

CBSE Class 12 Physics Question Paper 2024 with Solution PDF-Set 55/3/3



Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

- (i) This question paper contains **33** questions. **All** questions are **compulsory**.
- (ii) This question paper is divided into **five** sections – **Sections A, B, C, D** and **E**.
- (iii) In **Section A** – Questions no. **1 to 16** are Multiple Choice type questions. Each question carries **1** mark.
- (iv) In **Section B** – Questions no. **17 to 21** are Very Short Answer type questions. Each question carries **2** marks.
- (v) In **Section C** – Questions no. **22 to 28** are Short Answer type questions. Each question carries **3** marks.
- (vi) In **Section D** – Questions no. **29** and **30** are case study based questions. Each question carries **4** marks.
- (vii) In **Section E** – Questions no. **31 to 33** are Long Answer type questions. Each question carries **5** marks.
- (viii) 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.
- (ix) Kindly note that there is a separate question paper for Visually Impaired candidates.
- (x) Use of calculators is not allowed.

You may use the following values of physical constants wherever necessary :

$$c = 3 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\text{Mass of electron } (m_e) = 9.1 \times 10^{-31} \text{ kg}$$

$$\text{Mass of neutron} = 1.675 \times 10^{-27} \text{ kg}$$

$$\text{Mass of proton} = 1.673 \times 10^{-27} \text{ kg}$$

$$\text{Avogadro's number} = 6.023 \times 10^{23} \text{ per gram mole}$$

$$\text{Boltzmann constant} = 1.38 \times 10^{-23} \text{ JK}^{-1}$$

Section A (16 marks)

1. The plates P_1 and P_2 of a $2\ \mu\text{F}$ capacitor are at potentials $25\ \text{V}$ and $-25\ \text{V}$ respectively. The charge on plate P_1 will be: [1 mark]

- (A) $0.02\ \text{mC}$
- (B) $0.1\ \text{mC}$
- (C) $0.1\ \mu\text{C}$
- (D) $1\ \mu\text{C}$

Correct Answer: (B) $0.1\ \text{mC}$

Solution:

Concept:

- For a capacitor, the charge on plate 1 is $Q_1 = C(V_1 - V_2)$, where C is capacitance and V_1, V_2 are the plate potentials.
- The higher-potential plate carries positive charge; $1\ \mu\text{C} = 10^{-6}\ \text{C}$.

Step 1: Calculate the potential difference Capacitance relates charge to the potential difference between the plates, not to either plate's potential alone.

$$V_1 - V_2 = 25 - (-25) = 50\ \text{V}.$$

Step 2: Substitute and convert the charge

$$Q_1 = (2 \times 10^{-6})(50) = 100 \times 10^{-6}\ \text{C} = 0.1\ \text{mC}.$$

The sign is positive because plate P_1 is at the higher potential. Option (A) gives only $20\ \mu\text{C}$, while (C) and (D) give $0.1\ \mu\text{C}$ and $1\ \mu\text{C}$, respectively; none equals the calculated charge.

Step 3: Conclusion The charge on plate P_1 is $+0.1\ \text{mC}$. Hence, the correct option is (B).

Quick Tip to Solve: Subtract the negative plate potential first: opposite potentials of equal magnitude give twice that magnitude across the capacitor.

2. A proton is taken from point P_1 to point P_2 , both located in an electric field. The potentials at points P_1 and P_2 are $-5\ \text{V}$ and $+5\ \text{V}$ respectively. Assuming that kinetic energies of the proton at points P_1 and P_2 are zero, the work done on the proton is: [1 mark]

- (A) $-1.6 \times 10^{-18}\ \text{J}$
- (B) $1.6 \times 10^{-18}\ \text{J}$
- (C) Zero
- (D) $0.8 \times 10^{-18}\ \text{J}$

Correct Answer: (B) $1.6 \times 10^{-18}\ \text{J}$

Solution:

Concept:

- The change in electrostatic potential energy is $\Delta U = q(V_2 - V_1)$, with q the particle's charge.
- For a transfer with no change in kinetic energy, the external work equals ΔU ; work done by the

electric field equals $-\Delta U$.

Step 1: Calculate the potential-energy increase A proton carries positive charge $e = 1.6 \times 10^{-19}$ C. Its potential rises by

$$\Delta V = 5 - (-5) = 10 \text{ V.}$$

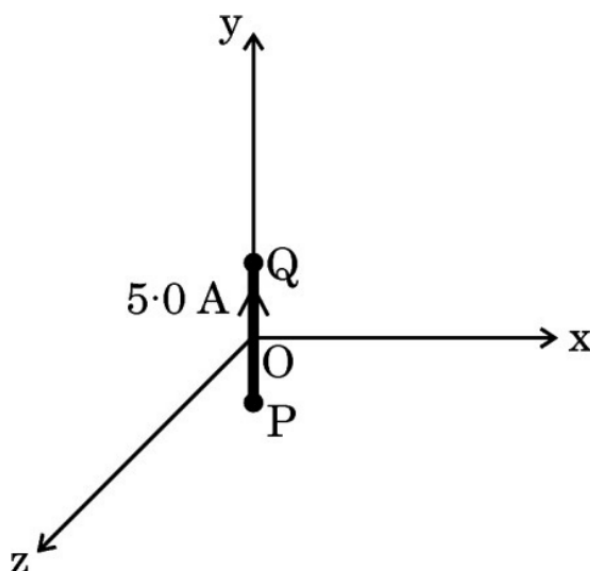
Hence $\Delta U = (1.6 \times 10^{-19})(10) = 1.6 \times 10^{-18}$ J.

Step 2: Identify the work required for the transfer Interpreting the work in taking the proton as the external work, the zero initial and final kinetic energies give $W_{\text{ext}} + W_{\text{field}} = 0$. Thus the external agent supplies the positive increase in potential energy. Option (A) is the electric field's work, (C) is the net work of all forces, and (D) incorrectly uses a potential difference of only 5 V.

Step 3: Conclusion The external work required is $+1.6 \times 10^{-18}$ J. Hence, the correct option is (B).

Quick Tip to Solve: For a charge taken between two potentials at rest, distinguish external work $q\Delta V$ from field work $-q\Delta V$ and net work ΔK .

3. A 2.0 cm segment of wire, carrying 5.0 A current in positive y-direction lies along y-axis, as shown in the figure. The magnetic field at a point (3 m, 4 m, 0) due to this segment (part of a circuit) is: [1 mark]



- (A) $(0.12 \text{ nT}) \hat{j}$
- (B) $-(0.10 \text{ nT}) \hat{j}$
- (C) $-(0.24 \text{ nT}) \hat{k}$
- (D) $(0.24 \text{ nT}) \hat{k}$

Correct Answer: (C) $-(0.24 \text{ nT}) \hat{k}$

Solution:

Concept:

- For a short current element, Biot-Savart law gives $\vec{B} = \frac{\mu_0 I}{4\pi} \frac{\Delta \vec{l} \times \vec{r}}{r^3}$, where $\vec{r}$ points from the element to the observation point.
- The field direction follows the cross product: $\hat{j} \times \hat{i} = -\hat{k}$, and $\mu_0/(4\pi) = 10^{-7} \text{ T m A}^{-1}$.

Step 1: Form the position vector and cross product Since the 0.020 m segment is very short compared

with the distance to the point, treat it as a current element at the origin. Then $\vec{r} = (3\hat{i} + 4\hat{j}) \text{ m}$, $r = 5 \text{ m}$, and $\Delta\vec{l} = 0.020\hat{j} \text{ m}$.

$$\Delta\vec{l} \times \vec{r} = 0.020\hat{j} \times (3\hat{i} + 4\hat{j}) = -0.060\hat{k} \text{ m}^2.$$

Step 2: Substitute in Biot–Savart law

$$\vec{B} = 10^{-7} \frac{5.0(-0.060\hat{k})}{5^3} \text{ T} = -2.4 \times 10^{-10}\hat{k} \text{ T}.$$

Since $1 \text{ nT} = 10^{-9} \text{ T}$, the magnitude is 0.24 nT . Options (A) and (B) have the wrong direction, along the current; (D) reverses the correct cross-product sign.

Step 3: Conclusion The magnetic field is $\vec{B} = -(0.24 \text{ nT})\hat{k}$. Hence, the correct option is (C).

Quick Tip to Solve: Determine $\hat{j} \times \hat{i} = -\hat{k}$ before calculating the magnitude; the component of position parallel to the wire contributes zero.

