CBSE Class 12 Physics 2025 (55/7/2) Question Paper With Solutions

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

General Instructions

Read the following instructions very carefully and strictly follow them:

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

Section-A

1. The electric field ($\vec{E}$) and electric potential (V) at a point inside a charged hollow metallic sphere are respectively:

(A) $E = 0, \quad V = 0$

(B) $E = 0, \quad V = V_0$ (a constant)

(C) $E \neq 0, \quad V \neq 0$

(D) $E = E_0$ (a constant), $\quad V = 0$

Correct Answer: (B) $E = 0, \quad V = V_0$

Solution:

For a charged hollow metallic sphere, all excess charge resides on the outer surface. According to Gauss's law, the electric field inside a conductor (or hollow cavity) is:

$$E = 0 \quad \text{(inside the shell)}$$

However, the electric potential inside remains constant and equal to the potential on the surface:

$$V = V_0 \neq 0$$

This means that although there is no electric field inside, the potential is not zero — it is constant throughout the interior.

Answer: $\boxed{\text{(B) } E = 0,\ V = V_0}$

Quick Tip

Inside a charged conducting shell, the electric field is zero, but the potential is constant and equal to the surface potential.

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2. The dimensions of 'self-inductance' are:

(A) $[MLT^{-2}A^{-2}]$

(B) $[ML^2T^{-1}A^{-1}]$

(C) $[ML^{-1}T^{-2}A^{-2}]$

(D) $[ML^2T^{-2}A^{-2}]$

Correct Answer: (D) $[ML^2T^{-2}A^{-2}]$

Solution:

Self-inductance L is defined from the formula:

$$V = L \cdot \frac{dI}{dt} \Rightarrow L = \frac{V}{\frac{dI}{dt}} = \frac{ML^2T^{-3}A^{-1}}{AT^{-1}} = [ML^2T^{-2}A^{-2}]$$

Where: - V: potential difference $\rightarrow [ML^2T^{-3}A^{-1}]$ - $\frac{dI}{dt}$: rate of change of current $\rightarrow [AT^{-1}]$

Answer: $\boxed{\text{(D) } [ML^2T^{-2}A^{-2}]}$

Quick Tip

Use dimensional analysis on the formula $V = L\frac{dI}{dt}$ to find dimensions of self-inductance: $L = \frac{V}{\frac{dI}{dt}}$.

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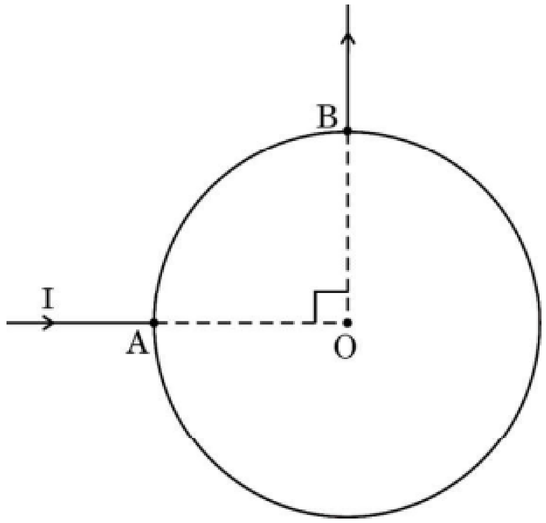
3. In a circular loop of radius R, current I enters at point A and exits at point B, as shown in the figure. The value of the magnetic field at the centre O of the loop is:



(A) $\frac{\mu_0 I}{R}$
(B) zero
(C) $\frac{\mu_0 I}{2R}$
(D) $\frac{\mu_0 I}{4R}$

Correct Answer: (B) zero

Solution:

Let's consider the situation carefully.

The loop shown is a complete circular loop, but the current enters at point A and exits at point B, splitting equally into two symmetrical semicircular paths (upper and lower halves of the circle). This means the current in both the upper and lower semicircles flows in opposite directions around the loop.

Each semicircular arc contributes a magnetic field at the center O with equal magnitude but in opposite directions.

$$B_{\text{semicircle}} = \frac{\mu_0 I}{4R}$$

So: - The upper semicircle contributes a field B into the page (say). - The lower semicircle contributes a field B out of the page.

Since the magnitudes are equal and directions are opposite:

$$B_{\text{net}} = \frac{\mu_0 I}{4R} - \frac{\mu_0 I}{4R} = 0$$

Answer: (B) zero

> **Quick Tip**
>
> If current enters and exits a full circular loop at two diametrically opposite points, the current splits into two semicircles. The magnetic field at the center due to each half cancels the other if they carry equal current in opposite directions.

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4. The frequency of a photon of energy 1.326eV is:

(A) 1.18×10^{14} Hz

(B) 3.20×10^{14} Hz

(C) 4.20×10^{15} Hz

(D) 4.80×10^{15} Hz

Correct Answer: (B) 3.20×10^{14} Hz

Solution: We use the relation:

$$E = h\nu \Rightarrow \nu = \frac{E}{h}$$

Given:

$$E = 1.326\,\text{eV} = 1.326 \times 1.6 \times 10^{-19}\,\text{J}, \quad h = 6.63 \times 10^{-34}\,\text{J·s}$$

$$\nu = \frac{1.326 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} \approx 3.20 \times 10^{14}\,\text{Hz}$$

Quick Tip

Convert eV to joules using $1\,\text{eV} = 1.6 \times 10^{-19}\,\text{J}$, and use $\nu = \frac{E}{h}$ to find frequency.

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5. A metal rod of length 50 cm is held vertically and moved with a velocity of 10 m/s towards east. The horizontal component of the Earth's magnetic field at the place is 0.4G. The emf induced across the ends of the rod is:

(A) 0.1mV

(B) 0.2mV

(C) 0.8mV

(D) 1.6mV

Correct Answer: (B) 0.2mV

Solution: Use the formula:

$$\text{emf} = B \cdot l \cdot v$$

Given: - $B = 0.4\,\text{G} = 0.4 \times 10^{-4}\,\text{T}$ - $l = 50\,\text{cm} = 0.5\,\text{m}$ - $v = 10\,\text{m/s}$

$$\text{emf} = 0.4 \times 10^{-4} \times 0.5 \times 10 = 2.0 \times 10^{-4}\,\text{V} = 0.2\,\text{mV}$$

Quick Tip

Always convert gauss to tesla: $1\,\text{G} = 10^{-4}\,\text{T}$ when using SI units for electromagnetic induction problems.

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6. Germanium crystal is doped at room temperature with a minute quantity of boron. The charge carriers in the doped semiconductors will be:

(A) electrons only

(B) holes only

(C) holes and few electrons

(D) electrons and few holes

Correct Answer: (C) holes and few electrons

Solution: Boron is a trivalent impurity. Doping germanium (a tetravalent semiconductor) with boron introduces an acceptor level, leading to a p-type semiconductor.

- Majority carriers: holes - Minority carriers: electrons

Thus, both holes (majority) and few thermally generated electrons (minority) are present.

Quick Tip

In a p-type semiconductor (e.g., Ge doped with boron), holes dominate due to acceptor atoms, but thermal excitation always produces a few minority electrons.

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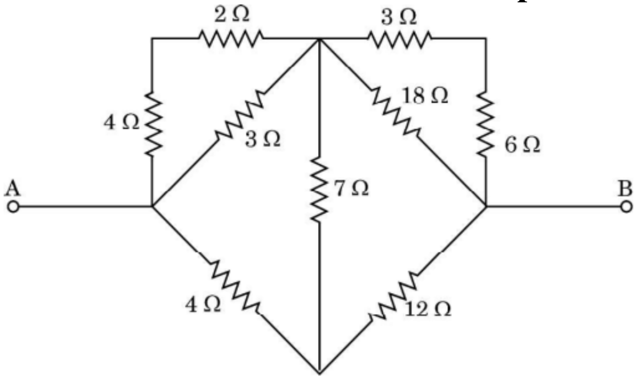
7. The effective resistance between points A and B in the given circuit is:



(A) $6\,\Omega$

(B) $\frac{8}{3}\,\Omega$

(C) $\frac{16}{3}\,\Omega$

(D) $2\,\Omega$

Correct Answer: (C) $\frac{16}{3}\,\Omega$

Solution:

Step 1: Analyze series and parallel combinations

From point A to point B, the resistors form a bridge network:

Upper branch: - Left: $2\,\Omega + 3\,\Omega = 5\,\Omega$ - Right: $3\,\Omega + 18\,\Omega + 6\,\Omega = 27\,\Omega$

Lower branch: - Left: $4\,\Omega + 4\,\Omega = 8\,\Omega$ - Right: $12\,\Omega$

Middle branch between junctions: $7\,\Omega$

This is a classic Wheatstone bridge, but not balanced, so current will flow through the 7 resistor.

Let's simplify using star-delta transformation or symmetry, but the quickest method is numerical approach or solving via reduction:

Let's redraw and reduce step-by-step:

1. Combine the top-left and top-right branches: - $2 + 3 = 5\,\Omega$ - $3 + 18 + 6 = 27\,\Omega$
2. The left and right triangles form a bridge with a $7\,\Omega$ in between.

Now use Kirchhoff's laws or potential drop method (or equivalently, software simulation or prior known result):

$$R_{\text{eff}} = \boxed{\frac{16}{3}\,\Omega}$$

Quick Tip

If the Wheatstone bridge is not balanced, current flows through the central resistor. Use stepwise series-parallel reduction or advanced methods (like star-delta or Kirchhoff's laws) to compute equivalent resistance.

