electric fields will have equal magnitudes but different directions.

The electric field due to each charge will have a component along the line AC and along the line BC. By symmetry, the horizontal components (along AB) of these two electric fields will cancel each other out, while the vertical components (along line CM) will add up.

Step 4: Net electric field direction.

Since the vertical components of the electric fields reinforce each other, the net electric field at point C will point along the line CM, which is the perpendicular bisector of line AB.

> **Quick Tip**
>
> In problems involving electric fields due to symmetric charge distributions, use symmetry to simplify the problem. The net electric field will be along the symmetry axis.

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2. A student has three resistors, each of resistance R. To obtain a resistance of $\frac{2}{3}R$, she should connect:

(A) all the three resistors in series.

(B) all the three resistors in parallel.

(C) two resistors in series and then this combination in parallel with the third resistor.

(D) two resistors in parallel and then this combination in series with the third resistor.

Correct Answer: (C) two resistors in series and then this combination in parallel with the third resistor.

Solution:

Step 1: Understanding the total resistance in series and parallel.

We are given three resistors, each with resistance R, and we need to obtain a total resistance of $\frac{2}{3}R$. We will use the formulas for resistances in series and parallel to find the correct configuration.

The formula for the total resistance R_{eq} of resistors in parallel is:

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

The total resistance of resistors in series is the sum of their resistances:

$$R_{\text{total}} = R_1 + R_2 + \cdots$$

Step 2: Combining two resistors in series.

When two resistors are connected in series, their equivalent resistance is:

$$R_{\text{eq, series}} = R + R = 2R.$$

Step 3: Adding the third resistor in parallel.

Now, if this series combination of two resistors ($2R$) is connected in parallel with the third resistor R, the total equivalent resistance R_{total} is given by:

$$\frac{1}{R_{\text{total}}} = \frac{1}{2R} + \frac{1}{R}.$$

Simplifying the right-hand side:

$$\frac{1}{R_{\text{total}}} = \frac{1}{2R} + \frac{2}{2R} = \frac{3}{2R}.$$

Thus, the equivalent resistance is:

$$R_{\text{total}} = \frac{2R}{3}.$$

This matches the required total resistance of $\frac{2}{3}R$.

Therefore, the correct configuration is to connect two resistors in series and then this combination in parallel with the third resistor.

Quick Tip

For resistors in parallel, the total resistance decreases as more resistors are added. For resistors in series, the total resistance increases. Combine series and parallel resistors to achieve specific resistance values.

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3. 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) $1.0 \times 10^{-9}\,\hat{k}\,\text{T}$

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

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

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

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

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

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

Step 3: Cross product calculation

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

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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4. The magnetic field due to a small magnetic dipole of dipole moment M at a distance r from the center along the axis of the dipole is given by:

(A) $\frac{\mu_0}{4\pi} \times \frac{2M}{r^3}$

(B) $\frac{\mu_0}{4\pi} \times \frac{M}{r^3}$

(C) $\frac{\mu_0}{4\pi} \times \frac{M}{2r^3}$

(D) $\frac{\mu_0}{4\pi} \times \frac{2M}{r^2}$

Correct Answer: (A) $\frac{\mu_0}{4\pi} \times \frac{2M}{r^3}$

Solution:

The magnetic field at a point on the axis of a magnetic dipole can be derived from the expression for the potential due to a dipole. For a dipole with dipole moment M, the magnetic field along the axis at a distance r from the center is given by the formula:

$$B = \frac{\mu_0}{4\pi} \times \frac{2M}{r^3}$$

where: μ_0 is the permeability of free space,

M is the magnetic dipole moment,

r is the distance from the dipole along its axis.

This is a standard result for the magnetic field produced by a small dipole. The field decreases with the cube of the distance from the dipole. Therefore, the correct answer is option (A).

Quick Tip

The magnetic field along the axis of a dipole falls off as $1/r^3$, which means it decreases much faster compared to the electric field around a point charge. This is important when considering the strength of magnetic fields near dipoles.

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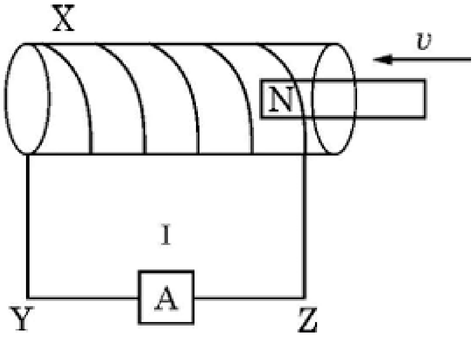
5. In the figure, X is a coil wound over a hollow wooden pipe. A permanent magnet is pushed at a constant speed v from the right into the pipe and it comes out at the left end of the pipe. During the entry and the exit of the magnet, the current in the wire YZ will be from:



(A) Y to Z and then Z to Y

(B) Z to Y and then Y to Z

(C) Y to Z and then Z to Y

(D) Z to Y and then Z to Y

Correct Answer: (B) Z to Y and then Y to Z

Solution:

In this scenario, the magnet is moving through the coil, and as it enters and exits the coil, it causes a change in the magnetic flux through the coil. According to Faraday's Law of Induction, a changing magnetic flux induces an electromotive force (EMF) in the coil, which results in a current.