4. Which of the following is a diamagnetic substance?

[1 mark]

- (A) Gadolinium
- (B) Sodium
- (C) Copper chloride
- (D) Sodium chloride

Correct Answer: (D) Sodium chloride

Solution:

Concept:

- Diamagnetic substances acquire an induced magnetic moment opposite to the applied magnetic field and are weakly repelled by it; their susceptibility is negative.
- Closed electron shells have paired electrons and no permanent net atomic or ionic magnetic moment, favouring diamagnetism.

Step 1: Examine sodium chloride Sodium chloride contains Na^+ and Cl^- ions. They have closed-shell electronic configurations like neon and argon, respectively. All their electrons are paired, so the ionic permanent magnetic moments vanish and sodium chloride is diamagnetic.

Step 2: Eliminate the other materials Gadolinium has unpaired electrons and is a standard ferromagnetic material below its Curie temperature. Sodium metal is paramagnetic. Copper chloride, in the usual copper(II) chloride sense used here, contains Cu^{2+} with a $3d^9$ configuration and an unpaired electron, making it paramagnetic. Thus these choices do not identify the closed-shell diamagnetic salt.

Step 3: Conclusion Sodium chloride is diamagnetic. Hence, the correct option is (D).

Quick Tip to Solve: Distinguish sodium metal from its salt: formation of Na^+ removes the unpaired valence electron and gives a closed shell.

5. A current carrying circular loop of magnetic moment $\vec{M}$ is suspended in a vertical plane in an external magnetic field $\vec{B}$ such that its plane is normal to $\vec{B}$. The work done in rotating this loop by 45° about an axis perpendicular to $\vec{B}$ is closest to: [1 mark]

- (A) $-0.3 MB$
- (B) $0.3 MB$
- (C) $-1.7 MB$
- (D) $1.7 MB$

Correct Answer: (B) $0.3 MB$

Solution:

Concept:

- A magnetic dipole has potential energy $U = -MB \cos \theta$, where θ is the angle between its magnetic moment and the field.
- The moment of a current loop is normal to its plane. External work in a slow rotation is $W = U_f - U_i$.

Step 1: Identify the initial and final dipole angles The loop's plane is perpendicular to the field. For the usual initial stable orientation, its moment is parallel to $\vec{B}$, so $\theta_i = 0^\circ$. Rotating the loop through 45° about an axis perpendicular to the field makes $\theta_f = 45^\circ$. The angle in the energy formula is measured from the moment, not from the plane.

Step 2: Calculate the external work

$$W = -MB \cos 45^\circ - (-MB \cos 0^\circ) = MB \left(1 - \frac{1}{\sqrt{2}} \right).$$

The numerical factor is 0.2929, close to 0.3. Negative work would describe energy released rather than supplied for this rotation away from stable equilibrium. The 1.7 choices use a sum of the cosines instead of their required difference.

Step 3: Conclusion The required work is approximately $0.3 MB$. Hence, the correct option is (B), for the initially stable alignment.

Quick Tip to Solve: Convert the loop-plane orientation into the moment's orientation before using $MB(\cos \theta_i - \cos \theta_f)$.

6. The average value of the alternating voltage $v = (157 \text{ V}) \sin \omega t$ over its first half-cycle is: [1 mark]

- (A) 157 V
- (B) $\frac{157}{\sqrt{2}}$ V
- (C) 78.5 V
- (D) 100 V

Correct Answer: (D) 100 V

Solution:

Concept:

- The mean value of a quantity over a time interval is its integral over that interval divided by the interval's duration.
- For $v = V_0 \sin \omega t$, the first half-cycle runs from $t = 0$ to $t = \pi/\omega$; its mean is $2V_0/\pi$.

Step 1: Average over the positive half-cycle Put $\theta = \omega t$. The requested mean is

$$V_{\text{av}} = \frac{1}{\pi} \int_0^{\pi} V_0 \sin \theta \, d\theta = \frac{V_0}{\pi} [-\cos \theta]_0^{\pi} = \frac{2V_0}{\pi}.$$

The integral is positive because the voltage remains nonnegative throughout this interval.

Step 2: Substitute the peak voltage

$$V_{\text{av}} = \frac{2(157)}{\pi} \text{ V} \simeq 100 \text{ V}.$$

Option (A) is the peak value and option (B) is the root-mean-square value. Option (C), half the peak, would be obtained by averaging only the endpoints of a linear ramp; the sinusoid must instead be averaged by its area.

Step 3: Conclusion The average voltage over the first half-cycle is 100 V. Hence, the correct option is (D).

Quick Tip to Solve: For a sine wave, use $0.637V_0$ for the positive half-cycle mean and $0.707V_0$ for the rms value.

7. Consider a solenoid of length l and area of cross-section A with fixed number of turns. The self-inductance of the solenoid will increase if: [1 mark]

- (A) both l and A are increased
- (B) l is decreased and A is increased
- (C) l is increased and A is decreased
- (D) both l and A are decreased

Correct Answer: (B) l is decreased and A is increased

Solution:

Concept:

- A long solenoid of N turns, length l , cross-sectional area A , and core permeability μ has self-inductance $L = \mu N^2 A / l$.
- With the number of turns and core material unchanged, L is directly proportional to A and inversely proportional to l .

Step 1: Compare the factors that control inductance Increasing A increases the magnetic flux linked with each turn for the same field. Decreasing l raises the turns per unit length, increasing the field at the same current. Both changes therefore raise the total flux linkage per unit current, which defines inductance.

Step 2: Test the proposed changes In option (B), the numerator A increases while the denominator l decreases, so A/l certainly increases. Option (C) makes both effects decrease the inductance. In options (A) and (D), the two changes compete; without their relative sizes, the ratio might increase, decrease or stay constant. They therefore do not guarantee an increase.

Step 3: Conclusion The self-inductance increases when l is decreased and A is increased. Hence, the correct option is (B).

Quick Tip to Solve: Write $L \propto A/l$ with fixed total turns; do not hold the turns per unit length fixed when the solenoid length changes.

8. A plane electromagnetic wave is travelling in air in $+x$ direction. At a particular moment, its electric field $\vec{E}$ is along $+y$ direction. At that moment, the magnetic field $\vec{B}$ is along: [1 mark]

- (A) $+z$ direction and in phase with $\vec{E}$
- (B) $-z$ direction and in phase with $\vec{E}$
- (C) $+z$ direction and out of phase with $\vec{E}$
- (D) $-z$ direction and out of phase with $\vec{E}$

Correct Answer: (A) $+z$ direction and in phase with $\vec{E}$

Solution:

Concept:

- The propagation direction of an electromagnetic wave is along $\vec{E} \times \vec{B}$, perpendicular to both fields.
- In a travelling plane wave in air, the electric and magnetic fields oscillate in phase: their maxima and zeros occur together.

Step 1: Apply the right-hand rule Since the wave travels along $+x$ and $\vec{E}$ points along $+y$, we require $\hat{y} \times \hat{B} = \hat{x}$. The cyclic vector identity $\hat{y} \times \hat{z} = \hat{x}$ therefore fixes the magnetic field direction as $+z$. A field along $-z$ would instead give propagation along $-x$, ruling out (B) and (D).

Step 2: Check the relative phase The fields in a travelling electromagnetic wave have the same phase, even though their spatial directions are perpendicular. Thus the out-of-phase statement in (C) is incorrect; perpendicular directions must not be confused with a phase difference.

Step 3: Conclusion The magnetic field points along $+z$ and is in phase with $\vec{E}$. Hence, the correct option is (A).

Quick Tip to Solve: Use the cyclic order x, y, z to evaluate $\vec{E} \times \vec{B}$, then check phase separately from direction.

9. A proton and an alpha particle having equal velocities approach a target nucleus. They come momentarily to rest and then reverse their directions. The ratio of the distance of closest approach of the proton to that of the alpha particle will be: [1 mark]

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

Correct Answer: (B) 2

Solution:

Concept:

- At the distance of closest approach r in a head-on encounter, the projectile's initial kinetic energy becomes electrostatic potential energy: $\frac{1}{2}mv^2 = kZe q/r$. Here Ze is the target charge and q the projectile charge.
- A proton has charge e and mass m_p ; an alpha particle has charge $2e$ and mass approximately $4m_p$.

Step 1: Express the closest distance Rearranging energy conservation gives $r = 2kZe q/(mv^2)$. Since both particles approach the same nucleus at equal speeds, the common factors cancel and r is proportional to q/m , not simply to charge.