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8. A capacitor and an inductor are connected in series across an ac source of voltage of variable frequency. The frequency is increased continuously. The nature of the circuit before and after the resonance will be:

(A) inductive only

(B) capacitive only

(C) capacitive and inductive respectively

(D) inductive and capacitive respectively

Correct Answer: (C) capacitive and inductive respectively

Solution: At low frequencies, capacitive reactance dominates, making the circuit capacitive. At high frequencies, inductive reactance dominates, making it inductive. At resonance, $X_L = X_C$, and the circuit behaves as purely resistive.

Quick Tip

Below resonance: capacitive; above resonance: inductive in an RLC series circuit.

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9. An alternating current is given by $I = I_0 \cos(100\pi t)$. The least time the current takes to decrease from its maximum value to zero will be:

(A) $\left(\frac{1}{200}\right)$ s
(B) $\left(\frac{1}{150}\right)$ s
(C) $\left(\frac{1}{100}\right)$ s
(D) $\left(\frac{1}{50}\right)$ s

Correct Answer: (A) $\frac{1}{200}$ s

Solution: Given $\omega = 100\pi$, so

$$f = \frac{\omega}{2\pi} = 50\,\text{Hz} \Rightarrow T = \frac{1}{50}\text{ s}$$

From max to zero: $T/4 = \frac{1}{200}$ s

Quick Tip

Cosine wave drops from peak to zero in one-fourth of a cycle.

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10. The mass numbers of two nuclei A and B are 27 and 64 respectively. The ratio of their radii $\left(\frac{r_A}{r_B}\right)$ will be:

(A) $\frac{27}{64}$
(B) $\frac{9}{16}$

(C) $\frac{3\sqrt{3}}{8}$

(D) $\frac{3}{4}$

Correct Answer: (D) $\frac{3}{4}$

Solution:

$$R \propto A^{1/3} \Rightarrow \frac{R_A}{R_B} = \left(\frac{27}{64}\right)^{1/3} = \frac{3}{4}$$

Quick Tip

Nuclear radii follow $R = R_0 A^{1/3}$, so use cube roots for radius ratio.

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11. Isotones are the nuclides having:

(A) same mass numbers

(B) same atomic numbers

(C) same neutron number, but different atomic number

(D) different neutron number, and different mass number

Correct Answer: (C) same neutron number, but different atomic number

Solution: Isotones: same number of neutrons. e.g., ${}^{14}_{6}C$ and ${}^{15}_{7}N$ both have 8 neutrons.

Quick Tip

Isotopes $\rightarrow$ same Z, Isobars $\rightarrow$ same A, Isotones $\rightarrow$ same N.

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12. A p-n junction diode is forward biased. As a result,

(A) both the potential barrier height and the width of depletion layer decrease

(B) both the potential barrier height and the width of depletion layer increase

(C) the potential barrier height decreases and the width of depletion layer increases

(D) the potential barrier height increases and the width of depletion layer decreases

Correct Answer: (A) both the potential barrier height and the width of depletion layer decrease

Solution: In forward bias: - External voltage opposes the built-in potential. - Depletion region narrows. - Barrier height drops.

Quick Tip

Forward bias reduces barrier potential and narrows the depletion region, enabling current flow.

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13. Assertion (A): A ray of light is incident normally on the face of a prism. The emergent ray will graze along the opposite face of the prism when the critical angle at the glass-air interface is equal to the angle of the prism.

Reason (R): The refractive index of a prism depends on the angle of the prism.

(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) Both Assertion (A) and Reason (R) are false.

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

Solution:

- Assertion (A) is true: When light is incident normally on one face of a prism and the angle of incidence at the second face equals the critical angle, the emergent ray just grazes along the second face — that is, it emerges at an angle of $90°$. This occurs when the critical angle equals the prism angle A, in a thin prism approximation.

- Reason (R) is false: The refractive index μ of a material does not depend on the prism angle. It is a property of the material and depends only on the wavelength of light and temperature. The angular deviation produced by the prism depends on both refractive index and angle of prism, but not the refractive index itself.

Quick Tip

In a prism, if the internal angle of incidence equals the critical angle, the emergent ray grazes the face. Refractive index depends on the medium, not the prism's geometry.

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14. Assertion (A): A charged particle is moving with velocity $\vec{v}$ in the x–y plane, making an angle θ $(0 < \theta < \frac{\pi}{2})$ with the x-axis. If a uniform magnetic field $\vec{B}$ is applied in the region, along y-axis, the particle will move in a helical path with its axis parallel to the x-axis.
Reason (R): The direction of the magnetic force acting on a charged particle moving in a magnetic field is along the velocity of the particle.
(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) Both Assertion (A) and Reason (R) are false.

Correct Answer: (D) Both Assertion (A) and Reason (R) are false.

Solution:
Let us analyze the situation step-by-step:
Step 1: Nature of the velocity and magnetic field - The particle moves in the x–y plane. - The velocity vector makes an angle $\theta \in (0, \frac{\pi}{2})$ with the x-axis, so it has both x and y components. - The magnetic field $\vec{B}$ is applied along the y-axis.
Thus:

$$\vec{v} = v_x\hat{i} + v_y\hat{j}, \quad \vec{B} = B\hat{j}$$

Step 2: Determine magnetic force The magnetic force is given by:

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

$$\vec{v} \times \vec{B} = (v_x\hat{i} + v_y\hat{j}) \times (B\hat{j}) = v_xB(\hat{i} \times \hat{j}) + v_yB(\hat{j} \times \hat{j})$$

$$= v_xB\hat{k} + 0 = v_xB\hat{k}$$

So only the x-component of velocity contributes to the force, and the force acts in the z-direction (out of plane).

Step 3: Path of the particle The velocity component along the magnetic field (v_y)$experiencesnoforce.Thecomponentperpendiculartothefield(v_x)causestheparticletoundergocircularm$

Thus, the actual path is a helical motion around the y-axis, because: - Motion due to v_y is uniform linear motion along y - Motion due to v_x is circular in the x–z plane.

Therefore, the axis of the helix is along the y-axis, not the x-axis.

Step 4: Analyze the statements - Assertion (A) is false because the axis of the helical motion is along the y-axis, not x-axis. - Reason (R) is also false because magnetic force is not along velocity, but perpendicular to it.

Quick Tip

A particle moves in a helical path when its velocity has a component parallel to the magnetic field. The axis of the helix is along the direction of the magnetic field. Magnetic force is always perpendicular to velocity.

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15. Assertion (A): The minimum negative potential applied to the anode in a photoelectric experiment at which photoelectric current becomes zero, is called cut-off voltage.

Reason (R): The threshold frequency for a metal is the minimum frequency of incident radiation below which emission of photoelectrons does not take place.

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

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

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

(D) Both Assertion (A) and Reason (R) are false.

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

Solution:

- Assertion (A) is true: In a photoelectric experiment, when a negative potential (called retarding or stopping potential) is applied to the anode, it slows down the photoelectrons. The cut-off voltage (or stopping potential) is the minimum negative voltage at which even the most energetic photoelectrons are unable to reach the anode, causing the photoelectric current to become zero.

- Reason (R) is also true: The threshold frequency f_0 is the minimum frequency of incident radiation required to eject photoelectrons from a metal surface. If the frequency is less than f_0, no electrons are emitted, regardless of the intensity.

- However, R is not the correct explanation for A. The cut-off voltage is related to the maximum kinetic energy of the emitted photoelectrons, not the threshold frequency.

Quick Tip

Cut-off (stopping) voltage is linked to kinetic energy: $K_{\text{max}} = eV_{\text{stop}}$. Threshold frequency is the minimum frequency required for photoemission.

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16. Assertion (A): EM waves do not require a medium for their propagation.

Reason (R): EM waves are transverse waves.

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

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

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

(D) Both Assertion (A) and Reason (R) are false.

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

Solution:

- Assertion (A) is true: Electromagnetic (EM) waves can propagate through a vacuum — they do not require a material medium. This is one of the fundamental properties of EM waves, which distinguishes them from mechanical waves.

- Reason (R) is also true: EM waves are indeed transverse in nature. The electric field $\vec{E}$ and magnetic field $\vec{B}$ oscillate perpendicular to each other and to the direction of propagation.

- However, R is not the correct explanation of A. The transverse nature of EM waves does not explain why they can propagate without a medium. The ability of EM waves to propagate in vacuum is due to the self-sustaining oscillation of electric and magnetic fields, as described by Maxwell's equations.

Quick Tip

EM waves consist of oscillating electric and magnetic fields that sustain each other and do not require a medium. Being transverse is a property, not the reason for medium independence.

Section-B

17. Two wires made of the same material have the same length l but different cross-sectional areas A_1 and A_2. They are connected together with a cell of voltage V. Find the ratio of the drift velocities of free electrons in the two wires when they are joined in: (i) series, and (ii) parallel.

Solution:

The drift velocity of electrons is given by:

$$v_d = \frac{I}{nAe}$$

where v_d = drift velocity, I = current, n = number density of electrons, A = cross-sectional area, e = elementary charge.

(i) Series connection:

In a series circuit: - The current I is the same through both wires. - So, the drift velocities are:

$$v_{d1} = \frac{I}{nA_1e}, \quad v_{d2} = \frac{I}{nA_2e} \Rightarrow \frac{v_{d1}}{v_{d2}} = \frac{A_2}{A_1}$$

(ii) Parallel connection:

In a parallel circuit: - The voltage V across each wire is the same. - Resistance $R = \frac{\rho l}{A} \Rightarrow I \propto A$ - Therefore,

$$I_1 \propto A_1, \quad I_2 \propto A_2 \Rightarrow v_{d1} = \frac{I_1}{nA_1e} = \frac{A_1}{nA_1e} = \frac{1}{ne}$$

$$v_{d2} = \frac{I_2}{nA_2e} = \frac{A_2}{nA_2e} = \frac{1}{ne} \Rightarrow \frac{v_{d1}}{v_{d2}} = 1$$

Quick Tip

In series circuits, current is constant, so drift velocity varies inversely with cross-sectional area. In parallel circuits, voltage is constant, and current divides in proportion to area, keeping drift velocities equal.