When the magnet is entering the coil, the flux through the coil is increasing. By Lenz's Law, the induced current will oppose this increase, so the current will flow from Z to Y to oppose the entry of the magnet.

When the magnet exits the coil, the flux through the coil decreases. To oppose this decrease, the induced current will reverse direction, flowing from Y to Z.

Thus, the current flows from Z to Y during the entry of the magnet and from Y to Z during its exit.

Quick Tip

When dealing with changing magnetic fields and induced currents, always apply Lenz's Law: the induced current flows in such a direction as to oppose the change in magnetic flux through the coil.

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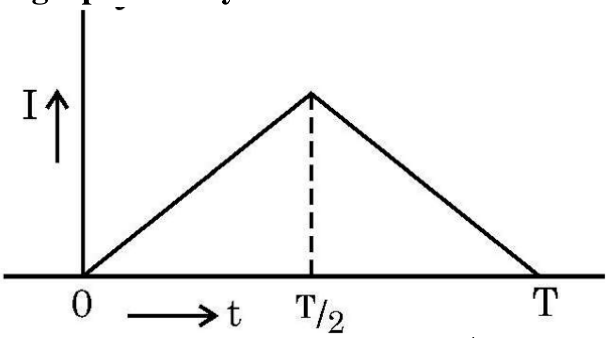
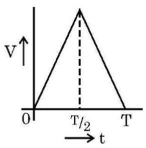
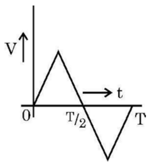
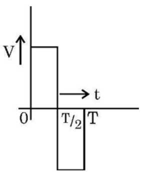
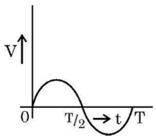
6. The alternating current I in an inductor is observed to vary with time t as shown in the graph for a cycle.



(A) 

(B) 

(C) 

(D) 

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

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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7. A transformer is connected to a 200 V AC source. The transformer supplies 3000 V to a device. If the number of turns in the primary coil is 450, then the number of turns in its secondary coil is –

(A) 30

(B) 450

(C) 4500

(D) 6750

Correct Answer: (D) 6750

Solution:

Step 1: Use the transformer voltage-turns ratio formula:

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

where:

V_s = Voltage across secondary coil = $3000\,\text{V}$

V_p = Voltage across primary coil = $200\,\text{V}$

N_p = Number of turns in primary coil = 450

Step 2: Substitute known values:

$$\frac{3000}{200} = \frac{N_s}{450} \Rightarrow 15 = \frac{N_s}{450}$$

Step 3: Solve for N_s:

$$N_s = 15 \times 450 = 6750$$

Hence, number of turns in the secondary coil is 6750.

> **Quick Tip**
>
> Transformers follow the relation $\frac{V_s}{V_p} = \frac{N_s}{N_p}$. If output voltage is greater than input, it's a step-up transformer.

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8. 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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9. A tub is filled with a transparent liquid to a height of 30.0 cm. The apparent depth of a coin lying at the bottom of the tub is found to be 16.0 cm. The speed of light in the liquid will be:

(A) 1.6×10^8 m/s

(B) 2.0×10^8 m/s

(C) 3.0×10^8 m/s

(D) 2.5×10^8 m/s

Correct Answer: (A) 1.6×10^8 m/s

Solution:

Step 1: Use the formula for refractive index based on real and apparent depth:

$$n = \frac{\text{Real depth}}{\text{Apparent depth}} = \frac{30.0}{16.0} = 1.875$$

Step 2: Use the relation between speed of light and refractive index:

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

where $c = 3.0 \times 10^8$ m/s is the speed of light in vacuum.

$$v = \frac{3.0 \times 10^8}{1.875} = 1.6 \times 10^8 \text{ m/s}$$

Therefore, the speed of light in the liquid is $\boxed{1.6 \times 10^8 \text{ m/s}}$.

Quick Tip

To find speed of light in a medium, use $v = \frac{c}{n}$, where $n = \frac{\text{real depth}}{\text{apparent depth}}$.

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10. 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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11. 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 $-0.544\,$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.

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12. 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).

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 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.

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15. 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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16. 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.

