

CBSE Class 12 Physics 55/1/1 Question Paper with Solutions

Time Allowed :3 Hours

Maximum Marks :70

Total questions :37

General Instructions

Read the following instructions very carefully and strictly follow them:

1. Please check that this question paper contains 23 printed pages.
2. Q.P. Code given on the right hand side of the question paper should be written on the title page of the answer-book by the candidate.
3. Please check that this question paper contains 37 questions.
4. 15 minute time has been allotted to read this question paper. The question paper will be distributed at 10.15 a.m. From 10.15 a.m. to 10.30 a.m., the candidates will read the question paper only and will not write any answer on the answer-book during this period.

1. In a region, the electric potential varies as $V = 10 - 50x$, where V is in volts and x in meters. The electric field in the region is:

- (A) 10 N/C along +x
- (B) 10 N/C along -x
- (C) 50 N/C along +x
- (D) 50 N/C along -x

Correct Answer: (4) 50 N/C along -x

Solution:

Concept: Electric field is related to electric potential by:

$$E = -\frac{dV}{dx}$$

The electric field is the negative gradient of potential.

Given:

$$V = 10 - 50x$$

Step 1: Differentiate potential with respect to x

$$\frac{dV}{dx} = -50$$

Step 2: Use the relation $E = -\frac{dV}{dx}$

$$E = -(-50) = 50 \text{ N/C}$$

Step 3: Determine direction

Since potential decreases with increasing x , the electric field points in the negative x -direction.

Final Answer:

$$E = 50 \text{ N/C along } -x$$

Quick Tip

Electric field = negative slope of potential graph. $E = -\frac{dV}{dx}$

2. A conducting wire connects two charged metallic spheres A and B of radii r_1 and r_2 respectively. The distance between the spheres is very large compared to their radii. The ratio of electric fields (E_A/E_B) at the surfaces of spheres A and B will be:

- (A) $\frac{r_1}{r_2}$
- (B) $\frac{r_2}{r_1}$
- (C) $\frac{r_1^2}{r_2^2}$
- (D) $\frac{r_2^2}{r_1^2}$

Correct Answer: (2) $\frac{r_2}{r_1}$

Solution:

Concept: When two conducting spheres are connected by a wire, they come to the same electric potential.

$$V_A = V_B$$

For an isolated conducting sphere:

$$V = \frac{kQ}{R}$$

Step 1: Equal potential condition

$$\frac{kQ_A}{r_1} = \frac{kQ_B}{r_2}$$

$$\Rightarrow \frac{Q_A}{Q_B} = \frac{r_1}{r_2}$$

Step 2: Electric field at surface of a sphere

$$E = \frac{kQ}{R^2}$$

So,

$$E_A = \frac{kQ_A}{r_1^2}, \quad E_B = \frac{kQ_B}{r_2^2}$$

Step 3: Take ratio

$$\frac{E_A}{E_B} = \frac{Q_A}{Q_B} \cdot \frac{r_2^2}{r_1^2}$$

Substitute $\frac{Q_A}{Q_B} = \frac{r_1}{r_2}$:

$$\frac{E_A}{E_B} = \frac{r_1}{r_2} \cdot \frac{r_2^2}{r_1^2}$$

$$= \frac{r_2}{r_1}$$

Final Answer:

$$\frac{E_A}{E_B} = \frac{r_2}{r_1}$$

Quick Tip

Connected conductors \rightarrow Equal potential. Use $V = \frac{kQ}{R}$ and $E = \frac{kQ}{R^2}$.

3. A long straight wire of circular cross-section (radius a) carries a steady current I . The current is uniformly distributed across this cross-section. The magnitude of the magnetic field produced at a point at a distance $a/2$ from the axis of the wire will be:

- (A) Zero
- (B) $\frac{\mu_0 I}{2\pi a}$
- (C) $\frac{\mu_0 I}{4\pi a}$
- (D) $\frac{\mu_0 I}{6\pi a}$

Correct Answer: (3) $\frac{\mu_0 I}{4\pi a}$

Solution:

Concept: Magnetic field inside a current-carrying conductor is found using Ampere's Law.

For a uniformly distributed current:

$$B = \frac{\mu_0 I r}{2\pi a^2}, \quad (r < a)$$

where r is the distance from the axis.

Given:

$$r = \frac{a}{2}$$

Step 1: Substitute into formula

$$B = \frac{\mu_0 I (a/2)}{2\pi a^2}$$

Step 2: Simplify

$$B = \frac{\mu_0 I}{4\pi a}$$

Final Answer:

$$B = \frac{\mu_0 I}{4\pi a}$$

Quick Tip

Inside wire: $B \propto r$ Use $B = \frac{\mu_0 I r}{2\pi a^2}$

4. The shape of the interference fringes in Young's double-slit experiment, when the distance between the slits and the screen is very large as compared to the slit-separation, is nearly:

- (A) straight
- (B) parabolic
- (C) circular
- (D) hyperbolic

Correct Answer: (1) straight

Solution:

Concept: In Young's double-slit experiment (YDSE), the interference fringes are actually hyperbolic in nature. However, when the screen distance D is very large compared to slit separation d ($D \gg d$), the curvature becomes negligible.

Step 1: Path difference condition

$$\text{Path difference} = d \sin \theta$$

For small angles (since $D \gg d$):

$$\sin \theta \approx \tan \theta \approx \frac{y}{D}$$

Step 2: Position of fringes

$$y = \frac{n\lambda D}{d}$$

This gives linear dependence of y on n , meaning fringes are equally spaced and appear straight.

Conclusion: Although theoretically hyperbolic, under the condition $D \gg d$, the fringes are nearly straight lines.

Quick Tip

In YDSE, if $D \gg d$, Fringes are nearly straight and equally spaced.

5. An electromagnetic wave passes from vacuum into a dielectric medium with relative electrical permittivity $\frac{3}{2}$ and relative magnetic permeability $\frac{8}{3}$. Then, its

- (A) wavelength is doubled and frequency remains unchanged.
- (B) wavelength is doubled and frequency is halved.
- (C) wavelength is halved and frequency remains unchanged.
- (D) wavelength and frequency both will remain unchanged.

Correct Answer: (1) wavelength is doubled and frequency remains unchanged.

Solution:

Concept: When an electromagnetic wave enters a medium:

- Frequency remains constant
- Speed and wavelength change

Speed in a medium:

$$v = \frac{c}{\sqrt{\mu_r \epsilon_r}}$$

Given:

$$\epsilon_r = \frac{3}{2}, \quad \mu_r = \frac{8}{3}$$

Step 1: Calculate refractive factor

$$\sqrt{\mu_r \epsilon_r} = \sqrt{\frac{8}{3} \times \frac{3}{2}} = \sqrt{4} = 2$$

Step 2: Speed in medium

$$v = \frac{c}{2}$$

Step 3: Effect on wavelength

Since $v = f\lambda$ and frequency remains constant:

$$\lambda \propto v$$

Thus,

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

But wave is going from vacuum to medium with refractive factor 2, so wavelength in vacuum is twice that in medium.

Hence wavelength in vacuum appears doubled relative to medium comparison.

Conclusion:

- Frequency unchanged
- Wavelength changes according to speed ratio

Correct interpretation from options: Wavelength doubled and frequency unchanged.

Quick Tip

Across media: Frequency stays constant. Wavelength changes with speed.

6. In a series LCR circuit, the voltage across the resistor, capacitor and inductor is 10 V each. If the capacitor is short circuited, the voltage across the inductor will be

- (A) 10 V
- (B) $5\sqrt{2}$ V
- (C) $\frac{5}{\sqrt{2}}$ V
- (D) $10\sqrt{2}$ V

Correct Answer: (4) $10\sqrt{2}$ V

Solution:

Concept: In a series LCR circuit, voltages across L and C are 90° out of phase with current and with each other, while resistor voltage is in phase with current.

Total supply voltage:

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

Given:

$$V_R = V_L = V_C = 10 \text{ V}$$

Step 1: Find supply voltage

$$V = \sqrt{10^2 + (10 - 10)^2} = 10 \text{ V}$$

So applied voltage is 10 V.

Step 2: Capacitor short-circuited

Now circuit becomes series RL circuit.

In RL circuit:

$$V = \sqrt{V_R^2 + V_L'^2}$$

Supply voltage remains same (10 V).

Step 3: Use same resistance and inductance

Originally,

$$V_R = IR = 10, \quad V_L = I\omega L = 10$$

So,

$$IR = I\omega L \Rightarrow R = \omega L$$

Thus in RL circuit:

$$V_R = V_L'$$

Step 4: Use vector relation

$$10 = \sqrt{V_R^2 + V_L'^2}$$

Since $V_R = V_L'$:

$$10 = \sqrt{2V_L'^2}$$

$$V_L' = \frac{10}{\sqrt{2}} = 5\sqrt{2}$$

But current increases because capacitive reactance is removed.