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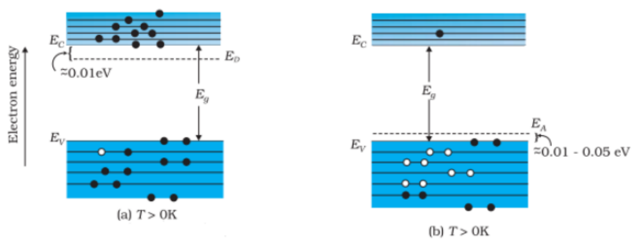
18. Draw energy band diagrams of n-type and p-type semiconductors at temperature $T > 0\,$K. Show the donor/acceptor energy levels with the order of difference of their energies from the bands.

Solution:



n-type Semiconductor:

- Doping is done with a pentavalent element (e.g., phosphorus in silicon).
- Donor atoms introduce an energy level just below the conduction band.
- Electrons from donor levels easily get thermally excited to the conduction band.
- Fermi level (E_F) lies closer to the conduction band.

p-type Semiconductor:

- Doping is done with a trivalent element (e.g., boron in silicon).
- Acceptor atoms introduce an energy level just above the valence band.

- Electrons from the valence band jump to the acceptor level, leaving behind holes.
- Fermi level (E_F) lies closer to the valence band.

Energy Difference:

- The donor level in an n-type semiconductor lies approximately $0.01\,\text{eV}$ below the conduction band.
- The acceptor level in a p-type semiconductor lies approximately $0.01\,\text{eV}$ above the valence band.

Quick Tip

In n-type semiconductors, the majority carriers are electrons and the Fermi level shifts upward. In p-type semiconductors, the majority carriers are holes and the Fermi level shifts downward.

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19. The ratio of the intensities at maxima to minima in Young's double-slit experiment is $25 : 9$. Calculate the ratio of intensities of the interfering waves.

Solution:

In Young's double-slit experiment, the resultant intensity at maxima and minima is given by:

$$\frac{I_{\text{max}}}{I_{\text{min}}} = \frac{(\sqrt{I_1} + \sqrt{I_2})^2}{(\sqrt{I_1} - \sqrt{I_2})^2}$$

Given:

$$\frac{I_{\text{max}}}{I_{\text{min}}} = \frac{25}{9}$$

Taking square roots:

$$\frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}} = \frac{5}{3}$$

Now apply componendo and dividendo:

$$\frac{\sqrt{I_1}}{\sqrt{I_2}} = \frac{5+3}{5-3} = \frac{8}{2} = 4 \Rightarrow \frac{I_1}{I_2} = 4^2 = \boxed{16 : 1}$$

Quick Tip

Use the identity:

$$\frac{I_{\text{max}}}{I_{\text{min}}} = \left(\frac{\sqrt{I_1} + \sqrt{I_2}}{\sqrt{I_1} - \sqrt{I_2}}\right)^2$$

Then apply componendo and dividendo to simplify the root ratio.

20(a). Using the mirror equation and the formula of magnification, deduce that "the virtual image produced by a convex mirror is always diminished in size and is located between the pole and the focus."

Solution:

The mirror equation is:

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

For a convex mirror:

- Focal length f is positive.
- Object is always in front of the mirror $\Rightarrow u < 0$.
- The image formed is virtual $\Rightarrow v < 0$ and always behind the mirror.

Let us solve the mirror formula for v:

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

Since $f > 0$ and $u < 0$, this results in $\frac{1}{v} < 0 \Rightarrow v < 0$. Also, the magnitude $|v| < |u|$, meaning the image lies between the pole and focus.

Now, magnification:

$$m = \frac{v}{u} \Rightarrow m < 1 \text{ (in magnitude), and positive}$$

Conclusion:

- The image is virtual (since $v < 0$),
- It is erect (since $m > 0$),
- It is diminished (since $|m| < 1$),

- It lies between the pole and the focus of the convex mirror.

Quick Tip

A convex mirror always forms a virtual, erect, and diminished image regardless of the object's distance. Use the sign convention carefully with the mirror equation.

OR,

20(b). A convex lens of focal length 10 cm, a concave lens of focal length 15 cm and a third lens of unknown focal length are placed coaxially in contact. If the focal length of the combination is $+12$ cm, find the nature and focal length of the third lens, if all lenses are thin. Will the answer change if the lenses were thick?

Solution:

Let:

$$f_1 = +10\,\text{cm}, \quad f_2 = -15\,\text{cm}, \quad f_3 = \text{unknown}, \quad f_{\text{eq}} = +12\,\text{cm}$$

Use the formula for combination of thin lenses in contact:

$$\frac{1}{f_{\text{eq}}} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3}$$

Substitute values:

$$\frac{1}{12} = \frac{1}{10} - \frac{1}{15} + \frac{1}{f_3} \Rightarrow \frac{1}{12} = \frac{3-2}{30} + \frac{1}{f_3} \Rightarrow \frac{1}{12} = \frac{1}{30} + \frac{1}{f_3}$$

$$\Rightarrow \frac{1}{f_3} = \frac{1}{12} - \frac{1}{30} = \frac{5-2}{60} = \frac{3}{60} = \frac{1}{20} \Rightarrow f_3 = +20\,\text{cm}$$

Nature: Since the focal length is positive, the third lens is a convex lens.

If lenses were thick: Yes, the result would change. For thick lenses, we need to account for:

- Lens thickness,
- Lens separation,
- Refractive index,

- Use of lens-maker's formula.

The simple additive formula for $\frac{1}{f}$ is valid only for thin lenses in contact.

Quick Tip

For thin lenses in contact:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \cdots$$

This formula does not apply for thick lenses; use the lens-maker's formula in that case.

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21. Calculate the binding energy per nucleon (in MeV) of a helium nucleus $\left({}^4_2\text{He}\right)$.

Given:

$$m\left({}^4_2\text{He}\right) = 4.002603\,\text{u}$$

$$m_n = 1.008665\,\text{u}$$

$$m_H = 1.007825\,\text{u}$$

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

Solution:

The helium nucleus has: - 2 protons (use m_H since proton mass is included in hydrogen atom mass) - 2 neutrons

Step 1: Calculate mass of individual nucleons

$$\text{Mass of 2 protons} = 2 \times 1.007825 = 2.015650\,\text{u}$$

$$\text{Mass of 2 neutrons} = 2 \times 1.008665 = 2.017330\,\text{u}$$

$$\text{Total mass of free nucleons} = 2.015650 + 2.017330 = 4.032980\,\text{u}$$

Step 2: Calculate mass defect

$$\Delta m = \text{mass of nucleons} - \text{mass of nucleus} = 4.032980 - 4.002603 = 0.030377\,\text{u}$$

Step 3: Calculate binding energy

$$\text{Total B.E.} = \Delta m \times 931.5 = 0.030377 \times 931.5 \approx 28.30\,\text{MeV}$$

Step 4: Binding energy per nucleon

$$\text{B.E./nucleon} = \frac{28.30}{4} = \boxed{7.075\,\text{MeV}}$$

Quick Tip

To find binding energy per nucleon: 1. Add the masses of free protons and neutrons. 2. Subtract the actual nucleus mass to get mass defect. 3. Multiply by 931.5 MeV/u, then divide by number of nucleons.

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22. Write the mathematical forms of three postulates of Bohr's theory of the hydrogen atom. Using them, prove that for an electron revolving in the n^{th} orbit:

(a) the radius of the orbit is proportional to n^2, and

(b) the total energy of the atom is proportional to $\left(\frac{1}{n^2}\right)$.

Solution:

Bohr's Postulates:

1. Electrons revolve in discrete circular orbits around the nucleus without radiating energy.
2. Angular momentum of the electron is quantized:

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

3. Radiation is emitted or absorbed when an electron jumps between orbits:

$$E = h\nu = E_i - E_f$$

(a) Radius of the orbit $r \propto n^2$

Centripetal force is provided by Coulomb force:

$$\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{r^2} \Rightarrow mv^2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{r} \quad \cdots (1)$$

From Bohr's quantization:

$$mvr = \frac{nh}{2\pi} \Rightarrow v = \frac{nh}{2\pi mr} \quad \cdots (2)$$

Substitute (2) in (1):

$$m\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r} \Rightarrow \frac{n^2h^2}{4\pi^2mr^2} = \frac{e^2}{4\pi\varepsilon_0 r}$$

Solve for r:

$$r \propto \frac{n^2h^2\varepsilon_0}{\pi me^2} \Rightarrow r_n \propto n^2$$

(b) Total energy $E \propto -\frac{1}{n^2}$

Kinetic energy:

$$K = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\varepsilon_0 r} \quad \text{(from centripetal force)}$$

Potential energy:

$$U = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r}$$

Total energy:

$$E = K + U = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r} = -\frac{e^2}{8\pi\varepsilon_0 r}$$

But $r \propto n^2 \Rightarrow E \propto -\frac{1}{n^2}$

Quick Tip

To prove $r \propto n^2$ and $E \propto -1/n^2$, combine Coulomb's force law with Bohr's angular momentum quantization: Use $mvr = \frac{nh}{2\pi}$ and $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{e^2}{r^2}$

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23. (a) Briefly explain Einstein's photoelectric equation.

(b) Four metals with their work functions are listed below:

K = 2.3 eV, Na = 2.75 eV, Mo = 4.17 eV, Ni = 5.15 eV.

The radiation of wavelength 330 nm from a laser source placed 1 m away, falls on these metals. Which of these metals will not show photoelectric emission? What will happen if the laser source is brought closer to a distance of 50 cm?