Step 2: Compare the two projectiles The alpha particle has four times the kinetic energy but only twice the charge. Thus

$$\frac{r_p}{r_\alpha} = \frac{e/m_p}{2e/(4m_p)} = 2.$$

Option (A) reverses the ratio. Options (C) and (D) incorrectly use the mass factor alone and neglect the difference in charge.

Step 3: Conclusion The distance ratio is $r_p : r_\alpha = 2 : 1$. Hence, the correct option is (B).

Quick Tip to Solve: For equal incident speeds and the same target nucleus, compare projectile q/m ; for equal energies, compare charges instead.

10. The wavelength of matter wave associated with an electron of kinetic energy K is λ . If the kinetic energy of the electron is doubled, the associated wavelength becomes: [1 mark]

- (A) $\frac{\lambda}{\sqrt{2}}$
 (B) $\frac{\lambda}{2}$
 (C) $\sqrt{2}\lambda$
 (D) 2λ

Correct Answer: (A) $\frac{\lambda}{\sqrt{2}}$

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p is the momentum.
- For a non-relativistic electron of mass m_e , $K = p^2/(2m_e)$; hence $\lambda = h/\sqrt{2m_e K}$.

Step 1: Establish the energy dependence For the same electron, h and m_e are constant. The wavelength therefore varies as $K^{-1/2}$. Doubling kinetic energy increases momentum by $\sqrt{2}$, so the wavelength must decrease.

Step 2: Take the wavelength ratio Substituting $K' = 2K$ gives

$$\frac{\lambda'}{\lambda} = \sqrt{\frac{K}{K'}} = \frac{1}{\sqrt{2}}.$$

Option (B) treats wavelength as inversely proportional to energy itself. Options (C) and (D) predict an increase, contrary to the inverse relation between wavelength and momentum.

Step 3: Conclusion The new wavelength is $\lambda' = \lambda/\sqrt{2}$. Hence, the correct option is (A).

Quick Tip to Solve: When the kinetic energy is multiplied by a factor f , divide the non-relativistic de Broglie wavelength by $\sqrt{f}$.

11. An electron makes a transition from $n = 2$ level to $n = 1$ level in the Bohr model of a hydrogen atom. Its period of revolution: [1 mark]

- (A) increases by 87.5%
- (B) decreases by 87.5%
- (C) increases by 43.75%
- (D) decreases by 43.75%

Correct Answer: (B) decreases by 87.5%

Solution:

Concept:

- In the Bohr model of hydrogen, orbital radius varies as $r_n \propto n^2$ and electron speed as $v_n \propto 1/n$, where n is the principal quantum number.
- The revolution period is circumference divided by speed: $T_n = 2\pi r_n/v_n$, so $T_n \propto n^3$.

Step 1: Compare the orbital periods The initial level is $n_i = 2$ and the final level is $n_f = 1$. Therefore

$$\frac{T_f}{T_i} = \left(\frac{n_f}{n_i}\right)^3 = \frac{1}{8}.$$

The smaller orbit and greater speed both shorten the revolution period.

Step 2: Calculate the percentage decrease Measure the change relative to the initial period:

$$\frac{T_i - T_f}{T_i} \times 100\% = \left(1 - \frac{1}{8}\right) 100\% = 87.5\%.$$

Thus (A) and (C) have the wrong direction of change. The decrease in (D) does not follow the cubic dependence on n ; the final period is only 12.5% of its initial value.

Step 3: Conclusion The period of revolution decreases by 87.5%. Hence, the correct option is (B).

Quick Tip to Solve: Remember $r \propto n^2$, $v \propto n^{-1}$, and therefore $T \propto n^3$; calculate percentage changes using the initial period.

12. Si is doped with a pentavalent element. The energy required to set the additional electron free is about:

[1 mark]

- (A) 0.01 eV
- (B) 0.05 eV
- (C) 0.72 eV
- (D) 1.1 eV

Correct Answer: (B) 0.05 eV

Solution:

Concept:

- A pentavalent impurity in silicon contributes four electrons to covalent bonds and has one additional, weakly bound donor electron.
- The donor level lies just below the conduction band. The small energy needed to lift its electron into that band is about 0.05 eV for silicon.

Step 1: Identify which electron is released The question concerns the extra electron supplied by the dopant, not a silicon valence electron in a covalent bond. Releasing it means ionising the donor and placing its electron in the conduction band, where it can participate in conduction.

Step 2: Compare the energy scales The standard approximate donor ionisation energy for silicon is 0.05 eV. The smaller value 0.01 eV is associated with typical donors in germanium. Values near 0.72 eV and 1.1 eV are band-gap scales for germanium and silicon, respectively, and do not describe release of this weakly bound additional electron.

Step 3: Conclusion The required energy is about 0.05 eV. Hence, the correct option is (B).

Quick Tip to Solve: Distinguish donor ionisation energy from the host band gap: for silicon the relevant scales are about 0.05 eV and 1.1 eV, respectively.

13. Assertion (A): In a semiconductor, the electrons in the conduction band have lesser energy than those in the valence band.

Reason (R): Donor energy level is just above the valence band in a semiconductor.

[1 mark]

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

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

Solution:

Concept:

- The conduction band lies above the valence band in electron energy, separated by the forbidden energy gap.
- Donor levels lie just below the conduction band; acceptor levels lie just above the valence band.

Step 1: Evaluate the assertion A valence-band electron must gain energy to reach the conduction

band. Thus conduction-band electrons have greater energy than valence-band electrons, whereas the assertion says they have lesser energy. The assertion is false.

Step 2: Evaluate the reason A donor supplies a weakly bound extra electron, so its level is close to, and below, the conduction-band edge. A level just above the valence band is an acceptor level. The reason incorrectly interchanges the two impurity types and is false.

Step 3: Check the explanatory connection Since both statements are false, the reason cannot correctly explain the assertion. The printed codes (A) and (B) require both statements to be true, and (C) requires the assertion to be true, so none of these codes applies.

Step 4: Conclusion Both the assertion and the reason are false. Hence, the correct option is (D).

Quick Tip to Solve: Read an energy-band diagram upward: valence band, acceptor level, donor level, conduction band; donors sit near the conduction band.

14. Assertion (A): Photoelectric effect demonstrates the particle nature of light.

Reason (R): Photoelectric current is proportional to frequency of incident radiation.

[1 mark]

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

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

Solution:

Concept:

- In the photon model, one photon transfers energy $h\nu$ to one electron; Einstein's equation is $K_{\max} = h\nu - \phi$, where ϕ is the work function.
- Photoelectric current measures the rate of collection of emitted electrons. For a fixed frequency above threshold and fixed collection conditions, it increases with incident intensity.

Step 1: Evaluate the assertion The threshold frequency and the dependence of maximum electron energy on frequency are explained by discrete packets of light energy, or photons. Thus the photoelectric effect demonstrates the particle nature of light, and the assertion is true.

Step 2: Evaluate the reason Increasing frequency changes the photon energy and hence the maximum kinetic energy of photoelectrons. Photoelectric current is not generally proportional to frequency; it depends on the number of electrons emitted and collected per second. At fixed frequency above threshold, intensity controls the incident photon rate. The reason is false.

Step 3: Check the explanatory connection A false statement about current cannot explain the true assertion about particle behaviour. Codes (A) and (B) require a true reason, while (D) requires a false assertion, so those alternatives are excluded.

Step 4: Conclusion The assertion is true, but the reason is false. Hence, the correct option is (C).

Quick Tip to Solve: Associate frequency with maximum photoelectron energy and intensity with photocurrent, keeping frequency above the threshold.

15. Assertion (A): A proton and an electron enter a uniform magnetic field $\vec{B}$ with the same momentum $\vec{p}$ such that $\vec{p}$ is perpendicular to $\vec{B}$. They describe circular paths of the same radius.

Reason (R): In a magnetic field, orbital radius r is equal to $\frac{p}{qB}$.

[1 mark]

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

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

Solution:

Concept:

- For motion perpendicular to a uniform magnetic field, the magnetic force supplies the centripetal force: $|q|vB = mv^2/r$.
- The orbit radius is $r = p/(|q|B)$, where $p = mv$ is the momentum magnitude and $|q|$ is the charge magnitude.

Step 1: Evaluate the assertion A proton and an electron have equal charge magnitudes e . They enter the same field with equal momentum magnitudes, so their radii are $r_p = p/(eB)$ and $r_e = p/(eB)$. Thus the assertion is true. Their different masses change their speeds but do not change this equality.