Section - B

17(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:

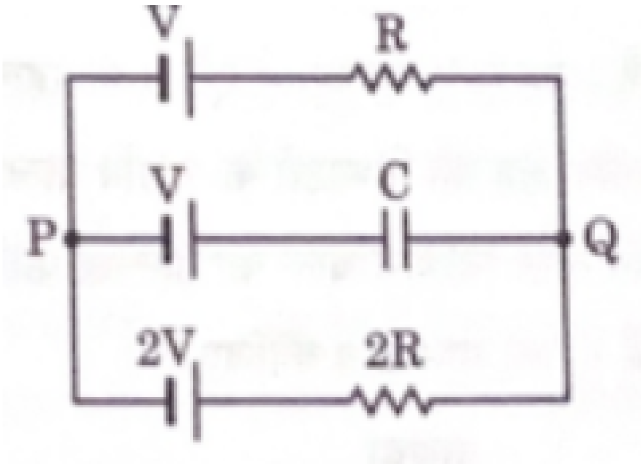
$$I_2 = \frac{V}{R_2} = \frac{6R_2}{R_2} = 6\,\text{A}$$

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.

17(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.

---

18. In a double-slit experiment, the 6^{th} dark fringe is observed at a certain point of the screen. A transparent sheet of thickness t and refractive index n is now introduced in the path of one of the two interfering waves to increase its phase by $\frac{2\pi(n-1)t}{\lambda}$. The pattern is shifted and 8^{th} bright fringe is observed at the same point. Find the relation for thickness t in terms of n and λ.

Solution:

Step 1: Understand the fringe order change.

Originally, the 6^{th} dark fringe was observed at the point. This corresponds to:

$$\Delta x_1 = (2m+1)\frac{\lambda}{2}, \quad \text{where } m = 5 \Rightarrow \Delta x_1 = \frac{11\lambda}{2}$$

After introducing the plate, the point corresponds to the 8^{th} bright fringe:

$$\Delta x_2 = m'\lambda, \quad \text{where } m' = 8 \Rightarrow \Delta x_2 = 8\lambda$$

Step 2: Path difference added by the transparent sheet:

$$\text{Extra path difference } = \Delta x_2 - \Delta x_1 = 8\lambda - \frac{11\lambda}{2} = \frac{5\lambda}{2}$$

Step 3: This extra path difference is due to the insertion of a plate of thickness t:

$$\frac{2\pi}{\lambda}(n-1)t = \frac{2\pi}{\lambda}\cdot\frac{5\lambda}{2} \Rightarrow (n-1)t = \frac{5\lambda}{2}$$

Step 4: Solve for t:

$$t = \frac{5\lambda}{2(n-1)}$$

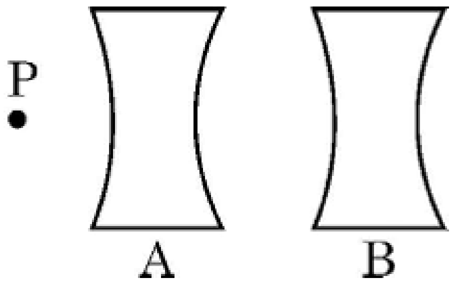
Required relation: $\boxed{t = \frac{5\lambda}{2(n-1)}}$

Quick Tip

In fringe shift problems, use the relation Path difference $= (n-1)t$, and compare it with the change in fringe order to find thickness or refractive index.

---

19. Two concave lenses A and B, each of focal length 8.0 cm are arranged coaxially 16 cm apart. An object P is placed at a distance of 4.0 cm from A. Find the position and nature of the final image formed.



Solution:

Step 1: Identify given parameters and sign conventions for the first lens (Lens A).

- Type of lens A: Concave lens.
- Focal length of lens A, $f_A = -8.0$ cm (focal length of a concave lens is negative).
- Object distance from lens A, $u_A = -4.0$ cm (object placed to the left of the lens is negative).

Step 2: Calculate the image formed by the first lens (Lens A).

Using the lens formula: $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$
For lens A: $\frac{1}{f_A} = \frac{1}{v_A} - \frac{1}{u_A}$
$\frac{1}{-8.0} = \frac{1}{v_A} - \frac{1}{-4.0}$
$\frac{1}{v_A} = \frac{1}{-8.0} + \frac{1}{-4.0}$
$\frac{1}{v_A} = -\frac{1}{8.0} - \frac{1}{4.0}$
$\frac{1}{v_A} = \frac{-1-2}{8.0}$
$\frac{1}{v_A} = \frac{-3}{8.0}$
$v_A = -\frac{8.0}{3}$ cm ≈ -2.67 cm
The negative sign for v_A indicates that the image formed by lens A is virtual and on the same side as the object (to the left of lens A).

Step 3: Determine the object for the second lens (Lens B).