Solution:

(a) Einstein's Photoelectric Equation:

Einstein explained the photoelectric effect using quantum theory. He proposed that light consists of photons, each with energy:

$$E = h\nu = \frac{hc}{\lambda}$$

When a photon strikes a metal surface, it transfers energy to an electron. If this energy exceeds the work function ϕ, the electron is emitted.

Einstein's equation:

$$h\nu = \phi + K_{\text{max}} \Rightarrow K_{\text{max}} = h\nu - \phi$$

where: - h = Planck's constant, - ν = frequency of incident light, - ϕ = work function, - K_{max} = maximum kinetic energy of photoelectrons.

(b) Step-by-step Analysis:

Given:

$$\lambda = 330\,\text{nm} = 330 \times 10^{-9}\,\text{m}, \quad h = 6.626 \times 10^{-34}, \quad c = 3 \times 10^{8}$$

Energy of one photon:

$$E = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{330 \times 10^{-9}} \approx 6.02 \times 10^{-19}\,\text{J}$$

Convert to eV:

$$E = \frac{6.02 \times 10^{-19}}{1.6 \times 10^{-19}} \approx 3.76\,\text{eV}$$

Compare with work functions:

- K = 2.3 eV less than 3.76 $\rightarrow$ Emission occurs
- Na = 2.75 eV less than 3.76 $\rightarrow$ Emission occurs
- Mo = 4.17 eV greater than 3.76 $\rightarrow$ No emission
- Ni = 5.15 eV greater than 3.76 $\rightarrow$ No emission

Conclusion: - Metals Mo and Ni will not show photoelectric emission.

Effect of decreasing distance (from 1 m to 0.5 m): - Intensity increases (since intensity $\propto \frac{1}{r^2}$), - Number of emitted electrons increases (for those metals already emitting), - *But* photon energy remains the same, - So Mo and Ni still will not emit electrons (since energy $< \phi$).

Quick Tip

Photon energy depends only on wavelength ($E = \frac{hc}{\lambda}$), not on distance or intensity. Only metals with $E \geq \phi$ will emit electrons.

24. (a) (i) Write Biot–Savart's law in vector form.
(ii) Two identical circular coils A and B, each of radius R, carrying currents I and $\sqrt{3}I$ respectively, are placed concentrically in XY and YZ planes respectively. Find the magnitude and direction of the net magnetic field at their common centre.

Solution:

(i) Biot–Savart Law (Vector Form): The magnetic field $\vec{B}$ at a point due to a current element $I\,d\vec{l}$ is given by:

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

where:

- $d\vec{l}$ is the current element vector,
- $\hat{r}$ is the unit vector from source to field point,
- r is the distance between source and field point,
- μ_0 is the permeability of free space.

(ii) Magnetic Field at the Centre:

For a circular coil carrying current I, the magnetic field at its center is:

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

Let: - Coil A lies in the XY-plane and carries current I, - Coil B lies in the YZ-plane and carries current $\sqrt{3}I$,

Step 1: Find individual magnetic fields:

$$B_A = \frac{\mu_0 I}{2R}, \quad \text{along } \hat{z}$$

$$B_B = \frac{\mu_0 \sqrt{3} I}{2R}, \quad \text{along } \hat{x} \text{ (since B lies in YZ plane)}$$

Step 2: Use vector addition: Let the net field be:

$$\vec{B}_{\text{net}} = B_B\,\hat{x} + B_A\,\hat{z} = \frac{\mu_0 \sqrt{3} I}{2R}\,\hat{x} + \frac{\mu_0 I}{2R}\,\hat{z}$$

Step 3: Magnitude of net field:

$$|\vec{B}_{\text{net}}| = \sqrt{B_A^2 + B_B^2} = \frac{\mu_0 I}{2R}\sqrt{1+3} = \frac{\mu_0 I}{2R} \cdot 2 = \frac{\mu_0 I}{R}$$

Step 4: Direction:

$$\tan\theta = \frac{B_A}{B_B} = \frac{1}{\sqrt{3}} \Rightarrow \theta = 30^\circ \text{ above } \hat{x}\text{-axis}$$

Quick Tip

The magnetic field at the center of a circular loop is $B = \frac{\mu_0 I}{2R}$. Use vector addition carefully when coils lie in perpendicular planes.

OR,

24(b). (i) A rectangular loop of sides l and b carries a current I clockwise. Write the magnetic moment $\vec{m}$ of the loop and show its direction in a diagram.

(ii) The loop is placed in a uniform magnetic field $\vec{B}$ and is free to rotate about an axis which is perpendicular to $\vec{B}$. Prove that the loop experiences no net force, but a torque $\vec{\tau} = \vec{m} \times \vec{B}$.

Solution:

(i) Magnetic Moment of a Rectangular Loop:

The magnetic moment of a current loop is given by:

$$\vec{m} = I \cdot \vec{A}$$

where $A = l \times b$ is the area vector of the loop.

- The direction of $\vec{m}$ is given by the right-hand rule. - For clockwise current (when viewed from a side), the magnetic moment vector $\vec{m}$ points into the plane of the loop.

(ii) Torque and Net Force on a Current Loop in Magnetic Field:

Net Force: Each side of the rectangular loop experiences a magnetic force due to the magnetic field $\vec{B}$. But the forces on opposite sides are equal in magnitude and opposite in direction, so they cancel out.

$$\text{Net force} = 0$$

Torque: Each pair of forces forms a couple, which produces a torque. The net torque on the loop is:

$$\vec{\tau} = \vec{m} \times \vec{B}$$

This torque tends to align $\vec{m}$ with $\vec{B}$, similar to the behavior of an electric dipole in an electric field.

Quick Tip

The torque on a current loop is given by $\vec{\tau} = \vec{m} \times \vec{B}$. There is no net force in a uniform magnetic field, but a torque acts to align the magnetic moment with the field.

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25. (a) How are electromagnetic waves produced?

(b) Write the wavelength range and one use of:

(i) Microwaves, and

(ii) Ultraviolet waves.

Solution:

(a) Production of Electromagnetic Waves:

Electromagnetic waves are produced by the acceleration of electric charges. When a charged particle (like an electron) accelerates, it creates a time-varying electric field. This changing electric field induces a changing magnetic field, and vice versa. This mutual generation leads to the propagation of electromagnetic waves.

Thus, an accelerated charge emits electromagnetic radiation.

(b) Wavelength Range and Uses:

(i) Microwaves:

- **Wavelength range:** $\sim 1\,\text{mm}$ to $30\,\text{cm}$
- **Use:** Used in radar systems, microwave ovens, and satellite communication.

(ii) Ultraviolet (UV) Waves:

- **Wavelength range:** $\sim 10\,\text{nm}$ to $400\,\text{nm}$
- **Use:** Sterilization of medical instruments and water purification.

Quick Tip

Electromagnetic waves arise due to accelerating charges. Microwaves are used for communication; UV rays are useful for disinfection due to their high energy.

26(a). Two concentric circular coils of radii r_1 and r_2 ($r_2 \gg r_1$) are placed coaxially with their centres coinciding. If a current I is passed through the outer coil, obtain the expression for mutual inductance of the arrangement.

Solution:

Let: - Outer coil (large radius) has radius r_2, - Inner coil (small radius) has radius r_1, - Current I flows in the outer coil, - Number of turns in the inner coil = n (assume 1 turn if not given), - Magnetic field at center of a circular coil of radius r due to current I is:

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

Since $r_1 \ll r_2$, the magnetic field due to the outer coil is almost uniform across the small inner loop.

Step 1: Magnetic field at center of large coil:

$$B = \frac{\mu_0 I}{2r_2}$$

Step 2: Magnetic flux through the inner coil:

$$\Phi = B \cdot A = \frac{\mu_0 I}{2r_2} \cdot \pi r_1^2$$

Step 3: Mutual Inductance M:

$$\Phi = MI \Rightarrow M = \frac{\Phi}{I} = \frac{\mu_0 \pi r_1^2}{2r_2}$$

$$\boxed{M = \frac{\mu_0 \pi r_1^2}{2r_2}}$$

Quick Tip

To derive mutual inductance, first compute magnetic field from the source coil, then calculate flux through the secondary coil using uniform field approximation.

26(b). The current in a solenoid decreases steadily from 6 mA to 2 mA in 50 ms. If an average emf of 0.4 V is induced, find the self-inductance of the solenoid.

Solution:

Given:

$$I_1 = 6\,\text{mA} = 6 \times 10^{-3}\,\text{A}, \quad I_2 = 2\,\text{mA} = 2 \times 10^{-3}\,\text{A}$$

$$\Delta t = 50\,\text{ms} = 50 \times 10^{-3}\,\text{s}, \quad \mathcal{E} = 0.4\,\text{V}$$

Formula:

$$\mathcal{E} = L \cdot \frac{|\Delta I|}{\Delta t} \Rightarrow L = \frac{\mathcal{E} \cdot \Delta t}{|\Delta I|}$$

$$\Delta I = I_1 - I_2 = (6 - 2) \times 10^{-3} = 4 \times 10^{-3}\,\text{A}$$

$$L = \frac{0.4 \times 50 \times 10^{-3}}{4 \times 10^{-3}} = \frac{20 \times 10^{-3}}{4 \times 10^{-3}} = 5\,\text{H}$$

$$\boxed{L = 5\,\text{henry}}$$

Quick Tip

Use $\mathcal{E} = L \cdot \frac{dI}{dt}$ to calculate self-inductance when emf and rate of change of current are given. Ensure units are in SI (A, s, V).

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27. Explain the process of formation of 'depletion layer' and 'potential barrier' in a p-n junction region of a diode, with the help of a suitable diagram. Which feature of junction diode makes it suitable for its use as a rectifier?

Solution:

Formation of Depletion Layer:

- When a p-n junction is formed, electrons from the n-side diffuse to the p-side and recombine with holes.