Step 2: Evaluate the reason Equating the magnetic and centripetal forces gives $r = mv/(|q|B) = p/(|q|B)$. The printed expression uses q for the charge magnitude, as appropriate for a positive radius, and is therefore true.

Step 3: Check the explanatory connection The reason directly explains the assertion because both particles have the same p , the same $|q|$, and the same B . Opposite charge signs cause opposite senses of curvature, not different radii. Option (B) misses this direct explanation, while (C) and (D) incorrectly reject a true statement.

Step 4: Conclusion Both statements are true and the reason correctly explains the assertion. Hence, the correct option is (A).

Quick Tip to Solve: At equal momentum in the same magnetic field, compare charge magnitudes to compare orbit radii; charge signs only change the bending direction.

16. Assertion (A): A convex lens, when immersed in a liquid, disappears.

Reason (R): The refractive indices of material of the lens and the liquid are equal.

[1 mark]

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

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

Solution:

Concept:

- Refraction at a transparent boundary requires a difference between the refractive indices of the two media.
- For a thin lens in a liquid, $P = (n_l/n_m - 1)(1/R_1 - 1/R_2)$, where n_l and n_m are the lens and liquid indices and R_1, R_2 are its signed radii of curvature.

Step 1: Evaluate the assertion in the stated situation A transparent convex lens appears to disappear when it is immersed in a liquid with the same refractive index. In this matched-index situation, its boundary does not deviate the light passing through it, so it cannot be distinguished optically from the surrounding liquid. The assertion describes this situation and is true; immersion in just any liquid would not suffice.

Step 2: Evaluate the reason The stated equality $n_l = n_m$ makes the relative refractive index unity. Snell's law then gives equal incidence and refraction angles. Also, the lens-maker factor $n_l/n_m - 1$ becomes zero, giving zero lens power. The reason is true for the situation described.

Step 3: Link the two statements The equality of refractive indices removes the optical contrast at the lens surfaces and explains why the lens appears to disappear. Thus (B) is unsuitable because there is a direct explanatory link; (C) and (D) incorrectly call the reason false.

Step 4: Conclusion Both statements are true in the matched-index situation, and the reason correctly explains the assertion. Hence, the correct option is (A).

Quick Tip to Solve: When a transparent object disappears in a liquid, check for equal refractive indices; the relative index is then one and the lens power is zero.

Section B (10 marks)

17(a). What is meant by 'relaxation time' of free electrons in a conductor? Show that the resistance of a conductor can be expressed by $R = \frac{ml}{ne^2\tau A}$, where symbols have their usual meanings. [2 marks]

Solution:

Concept:

- Relaxation time τ is the average time interval between two successive collisions of a conduction electron with the lattice ions in a conductor.
- The current magnitude is $I = neAv_d$, where n is the number of free electrons per unit volume, e

the elementary charge, A the cross-sectional area, and v_d the drift-speed magnitude.

Step 1: Relate drift speed to the applied field Consider a uniform conductor of length l and area A , with potential difference V across its ends. The field magnitude is $E = V/l$. Between collisions, an electron of mass m has acceleration magnitude eE/m . Collisions randomise its motion, and the mean interval between them is the relaxation time τ . Thus its mean drift-speed magnitude is

$$v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml}.$$

Electron drift is opposite to the electric field; the conventional current is along the field.

Step 2: Substitute into the current and use Ohm's law Substituting the drift speed into the current expression gives

$$I = neA \left(\frac{eV\tau}{ml} \right) = \frac{ne^2 A \tau}{ml} V.$$

Resistance is the ratio V/I . Therefore, using the magnitude of the current,

$$\frac{V}{I} = \frac{ml}{ne^2 \tau A}.$$

The factor $m/(ne^2\tau)$ is the resistivity of the conductor, while l/A describes its geometry.

Step 3: Conclusion Relaxation time is the mean time between successive collisions of a free electron.

The conductor's resistance is $R = \frac{ml}{ne^2 \tau A}$.

Quick Tip to Solve: Derive the resistance in the order $E = V/l$, $v_d = eE\tau/m$, $I = neAv_d$, then $R = V/I$.

OR

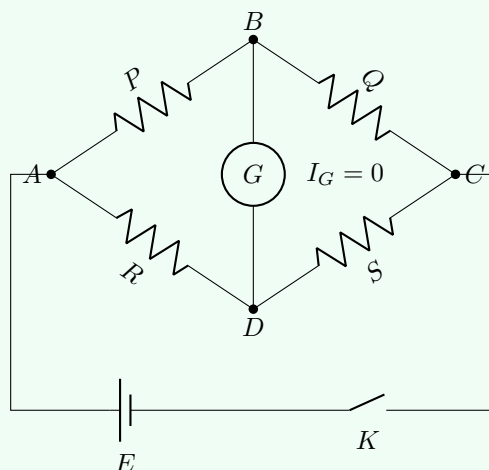
17(b). Draw the circuit diagram of a Wheatstone bridge. Obtain the condition when no current flows through the galvanometer in it. [2 marks]

Solution:

Concept:

- A Wheatstone bridge contains four resistances in its arms, with a galvanometer across one diagonal and a cell across the other.
- At balance, the galvanometer current is zero, so its two terminals have equal potentials. Ohm's law then relates the potential drops in the bridge arms.

Step 1: Draw and identify the bridge connections Connect resistances P, Q, R, S in arms AB, BC, AD, DC , respectively. Connect the galvanometer G between B and D , and the cell with a key K between A and C , as shown. Close the key to operate the bridge. Let the current in the upper path ABC be I_1 and that in the lower path ADC be I_2 at balance.



Wheatstone bridge: cell across AC, galvanometer across BD.

Step 2: Equate potential drops at balance When no current flows through G , $V_B = V_D$. Since no current branches into the galvanometer, the same current I_1 flows through P and Q , and the same current I_2 flows through R and S . Comparing drops from A and towards C ,

$$V_A - V_B = V_A - V_D \Rightarrow I_1 P = I_2 R,$$

$$V_B - V_C = V_D - V_C \Rightarrow I_1 Q = I_2 S.$$

Dividing the first relation by the second eliminates both currents and gives $P/Q = R/S$. Conversely, this ratio makes the junction potentials equal, so the galvanometer has no potential difference across it.

Step 3: Conclusion The Wheatstone bridge is balanced and no current flows through the galvanometer when $\boxed{\frac{P}{Q} = \frac{R}{S}}$, or equivalently $PS = QR$.

Quick Tip to Solve: Label the four arms before writing the balance condition: equal ratios along the two paths from the cell's first terminal to its second give a null galvanometer current.

18. The magnifying power of an astronomical telescope is 24. In normal adjustment, distance between its two lenses is 150 cm. Find the focal length of the objective lens. [2 marks]

Solution:

Concept:

- In normal adjustment, an astronomical telescope has its final image at infinity, with the objective's image in the eyepiece's focal plane.
- The magnitude of magnifying power is $M = f_o/f_e$, and the lens separation is $L = f_o + f_e$, where f_o and f_e are the positive focal lengths of the objective and eyepiece.

Step 1: Translate the magnification and separation into equations The given magnifying power 24 is its magnitude. The image in an astronomical telescope is inverted, but this sign does not affect the positive focal lengths. Hence,

$$\frac{f_o}{f_e} = 24 \Rightarrow f_o = 24f_e.$$

Normal adjustment places the rear focal plane of the objective at the front focal plane of the eyepiece, so their separation gives

$$f_o + f_e = 150 \text{ cm.}$$

Step 2: Solve for the two focal lengths Substitute $f_o = 24f_e$ into the separation equation:

$$24f_e + f_e = 150 \text{ cm,}$$

$$f_e = \frac{150}{25} \text{ cm} = 6 \text{ cm,}$$

$$f_o = 24 \times 6 \text{ cm} = 144 \text{ cm.}$$

As a check, the focal lengths add to 150 cm and their ratio is $144/6 = 24$, satisfying both observations.

Step 3: Conclusion The focal length of the objective lens is $f_o = 144 \text{ cm} = 1.44 \text{ m}$.

Quick Tip to Solve: In normal adjustment, use $f_o = ML/(M + 1)$ directly when the magnifying-power magnitude M and the lens separation L are given.