The image formed by lens A acts as the object for lens B.

- Distance between lenses A and B = 16 cm.
- The image from lens A is located at $v_A = -8/3$ cm from lens A. Since v_A is negative, it means the image is $8/3$ cm to the left of lens A.
- Since lens B is to the right of lens A, the distance of this virtual image from lens B is:
  $u_B =$ Distance between lenses $+ |v_A|$ (because the virtual image is to the left of A, hence to the left of B)
  $u_B = 16$ cm $+ \frac{8}{3}$ cm
  $u_B = 16 + 2.67 = 18.67$ cm.
  Since this object for lens B is to the left of lens B, $u_B = -18.67$ cm or
  $-\left(16 + \frac{8}{3}\right) = -\left(\frac{48+8}{3}\right) = -\frac{56}{3}$ cm.

Step 4: Calculate the final image formed by the second lens (Lens B).

- Type of lens B: Concave lens.
- Focal length of lens B, $f_B = -8.0$ cm.
- Object distance for lens B, $u_B = -\frac{56}{3}$ cm.

Using the lens formula for lens B: $\frac{1}{f_B} = \frac{1}{v_B} - \frac{1}{u_B}$

$\frac{1}{-8.0} = \frac{1}{v_B} - \frac{1}{-\frac{56}{3}}$
$\frac{1}{v_B} = \frac{1}{-8.0} - \frac{3}{56}$
$\frac{1}{v_B} = -\frac{1}{8} - \frac{3}{56}$
To combine these, find a common denominator, which is 56.
$\frac{1}{v_B} = -\frac{7}{56} - \frac{3}{56}$
$\frac{1}{v_B} = \frac{-7-3}{56}$
$\frac{1}{v_B} = \frac{-10}{56}$
$v_B = -\frac{56}{10}$ cm
$v_B = -5.6$ cm

Step 5: Determine the nature of the final image.

The negative sign for v_B indicates that the final image is virtual.

Since the image is on the same side as the object for lens B (to the left of lens B), and the calculation yielded a negative result, it is a virtual image.

Step 6: State the position and nature of the final image.

- **Position:** The final image is formed at 5.6 cm to the left of lens B.
- **Nature:** The final image is virtual and erect.

$$\boxed{\text{Position: 5.6 cm to the left of lens B, Nature: Virtual and Erect}}$$

Quick Tip

Always use sign convention consistently in multiple-lens problems. Negative object/image distances imply left of the lens; concave lenses have negative focal length.

---

20. A light of wavelength 400 nm is incident on a metal surface whose work function is 3.0×10^{-19} J. Calculate the speed of the fastest photoelectrons emitted.

Correct Answer: The speed of the fastest photoelectrons is 6.53×10^5 m/s.

Solution:

First, let's calculate the energy of the incident photon using the formula:

$$E_{\text{photon}} = \frac{hc}{\lambda}$$

Where:

$h = 6.626 \times 10^{-34}$ J·s (Planck's constant)

$c = 3.0 \times 10^8$ m/s (speed of light)

$\lambda = 400 \times 10^{-9}$ m (wavelength of the light)

Substitute the values:

$$E_{\text{photon}} = \frac{(6.626 \times 10^{-34}) \times (3.0 \times 10^8)}{400 \times 10^{-9}} = 4.97 \times 10^{-19}\,\text{J}$$

Next, the maximum kinetic energy of the emitted photoelectron is given by the photoelectric equation:

$$K_{\text{max}} = E_{\text{photon}} - \text{Work Function}$$

Substitute the known values:

$$K_{\text{max}} = 4.97 \times 10^{-19} - 3.0 \times 10^{-19} = 1.97 \times 10^{-19}\,\text{J}$$

Now, using the kinetic energy formula for the fastest photoelectron:

$$K_{\text{max}} = \frac{1}{2}mv^2$$

Where:

$m = 9.11 \times 10^{-31}$ kg (mass of the electron)

v is the speed of the electron

Solving for v:

$$v = \sqrt{\frac{2K_{\text{max}}}{m}} = \sqrt{\frac{2 \times 1.97 \times 10^{-19}}{9.11 \times 10^{-31}}} = 6.53 \times 10^5\,\text{m/s}$$

Thus, the speed of the fastest photoelectrons is $\boxed{6.53 \times 10^5\,\text{m/s}}$.

Quick Tip

For the photoelectric effect, use the equation $K_{\text{max}} = E_{\text{photon}} - \text{Work Function}$ to find the kinetic energy of the photoelectrons, and then apply the formula for kinetic energy to find their speed.

---

21. 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.

Section - C

22. (a) A cell of e.m.f E and internal resistance r is connected with a variable external resistance R and a voltmeter showing potential drop V across R. Obtain the relationship between V, E, R, and r.