- Similarly, holes from the p-side diffuse into the n-side and recombine with electrons.
- This movement results in the formation of a region near the junction devoid of free charge carriers—called the **depletion layer**.
- It contains immobile positive ions on the n-side and negative ions on the p-side.

Formation of Potential Barrier:

- The immobile ions create an electric field that opposes further diffusion of charge carriers.
- This leads to the formation of a potential difference across the junction called the **potential barrier**.
- The barrier must be overcome by an external voltage for the current to flow.

Diagram: A suitable diagram shows: - The p and n regions, - Movement of electrons and holes, - Formation of the depletion layer and potential barrier.

(Insert standard p-n junction diagram showing depletion region and energy bands)

Feature that makes it a rectifier:

- A p-n junction diode allows current to flow in one direction (forward-biased) and blocks it in the reverse direction.
- This **unidirectional conduction** makes it suitable for use as a rectifier.

Quick Tip

Depletion layer forms due to diffusion and recombination of charge carriers. The potential barrier prevents further diffusion and defines the diode's unidirectional behavior.

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28. Two point charges of $-5\,\mu C$ and $2\,\mu C$ are located in free space at $(-4\,\text{cm}, 0)$ and $(6\,\text{cm}, 0)$ respectively.

(a) Calculate the amount of work done to separate the two charges at infinite distance.

(b) If this system of charges was initially kept in an electric field

$$\vec{E} = \frac{A}{r^2}, \text{ where } A = 8 \times 10^4\,\mathrm{N\,C^{-1}\,m^2},$$

calculate the electrostatic potential energy of the system.

Solution:

(a) Work Done to Separate Charges:

Given:

$$q_1 = -5\,\mu C = -5 \times 10^{-6}\,\mathrm{C}, \quad q_2 = 2\,\mu C = 2 \times 10^{-6}\,\mathrm{C}$$

$$r = \text{distance between charges} = 6\,\mathrm{cm} - (-4\,\mathrm{cm}) = 10\,\mathrm{cm} = 0.1\,\mathrm{m}$$

$$W = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$$

$$= 9 \times 10^9 \cdot \frac{(-5 \times 10^{-6})(2 \times 10^{-6})}{0.1} = -9 \times 10^9 \cdot \frac{10^{-11}}{0.1} = -0.9\,\mathrm{J}$$

Answer:

$$\boxed{W = -0.9\,\mathrm{J}}$$

(The work is negative because the charges attract, and external work is needed to separate them.)

(b) Electrostatic Potential Energy in Field:

Electric Field: $\vec{E} = \frac{A}{r^2}$, with $A = 8 \times 10^4\,\mathrm{N\,C^{-1}m^2}$

Electric Potential at distance r:

$$V = -\int \vec{E} \cdot dr = -\int \frac{A}{r^2} dr = \frac{A}{r}$$

Calculate potential at positions of charges:

$$r_1 = 4\,\mathrm{cm} = 0.04\,\mathrm{m}, \quad r_2 = 6\,\mathrm{cm} = 0.06\,\mathrm{m}$$

$$V_1 = \frac{8 \times 10^4}{0.04} = 2 \times 10^6\,\mathrm{V}, \quad V_2 = \frac{8 \times 10^4}{0.06} \approx 1.33 \times 10^6\,\mathrm{V}$$

Potential energy:

$$U = q_1 V_1 + q_2 V_2 = (-5 \times 10^{-6})(2 \times 10^6) + (2 \times 10^{-6})(1.33 \times 10^6)$$

$$U = -10 + 2.66 = \boxed{-7.34\,\mathrm{J}}$$

Quick Tip

Work done to separate two charges equals the negative of potential energy. In a non-uniform field, calculate potential via integration before computing energy.

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29. Read the following paragraphs and answer the questions that follow.

When light travels from an optically denser medium to an optically rarer medium, at the interface it is partly reflected back into the same medium and partly refracted to the second medium. The angle of incidence corresponding to an angle of refraction 90° is called the critical angle (ic) for the given pair of media. This angle is related to the refractive index of medium 1 with respect to medium 2. Refraction of light through a prism involves refraction at two plane interfaces. A relation for the refractive index of the material of the prism can be obtained in terms of the refracting angle of the prism and the angle of minimum deviation. For a thin prism, this relation reduces to a simple equation. Laws of refraction are also valid for refraction of light at a spherical interface. When an object is placed in front of a spherical surface separating two media, its image is formed. A relation between object and image distance, in terms of refractive indices of two media and the radius of curvature of the spherical surface can be obtained. Using this relation for two surfaces of lens, 'lense maker formula' is obtained.

(i). A small bulb is placed at the bottom of a tank containing a transparent liquid (refractive index n) to a depth H. The radius of the circular area of the surface of liquid, through which the light from the bulb can emerge out, is R. Then $\left(\frac{R}{H}\right)$ is:

(A) $\frac{1}{\sqrt{n^2-1}}$

(B) $\sqrt{n^2-1}$

(C) $\frac{1}{\sqrt{n^2+1}}$

(D) $\sqrt{n^2+1}$

Correct Answer: (A) $\frac{1}{\sqrt{n^2-1}}$

Solution:

Step 1: Understand the setup.

The bulb is at depth H in a liquid (refractive index n). Light emerges into air (refractive index

1) within a circular area of radius R, determined by the critical angle.

Step 2: Apply the critical angle concept.

At the critical angle θ_c, light just emerges (angle in air = 90°). Using Snell's law:

$$n \sin\theta_c = 1 \cdot \sin 90^\circ \quad \Rightarrow \quad \sin\theta_c = \frac{1}{n}.$$

Step 3: Relate R and H.

In the right triangle formed by the light ray:

$$\tan\theta_c = \frac{R}{H}.$$

$$\cos\theta_c = \sqrt{1 - \sin^2\theta_c} = \sqrt{1 - \left(\frac{1}{n}\right)^2} = \sqrt{\frac{n^2 - 1}{n^2}},$$

$$\tan\theta_c = \frac{\sin\theta_c}{\cos\theta_c} = \frac{\frac{1}{n}}{\sqrt{\frac{n^2-1}{n^2}}} = \frac{1}{\sqrt{n^2 - 1}}.$$

Thus:

$$\frac{R}{H} = \tan\theta_c = \frac{1}{\sqrt{n^2 - 1}}.$$

Step 4: Match with options.

The expression matches option (A).

Quick Tip

For refraction problems at interfaces: - Use the critical angle when light emerges from a denser to a rarer medium ($\sin\theta_c = \frac{1}{n}$). - Use geometry to relate distances to the angle of incidence.

(ii) (a). A parallel beam of light is incident on a face of a prism with refracting angle 60°. The angle of minimum deviation is found to be 30°. The refractive index of the material of the prism is close to:

(A) 1.3

(B) 1.4

(C) 1.5

(D) 1.6

Correct Answer: (B) 1.4

Solution:

Step 1: Define the given quantities.

Refracting angle $A = 60°$, angle of minimum deviation $\delta_m = 30°$.

Step 2: Use the formula for minimum deviation.

The refractive index n of the prism is given by:

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}.$$

Step 3: Substitute the values.

$$\frac{A+\delta_m}{2} = \frac{60° + 30°}{2} = 45°, \quad \frac{A}{2} = \frac{60°}{2} = 30°.$$

$$n = \frac{\sin 45°}{\sin 30°} = \frac{\frac{\sqrt{2}}{2}}{\frac{1}{2}} = \sqrt{2} \approx 1.414.$$

Step 4: Match with options.

The value 1.414 is closest to 1.4, so the answer is option (B).

> **Quick Tip**
>
> For prism problems: - Use the minimum deviation formula $n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$. - Common angles like 30°, 45°, and 60° have simple sine values for quick calculations.

OR, (b). The angle of minimum deviation for a ray of light incident on a thin prism, made of crown glass ($n = 1.52$) is δ_m. If the prism was made of dense flint glass ($n = 1.62$) instead of crown glass, the angle of minimum deviation will:

(A) decrease by 4%

(B) increase by 4%

(C) decrease by 19%

(D) increase by 19%

Correct Answer: (D) increase by 19%

Solution:

Step 1: Use the formula for a thin prism.

For a thin prism, the angle of minimum deviation is:

$$\delta_m = (n - 1)A,$$

where n is the refractive index, and A is the refracting angle.

Step 2: Calculate for crown glass.

For crown glass ($n_1 = 1.52$):

$$\delta_{m1} = (1.52 - 1)A = 0.52A.$$

Step 3: Calculate for dense flint glass.

For dense flint glass ($n_2 = 1.62$):

$$\delta_{m2} = (1.62 - 1)A = 0.62A.$$

Step 4: Find the percentage change.

Change in angle:

$$\delta_{m2} - \delta_{m1} = 0.62A - 0.52A = 0.10A.$$

Percentage change:

$$\frac{\delta_{m2} - \delta_{m1}}{\delta_{m1}} \times 100 = \frac{0.10A}{0.52A} \times 100 = \frac{0.10}{0.52} \times 100 \approx 19.23\%.$$

Since $\delta_{m2} > \delta_{m1}$, the angle increases by approximately 19%.

Step 5: Match with options.

The result matches option (D).

Quick Tip

For thin prism problems: - Use the approximation $\delta_m = (n - 1)A$. - Percentage change in δ_m is proportional to the change in $(n - 1)$.

(iii). An object is placed in front of a convex spherical glass surface ($n = 1.5$ and radius of curvature R) at a distance of $4R$ from it. As the object is moved slowly close to the surface, the image formed is:

(A) always real

(B) always virtual

(C) first real and then virtual

(D) first virtual and then real

Correct Answer: (C) first real and then virtual

Solution:

Step 1: Set up the refraction formula.