19. What is a sustained or stable interference pattern? What are the conditions for obtaining such an interference pattern? [2 marks]

Solution:

Concept:

- Interference is the redistribution of intensity when two light waves superpose. For intensities I_1, I_2 and phase difference ϕ , $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$.
- Coherent sources have the same frequency and maintain a constant phase difference, so the intensity at each observation point remains steady.

Step 1: Define a sustained pattern A sustained or stable interference pattern is one in which the positions of the bright and dark fringes and their intensities remain unchanged with time. At a fixed point, the phase difference must therefore be constant; a randomly changing phase would wash out the fringes on observation.

Step 2: State the conditions for observing it The sources must be coherent, emitting light of the same frequency with a constant phase difference. The interfering waves should have the same state of polarization and overlap in the observation region. Monochromatic light gives a well-defined fringe system; comparable amplitudes give good contrast, with equal amplitudes producing completely dark minima. In practice, two narrow, closely spaced sources obtained from one source provide a clear, steady pattern.

Step 3: Conclusion A stable pattern has fixed bright and dark fringes. Its essential requirement is coherence: equal frequency and constant phase difference; matching polarization and comparable intensities make the fringes clearly visible.

Quick Tip to Solve: Separate stability from contrast: constant phase difference fixes the fringes, while equal amplitudes make the dark fringes fully dark.

20. Light of wavelength 600 nm is incident on potassium (work function 2.3 eV). Will photoemission of electrons occur? What is the longest wavelength that will cause photoemission of electrons? (Take $hc = 1240 \text{ eV}\cdot\text{nm}$) [2 marks]

Solution:

Concept:

- A photon of wavelength λ has energy $E = hc/\lambda$. Photoemission requires $E \geq \phi$, where ϕ is the metal's work function.
- At the threshold wavelength λ_0 , all the photon energy is used to liberate the electron: $hc/\lambda_0 = \phi$. This is the longest wavelength permitting emission.

Step 1: Compare the incident photon energy with the work function Using $hc = 1240 \text{ eV}\cdot\text{nm}$ and the incident wavelength in nanometres avoids a conversion to joules:

$$E = \frac{1240}{600} \text{ eV} = 2.067 \text{ eV}.$$

This is smaller than $\phi = 2.3 \text{ eV}$. An incident photon cannot supply the minimum energy required to remove an electron, so the incident light produces no photoemission. A negative value of $E - \phi$ indicates no emission, not negative electron kinetic energy.

Step 2: Calculate the longest permissible wavelength At the limiting wavelength the emitted electron has zero maximum kinetic energy. Hence,

$$\lambda_0 = \frac{hc}{\phi} = \frac{1240}{2.3} \text{ nm} \simeq 539 \text{ nm} = 5.39 \times 10^{-7} \text{ m}.$$

Longer wavelengths have smaller photon energies and cannot cause photoemission from potassium under the stated conditions.

Step 3: Conclusion No photoemission occurs for 600 nm light. The longest wavelength causing photoemission is approximately 539 nm.

Quick Tip to Solve: With the work function in eV, divide 1240 by it to get the threshold wavelength in nm; incident wavelengths above this limit cannot eject electrons.

21. Suppose a pure Si crystal has $5 \times 10^{28} \text{ atoms m}^{-3}$. It is doped by 1 ppm concentration of boron. Calculate the concentration of holes and electrons, given that $n_i = 1.5 \times 10^{16} \text{ m}^{-3}$. Is the doped crystal n -type or p -type? [2 marks]

Solution:

Concept:

- Trivalent boron is an acceptor impurity in silicon. For fully ionized acceptors with concentration $N_A \gg n_i$, the hole concentration is $p \simeq N_A$.
- At thermal equilibrium the mass-action law is $np = n_i^2$, where n and p are the electron and hole concentrations and n_i is the intrinsic carrier concentration.

Step 1: Convert the doping fraction into a hole concentration A concentration of 1 ppm means one boron atom per 10^6 silicon atoms. Thus the acceptor concentration is

$$N_A = 10^{-6}(5 \times 10^{28}) = 5 \times 10^{22} \text{ m}^{-3}.$$

Assuming complete ionization, each boron acceptor supplies one hole. Since N_A is much larger than $n_i = 1.5 \times 10^{16} \text{ m}^{-3}$, intrinsic holes make a negligible correction and $p \simeq 5 \times 10^{22} \text{ m}^{-3}$.

Step 2: Apply the mass-action law and identify the type The minority electron concentration follows from the product of the equilibrium carrier concentrations:

$$n = \frac{n_i^2}{p} = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{22}} = 4.5 \times 10^9 \text{ m}^{-3}.$$

Boron has three valence electrons, so it accepts an electron to complete a silicon bond and leaves a mobile hole. Holes are therefore the majority carriers and electrons are the minority carriers.

Step 3: Conclusion The hole concentration is $5 \times 10^{22} \text{ m}^{-3}$, the electron concentration is $4.5 \times 10^9 \text{ m}^{-3}$, and the doped crystal is p -type.

Quick Tip to Solve: Convert ppm to 10^{-6} first, then use the dopant density for the majority carriers and n_i^2 divided by that density for the minority carriers.

Section C (21 marks)

22. A current of 1.6 A flows through a wire when a potential difference of 1.0 V is applied across it. The length and cross-sectional area of the wire are 1.0 m and $1.0 \times 10^{-7} \text{ m}^2$ respectively. Calculate:

(a) Electric field across the wire

(b) Current density

(c) Average relaxation time (τ)

(Number density of free electrons in the wire is $9.0 \times 10^{28} \text{ m}^{-3}$)

[3 marks]

Solution:

Concept:

- For a uniform wire of length L , cross-sectional area A , potential difference V and current I , the field magnitude is $E = V/L$ and the current density magnitude is $J = I/A$.
- The drift-speed relations are $J = nev_d$ and $v_d = eE\tau/m_e$. Thus $J = ne^2\tau E/m_e$, where n is the free-electron density, e the charge magnitude and τ the mean time between successive collisions.

Step 1: Calculate the electric field for part (a) The potential falls uniformly along the wire, so the magnitude of the electric field is the potential difference per unit length:

$$E = \frac{V}{L} = \frac{1.0}{1.0} = 1.0 \text{ V m}^{-1}.$$

Its direction is from higher to lower potential, along the conventional current.

Step 2: Calculate the current density for part (b) The current is distributed over the wire's cross-sectional area $A = 1.0 \times 10^{-7} \text{ m}^2$. Therefore,

$$J = \frac{I}{A} = \frac{1.6}{1.0 \times 10^{-7}} = 1.6 \times 10^7 \text{ A m}^{-2}.$$

Current density has the direction of conventional current; electron drift is opposite to it.

Step 3: Determine the relaxation time for part (c) Between collisions, the electric force produces the

drift speed $v_d = eE\tau/m_e$. Substituting this into $J = nev_d$ and rearranging gives

$$\tau = \frac{m_e J}{ne^2 E}.$$

Use $m_e = 9.1 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C and the given $n = 9.0 \times 10^{28}$ m⁻³:

$$\begin{aligned}\tau &= \frac{(9.1 \times 10^{-31})(1.6 \times 10^7)}{(9.0 \times 10^{28})(1.6 \times 10^{-19})^2(1.0)} \\ &= \frac{1.456 \times 10^{-23}}{2.304 \times 10^{-9}} = 6.32 \times 10^{-15} \text{ s}.\end{aligned}$$

This is the average interval between successive scattering collisions of a conduction electron.

Step 4: Conclusion (a) $E = 1.0$ V m⁻¹; (b) $J = 1.6 \times 10^7$ A m⁻²; (c) $\tau \simeq 6.3 \times 10^{-15}$ s.

Quick Tip to Solve: Find $E = V/L$ and $J = I/A$ first, then use $\tau = m_e J / (ne^2 E)$; remember to square both the numerical value and the power of ten in e^2 .

23. An electron (charge $-e$, mass m) is revolving around a nucleus, in a hydrogen atom, in a circle of radius r . Derive an expression, in vector form, for the magnetic dipole moment, $\vec{\mu}$, in terms of its orbital angular momentum $\vec{L}$. What is gyromagnetic ratio? [3 marks]

Solution:

Concept:

- A charge moving periodically around a circle is equivalent to a current loop. For period T , the magnitude of its current is $I = e/T$, where e is the magnitude of the electron charge.
- A circular current loop of area A has magnetic moment magnitude $\mu = IA$. An electron of mass m , speed v and orbital radius r has angular momentum magnitude $L = mvr$.