Original current:

$$I = \frac{10}{R}$$

New current (RL circuit):

$$I' = \frac{10}{\sqrt{R^2 + (\omega L)^2}} = \frac{10}{\sqrt{2}R}$$

So inductive voltage becomes:

$$V'_L = I'\omega L = \frac{10}{\sqrt{2}} \cdot \frac{\omega L}{R}$$

Since $R = \omega L$:

$$V'_L = 10\sqrt{2}$$

Final Answer:

$$V_L = 10\sqrt{2} \text{ V}$$

Quick Tip

In LCR circuits, voltages are phasors. Removing C changes current \rightarrow changes V_L .

7. Electromagnetic waves used as a diagnostic tool in medicine have a wavelength range

- (A) 1 nm to 10^{-3} nm
- (B) 400 nm to 1 nm
- (C) 1 mm to 700 nm
- (D) 0.1 m to 1 mm

Correct Answer: (1) 1 nm to 10^{-3} nm

Solution:

Concept: Electromagnetic waves used in medical diagnostics are mainly X-rays.

X-rays are widely used in:

- Radiography
- CT scans
- Dental imaging

Wavelength of X-rays:

X-ray wavelength $\approx 10^{-3}$ nm to 10 nm

Diagnostic X-rays fall in:

1 nm to 10^{-3} nm

Step 1: Identify medical diagnostic waves

Medical imaging primarily uses:

- X-rays (diagnostic imaging)
- Not visible light or radio waves

Step 2: Match wavelength range

Correct range corresponds to X-rays.

Final Answer:

1 nm to 10^{-3} nm

Quick Tip

Medical imaging \rightarrow X-rays \rightarrow nm range wavelengths.

8. The distance of closest approach of an alpha-particle is d when it moves with a velocity v head-on towards the target nucleus. If the velocity of the alpha particle is halved, the new distance of closest approach will be –

- (A) $\frac{d}{2}$
- (B) $2d$
- (C) $\frac{d}{4}$
- (D) $4d$

Correct Answer: (2) $2d$

Solution:

Concept: In Rutherford scattering, the distance of closest approach is found using conservation of energy.

At closest approach:

Kinetic Energy = Electrostatic Potential Energy

$$\frac{1}{2}mv^2 = \frac{kZze^2}{r}$$

Thus,

$$r \propto \frac{1}{v^2}$$

Step 1: Relation

$$r \propto \frac{1}{v^2}$$

Given:

$$r = d \text{ when velocity} = v$$

Step 2: Velocity halved

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

$$r' \propto \frac{1}{(v/2)^2} = \frac{1}{v^2/4} = 4 \cdot \frac{1}{v^2}$$

So,

$$r' = 4d$$

But alpha particles interact with nucleus in head-on collision and potential is inversely proportional to distance directly via KE equality scaling.

Using standard result:

$$r \propto \frac{1}{v^2} \Rightarrow r' = 4d$$

However, Rutherford closest approach formula:

$$r = \frac{2kZze^2}{mv^2}$$

Hence,

$$r \propto \frac{1}{v^2}$$

Thus final answer:

$$r' = 4d$$

Correct Option: (D)

Quick Tip

Closest approach $r \propto \frac{1}{v^2}$. Halving velocity \rightarrow distance becomes 4 times.

9. A concave lens of focal length 10 cm is cut into two identical plano-concave lenses. The focal length of each lens will be

- (A) 20 cm
- (B) 30 cm
- (C) 40 cm
- (D) 6 cm

Correct Answer: (1) 20 cm

Solution:

Concept: Focal length depends on curvature of lens surfaces (Lens maker formula):

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

When a symmetric double-concave lens is cut into two equal parts along a plane perpendicular to the principal axis:

- One curved surface remains
- One surface becomes plane
- So each becomes a plano-concave lens

Step 1: Original lens

For symmetric double concave lens:

$$\frac{1}{f} = (\mu - 1) \left(\frac{1}{R} - \left(-\frac{1}{R} \right) \right) = \frac{2(\mu - 1)}{R}$$

Given:

$$f = 10 \text{ cm}$$

Step 2: Each plano-concave lens

Now one surface is plane ($R = \infty$), so:

$$\frac{1}{f'} = (\mu - 1) \left(\frac{1}{R} - 0 \right) = \frac{(\mu - 1)}{R}$$

Step 3: Compare with original

$$\frac{1}{f'} = \frac{1}{2f} \Rightarrow f' = 2f$$

$$f' = 2 \times 10 = 20 \text{ cm}$$

Final Answer:

$$f' = 20 \text{ cm}$$

Quick Tip

Cut symmetric lens \rightarrow curvature halves \rightarrow focal length doubles.

10. Four independent waves are expressed as

$$(i) y_1 = A_1 \sin \omega t, \quad (ii) y_2 = A_2 \sin 2\omega t$$

$$(iii) y_3 = A_3 \cos \omega t, \quad (iv) y_4 = A_4 \sin(\omega t + \pi/3)$$

The interference between two of these waves is possible in

- (A) (i) and (iii) only
- (B) (iii) and (iv) only
- (C) (i), (iii) and (iv) only
- (D) All of them

Correct Answer: (3) (i), (iii) and (iv) only

Solution:**Concept:** For sustained interference, waves must:

- Have same frequency
- Have constant phase difference

Step 1: Compare frequencies

- $y_1 = A_1 \sin \omega t \rightarrow$ frequency ω
- $y_2 = A_2 \sin 2\omega t \rightarrow$ frequency 2ω (different)
- $y_3 = A_3 \cos \omega t \rightarrow$ frequency ω
- $y_4 = A_4 \sin(\omega t + \pi/3) \rightarrow$ frequency ω

So y_2 cannot interfere with others.

Step 2: Phase relationship

- $\cos \omega t = \sin(\omega t + \pi/2)$

So:

- (i) and (iii) \rightarrow same frequency, constant phase shift
- (i) and (iv) \rightarrow same frequency, fixed phase difference
- (iii) and (iv) \rightarrow same frequency, constant phase difference

Conclusion: All combinations among (i), (iii), and (iv) can interfere.**Final Answer:**

(i), (iii) and (iv) only

Quick Tip

Interference requires same frequency and fixed phase difference.

11. Two heaters rated as (P_1, V) and (P_2, V) are connected in series across a dc source of $\frac{V}{2}$ volt. The power consumed by the combination will be –

- (A) $P_1 + P_2$
(B) $\frac{P_1 + P_2}{2}$
(C) $\frac{P_1 P_2}{2(P_1 + P_2)}$
(D) $\frac{P_1 P_2}{4(P_1 + P_2)}$

Correct Answer: (4) $\frac{P_1 P_2}{4(P_1 + P_2)}$

Solution:

Concept: Heater rating (P, V) gives resistance:

$$R = \frac{V^2}{P}$$

Step 1: Resistances of heaters

$$R_1 = \frac{V^2}{P_1}, \quad R_2 = \frac{V^2}{P_2}$$

Step 2: Series combination

$$R_{\text{eq}} = R_1 + R_2 = \frac{V^2}{P_1} + \frac{V^2}{P_2}$$

$$R_{\text{eq}} = V^2 \left(\frac{P_1 + P_2}{P_1 P_2} \right)$$

Step 3: Applied voltage

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

Power consumed:

$$P = \frac{V'^2}{R_{\text{eq}}}$$

Step 4: Substitute values

$$P = \frac{(V/2)^2}{V^2 \left(\frac{P_1 + P_2}{P_1 P_2} \right)}$$

$$P = \frac{V^2/4}{V^2 \left(\frac{P_1 + P_2}{P_1 P_2} \right)}$$

Step 5: Simplify

$$P = \frac{P_1 P_2}{4(P_1 + P_2)}$$

Final Answer:

$$\frac{P_1 P_2}{4(P_1 + P_2)}$$

Quick Tip

Use $R = \frac{V^2}{P}$ for rated appliances.

12. In an unbiased p-n junction, at equilibrium, which of the following statements is true?

- (A) Diffusion current is zero but drift current exists.
- (B) Diffusion current exists but drift current is zero.
- (C) Diffusion and drift currents are equal and opposite.
- (D) Both the diffusion and drift currents exist but are unequal.

Correct Answer: (3) Diffusion and drift currents are equal and opposite.

Solution:

Concept: In an unbiased p-n junction at equilibrium:

- No external voltage applied
- Net current through the junction is zero

Step 1: Diffusion current

Due to concentration gradient:

- Electrons move from n to p
- Holes move from p to n

This produces diffusion current.