Correct Answer: $V = E\left(\frac{R}{R+r}\right)$

Solution: Consider the circuit with the cell of e.m.f E and internal resistance r connected to an external resistance R.

Using Ohm's law, the total current I in the circuit is given by:

$$I = \frac{E}{R + r}$$

The potential drop V across the external resistance R is:

$$V = IR = \left(\frac{E}{R+r}\right) R$$

Simplifying the expression for V:

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

Thus, the relationship between the potential drop V, e.m.f E, external resistance R, and internal resistance r is:

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

Quick Tip

When calculating the voltage drop across the external resistance, always remember that the current in the circuit depends on the total resistance, which includes both internal and external resistances.

---

22. (b) Draw the shape of the graph showing the variation of terminal voltage V of the cell as a function of current I drawn from it. How can one determine the e.m.f of the cell and its internal resistance from this graph?

Correct Answer: The graph is a straight line with a slope of $-r$ and intercept E.

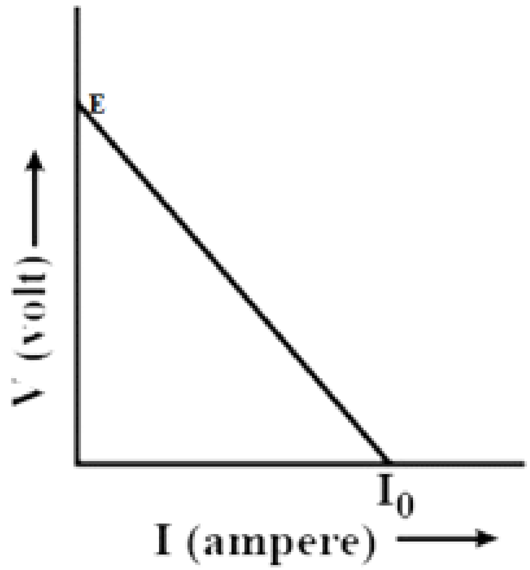
Solution: Step 1: From part (a), we have the relationship:

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

This equation represents the terminal voltage V as a linear function of the current I, with slope $-r$ and intercept E. The terminal voltage decreases linearly as the current increases, and the slope of the graph represents the internal resistance r.

Step 2: How to determine e.m.f and internal resistance from the graph:

The e.m.f E of the cell can be determined from the y-intercept of the graph (when $I = 0$). The internal resistance r can be determined from the slope of the graph (since the slope is $-r$).



Quick Tip

To determine the e.m.f and internal resistance from a graph of voltage vs. current, find the intercept for e.m.f and the slope for internal resistance.

---

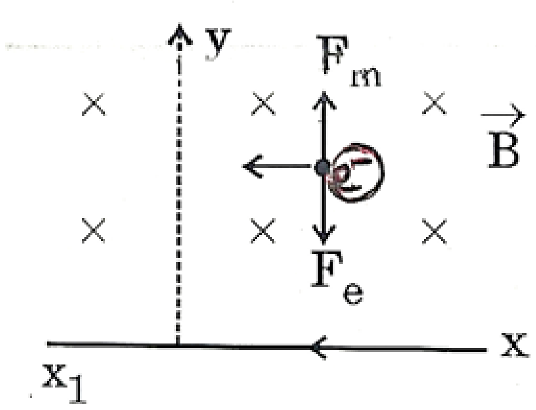
23. (a) In a region of a uniform electric field $\vec{E}$, a negatively charged particle is moving with a constant velocity $v = -v_0\hat{i}$ near a long straight conductor coinciding with XX' axis and carrying current I towards -X axis. The particle remains at a distance d from the conductor.

(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.

(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 $\mathbf{B}$ 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:

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

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

(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.

24(a) State Lenz's law.

Correct Answer: Lenz's Law states that the direction of an induced current (or emf) is always such that it opposes the change in magnetic flux that caused it.

Solution: Lenz's Law is a fundamental law of electromagnetism that describes the direction of induced current or electromotive force (emf) when a change in magnetic flux occurs. It was formulated by Heinrich Lenz in 1834.

According to Lenz's Law, the induced current in a circuit due to a changing magnetic field will always flow in such a direction that it opposes the change in the magnetic flux that caused it. In other words, if the magnetic flux through a coil is increasing, the induced current will flow in a direction to oppose this increase, and if the flux is decreasing, the current will oppose the decrease.