Step 1: Obtain the equivalent orbital current Let the electron move at speed v . It travels a distance $2\pi r$ in one revolution, so its orbital period and the magnitude of its equivalent current are

$$T = \frac{2\pi r}{v}, \quad I = \frac{e}{T} = \frac{ev}{2\pi r}.$$

Conventional current flows opposite to the electron's motion, because the electron carries negative charge.

Step 2: Relate the moment to angular momentum The area of the circular orbit is $A = \pi r^2$. Therefore

$$\mu = IA = \frac{ev}{2\pi r} \pi r^2 = \frac{evr}{2}.$$

Since the radius and velocity are perpendicular, $L = mvr$, and hence $\mu = (e/2m)L$ in magnitude. The right-hand rule applied to the electron's orbital motion gives the direction of $\vec{L}$. Applying the rule to conventional current gives the opposite direction for $\vec{\mu}$. Thus the vector relation must contain a negative sign.

Step 3: Define the gyromagnetic ratio The gyromagnetic ratio is the ratio of magnetic dipole moment to orbital angular momentum. As a ratio of magnitudes for an orbiting electron, it is

$$\frac{\mu}{L} = \frac{e}{2m}.$$

If defined as the signed proportionality coefficient γ in $\vec{\mu} = \gamma \vec{L}$, the electron's orbital gyromagnetic ratio is $\gamma = -e/(2m)$. Its SI unit is C kg^{-1} .

Step 4: Conclusion The required vector expression is $\vec{\mu} = -\frac{e}{2m} \vec{L}$. The orbital magnetic moment is antiparallel to angular momentum. The gyromagnetic ratio in magnitude is $e/(2m)$; the signed electron coefficient is $-e/(2m)$.

Quick Tip to Solve: First use $\mu = IA$ and $L = mvr$ for magnitudes; then reverse the magnetic-moment direction because conventional current opposes electron motion.

24. Prove that induced charge depends on the net change in the magnetic flux and not on the time interval of the flux change. [3 marks]

Solution:

Concept:

- Faraday's law gives the induced emf in a single loop as $\mathcal{E} = -d\Phi/dt$, where Φ is the magnetic flux through the loop. The minus sign specifies the direction according to Lenz's law.
- For a closed circuit of constant resistance R , neglecting self-inductance, Ohm's law gives $I = \mathcal{E}/R$. The signed charge passing a cross-section in time dt is $dq = I dt$.

Step 1: Express the small charge in terms of flux change Choose a fixed positive direction around the loop and its associated area normal. Let the magnetic flux change from Φ_i at time t_i to Φ_f at time t_f . At an intermediate instant, Faraday's law and Ohm's law give

$$I = -\frac{1}{R} \frac{d\Phi}{dt}.$$

Multiplying by the small time interval dt , the elementary charge transported in the chosen direction is

$$dq = I dt = -\frac{1}{R} d\Phi.$$

Thus the time differential cancels; a specified small flux change produces a specified charge transfer.

Step 2: Integrate over the complete change With R constant, integrate between the initial and final states:

$$q = \int_{t_i}^{t_f} I dt = -\frac{1}{R} \int_{\Phi_i}^{\Phi_f} d\Phi = -\frac{\Phi_f - \Phi_i}{R}.$$

Only the end values of flux enter this expression. The interval $t_f - t_i$ does not appear. A faster change increases the induced current but decreases the duration of flow, leaving the net transferred charge unchanged.

Step 3: State the coil form and meaning of net charge If a coil has N turns, each linked by the same flux Φ , and total resistance R , its flux linkage is $N\Phi$. The result becomes $q = -N(\Phi_f - \Phi_i)/R$. This is the algebraic net charge: if the flux reverses its change, the corresponding charge transfers in opposite directions subtract. The total unsigned charge need not equal the net charge in that case.

Step 4: Conclusion For a single loop, $q = -\Delta\Phi/R$, so $|q| = |\Delta\Phi|/R$. For N turns, $|q| = N|\Delta\Phi|/R$. At fixed resistance, the net induced charge depends on the net change in flux (or flux linkage), not on how long the change takes.

Quick Tip to Solve: Substitute Faraday's law into $dq = I dt$ before integrating: the cancellation of dt immediately reveals why only the initial and final flux matter.

25. The electric field in an electromagnetic wave in vacuum is given by:

$$\vec{E} = (6.3 \text{ N/C})[\cos((1.5 \text{ rad/m})y + (4.5 \times 10^8 \text{ rad/s})t)]\hat{i}$$

(a) Find the wavelength and frequency of the wave.

(b) What is the amplitude of the magnetic field of the wave?

(c) Write an expression for the magnetic field of this wave.

[3 marks]

Solution:

Concept:

- For a sinusoidal wave, the wave number and angular frequency satisfy $k = 2\pi/\lambda$ and $\omega = 2\pi f$, where λ is wavelength and f is frequency.
- In vacuum, $E_0 = cB_0$. The electric and magnetic fields are perpendicular and oscillate in phase; $\vec{E} \times \vec{B}$ points in the propagation direction.

Step 1: Identify the wave parameters and find part (a) Compare the given field with $\vec{E} = E_0 \cos(ky + \omega t)\hat{i}$. Its parameters are $E_0 = 6.3 \text{ N C}^{-1}$, $k = 1.5 \text{ rad m}^{-1}$ and $\omega = 4.5 \times 10^8 \text{ rad s}^{-1}$. Consequently,

$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{1.5} \text{ m} \simeq 4.19 \text{ m},$$

$$f = \frac{\omega}{2\pi} = \frac{4.5 \times 10^8}{2\pi} \text{ Hz} \simeq 7.16 \times 10^7 \text{ Hz}.$$

As a consistency check, $\omega/k = 3.0 \times 10^8 \text{ m s}^{-1}$, the speed of light in vacuum. The coefficient of t is angular frequency, so it must be divided by 2π to obtain frequency in hertz.

Step 2: Calculate the magnetic amplitude for part (b) Using the vacuum relation between the field amplitudes gives

$$B_0 = \frac{E_0}{c} = \frac{6.3}{3.0 \times 10^8} \text{ T} = 2.1 \times 10^{-8} \text{ T}.$$

This is the positive amplitude; the instantaneous field changes sign with the cosine factor.

Step 3: Determine the field direction and phase for part (c) At constant phase, $ky + \omega t = \text{constant}$, so $dy/dt = -\omega/k$. The wave therefore travels along $-\hat{j}$. Since the electric field is along the x -axis, the magnetic field must be along the z -axis. In particular, $\hat{i} \times \hat{k} = -\hat{j}$, so the required vector coefficient is $+\hat{k}$. Use the same cosine phase for both fields, as they oscillate in phase in vacuum. Even when both fields reverse, their cross product continues to point along $-\hat{j}$.

Step 4: Conclusion (a) $\lambda \simeq 4.19 \text{ m}$ and $f \simeq 7.16 \times 10^7 \text{ Hz}$. (b) $B_0 = 2.1 \times 10^{-8} \text{ T}$. (c) With y in

metres and t in seconds,

$$\vec{B}(y, t) = (2.1 \times 10^{-8} \text{ T}) \cos(1.5y + 4.5 \times 10^8 t) \hat{k}.$$

Quick Tip to Solve: Read the propagation direction from a constant phase first: $ky + \omega t$ travels toward negative y . Then choose $\vec{B}$ so that $\vec{E} \times \vec{B}$ points that way.

26. State Bohr's second postulate for his theory of hydrogen atom. Prove that the radius of Bohr's orbit of a hydrogen atom is directly proportional to n^2 , where n is the principal quantum number. [3 marks]

Solution:

Concept:

- In Bohr's model, an electron of mass m_e moves in a permitted circular orbit of radius r_n about a stationary proton.
- The electron's orbital angular momentum is quantised, while Coulomb attraction supplies the centripetal force. Here e is the magnitude of electronic charge, h is Planck's constant and ϵ_0 is the permittivity of free space.

Step 1: State Bohr's second postulate Only those orbits are allowed for which the electron's orbital angular momentum is an integral multiple of $h/(2\pi)$:

$$m_e v_n r_n = \frac{nh}{2\pi}, \quad n = 1, 2, 3, \dots$$

Here v_n is its speed in the n th orbit and n is the principal quantum number. This condition selects discrete permitted orbits from the continuous set that classical mechanics alone would allow.