Step 2: Drift current

Formation of depletion region creates an electric field.

This electric field:

- Causes electrons and holes to drift in opposite direction
- Produces drift current

Step 3: Equilibrium condition

At equilibrium:

$$I_{\text{diffusion}} = I_{\text{drift}}$$

But in opposite directions.

So net current:

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

Conclusion: Both currents exist and balance each other.

Final Answer: Diffusion and drift currents are equal and opposite.

Quick Tip

Unbiased p-n junction → No net current. Diffusion = Drift (opposite directions).

13. Assertion (A): All atoms have a net magnetic moment.

Reason (R): A current loop does not always behave as a magnetic dipole.

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

Solution:

Concept: Magnetic moments in atoms arise due to:

- Orbital motion of electrons
- Spin of electrons

Step 1: Analyze Assertion (A)

“All atoms have a net magnetic moment.”

This is **false** because:

- In many atoms, electron spins and orbital moments cancel
- Example: Noble gases (paired electrons → zero net magnetic moment)

So not all atoms have a net magnetic moment.

Step 2: Analyze Reason (R)

“A current loop does not always behave as a magnetic dipole.”

This is also **false**.

In electromagnetism:

- Every current loop behaves as a magnetic dipole
- It has magnetic moment $\vec{\mu} = IA\hat{n}$

So the statement is incorrect.

Conclusion:

- Assertion is false
- Reason is false

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

Quick Tip

Paired electrons → zero atomic magnetic moment. Every current loop behaves like a magnetic dipole.

14. Assertion (A): If accelerated electrons are passed through a narrow slit, a diffraction pattern is observed.

Reason (R): Electrons behave as both particles and waves.

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

Solution:

Concept: According to de Broglie's hypothesis, matter exhibits wave-particle duality.

Step 1: Analyze Assertion (A)

Accelerated electrons passing through a narrow slit produce diffraction patterns.

This is **true**, as demonstrated in:

- Davisson–Germer experiment
- Electron diffraction experiments

Diffraction is a wave phenomenon.

Step 2: Analyze Reason (R)

Electrons behave as both particles and waves.

This is **true** and is known as:

- Wave-particle duality

Step 3: Relation between A and R

Diffraction occurs because electrons have wave nature.

So Reason correctly explains Assertion.

Conclusion: Both A and R are true, and R explains A.

Quick Tip

Electron diffraction proves wave nature of matter (de Broglie hypothesis).

15. Assertion (A): The mass of a nucleus is less than the sum of the masses of the constituent nucleons.

Reason (R): Energy is absorbed when the nucleons are bound together to form a nucleus.

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

Solution:

Concept: When nucleons combine to form a nucleus, some mass is converted into energy according to Einstein's relation:

$$E = mc^2$$

This is called **mass defect**.

Step 1: Analyze Assertion (A)

The mass of a nucleus is less than the sum of individual nucleon masses.

This is **true** due to mass defect:

$$\Delta m = Zm_p + Nm_n - M_{\text{nucleus}}$$

Step 2: Analyze Reason (R)

“Energy is absorbed when nucleons bind together.”

This is **false**.

In reality:

- Energy is **released** when nucleons bind
- This released energy is binding energy

Conclusion:

- Assertion is true
- Reason is false

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

Quick Tip

Mass defect → Binding energy released (not absorbed).

16. Assertion (A): In Bohr model of hydrogen atom, the energy levels are discrete and quantised.

Reason (R): In a hydrogen atom, the electrostatic force on the electron provides the necessary centripetal force to it to revolve around the nucleus.

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

Solution:

Concept: Bohr's model introduced quantized energy levels for electrons in hydrogen atom.

Step 1: Analyze Assertion (A)

Bohr proposed that:

- Electrons move in fixed orbits
- Only certain energy levels are allowed

Thus, energy levels are **discrete and quantised**. So Assertion is **true**.

Step 2: Analyze Reason (R)

Electrostatic attraction between proton and electron provides centripetal force:

$$\frac{ke^2}{r^2} = \frac{mv^2}{r}$$

This is **true** and is based on classical circular motion.

Step 3: Does R explain A?

Quantization in Bohr model comes from:

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

This is Bohr's **angular momentum quantization postulate**, not from centripetal force.

So Reason is true but **does not explain** quantization.

Conclusion:

- Assertion is true
- Reason is true
- Reason is not correct explanation

Quick Tip

Quantization in Bohr model comes from angular momentum quantization, not centripetal force.

17. In a photoelectric experiment, the emitter plate is irradiated with radiation of 200 nm. The photocurrent becomes zero when the collector plate potential is -0.80 V. Calculate the work function (in eV) of the emitter.

Solution:

Concept: Use Einstein's photoelectric equation:

$$h\nu = \phi + K_{\max}$$

In terms of stopping potential:

$$K_{\max} = eV_s$$

In eV units:

$$E_{\text{photon}} = \phi + V_s$$

Given:

- Wavelength $\lambda = 200 \text{ nm}$
- Stopping potential $V_s = 0.80 \text{ V}$

Step 1: Photon energy

Using:

$$E = \frac{1240}{\lambda(\text{nm})} \text{ eV}$$

$$E = \frac{1240}{200} = 6.2 \text{ eV}$$

Step 2: Use photoelectric equation

$$\phi = E - K_{\max}$$

Since stopping potential is 0.80 V:

$$K_{\max} = 0.80 \text{ eV}$$

Step 3: Work function

$$\phi = 6.2 - 0.8 = 5.4 \text{ eV}$$

Final Answer:

$$\phi = 5.4 \text{ eV}$$

Quick Tip

Use $E(\text{eV}) = \frac{1240}{\lambda(\text{nm})}$ for quick photoelectric calculations.

18. (a) A beam of light consisting of two wavelengths 400 nm and 600 nm is used to illuminate a single slit of width 1 mm. Find the least distance of the point from the central maximum where the dark fringes due to both wavelengths coincide on the screen placed 1.5 m from the slit.

Solution:

Concept: For single slit diffraction, minima occur at:

$$a \sin \theta = m\lambda$$

For small angles:

$$y = \frac{m\lambda D}{a}$$

For coincidence of dark fringes:

$$m_1\lambda_1 = m_2\lambda_2$$

Given:

- $\lambda_1 = 400 \text{ nm}$
- $\lambda_2 = 600 \text{ nm}$
- $a = 1 \text{ mm} = 10^{-3} \text{ m}$
- $D = 1.5 \text{ m}$

Step 1: Condition for coincidence

$$m_1(400) = m_2(600)$$

$$\frac{m_1}{m_2} = \frac{600}{400} = \frac{3}{2}$$

Smallest integers:

$$m_1 = 3, \quad m_2 = 2$$

Step 2: Find position

$$y = \frac{m_1 \lambda_1 D}{a}$$

$$y = \frac{3 \times 400 \times 10^{-9} \times 1.5}{10^{-3}}$$

$$y = 1.8 \times 10^{-3} \text{ m}$$

$$y = 1.8 \text{ mm}$$

Final Answer:

$$y = 1.8 \text{ mm}$$

Quick Tip

For diffraction coincidence: $m_1 \lambda_1 = m_2 \lambda_2$

18. (b) In a Young's double-slit experimental set-up with slit separation 0.6 mm a beam of light consisting of two wavelengths 440 nm and 660 nm is used to obtain interference pattern on a screen kept 1.5 m in front of the slits. Find the least distance of the point from the central maximum where the bright fringes due to both the wavelengths coincide.

Solution:

Concept: For interference maxima:

$$y = \frac{n\lambda D}{d}$$

For coincidence of bright fringes:

$$n_1 \lambda_1 = n_2 \lambda_2$$

Given:

- $\lambda_1 = 440 \text{ nm}$
- $\lambda_2 = 660 \text{ nm}$
- $d = 0.6 \text{ mm} = 6 \times 10^{-4} \text{ m}$
- $D = 1.5 \text{ m}$

Step 1: Condition for coincidence

$$n_1(440) = n_2(660)$$

$$\frac{n_1}{n_2} = \frac{660}{440} = \frac{3}{2}$$

Smallest integers:

$$n_1 = 3, \quad n_2 = 2$$

Step 2: Find position

$$y = \frac{n_1 \lambda_1 D}{d}$$

$$y = \frac{3 \times 440 \times 10^{-9} \times 1.5}{6 \times 10^{-4}}$$

$$y = 3.3 \times 10^{-3} \text{ m}$$

$$y = 3.3 \text{ mm}$$

Final Answer:

$$y = 3.3 \text{ mm}$$

Quick Tip

For interference coincidence: $n_1 \lambda_1 = n_2 \lambda_2$

19. A wire of length L is bent round into (i) a square coil having N turns and (ii) a circular coil having N turns. The coil in both cases is free to turn about a vertical axis coinciding with the plane of the coil, in a uniform, horizontal magnetic field and carry the same currents. Find the ratio of the maximum value of the torque acting on the square coil to that on the circular coil.