The mathematical expression of Lenz's law is:

$$\text{Induced emf} = -\frac{d\Phi}{dt}$$

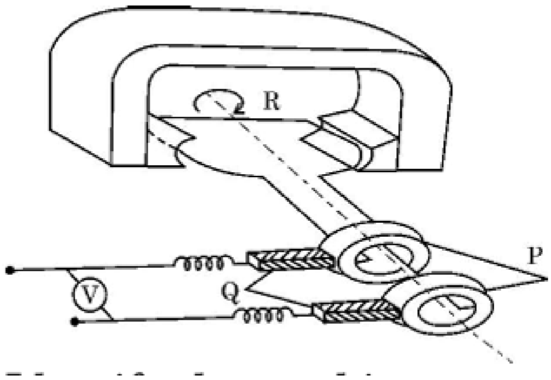
Where Φ is the magnetic flux, and the negative sign indicates the opposing nature of the induced current.

This law ensures the conservation of energy, as the induced current generates a magnetic field that opposes the change in flux, thereby preventing perpetual motion.

Quick Tip

Lenz's Law ensures the conservation of energy by always opposing the change in magnetic flux. Remember that the negative sign in the formula indicates the opposing nature of the induced current.

24(b) In the given figure:



24(b) (i) Identify the machine.

Correct Answer: Dynamo or Electric Generator

Solution: The machine shown in the figure is a dynamo or electric generator. A dynamo is a device that converts mechanical energy into electrical energy by rotating a coil (armature) within a magnetic field. The rotation induces an electromotive force (emf) across the coil due to the changing magnetic flux. This is an application of Faraday's law of electromagnetic induction.

A dynamo works by using mechanical energy (such as turning a wheel) to rotate the coil within the magnetic field, which induces an electric current that can be used for power.

Quick Tip

A dynamo works on the principle of electromagnetic induction, converting mechanical energy into electrical energy. The key component is the rotating armature within a magnetic field.

24(b) (ii) Name the parts P and Q and R of the machine.

Correct Answer:

- P: Commutator
- Q: Armature
- R: Field Magnet or Pole Pieces

Solution: In a dynamo:

P (Commutator): The commutator is a rotary switch that reverses the direction of the current in the coil every half-turn. It ensures that the current flows in one direction, providing a unidirectional output.

Q (Armature): The armature is the rotating part of the dynamo. It consists of a coil of wire that moves through the magnetic field generated by the field magnet, inducing an emf due to the changing magnetic flux.

R (Field Magnet): The field magnet provides the magnetic field within which the armature rotates. The field magnet can be an electromagnet or a permanent magnet. It is responsible for generating the magnetic flux required for induction.

Quick Tip

In a dynamo, the commutator ensures unidirectional current, the armature rotates to induce emf, and the field magnet creates the magnetic flux necessary for induction.

24(b) (iii) Give the polarities of the magnetic poles.

Correct Answer:

- N-pole (North Pole): The top of the field magnet.

- S-pole (South Pole): The bottom of the field magnet.

Solution: In the machine, the field magnet creates a magnetic field with the following polarities:
The N-pole (North Pole) is located at the top of the field magnet.
The S-pole (South Pole) is located at the bottom of the field magnet.
This magnetic field interacts with the armature as it rotates, inducing an electromotive force (emf) in the coil. The direction of the induced current is determined by the orientation of the magnetic poles and the rotation of the armature.

Quick Tip

The N-pole and S-pole of the field magnet create the magnetic flux that induces current in the armature. The direction of the current depends on the orientation of these poles.

24(b) (iv) Write the two ways of increasing the output voltage.
Correct Answer:

- Increase the speed of rotation of the armature.
- Increase the number of turns in the armature coil.

Solution: There are two ways to increase the output voltage of a dynamo:
1. Increase the speed of rotation of the armature: By rotating the armature faster, the rate of change of magnetic flux through the coil increases, leading to a higher induced emf and thus a higher output voltage.
2. Increase the number of turns in the armature coil: The induced voltage is proportional to the number of turns in the coil. By increasing the number of turns, the total induced voltage will be higher, leading to a greater output.
Both methods increase the rate of change of magnetic flux through the coil, either by increasing the mechanical motion or by increasing the number of conducting loops through which the flux changes.

Quick Tip

To increase the output voltage of a generator, either rotate the armature faster or use a coil with more turns. These changes enhance the rate of magnetic flux change, which increases the induced voltage.

25(a) The electric field $\vec{E}$ of an electromagnetic wave propagating in the north direction is oscillating in the up and down direction. Describe the direction of the magnetic field $\vec{B}$ of the wave.

Correct Answer: The magnetic field $\vec{B}$ will oscillate in the east-west direction.

Solution: In an electromagnetic wave, the electric field and magnetic field are always perpendicular to each other and to the direction of propagation.

Given that the electric field $\vec{E}$ is oscillating in the up and down direction (let's assume the vertical direction, or the y-axis) and the wave is propagating in the north direction (the x-axis), the magnetic field $\vec{B}$ must oscillate in the third perpendicular direction (the z-axis).