Step 2: Write the radial force equation For hydrogen the nucleus has charge $+e$. The electrostatic attraction provides precisely the force needed for circular motion:

$$\frac{m_e v_n^2}{r_n} = \frac{e^2}{4\pi\epsilon_0 r_n^2}.$$

Multiplying by r_n^2 gives $m_e v_n^2 r_n = e^2/(4\pi\epsilon_0)$.

Step 3: Eliminate the electron's speed The angular-momentum condition gives $v_n = nh/(2\pi m_e r_n)$. Substituting this expression into the force equation gives

$$\begin{aligned} \frac{n^2 h^2}{4\pi^2 m_e r_n} &= \frac{e^2}{4\pi\epsilon_0}, \\ r_n &= \frac{\epsilon_0 h^2}{\pi m_e e^2} n^2. \end{aligned}$$

All factors multiplying n^2 are constants for hydrogen; changing the orbit changes only the principal quantum number.

Step 4: Conclusion Bohr's second postulate is $m_e v_n r_n = nh/(2\pi)$. Hence $r_n = a_0 n^2$, where $a_0 = \epsilon_0 h^2 / (\pi m_e e^2)$; therefore $r_n \propto n^2$.

Quick Tip to Solve: Eliminate v_n using angular-momentum quantisation before simplifying the force equation; this exposes the n^2 dependence directly.

27. (a) Define atomic mass unit (u).

(b) Calculate the energy required to separate a deuteron into its constituent parts (a proton and a neutron). Given: $m(D) = 2.014102 \text{ u}$; $m_H = 1.007825 \text{ u}$; $m_n = 1.008665 \text{ u}$. [3 marks]

Solution:

Concept:

- The unified atomic mass unit, u, is defined using the mass of a neutral carbon-12 atom; $1 \text{ u} \simeq 1.6605 \times 10^{-27} \text{ kg}$.
- Nuclear binding energy is the energy needed to separate a nucleus completely into its free nucleons: $B = \Delta mc^2$, with $1 \text{ u } c^2 \simeq 931.5 \text{ MeV}$.

Step 1: Define the atomic mass unit One atomic mass unit is one-twelfth of the mass of a free, neutral carbon-12 atom in its ground state and at rest:

$$1 \text{ u} = \frac{1}{12} m(^{12}\text{C}).$$

It is a mass unit, so conversion to energy requires multiplication by c^2 .

Step 2: Calculate the mass defect A deuteron contains one proton and one neutron. The printed m_H is the hydrogen atomic mass; the supplied $m(D)$ is the deuterium atomic mass. Each neutral atom has one electron, so the electron masses cancel when subtracting their masses. The much smaller electronic binding-energy correction is negligible at this precision.

$$\begin{aligned} \Delta m &= m_H + m_n - m(D) \\ &= (1.007825 + 1.008665 - 2.014102) \text{ u} \\ &= 0.002388 \text{ u}. \end{aligned}$$

The free constituent masses exceed the bound mass. This positive mass defect corresponds to energy that must be supplied to break the nucleus apart.

Step 3: Convert the mass defect to separation energy Multiplying the mass defect by the rest-energy equivalent per atomic mass unit gives

$$B = 0.002388 \times 931.5 \text{ MeV} = 2.224422 \text{ MeV}.$$

Since $1 \text{ MeV} = 1.602 \times 10^{-13} \text{ J}$, the same energy is approximately $3.56 \times 10^{-13} \text{ J}$. This is the total binding energy, not the binding energy per nucleon.

Step 4: Conclusion 1 u is one-twelfth of the mass of a neutral carbon-12 atom. The energy required to separate the deuteron is $B \simeq 2.224 \text{ MeV}$, or $3.56 \times 10^{-13} \text{ J}$.

Quick Tip to Solve: With atomic masses, pair hydrogen and deuterium so their electron masses cancel; subtract the bound mass before multiplying by 931.5.

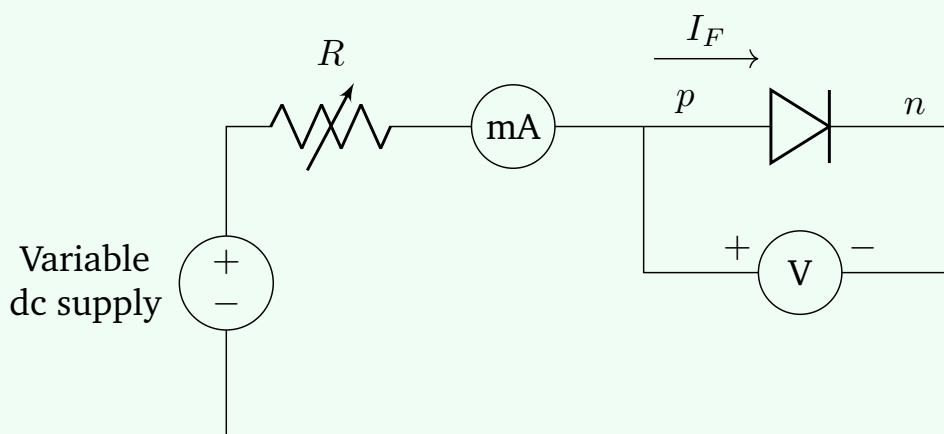
28(a). Draw the circuit diagrams for obtaining the $V - I$ characteristics of a $p-n$ junction diode. Explain briefly the salient features of the $V - I$ characteristics in (i) forward biasing, and (ii) reverse biasing. [3 marks]

Solution:

Concept:

- Bias changes the potential barrier and depletion-layer width of a $p-n$ junction. Forward bias reduces both; reverse bias increases both.
- For a $V-I$ characteristic, measure the diode voltage with a parallel voltmeter and the current with a series ammeter while varying the applied dc voltage.

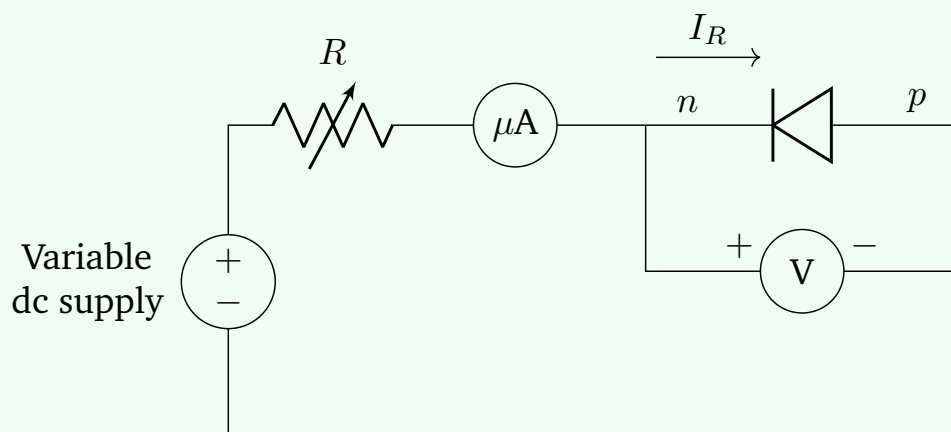
Step 1: Connect the forward-bias circuit Connect the p side (anode) to the positive supply terminal and the n side (cathode) to the negative terminal through a current-limiting variable resistor R . Use a milliammeter in series and connect the voltmeter across the diode, with its positive terminal on the p side. Increase the applied voltage gradually and record pairs (V_F, I_F) . The resistor protects the diode when its current rises sharply.



Forward bias: positive supply to the p side; voltmeter across the diode.

Step 2: Explain the forward characteristic At first the current is small because the junction barrier still opposes the majority carriers. Beyond the knee or cut-in voltage, current increases rapidly for a small increase in voltage. Typical room-temperature knee voltages are about 0.7 V for silicon and 0.3 V for germanium. The characteristic is nonlinear: the forward resistance becomes small in the conducting region. The knee is a practical threshold, not an abrupt onset of all current.

Step 3: Connect the reverse-bias circuit Reverse the diode connection so its n side is connected to the positive supply and its p side to the negative supply. Use a microammeter because the reverse current is very small. Keep the voltmeter across the diode with its positive terminal on the n side; its reading is the reverse-voltage magnitude V_R . Vary the supply and record (V_R, I_R) , limiting the current with R .



Reverse bias: positive supply to the n side; meters read reverse magnitudes.