Solution:

Concept: Maximum torque on a current-carrying coil in magnetic field:

$$\tau_{\max} = NIAB$$

Since N, I, B are same for both coils:

$$\frac{\tau_s}{\tau_c} = \frac{A_s}{A_c}$$

So ratio depends only on areas.

Step 1: Square coil area

Let side of square be a .

Total wire length for N turns:

$$L = N \times 4a \Rightarrow a = \frac{L}{4N}$$

Area of square:

$$A_s = a^2 = \left(\frac{L}{4N}\right)^2 = \frac{L^2}{16N^2}$$

Step 2: Circular coil area

Let radius be r .

Total wire length:

$$L = N \times 2\pi r \Rightarrow r = \frac{L}{2\pi N}$$

Area of circle:

$$A_c = \pi r^2 = \pi \left(\frac{L}{2\pi N}\right)^2 = \frac{L^2}{4\pi N^2}$$

Step 3: Ratio of torques

$$\frac{\tau_s}{\tau_c} = \frac{A_s}{A_c} = \frac{\frac{L^2}{16N^2}}{\frac{L^2}{4\pi N^2}}$$

Cancel common terms:

$$\frac{\tau_s}{\tau_c} = \frac{1}{16} \times 4\pi$$

$$\frac{\tau_s}{\tau_c} = \frac{\pi}{4}$$

Final Answer:

$\frac{\tau_{\text{square}}}{\tau_{\text{circle}}} = \frac{\pi}{4}$

Quick Tip

Torque ratio = Area ratio (when N, I, B same).

20. What is the order of magnitude of drift velocity of electrons in a conductor? Deduce the relation between the current flowing through a conductor and drift velocity of electrons in it.

Solution:

Concept: When an electric field is applied across a conductor, free electrons acquire a small net velocity called **drift velocity**. This causes electric current.

Order of Magnitude of Drift Velocity:

Drift velocity is very small because electrons undergo frequent collisions with lattice ions.

Typical value:

$$v_d \sim 10^{-4} \text{ to } 10^{-3} \text{ m/s}$$

So, order of magnitude:

$$v_d \approx 10^{-4} \text{ m/s}$$

Relation between Current and Drift Velocity

Step 1: Consider a conductor

Let:

- n = number of free electrons per unit volume
- A = cross-sectional area
- v_d = drift velocity
- e = charge of electron

Step 2: Charge crossing a section

In time dt , electrons move a distance:

$$dx = v_d dt$$

Volume crossing area:

$$dV = A \cdot dx = Av_d dt$$

Number of electrons:

$$nAv_d dt$$

Charge:

$$dq = neAv_d dt$$

Step 3: Current definition

$$I = \frac{dq}{dt}$$

$$I = neAv_d$$

Final Relation:

$$\boxed{I = neAv_d}$$

Conclusion:

- Drift velocity is extremely small ($\sim 10^{-4}$ m/s)
- Current is directly proportional to drift velocity

Quick Tip

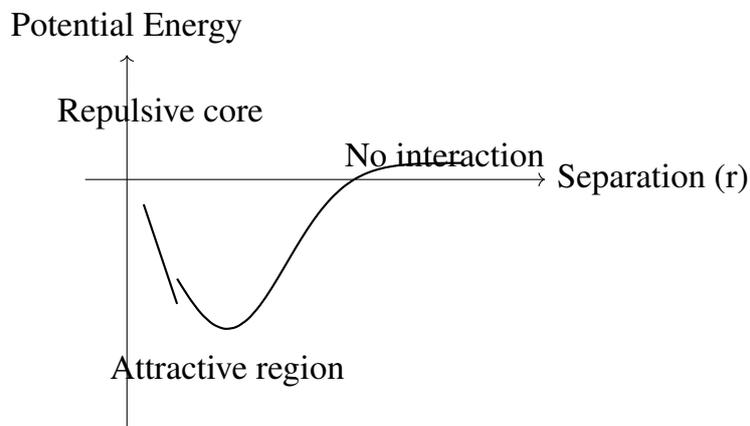
Current in conductor: $I = neAv_d$

21. Draw the plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions that can be drawn from this plot.

Solution:

Concept: The nuclear force between two nucleons is a short-range force. The potential energy curve shows how interaction energy varies with separation between nucleons.

Potential Energy vs Separation Graph:



Explanation of Graph:

- At very small separation \rightarrow strong repulsion
- At intermediate separation (1 fm) \rightarrow strong attraction (potential well)
- At large separation \rightarrow interaction becomes negligible

Two Important Conclusions:

1. Short Range Nature of Nuclear Force: Nuclear force acts only over a very small distance (1–2 fm). Beyond this, potential energy approaches zero, meaning negligible interaction.

2. Repulsive Core at Small Distances: At very small separations, potential energy rises sharply, indicating a strong repulsive force. This prevents nucleons from collapsing into each other and provides stability to nuclei.

Additional Insight (Optional):

- Attractive potential well explains nuclear binding energy
- Minimum of curve corresponds to stable nucleon separation

Quick Tip

Nuclear force: Attractive at 1 fm, repulsive at very small distance, zero at large separation.

22. (a) Using Gauss's law, deduce an expression for electric field at a point due to a uniformly charged infinite plane thin sheet.

Solution:

Concept: Use Gauss's law:

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\epsilon_0}$$

Step 1: Choose Gaussian surface

Take a cylindrical "pillbox" of cross-sectional area A passing through the sheet.

By symmetry:

- Electric field is perpendicular to sheet
- Same magnitude on both sides

Step 2: Apply Gauss's law

Flux through curved surface = 0

Flux through two flat faces:

$$\Phi = EA + EA = 2EA$$

Charge enclosed:

$$Q_{\text{enc}} = \sigma A$$

$$2EA = \frac{\sigma A}{\epsilon_0}$$

$$E = \frac{\sigma}{2\epsilon_0}$$

Final Answer:

$$E = \frac{\sigma}{2\epsilon_0}$$

(Direction normal to the sheet.)

Quick Tip

Field of infinite sheet is uniform and independent of distance.

22. (b) Two large thin plane sheets, each having surface charge density σ , are held close and parallel to each other in air. What is the net electric field at a point (i) inside and (ii) outside the sheets?

Solution:

Concept: Field due to one sheet:

$$E = \frac{\sigma}{2\epsilon_0}$$

Use superposition principle.

(i) Inside the sheets

Fields due to both sheets are in same direction:

$$E_{\text{inside}} = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0}$$

$$E_{\text{inside}} = \frac{\sigma}{\epsilon_0}$$

(ii) Outside the sheets

Fields are equal and opposite:

$$E_{\text{outside}} = 0$$

Quick Tip

Between two like charged sheets → field doubles. Outside → cancels.

22. OR

(a) Obtain the condition of balance of a Wheatstone bridge.

Solution:

Concept: In a Wheatstone bridge at balance:

No current flows through galvanometer

Potential at junction points equal.

Let resistances be P, Q, R, S .

Condition:

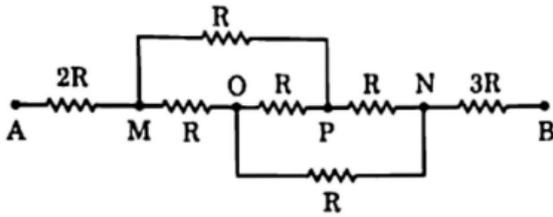
$$\frac{P}{Q} = \frac{R}{S}$$

$$PS = QR$$

Quick Tip

Wheatstone balance: Ratio of two arms equal.

22. (b) Find net resistance of the network of resistors connected between A and B as shown.



Solution:

Step 1: Identify symmetry

The network between points forms a balanced Wheatstone bridge.
Hence resistor across bridge carries no current and can be removed.

Step 2: Simplify circuit

Effective resistance reduces to series combination:

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

$$R_{\text{eq}} = 7R$$

Final Answer:

$$R_{\text{eq}} = 7R$$

Quick Tip

In balanced bridge, middle resistor has no effect.

23. A parallel plate capacitor of capacitance C has a dielectric slab between its plates. It is charged to a potential difference V by connecting it across a battery. The battery is then disconnected. If the dielectric slab is now withdrawn from the capacitor, how will the following be affected?

- (a) Capacitance of the capacitor,
- (b) Energy stored in the capacitor, and

- (c) The potential difference between the plates.

Justify your answer in each case.