Thus, the magnetic field $\vec{B}$ oscillates in the east-west direction (the z-axis).

Quick Tip

In electromagnetic waves, the direction of propagation, the electric field, and the magnetic field always form a right-handed coordinate system.

25(b) Are the wavelength of radio waves and microwaves longer or shorter than those detectable by human eyes?

Correct Answer: Longer

Solution: Radio waves and microwaves have wavelengths that are much longer than the visible light detected by human eyes.

The wavelength of visible light ranges from about 400 nm to 700 nm.

Radio waves typically have wavelengths from about 1 mm to 100 km.

Microwaves typically have wavelengths from about 1 mm to 30 cm.

Since these wavelengths are much longer than visible light, the wavelengths of radio waves and microwaves are longer than those detectable by human eyes.

Quick Tip

Radio waves and microwaves are non-visible electromagnetic waves, so they cannot be detected by the human eye.

25(c)(i) Write the main use of infrared waves in human life.

Correct Answer: Infrared waves are mainly used in thermal imaging, night vision, and remote sensing.

Solution: Infrared waves are used in various applications such as:

Thermal imaging: Infrared cameras detect heat emitted by objects, allowing us to see temperature variations.

Night vision: Infrared light allows devices to see in low light or complete darkness by detecting heat radiation from objects.

Remote sensing: Infrared waves are used to gather data on temperature, moisture, and other characteristics of Earth's surface in satellite imaging.

These uses leverage the ability of infrared waves to detect temperature differences and provide detailed thermal information.

Quick Tip

Infrared waves are useful in situations where visible light is unavailable, especially for heat detection and nighttime visibility.

25(c)(ii) Write the main use of gamma rays in human life.

Correct Answer: Gamma rays are used in cancer treatment (radiation therapy) and sterilization.

Solution: Gamma rays are high-energy electromagnetic waves that have the following uses:

Cancer treatment (radiation therapy): Gamma rays are used to kill or damage cancer cells, thereby reducing or eliminating tumors.

Sterilization: Gamma rays are used to sterilize medical equipment and food by killing bacteria and other microorganisms.

Because of their high energy, gamma rays can penetrate deep into materials and are effective in these medical and industrial applications.

Quick Tip

While gamma rays are powerful, they need to be carefully controlled due to their high energy and potential harmful effects.

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26. (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.

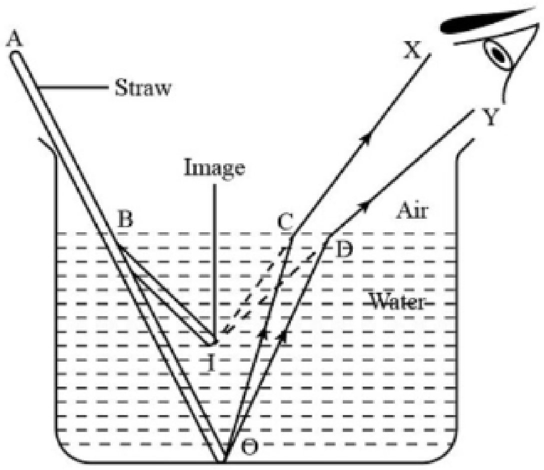
Quick Tip

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.



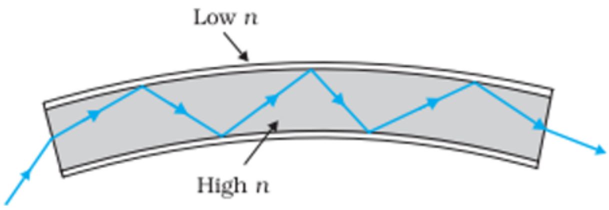
Quick Tip

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.

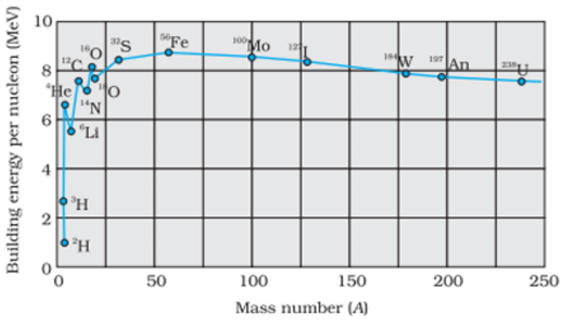
27.(a) Show the variation of binding energy per nucleon with mass number. Write the significance of the binding energy curve.

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.

---

28. (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.