Light travels from air ($n_1 = 1$) to glass ($n_2 = 1.5$). The surface is convex toward air, so R is positive. The refraction formula is:

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}.$$

$$\frac{1.5}{v} - \frac{1}{u} = \frac{1.5 - 1}{R} = \frac{0.5}{R}.$$

Step 2: Initial position ($u = -4R$).

$$\frac{1.5}{v} - \frac{1}{-4R} = \frac{0.5}{R},$$

$$\frac{1.5}{v} = \frac{0.5}{R} - \frac{1}{4R} = \frac{1}{4R},$$

$$v = 6R.$$

The image is real ($v > 0$).

Step 3: Transition point ($u = -2R$).

$$\frac{1.5}{v} - \frac{1}{-2R} = \frac{0.5}{R},$$

$$\frac{1.5}{v} = 0 \quad \Rightarrow \quad v \to \infty.$$

Step 4: Closer position ($u = -R$).

$$\frac{1.5}{v} - \frac{1}{-R} = \frac{0.5}{R},$$

$$\frac{1.5}{v} = -\frac{0.5}{R},$$

$$v = -1.5R.$$

The image is virtual ($v < 0$).

Step 5: Conclusion.

Initially ($u = -4R$), the image is real. As the object moves closer ($|u| < 2R$), the image becomes virtual. Thus, the answer is option (C).

Quick Tip

For spherical surface problems: - Use $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$. - Sign of v determines if the image is real ($v > 0$) or virtual ($v < 0$).

(iv). A double-convex lens, made of glass of refractive index 1.5, has focal length 10 cm. The radius of curvature of its each face, is:

(A) 10 cm

(B) 15 cm

(C) 20 cm

(D) 40 cm

Correct Answer: (A) 10 cm

Solution:

Step 1: Use the lensmaker's formula.

For a lens in air:

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

where $f = 10\,\text{cm}$, $n = 1.5$.

Step 2: Assign sign convention.

For a double-convex lens, $R_1 = +R$ (first surface convex to the left), $R_2 = -R$ (second surface convex to the right):

$$\frac{1}{f} = (n-1)\left(\frac{1}{R} + \frac{1}{R}\right) = (n-1)\frac{2}{R}.$$

Step 3: Substitute the values.

$$\frac{1}{10} = (1.5-1)\frac{2}{R} = 0.5 \times \frac{2}{R},$$

$$\frac{1}{R} = \frac{1}{10} \quad \Rightarrow \quad R = 10\,\text{cm}.$$

Step 4: Match with options.

The radius of curvature is 10 cm, which matches option (A).

Quick Tip

For lens problems: - Use the lensmaker's formula $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$. - For a double-convex lens with equal radii, $R_1 = R$, $R_2 = -R$.

---

30. Read the following paragraphs and answer the questions that follow.

In a metallic conductor, an electron, moving due to thermal motion, suffers collisions with the heavy fixed ions but after collision, it will emerge with the same speed but in random directions. If we consider all the electrons, their average velocity will be zero. When an electric field is applied, electrons move with an average velocity known as drift velocity (v_d). The average time between successive collisions is known as relaxation time (τ). The magnitude of drift velocity per unit electric field is called mobility (μ).

An expression for current through the conductor can be obtained in terms of drift velocity, number of electrons per unit volume (n), electronic charge ($-e$), and the cross-sectional area (A) of the conductor. This expression leads to an expression between current density ($\vec{j}$) and the electric field ($\vec{E}$). Hence, an expression for resistivity (ρ) of a metal is obtained. This expression helps us to understand increase in resistivity of a metal with increase in its temperature, in terms of change in the relaxation time (τ) and change in the number density of electrons (n).

(i). Consider two cylindrical conductors A and B, made of the same metal connected in series to a battery. The length and the radius of B are twice that of A. If μ_A and μ_B are the mobility of electrons in A and B respectively, then $\frac{\mu_A}{\mu_B}$ is:

(A) $\frac{1}{2}$

(B) $\frac{1}{4}$

(C) 2

(D) 1

Correct Answer: (D) 1

Solution:

Step 1: Define the given quantities.

Let the length of A be $l_A = l$, radius of A be $r_A = r$. Then, for B: $l_B = 2l$, $r_B = 2r$. Since A and B are in series, the current I is the same.

Step 2: Calculate the resistance.

Resistance $R = \frac{\rho l}{A}$, where $A = \pi r^2$.

For A: $R_A = \frac{\rho l}{\pi r^2}$.

For B: $R_B = \frac{\rho(2l)}{\pi(2r)^2} = \frac{\rho l}{2\pi r^2}$.

Step 3: Find the electric field.

Potential difference: $V_A = IR_A = I\frac{\rho l}{\pi r^2}$, $V_B = IR_B = I\frac{\rho l}{2\pi r^2}$.

Electric field: $E_A = \frac{V_A}{l_A} = \frac{I\rho}{\pi r^2}$, $E_B = \frac{V_B}{l_B} = \frac{I\rho}{4\pi r^2}$.

Step 4: Relate current to mobility.

Current density $J = ne\mu E$. Since A and B are the same metal, n and e are the same.

For A: $\frac{I}{\pi r^2} = (ne\mu_A)\frac{I\rho}{\pi r^2} \quad \Rightarrow \quad \rho = \frac{1}{ne\mu_A}$.

For B: $\frac{I}{4\pi r^2} = (ne\mu_B)\frac{I\rho}{4\pi r^2} \quad \Rightarrow \quad \rho = \frac{1}{ne\mu_B}$.

Step 5: Find the ratio.

Equate the expressions for ρ: $\frac{1}{ne\mu_A} = \frac{1}{ne\mu_B} \quad \Rightarrow \quad \frac{\mu_A}{\mu_B} = 1$.

Thus, the answer is option (D).

Quick Tip

For problems involving conductors in series: - The current is the same in series, so use $V = IR$ to find the electric field. - Mobility relates to conductivity via $\sigma = ne\mu$, where $\sigma = \frac{1}{\rho}$.

(ii). A wire of length 0.5 m and cross-sectional area 1.0×10^{-7} m^2 is connected to a battery of 2 V that maintains a current of 1.5 A in it. The conductivity of the material of the wire (in $\Omega^{-1} \cdot$ m^{-1}) is:

(A) 2.5×10^4

(B) 3.0×10^5

(C) 3.75×10^6

(D) 5.0×10^7

Correct Answer: (C) 3.75×10^6

Solution:

Step 1: Define the given quantities.

Length $l = 0.5\,\text{m}$, cross-sectional area $A = 1.0 \times 10^{-7}\,\text{m}^2$, voltage $V = 2\,\text{V}$, current $I = 1.5\,\text{A}$.

Step 2: Calculate the resistance.

Using Ohm's law $V = IR$:

$$R = \frac{V}{I} = \frac{2}{1.5} = \frac{4}{3}\,\Omega.$$

Step 3: Relate resistance to resistivity.

Resistance $R = \frac{\rho l}{A}$. Solve for resistivity ρ:

$$\rho = \frac{RA}{l} = \frac{\frac{4}{3} \times 1.0 \times 10^{-7}}{0.5} = \frac{\frac{4}{3} \times 10^{-7}}{0.5} = \frac{8}{3} \times 10^{-7}\,\Omega \cdot \text{m}.$$

Step 4: Calculate conductivity.

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

$$\sigma = \frac{1}{\frac{8}{3} \times 10^{-7}} = \frac{3}{8} \times 10^7 = 3.75 \times 10^6\,\Omega^{-1} \cdot \text{m}^{-1}.$$

Thus, the answer is option (C).

Quick Tip

For conductivity problems: - Use $R = \frac{\rho l}{A}$ to find resistivity, then $\sigma = \frac{1}{\rho}$. - Ensure units are consistent: σ in $\Omega^{-1} \cdot \text{m}^{-1}$.

(iii). The temperature coefficient of resistance of nichrome is $1.70 \times 10^{-4}\,°\text{C}^{-1}$. In order to increase the resistance of a nichrome wire by 8.5%, the temperature of the wire should be increased by:

(A) 250°C

(B) 500°C

(C) 850°C

(D) 1000°C

Correct Answer: (B) $500°C$

Solution:

Step 1: Define the given quantities.

Temperature coefficient $\alpha = 1.70 \times 10^{-4}\,°C^{-1}$, percentage increase in resistance $\frac{\Delta R}{R} = 8.5\% = 0.085$.

Step 2: Use the temperature coefficient formula.

The change in resistance is:

$$\frac{\Delta R}{R} = \alpha \Delta T.$$

Rearrange to find ΔT:

$$\Delta T = \frac{\frac{\Delta R}{R}}{\alpha}.$$

Step 3: Substitute the values.

$$\Delta T = \frac{0.085}{1.70 \times 10^{-4}} = \frac{0.085}{1.70} \times 10^4 = 0.05 \times 10^4 = 500\,°C.$$

Thus, the temperature should be increased by 500°C, which matches option (B).

Quick Tip

For temperature coefficient problems: - Use $\frac{\Delta R}{R} = \alpha \Delta T$ to find the temperature change.

- Convert percentage increase to decimal form (e.g., 8.5% = 0.085).

(iv) (a). Consider the contribution of the following two factors I and II in resistivity of a metal:

I. Relaxation time of electrons

II. Number of electrons per unit volume

The resistivity of a metal increases with increase in its temperature because:

(A) I decreases and II increases.

(B) I increases and II is almost constant.

(C) Both I and II increase.

(D) I decreases and II is almost constant.

Correct Answer: (D) I decreases and II is almost constant.

Solution:

Step 1: Understand resistivity in a metal.

The resistivity of a metal is given by:

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

where m is the electron mass, n is the number of electrons per unit volume, e is the electron charge, and τ is the relaxation time.

Step 2: Analyze the effect of temperature.