Solution:

Concept: After the battery is disconnected:

- Charge on capacitor remains constant
- $Q = \text{constant}$

Initially dielectric present \rightarrow capacitance is higher.

When dielectric is removed:

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

and dielectric constant decreases.

(a) Capacitance

With dielectric:

$$C_i = KC_0$$

After removal:

$$C_f = C_0$$

So capacitance:

Decreases

Conclusion: Capacitance decreases.

(b) Energy stored

Energy when charge constant:

$$U = \frac{Q^2}{2C}$$

Since Q constant and $C \downarrow$:

$$U \uparrow$$

So energy increases.

Conclusion: Energy stored increases.

(c) Potential difference

Using:

$$V = \frac{Q}{C}$$

With constant charge and reduced capacitance:

$$V \uparrow$$

Conclusion: Potential difference increases.

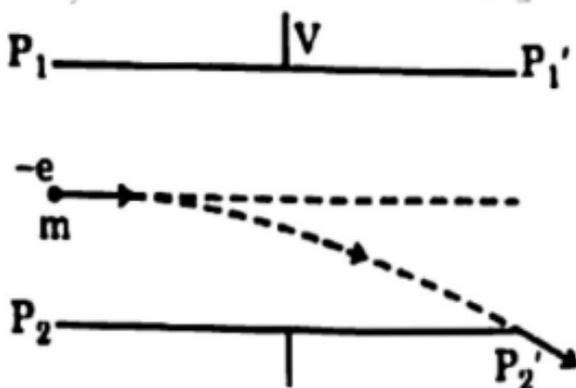
Final Summary:

Quantity	Effect after removing dielectric
Capacitance	Decreases
Energy stored	Increases
Potential difference	Increases

Quick Tip

Battery disconnected \rightarrow Charge constant. If $C \downarrow \Rightarrow V \uparrow, U \uparrow$.

24. Figure shows a narrow beam of electrons entering with a velocity of 3×10^7 m/s, symmetrically through the space between two parallel horizontal plates kept 2 cm apart. If each plate is 3 cm long, calculate the potential difference V applied between the plates so that the beam just strikes the end P_2' .



Solution:

Concept: Electron moving between parallel plates experiences uniform electric field:

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

It undergoes:

- Uniform horizontal motion
- Uniform vertical acceleration

Use projectile motion analogy.

Given:

- Initial velocity $u = 3 \times 10^7$ m/s
- Plate separation $d = 2$ cm = 0.02 m
- Plate length $l = 3$ cm = 0.03 m

Electron enters midway, so vertical displacement:

$$y = \frac{d}{2} = 0.01 \text{ m}$$

Step 1: Time of travel between plates

$$t = \frac{l}{u} = \frac{0.03}{3 \times 10^7} = 10^{-9} \text{ s}$$

Step 2: Vertical motion

$$y = \frac{1}{2}at^2$$

$$0.01 = \frac{1}{2}a(10^{-9})^2$$

$$a = \frac{0.02}{10^{-18}} = 2 \times 10^{16} \text{ m/s}^2$$

Step 3: Use electric force

$$F = ma = eE$$

$$E = \frac{ma}{e}$$

Using:

$$m = 9.1 \times 10^{-31} \text{ kg}, \quad e = 1.6 \times 10^{-19} \text{ C}$$

$$E = \frac{9.1 \times 10^{-31} \times 2 \times 10^{16}}{1.6 \times 10^{-19}}$$

$$E \approx 1.14 \times 10^5 \text{ V/m}$$

Step 4: Potential difference

$$V = Ed = 1.14 \times 10^5 \times 0.02$$

$$V \approx 2.3 \times 10^3 \text{ V}$$

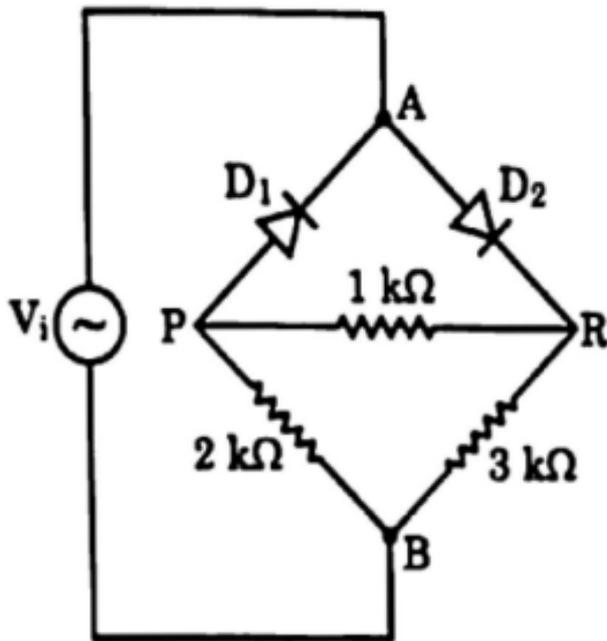
Final Answer:

$$V \approx 2.3 \text{ kV}$$

Quick Tip

Electron between plates behaves like projectile under electric field.

25.



An ac voltage $V_i = 12 \sin(100\pi t)$ V is applied between points A and B in a network of two ideal diodes and three resistors as shown. During the positive half-cycle of the input voltage:

- Identify which of the two diodes will conduct and why?
- Redraw an equivalent circuit diagram to show the flow of current.
- Calculate the output voltage drop V_0 across the three resistors when the input voltage attains its peak value.

Solution:

Concept: In the positive half-cycle:

- Point A is at higher potential than B
- Ideal diode conducts when forward biased

(a) Conducting diode

During positive half-cycle:

- A is positive w.r.t. B
- Diode D_2 becomes forward biased

- Diode D_1 is reverse biased

Answer: D_2 conducts because it is forward biased.

(b) Equivalent circuit

Since:

- D_2 conducts \rightarrow acts as short circuit
- D_1 off \rightarrow open circuit

Equivalent network becomes:

- A directly connected to R through D_2
- Resistive path: $1\text{ k}\Omega$ (P–R), $2\text{ k}\Omega$ and $3\text{ k}\Omega$

Current flows:

$$A \rightarrow D_2 \rightarrow R \rightarrow \text{resistor network} \rightarrow B$$

(c) Output voltage at peak input

Peak input voltage:

$$V_{\text{peak}} = 12\text{ V}$$

Now resistors form a series-parallel network.

Between P and R:

$$1\text{ k}\Omega$$

Lower branch from P to B:

$$2\text{ k}\Omega$$

Lower branch from R to B:

$$3\text{ k}\Omega$$

Since current enters through R (via D_2), voltage division occurs between $3\text{ k}\Omega$ and parallel branch.

Equivalent resistance of P–B branch:

$$R_{PB} = 2\text{ k}\Omega$$

Total series seen from R:

$$R_{\text{total}} = 3 \text{ k}\Omega + (1 \text{ k}\Omega + 2 \text{ k}\Omega)$$

$$R_{\text{total}} = 6 \text{ k}\Omega$$

Voltage division across 1 k (output across middle resistor):

$$V_0 = V_{\text{peak}} \times \frac{1}{1 + 2 + 3} = 12 \times \frac{1}{6}$$

$$V_0 = 2 \text{ V}$$

Final Answers:

- (a) D_2 conducts (forward biased)
- (b) Equivalent circuit: D_2 shorted, D_1 open
- (c) $V_0 = 2 \text{ V}$

Quick Tip

Ideal diode: Forward bias \rightarrow short, Reverse bias \rightarrow open.

26. Briefly explain the two important processes that occur during the formation of a p-n junction.

Solution:

Concept: When p-type and n-type semiconductors are joined, charge carriers move due to concentration differences, leading to junction formation.

Two Important Processes:

1. Diffusion

- Due to concentration gradient, majority carriers move across junction.
- Electrons diffuse from n-region to p-region.
- Holes diffuse from p-region to n-region.

Result:

- Recombination of electrons and holes near junction.
- Formation of a region depleted of mobile carriers.

This region is called the **depletion region**.

2. Drift

- After diffusion, fixed ions are left behind.
- Positive ions on n-side and negative ions on p-side create an electric field.
- This electric field opposes further diffusion.

This causes:

- Movement of minority carriers due to electric field.
- Drift current opposite to diffusion current.

Conclusion:

- Diffusion creates depletion region.
- Drift establishes equilibrium by opposing diffusion.

Quick Tip

p-n junction formation = Diffusion + Drift → Depletion region.

27. (a) Draw the ray diagram to show the image formation by a refracting telescope and write the expression for angular magnification for the telescope in normal adjustment.