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

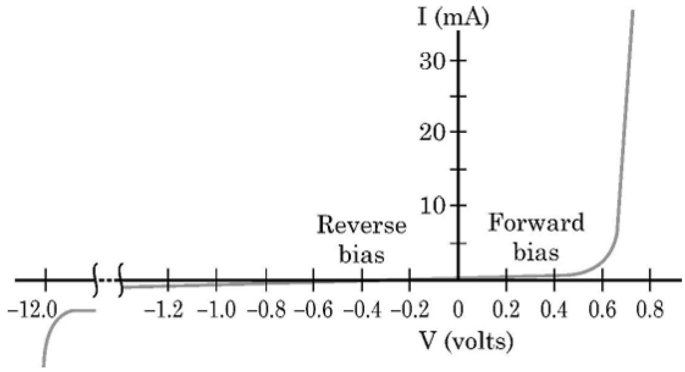
Solution:

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.



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.

Section - D

29. 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:

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

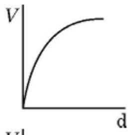
Thus, the new electric field between the plates will be half of the initial value, corresponding to option (D).

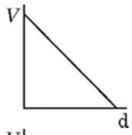
Quick Tip

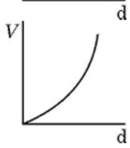
The electric field in a parallel plate capacitor is directly proportional to the potential difference and inversely proportional to the separation between the plates.

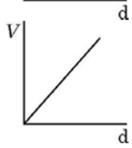
(ii) A constant electric field is to be maintained between the two plates of a capacitor

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:

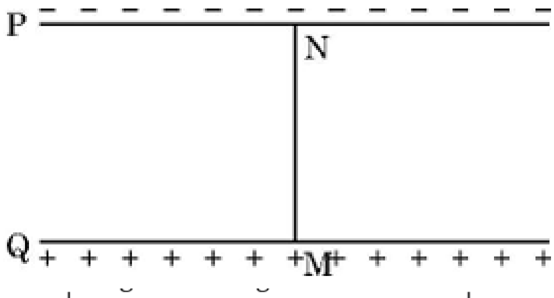
$$V = E \cdot d$$

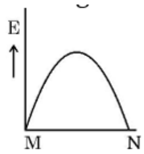
This relationship indicates that V increases linearly with d. Hence, the graph of V versus d will be a straight line, confirming that option (C) is correct.

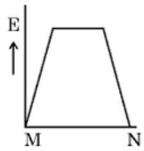
Quick Tip

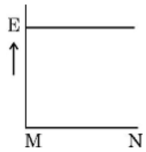
To maintain a constant electric field in a parallel plate capacitor, the potential difference must be proportional to the separation between the plates.

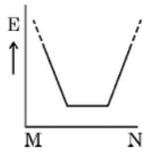
(iii) In the above figure, P and Q are the two parallel plates of a capacitor. Plate Q is at positive potential with respect to plate P. MN is an imaginary line drawn perpendicular to the plates. Which of the graphs shows correctly the variations of the magnitude of electric field strength E along the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

$$C' = K \cdot C$$

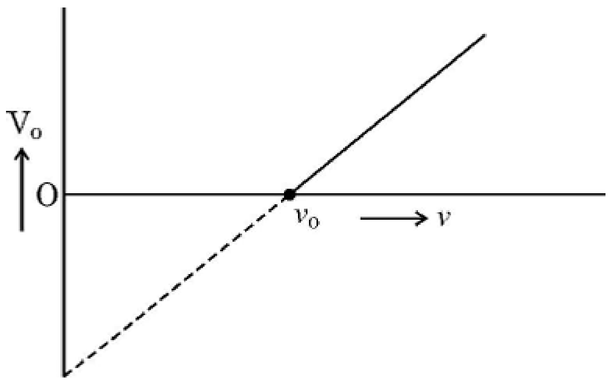
Thus, the new capacitance becomes CK, corresponding to option (C).

Quick Tip

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

---

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

Section - E

31. (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.

---

32. (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.

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33. (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:

$$i = 15^\circ$$

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:

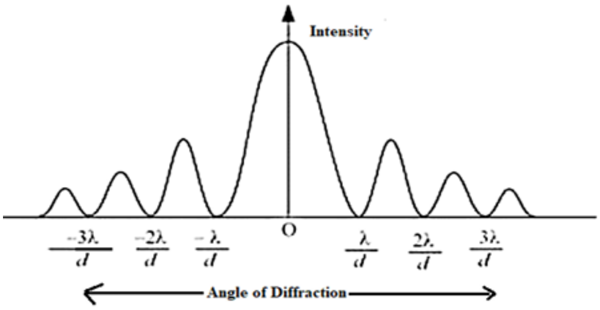
m_1 and m_2 are the fringe orders for the two wavelengths, $\lambda_1 = 600\,\text{nm}$ and $\lambda_2 = 480\,\text{nm}$. Solving for m, we find the least value where the bright fringes coincide. The distance will be found similarly to the earlier calculation, using the conditions for interference.

> **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.

33(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.