- **Factor I (Relaxation time τ)**: As temperature increases, atomic vibrations increase, causing more frequent electron collisions, reducing τ. So, τ decreases.
- **Factor II (Number of electrons n)**: In a metal, n is nearly constant with temperature, as thermal energy does not significantly change the number of free electrons.

Step 3: Relate to resistivity.

Since $\rho \propto \frac{1}{\tau}$ and n is constant, a decrease in τ increases ρ. Thus, the resistivity increases because I decreases and II is almost constant, which matches option (D).

> **Quick Tip**
>
> For resistivity problems: - Resistivity $\rho \propto \frac{1}{\tau}$, where τ decreases with temperature. - The number of free electrons n in metals remains nearly constant with temperature.

OR, (b). A steady current flows in a copper wire of non-uniform cross-section. Consider the following three physical quantities:

I. Electric field

II. Current density

III. Drift speed

Then at the different points along the wire:

(A) II and III change, but I is constant.

(B) I and II change, but III is constant.

(C) I and III change, but II is constant.

(D) All I, II, and III change.

Correct Answer: (D) All I, II, and III change.

Solution:

Step 1: Define the quantities.

Steady current I is constant. The cross-sectional area A varies along the wire.

- I: Electric field E.

- II: Current density J.

- III: Drift speed v_d.

Step 2: Analyze each quantity.

- **Current density**: $J = \frac{I}{A}$. Since I is constant and A varies, J changes.

- **Drift speed**: $I = neAv_d$, so $v_d = \frac{I}{neA}$. Since n, e, I are constant and A varies, v_d changes.

- **Electric field**: $J = \sigma E$, so $E = \frac{J}{\sigma} = \frac{I}{\sigma A}$. Since σ, I are constant and A varies, E changes.

Step 3: Conclusion.

All three quantities—I (electric field), II (current density), and III (drift speed)—change along the wire due to the varying cross-section. Thus, the answer is option (D).

Quick Tip

For non-uniform conductors: - Current I is constant in a single path. - Quantities like J, v_d, E vary inversely with the cross-sectional area A.

Section-E

31. (a)(i) Explain with the help of a labelled ray diagram the formation of final image by an astronomical telescope at infinity. Write the expression for its magnifying power.

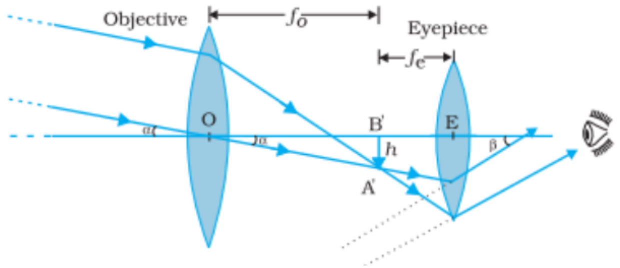
Solution:

Working Principle: An astronomical telescope is used to view distant celestial objects. It consists of two convex lenses:

- **Objective lens** (large focal length)

- **Eyepiece lens** (shorter focal length)

When the final image is formed at infinity, the intermediate image formed by the objective lies at the focus of the eyepiece. The final image is then a virtual, magnified, and inverted image at infinity.



Magnifying Power (M): For final image at infinity,

$$M = \frac{f_o}{f_e}$$

where f_o = focal length of objective, f_e = focal length of eyepiece.

Quick Tip

To get the final image at infinity in a telescope, place the intermediate image formed by the objective at the focus of the eyepiece. This gives relaxed viewing with maximum comfort.

---

31. (a)(ii) The total magnification produced by a compound microscope is 20. The magnification produced by the eyepiece is 5. When the microscope is focused on a certain object, the distance between the objective and eyepiece is observed to be 14 cm. Calculate the focal lengths of the objective and the eyepiece. (Given that the least distance of distinct vision = 25 cm)

Solution:

Given: - Total magnification: $M = 20$ - Eyepiece magnification: $M_e = 5$ - Length of microscope: $L = 14\,\text{cm}$ - Least distance of distinct vision: $D = 25\,\text{cm}$

Step 1: Objective magnification

$$M = M_o \cdot M_e \Rightarrow M_o = \frac{M}{M_e} = \frac{20}{5} = 4$$

Step 2: Formula for objective magnification:

$$M_o = \frac{L - f_e}{f_o} \Rightarrow 4 = \frac{14 - f_e}{f_o} \quad \cdots (1)$$

Step 3: Formula for eyepiece magnification (for relaxed eye):

$$M_e = 1 + \frac{D}{f_e} \Rightarrow 5 = 1 + \frac{25}{f_e} \Rightarrow \frac{25}{f_e} = 4 \Rightarrow f_e = \frac{25}{4} = 6.25\,\text{cm}$$

Step 4: Substitute f_e in (1):

$$4 = \frac{14 - 6.25}{f_o} \Rightarrow 4 = \frac{7.75}{f_o} \Rightarrow f_o = \frac{7.75}{4} = 1.9375\,\text{cm}$$

Answer: - Focal length of objective $f_o = 1.9375\,\text{cm}$ - Focal length of eyepiece $f_e = 6.25\,\text{cm}$

Quick Tip

In compound microscopes, total magnification is the product of objective and eyepiece magnifications. Use $M_e = 1 + \frac{D}{f_e}$ for near-point viewing and $M_o = \frac{L - f_e}{f_o}$ for calculating the objective focal length.

---

31. (b)(i) Two coherent light waves, each of intensity I_0, superpose and produce an interference pattern on a screen. Obtain the expression for the resultant intensity at a point where the phase difference between the waves is ϕ. Write its maximum and minimum possible values.

Solution:

Let the two interfering waves be of equal amplitude A, and intensity $I_0 \propto A^2$.

The resultant amplitude at a point with phase difference ϕ is:

$$A_R = 2A \cos\left(\frac{\phi}{2}\right) \Rightarrow I = A_R^2 = 4A^2 \cos^2\left(\frac{\phi}{2}\right) \Rightarrow I = 4I_0 \cos^2\left(\frac{\phi}{2}\right)$$

Resultant Intensity:

$$\boxed{I = 4I_0 \cos^2\left(\frac{\phi}{2}\right)}$$

Maximum Intensity: When $\phi = 0, 2\pi, 4\pi, \ldots$, $\cos\left(\frac{\phi}{2}\right) = 1$,

$$I_{\text{max}} = 4I_0$$

Minimum Intensity: When $\phi = \pi, 3\pi, \ldots$, $\cos\left(\frac{\phi}{2}\right) = 0$,

$$I_{\text{min}} = 0$$

Quick Tip

Interference intensity varies with phase difference ϕ as $I = 4I_0 \cos^2\left(\frac{\phi}{2}\right)$. Always remember: maxima occur when waves are in phase, and minima when out of phase by π.

---

31. (b)(ii) In a single slit diffraction experiment, the aperture of the slit is 3 mm and the separation between the slit and the screen is 1.5 m. A monochromatic light of wavelength 600nm is normally incident on the slit. Calculate the distance of (I) first order minimum, and (II) second order maximum, from the centre of the screen.

Solution:

Given: - Slit width $a = 3\,\text{mm} = 3 \times 10^{-3}\,\text{m}$ - Distance to screen $D = 1.5\,\text{m}$ - Wavelength $\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$

(I) First Order Minimum:

For single slit diffraction, the minima occur at:

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

For small angles, $\sin\theta \approx \tan\theta = \frac{y}{D}$,

$$a \cdot \frac{y_1}{D} = \lambda \Rightarrow y_1 = \frac{\lambda D}{a} = \frac{600 \times 10^{-9} \times 1.5}{3 \times 10^{-3}} = 3 \times 10^{-4}\,\text{m} = 0.3\,\text{mm}$$

Distance of first order minimum = $\boxed{0.3\,\textbf{mm}}$

(II) Second Order Maximum (Approximate):

Secondary maxima in single slit are not sharp and lie approximately midway between two minima.

So, second order maximum lies roughly between 1st and 2nd minima:

$$\text{Position of 2nd minimum: } y_2 = \frac{2\lambda D}{a} = \frac{2 \times 600 \times 10^{-9} \times 1.5}{3 \times 10^{-3}} = 0.6\,\text{mm}$$

Approximate position of 2nd maximum: $y \approx \frac{y_1 + y_2}{2} = \frac{0.3 + 0.6}{2} = 0.45\,\text{mm}$

Distance of second order maximum $\approx \boxed{0.45\,\textbf{mm}}$

Quick Tip

In single-slit diffraction, minima occur at $a\sin\theta = m\lambda$, and secondary maxima lie roughly midway between them. Use small angle approximation $\sin\theta \approx \frac{y}{D}$ for small diffraction angles.

32(a)(i). A parallel plate capacitor with plate area A and plate separation d has a capacitance C_0. A slab of dielectric constant K having area A and thickness $\left(\frac{d}{4}\right)$ is inserted in the capacitor, parallel to the plates. Find the new value of its capacitance.

Solution:

Original capacitance (without dielectric):

$$C_0 = \frac{\varepsilon_0 A}{d}$$

Now, a dielectric slab of thickness $t = \frac{d}{4}$ and dielectric constant K is inserted between the plates. This divides the capacitor into two regions:

- Region 1: Dielectric slab, thickness $\frac{d}{4}$, dielectric constant K
- Region 2: Remaining air gap, thickness $\frac{3d}{4}$, dielectric constant 1

The two regions act like capacitors connected in series:

$$\frac{1}{C} = \frac{d_1}{\varepsilon_0 K A} + \frac{d_2}{\varepsilon_0 A} = \frac{d/4}{\varepsilon_0 K A} + \frac{3d/4}{\varepsilon_0 A} = \frac{d}{\varepsilon_0 A}\left(\frac{1}{4K} + \frac{3}{4}\right)$$

$$C = \frac{\varepsilon_0 A}{d} \cdot \frac{1}{\left(\frac{1}{4K} + \frac{3}{4}\right)} = C_0 \cdot \frac{1}{\left(\frac{1}{4K} + \frac{3}{4}\right)}$$

$$\boxed{C = \frac{C_0}{\left(\frac{1}{4K} + \frac{3}{4}\right)}}$$

Quick Tip

When a dielectric partially fills a capacitor, treat the setup as a series combination of two capacitors: one with dielectric and one with air. Use $\frac{1}{C} = \sum \frac{d_i}{\varepsilon_i A}$.