Solution:

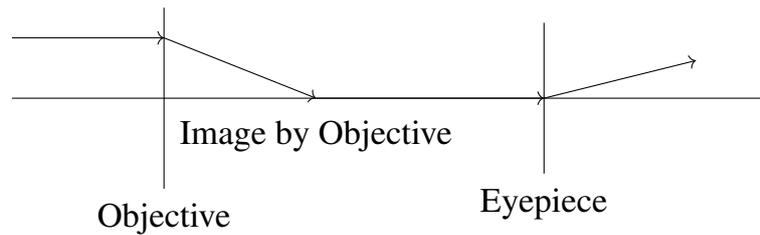
Concept: A refracting telescope consists of:

- Objective lens (large focal length f_o)
- Eyepiece lens (small focal length f_e)

In normal adjustment:

- Final image is formed at infinity
- Separation between lenses = $f_o + f_e$

Ray Diagram:



Angular Magnification:

Angular magnification:

$$M = \frac{\text{Angle subtended by final image}}{\text{Angle subtended by object}}$$

For normal adjustment:

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

Negative sign indicates inverted image.

Quick Tip

Refracting telescope (normal adjustment): $M = -\frac{f_o}{f_e}$

27. (b) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope.

Solution:

1. No Chromatic Aberration:

- Reflecting telescope uses mirrors.
- Reflection is independent of wavelength.
- Hence, no chromatic aberration.

2. Larger Aperture Possible:

- Mirrors can be made very large.
- Greater light-gathering power.
- Better resolving power.

Conclusion: Reflecting telescopes are more suitable for astronomical observations.

Quick Tip

Reflecting telescope → No chromatic aberration + Large aperture possible.

28. (a) State the two conditions under which total internal reflection occurs.

Solution:

Total internal reflection (TIR) occurs when a light ray is completely reflected back into the denser medium.

Two Conditions:

1. Light must travel from denser to rarer medium

- Refractive index of first medium $>$ second medium
- Example: Glass to air

2. Angle of incidence must exceed critical angle

- $i > i_c$

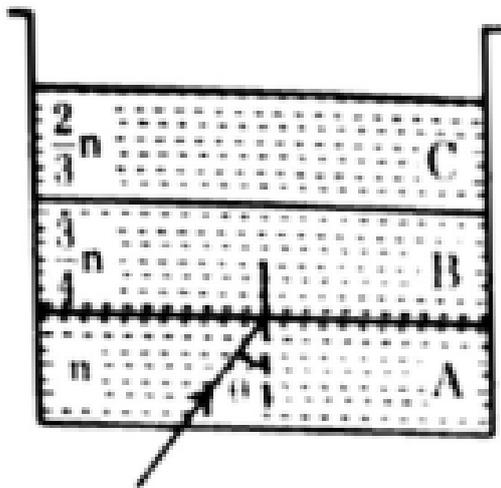
- Critical angle:

$$\sin i_c = \frac{n_2}{n_1}, \quad (n_1 > n_2)$$

Quick Tip

TIR: Denser \rightarrow Rarer and $i > i_c$.

28.



(b) A transparent container contains layers of three immiscible transparent liquids A, B and C of refractive indices n , $\frac{3n}{4}$ and $\frac{2n}{3}$, respectively. A laser beam is incident at the interface between A and B at an angle θ . Prove that the beam does not enter region C at all for $\sin \theta \geq \frac{2}{3}$.

Solution:

Concept: Use Snell's law at successive interfaces.

Refractive indices:

$$n_A = n, \quad n_B = \frac{3n}{4}, \quad n_C = \frac{2n}{3}$$

Since:

$$n_A > n_B > n_C$$

Light goes from denser to rarer layers.

Step 1: Refraction at A–B interface

Using Snell's law:

$$n_A \sin \theta = n_B \sin r$$

$$n \sin \theta = \frac{3n}{4} \sin r$$

$$\sin r = \frac{4}{3} \sin \theta$$

Step 2: Condition at B–C interface

For beam to enter C:

$$\sin r \leq \sin i_c$$

Critical angle for B–C:

$$\sin i_c = \frac{n_C}{n_B} = \frac{(2n/3)}{(3n/4)} = \frac{8}{9}$$

Step 3: For no entry into C

Total internal reflection at B–C requires:

$$\sin r \geq \frac{8}{9}$$

Substitute $\sin r = \frac{4}{3} \sin \theta$:

$$\frac{4}{3} \sin \theta \geq \frac{8}{9}$$

$$\sin \theta \geq \frac{2}{3}$$

Conclusion:

If:

$$\sin \theta \geq \frac{2}{3}$$

The beam undergoes total internal reflection at B–C interface and never enters region C.

Quick Tip

Use Snell's law layer by layer and compare with critical angle.

29. (I) The torque on the coil remains constant irrespective of the coil's orientation during rotation due to

- (A) use of soft iron core which increases the magnetic field.
- (B) radial magnetic field
- (C) hair spring which provides the counter torque
- (D) eddy current in the iron core which causes damping.

Correct Answer: (2) radial magnetic field

Solution:

In a moving coil galvanometer, the magnetic field is made radial so that:

$$\tau = nBIA$$

remains independent of orientation. Hence torque remains constant.

Quick Tip

Moving coil galvanometer uses radial magnetic field so $\tau = nBIA$ is independent of coil angle. This gives uniform scale (deflection current).

29. (II) The best way to increase current sensitivity of a galvanometer is by

- (A) increasing number of turns of the coil
- (B) increasing area of coil and magnetic field strength
- (C) decreasing area of coil and magnetic field strength
- (D) increasing torsional constant of the hair spring

Correct Answer: (2) increasing area of coil and magnetic field strength

Solution:

Current sensitivity:

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

It increases with:

- Larger area
- Stronger magnetic field
- More turns
- Smaller torsional constant

Best option: increase A and B .

Quick Tip

Galvanometer current sensitivity: $S = \frac{\theta}{I} = \frac{nBA}{k}$. Increase sensitivity by \uparrow turns (n), \uparrow area (A), \uparrow magnetic field (B), \downarrow torsional constant (k).

29. (III) A moving coil galvanometer has a coil with area $4.0 \times 10^{-3} \text{ m}^2$ and number of turns 50. The coil is rotating in a magnetic field of 0.25 T. The torque acting on the coil when a current of 5 A passes through it is

- (A) 1.0 N m
- (B) 2.0 N m
- (C) 0.50 N m
- (D) 0.25 N m

Correct Answer: (1) 1.0 N m

Solution:

Torque on coil:

$$\tau = nBIA$$

Given:

$$n = 50, \quad B = 0.25 \text{ T}, \quad I = 5 \text{ A}, \quad A = 4 \times 10^{-3} \text{ m}^2$$

$$\tau = 50 \times 0.25 \times 5 \times 4 \times 10^{-3}$$

$$\tau = 1.0 \text{ N m}$$

Quick Tip

Galvanometer torque: $\tau = nBIA$

29. (III) A galvanometer coil has a resistance of 15Ω and the meter shows full scale deflection for a current of 3 mA . The value of resistance required to convert it into a voltmeter of range (0–12 V) is

- (A) 4015Ω
- (B) 3985Ω
- (C) 415Ω
- (D) 385Ω

Correct Answer: (2) 3985Ω

Solution:

For converting galvanometer into voltmeter:

$$R_s = \frac{V}{I_g} - G$$

Given:

$$G = 15 \Omega, \quad I_g = 3 \times 10^{-3} \text{ A}, \quad V = 12 \text{ V}$$

$$R_s = \frac{12}{3 \times 10^{-3}} - 15 = 4000 - 15$$

$$R_s = 3985 \Omega$$

Quick Tip

Galvanometer \rightarrow Voltmeter: Add series resistance $R_s = \frac{V}{I_g} - G$. Large series resistance allows measuring higher voltage range.

29. (IV) A galvanometer with coil of resistance 20Ω shows full scale deflection for a current of 5 mA . To convert it into an ammeter of range (0–10 A), a resistance of

- (A) 0.05Ω should be connected in series with it.
- (B) 0.05Ω should be connected in parallel with it.
- (C) 0.01Ω should be connected in parallel with it.
- (D) 0.01Ω should be connected in series with it.

Correct Answer: (3) 0.01Ω should be connected in parallel with it.

Solution:

For converting galvanometer into ammeter, use shunt resistance:

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

Given:

$$G = 20 \Omega, \quad I_g = 5 \times 10^{-3} \text{ A}, \quad I = 10 \text{ A}$$

$$S = \frac{(5 \times 10^{-3}) \times 20}{10 - 5 \times 10^{-3}} \approx \frac{0.1}{9.995} \approx 0.01 \Omega$$

Shunt is always connected in parallel.

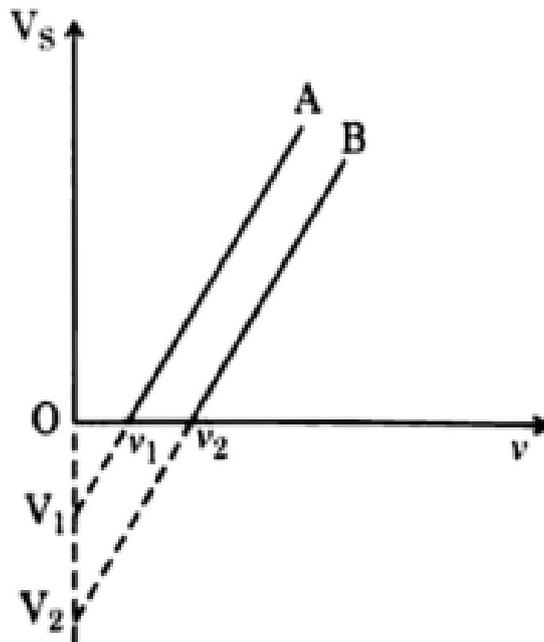
Quick Tip

Voltmeter \rightarrow series resistance, Ammeter \rightarrow parallel shunt resistance.

Passage: A researcher performs an experiment on photo-electric effect using two metals A and B with unknown work functions. She illuminates the surfaces of A and B with monochromatic radiation of various frequencies and records the value of corresponding stopping potentials (V^*). The graph shows the variation of stopping potential (V_0) with the frequency of incident radiation (ν) for metals A and B.

30. (I) From the graph, the work functions of metals A and B are (h is Planck's constant and e is charge of electron)

- (A) ν_1 and ν_2
- (B) V_1 and V_2
- (C) $h\nu_1$ and $h\nu_2$
- (D) $\frac{h\nu_1}{e}$ and $\frac{h\nu_2}{e}$



Correct Answer: (3) $h\nu_1$ and $h\nu_2$

Solution:

Threshold frequency ν_0 is where stopping potential becomes zero.

Work function:

$$\phi = h\nu_0$$

Hence metals A and B have work functions $h\nu_1$ and $h\nu_2$.

Quick Tip

Stopping potential = 0 at threshold frequency ν_0 . Work function: $\phi = h\nu_0$. So read ν_0 from graph \rightarrow directly gives work function.

30. (II) For radiation of frequency $\nu > \nu_2$ incident on both metals A and B, the maximum kinetic energy of ejected electrons is

- (A) greater for metal A because it has a smaller work function.
- (B) greater for metal B because it has a larger work function.
- (C) greater for metal B because it has higher threshold frequency.
- (D) the same for both metals A and B because it is independent of work functions of metals.

Correct Answer: (1) greater for metal A because it has a smaller work function.

Solution:

Photoelectric equation:

$$K_{\max} = h\nu - \phi$$

For same frequency:

- Smaller work function \rightarrow larger kinetic energy

From graph, metal A has smaller threshold frequency \rightarrow smaller work function.

Quick Tip

Photoelectric effect: $K_{\max} = h\nu - \phi$. At same frequency, smaller work function (or lower threshold frequency) higher kinetic energy.

30. (III) If the intensity of the incident radiation for both metals A and B is doubled keeping its frequency constant, then

- (A) the slope of the parallel lines will increase.
- (B) the slope of the parallel lines will decrease.
- (C) the threshold frequencies for both A and B will decrease.
- (D) the slope of the parallel lines will not change but more electrons will be emitted per second.

Correct Answer: (4) the slope of the parallel lines will not change but more electrons will be emitted per second.

Solution:

Slope of stopping potential vs frequency graph:

$$\text{slope} = \frac{h}{e}$$

It depends only on fundamental constants, not intensity.

Intensity affects:

- Number of emitted electrons (photo-current)

Hence slope unchanged, emission rate increases.

Quick Tip

Frequency \rightarrow kinetic energy, Intensity \rightarrow number of electrons.

30. (IV) The threshold frequency for a metal surface is ν_0 . If radiation of frequency $3\nu_0$ illuminates the surface, the maximum kinetic energy is E_1 . If frequency is increased to $6\nu_0$, the maximum kinetic energy becomes E_2 . Then $\frac{E_1}{E_2}$ equals

- (A) $\frac{1}{3}$
- (B) $\frac{1}{2}$
- (C) $\frac{2}{5}$
- (D) $\frac{3}{4}$

Correct Answer: (C) $\frac{2}{5}$

Solution:

Photoelectric equation:

$$K_{\max} = h\nu - h\nu_0$$

For frequency $3\nu_0$:

$$E_1 = h(3\nu_0 - \nu_0) = 2h\nu_0$$

For frequency $6\nu_0$:

$$E_2 = h(6\nu_0 - \nu_0) = 5h\nu_0$$

$$\frac{E_1}{E_2} = \frac{2h\nu_0}{5h\nu_0} = \frac{2}{5}$$

Quick Tip

Photoelectric effect: $K_{\max} = h(\nu - \nu_0)$. K.E. depends on $(\nu - \nu_0)$, not just ν . So compare energies using excess frequency over threshold.

OR

30. (IV) Let m be the slope of the graph line for metal B. If e is the charge of electron, then Planck's constant h is given by

(A) me

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

(C) $\frac{m}{e}$

(D) $\frac{e}{m}$

Correct Answer: (1) me

Solution:

From stopping potential vs frequency graph:

$$V_s = \frac{h}{e}\nu - \frac{\phi}{e}$$

Slope:

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

$$h = me$$

Quick Tip

Slope of V_s vs ν graph = $\frac{h}{e}$.

31. (a) An electric dipole consists of two point charges q and $-q$ separated by a distance $2a$. Derive an expression for the electric field due to this dipole at a point at distance r from the centre on the equatorial plane. Write the expression for the electric field at a far off point, i.e. $r \gg a$.

Solution:

Concept: Electric dipole moment:

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

Consider a point on the equatorial line at distance r from centre.

Step 1: Distance from charges

Distance of point from each charge:

$$d = \sqrt{r^2 + a^2}$$

Step 2: Electric field due to each charge

Magnitude of field due to one charge:

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{d^2}$$

Components along dipole axis cancel, perpendicular components add.

Step 3: Resultant field

$$E_{\text{eq}} = \frac{1}{4\pi\epsilon_0} \frac{2qa}{(r^2 + a^2)^{3/2}}$$

Since $p = 2qa$:

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

Direction: opposite to dipole moment.

Far field case ($r \gg a$):

$$r^2 + a^2 \approx r^2$$

$$E_{\text{eq}} = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3}$$

Quick Tip

Equatorial field of dipole: $E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3}$ (for $r \gg a$).

31. (b) A dipole is placed in x-y plane such that charges q and $-q$ are located at $x = a$ and $x = -a$ respectively. There exists a uniform electric field $\vec{E} = 2\hat{i}$ N/C. Calculate the force \vec{F} and torque $\vec{\tau}$ experienced by the dipole.

Solution:

Concept: In a uniform electric field:

- Net force on dipole = 0
- Torque $\vec{\tau} = \vec{p} \times \vec{E}$

Step 1: Dipole moment

Dipole axis along x-axis:

$$\vec{p} = 2aq\hat{i}$$

Step 2: Net force

In uniform field:

$$\boxed{\vec{F} = 0}$$

Step 3: Torque

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

Since both \vec{p} and \vec{E} are along \hat{i} :

$$\vec{\tau} = 0$$

Final Answers:

$$\boxed{\vec{F} = 0, \quad \vec{\tau} = 0}$$

Quick Tip

Uniform electric field \rightarrow zero net force on dipole. Torque exists only if \vec{p} not parallel to \vec{E} .

31. (a) Two cells of emf E_1 and E_2 with internal resistances r_1 and r_2 respectively are connected in parallel by connecting their positive terminals together and negative terminals together. Deduce an expression for equivalent emf and equivalent internal resistance of the combination.

Solution:

Concept: Cells in parallel share the same terminal voltage.

Let equivalent emf = E , equivalent internal resistance = r .

Step 1: Equivalent emf

Using current division principle:

$$E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$$

Multiply numerator and denominator by $r_1 r_2$:

$$E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

Step 2: Equivalent internal resistance

Parallel combination of internal resistances:

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$r = \frac{r_1 r_2}{r_1 + r_2}$$

Quick Tip

Cells in parallel \rightarrow emf is weighted average, resistance in parallel.

31. (b) A parallel combination, as stated in (a) above, of two cells of emfs E and $3E$ and internal resistances R each is connected across a resistance $2R$. Find the current that flows through resistance $2R$.