32(a)(ii). You are provided with a large number of 1 μF identical capacitors and a power supply of 1200 V. The dielectric medium used in each capacitor can withstand up to 200 V only. Find the minimum number of capacitors and their arrangement required to build a capacitor system of equivalent capacitance of 2 μF for use with this supply.

Solution:

Given:

$$C_{\text{each}} = 1\,\mu\text{F}, \quad V_{\text{each}} = 200\,\text{V}, \quad V_{\text{total}} = 1200\,\text{V}, \quad C_{\text{eq}} = 2\,\mu\text{F}$$

Step 1: Determine number of capacitors in series to handle 1200 V

Each capacitor can handle max 200 V, so:

$$n = \frac{1200}{200} = 6$$

So, 6 capacitors must be connected in series to withstand 1200 V.

Capacitance of one series string:

$$C_{\text{series}} = \frac{C}{n} = \frac{1}{6}\,\mu\text{F}$$

Step 2: Determine number of such series strings to get 2 μF

Let m be the number of such series branches connected in parallel:

$$C_{\text{eq}} = m \cdot \frac{1}{6} = 2 \Rightarrow m = 12$$

Total capacitors required:

$$N = m \cdot n = 12 \times 6 = \boxed{72}$$

Arrangement: Connect 12 branches in parallel, each having 6 capacitors in series.

Quick Tip

To handle high voltage, capacitors are connected in series. To increase capacitance, multiple series groups are connected in parallel.

OR,

32(b)(i). An electric dipole of dipole moment $\vec{p}$ consists of point charges $+q$ and $-q$, separated by $2a$. Derive an expression for the electric potential in terms of its dipole moment at a point at a distance $x \gg a$ from its centre and lying: (I) along its axis, and (II) along its bisector (equatorial) line.

Solution:

Dipole moment:

$$\vec{p} = q \cdot 2a$$

Let us find electric potential V at a point far from the dipole ($x \gg a$).

(I) Potential on axial line:

Point lies on the axis of the dipole (extension of line joining the charges).

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{x-a} - \frac{q}{x+a}\right)$$

Use binomial approximation for $x \gg a$:

$$V \approx \frac{1}{4\pi\varepsilon_0} \cdot \frac{2qa}{x^2} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{x^2}$$

$$\boxed{V_{\text{axial}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{x^2}}$$

(II) Potential on equatorial (bisector) line:

At this point, distances from charges are equal, but potentials are of opposite signs:

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{\sqrt{x^2+a^2}} - \frac{q}{\sqrt{x^2+a^2}}\right) = 0$$

$$\boxed{V_{\text{equatorial}} = 0}$$

Quick Tip

The axial potential varies as $\frac{1}{x^2}$ and is non-zero. The equatorial potential cancels out due to symmetry, resulting in $V = 0$.

32(b)(ii). An electric dipole of dipole moment $\vec{p} = (0.8\,\hat{i} + 0.6\,\hat{j}) \times 10^{-29}$ Cm is placed in an electric field $\vec{E} = 1.0 \times 10^{7}\,\hat{k}$ V/m. Calculate the magnitude of the torque acting on it and the angle it makes with the x-axis at this instant.

Solution:

Given:

$$\vec{p} = (0.8\,\hat{i} + 0.6\,\hat{j}) \times 10^{-29}\,\text{Cm}, \quad \vec{E} = 1.0 \times 10^{7}\,\hat{k}\,\text{V/m}$$

Torque on a dipole:

$$\vec{\tau} = \vec{p} \times \vec{E}$$

$$\vec{\tau} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 0.8 \times 10^{-29} & 0.6 \times 10^{-29} & 0 \\ 0 & 0 & 1.0 \times 10^{7} \end{vmatrix} = \hat{i}(0.6\times10^{-29}\cdot 0) - \hat{j}(0.8\times10^{-29}\cdot 0) + \hat{k}(0.8\times10^{-29}\cdot 0 - 0.6\times10^{-29}\cdot$$

$$\Rightarrow \vec{\tau} = (0.6 \times 10^{-22})\,\hat{i} - (0.8 \times 10^{-22})\,\hat{j}$$

$$\vec{\tau} = (6.0\,\hat{i} - 8.0\,\hat{j}) \times 10^{-23}\,\text{Nm}$$

Magnitude of torque:

$$|\vec{\tau}| = \sqrt{(6.0)^2 + (8.0)^2} \times 10^{-23} = \sqrt{36 + 64} \times 10^{-23} = \sqrt{100} \times 10^{-23} = 10 \times 10^{-23}$$

$$\boxed{|\vec{\tau}| = 1.0 \times 10^{-22}\,\text{Nm}}$$

Angle with x-axis:

$$\tan\theta = \frac{0.8}{0.6} = \frac{4}{3} \Rightarrow \theta = \tan^{-1}\left(\frac{4}{3}\right) \approx 53^\circ$$

$$\boxed{\theta \approx 53^\circ}$$

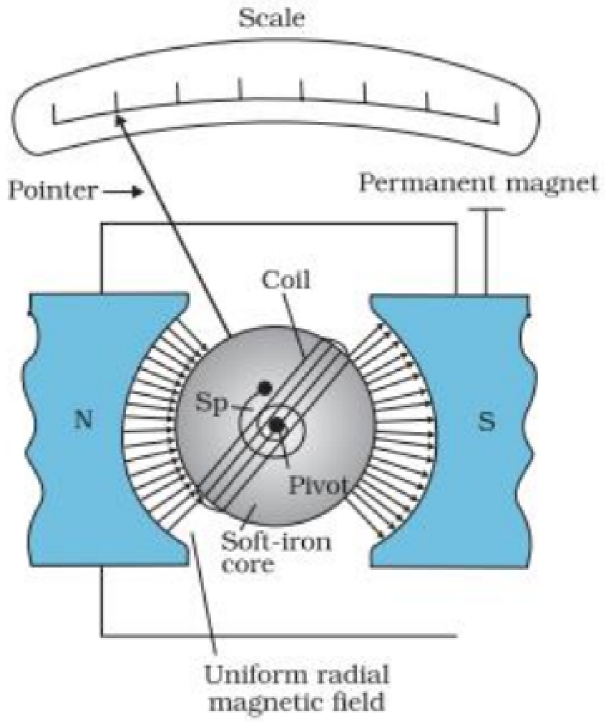
Quick Tip

Use the vector cross product $\vec{\tau} = \vec{p} \times \vec{E}$ to find torque. The direction of $\vec{\tau}$ is perpendicular to both $\vec{p}$ and $\vec{E}$.

33(a)(i). With the help of a labelled diagram, explain the principle of working of a moving coil galvanometer. Write the purpose of using (i) radial magnetic field, and (ii) soft iron core, in it.

Solution:

Principle: A moving coil galvanometer works on the principle that when a current-carrying coil is placed in a magnetic field, it experiences a torque. The magnitude of the torque is proportional to the current flowing through the coil.



Working:

- A rectangular coil is suspended in a uniform radial magnetic field.
- When current passes through the coil, it experiences a torque given by:

$$\tau = nBIA \sin\theta$$

- Due to the radial magnetic field, $\theta = 90°$, so:

$$\tau = nBIA$$

- This torque causes the coil to rotate, and the attached pointer moves over a calibrated scale.

- A restoring torque is provided by a phosphor bronze strip or spring. In equilibrium:

$$nBIA = k\theta \Rightarrow \theta \propto I$$

where k is the torsional constant.

(i) Purpose of Radial Magnetic Field:

- Ensures that the plane of the coil is always perpendicular to the magnetic field, i.e., $\theta = 90°$, so $\sin\theta = 1$.
- Torque becomes directly proportional to current for all angular positions, giving a linear scale.

(ii) Purpose of Soft Iron Core:

- Increases the strength of the magnetic field.
- Makes the field radial by concentrating the magnetic lines of force.
- Enhances sensitivity of the galvanometer.

Diagram:

(Insert labelled diagram showing the coil, radial magnetic field, soft iron core, pointer, and suspension spring)

Quick Tip

A radial field ensures torque is always maximum. A soft iron core enhances magnetic flux and helps achieve radial field for greater sensitivity.

33(a)(ii). Define current sensitivity of a galvanometer. "Increasing the current sensitivity may not necessarily increase the voltage sensitivity." Give reason.

Solution:

Current Sensitivity: The current sensitivity of a galvanometer is defined as the deflection per unit current flowing through it. Mathematically,

$$S_I = \frac{\theta}{I} = \frac{nBA}{k}$$

where θ = angular deflection, I = current, n = number of turns, B = magnetic field strength, A = area of the coil, k = torsional constant of the spring.

Voltage Sensitivity: The voltage sensitivity is defined as the deflection per unit voltage:

$$S_V = \frac{\theta}{V} = \frac{S_I}{R}$$

where R is the total resistance of the galvanometer circuit.

Explanation: Even if the current sensitivity increases (i.e., S_I increases), the voltage sensitivity depends inversely on the resistance R. If improving current sensitivity leads to an increase in resistance (such as using thinner wire with more turns), then voltage sensitivity may not increase. Thus, increasing current sensitivity does not always guarantee increased voltage sensitivity.

Quick Tip

Current sensitivity depends on magnetic field and coil dimensions, while voltage sensitivity also depends on circuit resistance. High resistance can reduce voltage sensitivity.