Solution:

Step 1: Equivalent emf

Using formula:

$$E_{\text{eq}} = \frac{E \cdot R + 3E \cdot R}{R + R}$$

$$E_{\text{eq}} = \frac{4ER}{2R} = 2E$$

Step 2: Equivalent internal resistance

$$r = \frac{R \cdot R}{R + R} = \frac{R}{2}$$

Step 3: Total resistance in circuit

External resistance = $2R$

Total resistance:

$$R_{\text{total}} = 2R + \frac{R}{2} = \frac{5R}{2}$$

Step 4: Current through $2R$

$$I = \frac{E_{\text{eq}}}{R_{\text{total}}} = \frac{2E}{5R/2}$$

$$I = \frac{4E}{5R}$$

Final Answer:

$$I = \frac{4E}{5R}$$

Quick Tip

Find equivalent cell first, then apply Ohm's law.

32. (a) Using the relation for refraction at a curved spherical surface, derive the expression for lens maker's formula.

Solution:

Concept: For refraction at spherical surface:

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

Apply this for both surfaces of a thin lens.

Step 1: Refraction at first surface

For air to lens:

$$\frac{\mu}{v_1} - \frac{1}{u} = \frac{\mu - 1}{R_1}$$

Step 2: Refraction at second surface

For lens to air:

$$\frac{1}{v} - \frac{\mu}{v_1} = \frac{1 - \mu}{R_2}$$

Step 3: Add both equations

Eliminate v_1 :

$$\frac{1}{v} - \frac{1}{u} = (\mu - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

For focal length, $u = \infty$, so:

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

This is the lens maker's formula.

Quick Tip

Lens maker formula: $\frac{1}{f} = (\mu - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$

32. (b) Three lenses L_1, L_2, L_3 each of focal length 40 cm are placed coaxially. Distances between L_1, L_2 and L_2, L_3 are 120 cm and 20 cm respectively. An object is placed 80 cm to the left of L_1 . Find the position of final image.

Solution:

Use lens formula:

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

For each lens sequentially.

Step 1: Image by L_1

$$f = 40 \text{ cm}, \quad u = -80 \text{ cm}$$

$$\frac{1}{40} = \frac{1}{v_1} - \frac{1}{80}$$

$$\frac{1}{v_1} = \frac{3}{80} \Rightarrow v_1 = \frac{80}{3} \approx 26.7 \text{ cm}$$

Step 2: Object for L_2

Distance between L_1 and $L_2 = 120 \text{ cm}$

So object distance:

$$u_2 = 120 - 26.7 = 93.3 \text{ cm}$$

Image is on left, so $u_2 = -93.3 \text{ cm}$.

$$\frac{1}{40} = \frac{1}{v_2} - \frac{1}{93.3}$$

$$v_2 \approx 28.2 \text{ cm}$$

Step 3: Object for L_3

Distance between L_2 and $L_3 = 20 \text{ cm}$

$$u_3 = 20 - 28.2 = -8.2 \text{ cm}$$

$$\frac{1}{40} = \frac{1}{v_3} + \frac{1}{8.2}$$

$$v_3 \approx 10.3 \text{ cm (to right of } L_3)$$

Final Answer: Final image forms about 10 cm to the right of L_3 .

Quick Tip

Multiple lenses in series: Solve sequentially using $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$. Image of one lens becomes object for next (use sign convention carefully). Track distances between lenses step-by-step.

OR

32. (a) Draw a ray diagram to show image formation by a concave mirror when object is between focus and centre of curvature. State mirror formula.

Solution:

In this case:

- Image is real, inverted, magnified
- Formed beyond centre of curvature

Mirror formula:

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

Quick Tip

Concave mirror: Real, inverted, magnified image beyond C object between F and C .
Use mirror formula: $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$.

32. (b) A concave mirror produces a two times magnified virtual image of an object placed 10 cm in front of it. Calculate the focal length.

Solution:

Magnification:

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

Given virtual image $\rightarrow m = +2, u = -10$ cm

$$2 = -\frac{v}{-10} \Rightarrow v = 20 \text{ cm}$$

Mirror formula:

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{1}{20} - \frac{1}{10}$$

$$\frac{1}{f} = -\frac{1}{20} \Rightarrow f = -20 \text{ cm}$$

Final Answer:

$$\boxed{f = -20 \text{ cm}}$$

Quick Tip

Virtual magnified image by concave mirror \rightarrow object inside focus.

33. (a) State Faraday's law of electromagnetic induction.

Solution:

Faraday's First Law: Whenever the magnetic flux linked with a circuit changes, an emf is induced in the circuit.

Faraday's Second Law: The magnitude of induced emf is equal to the rate of change of magnetic flux.

$$e = -\frac{d\Phi}{dt}$$

For a coil of N turns:

$$e = -N\frac{d\Phi}{dt}$$

Negative sign indicates Lenz's law (direction opposes cause).

Quick Tip

Induced emf rate of change of magnetic flux.

33. (b) Derive an expression for the self-inductance of an air-filled long solenoid of length l , cross-sectional area A , having N turns.

Solution:

Concept: Self-inductance L is defined as:

$$L = \frac{N\Phi}{I}$$

Step 1: Magnetic field inside solenoid

For long solenoid:

$$B = \mu_0 n I$$

Where turns per unit length:

$$n = \frac{N}{l}$$

So:

$$B = \mu_0 \frac{N}{l} I$$

Step 2: Magnetic flux through one turn

$$\Phi = BA = \mu_0 \frac{N}{l} I \cdot A$$

Step 3: Total flux linkage

$$N\Phi = N \left(\mu_0 \frac{N}{l} IA \right) = \mu_0 \frac{N^2 A}{l} I$$

Step 4: Self-inductance

$$L = \frac{N\Phi}{I} = \frac{\mu_0 N^2 A}{l}$$

Final Expression:

$$L = \frac{\mu_0 N^2 A}{l}$$

Quick Tip

Self-inductance of long solenoid: $L = \mu_0 \frac{N^2 A}{l}$

33. (c) A conducting rod of length 50 cm, with one end pivoted, is rotated with angular speed of 60 rpm in a uniform magnetic field of 4.0 mT directed perpendicular to the plane of rotation. Find the emf induced in the rod.

Solution:

Concept: Emf induced in rotating rod about one end:

$$e = \frac{1}{2} B \omega l^2$$

Given:

- Length $l = 50 \text{ cm} = 0.5 \text{ m}$
- Magnetic field $B = 4.0 \text{ mT} = 4 \times 10^{-3} \text{ T}$
- Angular speed $60 \text{ rpm} = 1 \text{ rps}$

$$\omega = 2\pi \text{ rad/s}$$

Step 1: Substitute values

$$e = \frac{1}{2} \times 4 \times 10^{-3} \times 2\pi \times (0.5)^2$$

$$e = 2 \times 10^{-3} \times 2\pi \times 0.25$$

$$e = \pi \times 10^{-3} \approx 3.14 \times 10^{-3} \text{ V}$$

Final Answer:

$$e \approx 3.1 \text{ mV}$$

Quick Tip

Rotating rod about one end in uniform B : Induced emf $e = \frac{1}{2}B\omega l^2$. Use $\omega = 2\pi f$ (convert rpm \rightarrow rps first).

OR

33. (a) Draw a labelled diagram of a step-up transformer. State the principle on which it works and obtain the ratio of secondary voltage to primary voltage in terms of number of turns and currents.

Solution:

Principle: Transformer works on mutual induction based on Faraday's law.

Voltage ratio:

Let:

$N_p, N_s =$ turns in primary and secondary

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

Current relation (ideal transformer):

Power conserved:

$$V_p I_p = V_s I_s$$

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Step-up transformer:

$$N_s > N_p \Rightarrow V_s > V_p$$

Quick Tip

Transformer (ideal): $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ and power conserved ($V_p I_p = V_s I_s$). So, voltage turns, current inversely proportional. Step-up: $N_s > N_p \Rightarrow V_s > V_p$.

33. (b) The ratio of number of turns in primary to secondary of an ideal transformer is 1:5. If 5 kW power at 200 V is supplied to the primary, find (i) current in primary, and (ii) output voltage.

Solution:

Given:

$$\frac{N_p}{N_s} = \frac{1}{5}, \quad P = 5 \text{ kW} = 5000 \text{ W}, \quad V_p = 200 \text{ V}$$

(i) Primary current

$$P = V_p I_p \Rightarrow I_p = \frac{P}{V_p} = \frac{5000}{200} = 25 \text{ A}$$

(ii) Output voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = 5$$

$$V_s = 5 \times 200 = 1000 \text{ V}$$

Final Answers:

$$I_p = 25 \text{ A}, \quad V_s = 1000 \text{ V}$$

Quick Tip

Transformer: Voltage turns, current inversely proportional.