Step 4: Explain the reverse characteristic Reverse bias suppresses majority-carrier conduction. A small reverse saturation current, due to minority carriers, flows and remains nearly constant as the reverse-voltage magnitude increases at fixed temperature. Hence the reverse resistance is very high. At the breakdown voltage the reverse current increases sharply; the external resistance must limit this current to prevent damage. On signed axes, the forward curve lies in the first quadrant and the reverse curve in the third quadrant.

Step 5: Conclusion Forward bias gives a rapidly increasing current beyond the knee voltage; reverse bias gives a very small, nearly constant current until breakdown. The circuits use a series milliammeter or microammeter respectively and a voltmeter in parallel with the diode.

Quick Tip to Solve: Check polarity at the diode itself: p to positive means forward bias. Use mA for forward current and μA for the small reverse current.

OR

28(b). On the basis of energy band diagrams, distinguish between (i) an insulator, (ii) a semiconductor, and (iii) a conductor. [3 marks]

Solution:

Concept:

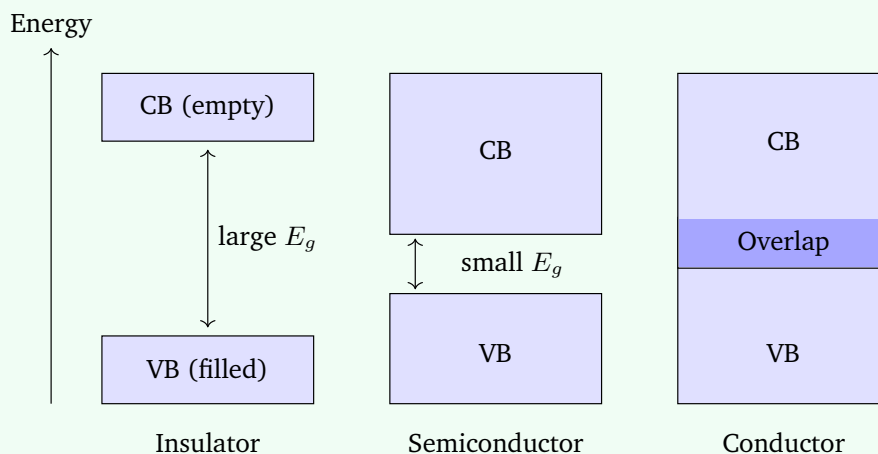
- The valence band (VB) contains the valence electrons; the conduction band (CB) provides accessible energy states in which electrons can conduct.
- The forbidden energy gap is $E_g = E_C - E_V$, where E_C is the bottom of the conduction band and E_V the top of the valence band. No allowed electron states lie in this gap.

Step 1: Examine an insulator The valence band is completely filled and the conduction band is empty at low temperature. A large forbidden gap, typically several electron-volts, separates them. Ordinary thermal energy cannot promote an appreciable number of electrons across this gap. A filled band cannot provide ordinary conduction because nearby available states are absent, so an insulator has negligible conductivity under normal conditions.

Step 2: Examine a semiconductor The valence band is full and the conduction band empty at absolute zero, but their gap is small, of the order of 1 eV. At ordinary temperatures some electrons gain enough thermal energy to enter the conduction band, leaving holes in the valence band. Both electrons and

holes conduct. Thus its conductivity is intermediate and generally increases with temperature as more charge carriers are generated.

Step 3: Examine a conductor A conductor has a partially filled allowed band, or its valence and conduction bands overlap. There is therefore no forbidden gap preventing electrons from reaching nearby empty states. Even a small applied electric field can redistribute electrons among these available states and produce a substantial current. The diagram represents the overlapping-band case; a partially filled band also explains metallic conduction.



Schematic band diagrams; shaded regions are allowed bands. Energy increases upward.

Step 4: Conclusion An insulator has a large forbidden gap, a semiconductor has a small forbidden gap, and a conductor has overlapping bands or a partially filled band. These differences determine the availability of mobile charge carriers.

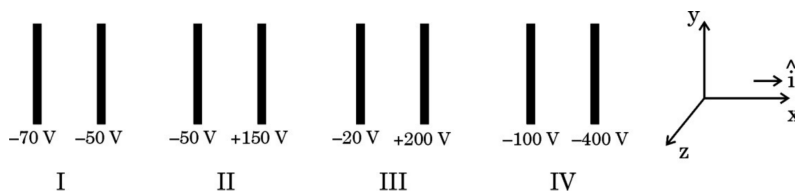
Quick Tip to Solve: Compare the gap and the availability of empty states: large gap means insulator, small gap means semiconductor, and an incompletely filled band or overlap means conductor.

Section D (8 marks)

Case Study Based Questions

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

29. The figure shows four pairs of parallel identical conducting plates, separated by the same distance 2.0 cm and arranged perpendicular to x-axis. The electric potential of each plate is mentioned. The electric field between a pair of plates is uniform and normal to the plates. [4 marks]



29(i). For which pair of the plates is the electric field $\vec{E}$ along $\hat{i}$? [1 mark]

- (A) I
- (B) II
- (C) III
- (D) IV

Correct Answer: (D) IV

Solution:

Concept:

- An electric field points from higher potential to lower potential: $E_x = -dV/dx$.
- Between parallel plates separated by d , $E_x = -(V_R - V_L)/d$, with left and right potentials V_L, V_R .

Step 1: Compare the potential changes from left to right The potential changes $V_R - V_L$ for pairs I, II, III and IV are respectively +20, +200, +220 and -300 V. The first three pairs therefore have fields towards negative x , eliminating options (A), (B) and (C).

Step 2: Determine the sign of the field for pair IV For pair IV, the potential falls from -100 V to -400 V as x increases. Since $d = 0.020$ m,

$$E_{4x} = -\frac{-300}{0.020} = +1.5 \times 10^4 \text{ V m}^{-1}.$$

The positive component means the field points along $\hat{i}$.

Step 3: Conclusion Only pair IV has its electric field along $\hat{i}$. Hence, the correct option is (D).

Quick Tip to Solve: Read the two plate potentials from left to right: a fall in potential means the field points to the right, even when both potentials are negative.

29(ii). An electron is released midway between the plates of pair IV. It will:

[1 mark]

- (A) move along $\hat{i}$ at constant speed
- (B) move along $-\hat{i}$ at constant speed
- (C) accelerate along $\hat{i}$
- (D) accelerate along $-\hat{i}$

Correct Answer: (D) accelerate along $-\hat{i}$

Solution:

Concept:

- The electric field points towards decreasing potential, so $E_x = -(V_R - V_L)/d$.
- The electric force on a charge is $\vec{F} = q\vec{E}$. An electron has $q = -e$, hence its acceleration is opposite to the field.

Step 1: Find the field direction between pair IV Potential decreases from -100 V at the left plate to -400 V at the right plate. Therefore the uniform electric field points to the right, along $+\hat{i}$, with magnitude $300/0.020 = 1.5 \times 10^4\text{ V m}^{-1}$.

Step 2: Apply the electron's negative charge The electron experiences a constant, nonzero force $-e\vec{E}$, directed to the left. Its acceleration $\vec{a} = -e\vec{E}/m$ is also to the left. Being released from rest does not imply zero subsequent speed: the force makes its speed increase. Thus (A) and (B), which claim constant speed, fail, while (C) incorrectly uses the field direction as the electron's acceleration direction.

Step 3: Conclusion The electron accelerates along $-\hat{i}$. Hence, the correct option is (D).

Quick Tip to Solve: First find the field direction from the potentials, then reverse it for the force and acceleration of a negatively charged electron.

29(iii). Let V_0 be the potential at the left plate of any set, taken to be at $x = 0\text{ m}$. Then the potential V at any point ($0 \leq x \leq 2\text{ cm}$) between the plates of that set can be expressed as (where α is a constant, positive or negative):

[1 mark]

- (A) $V = V_0 + \alpha x$
- (B) $V = V_0 + \alpha x^2$
- (C) $V = V_0 + \alpha x^{1/2}$
- (D) $V = V_0 + \alpha x^{3/2}$

Correct Answer: (A) $V = V_0 + \alpha x$

Solution:

Concept:

- Electric field and potential gradient are related by $E_x = -dV/dx$.
- A uniform field has a constant component E_x , so the potential changes linearly with position.

Step 1: Integrate the constant potential gradient Taking the potential to be V_0 at $x = 0$, integrate between the left plate and a point at coordinate x :

$$V(x) - V_0 = - \int_0^x E_x dx' = -E_x x.$$

Define the signed constant $\alpha = -E_x$, which may be positive or negative according to the plate potentials.

Step 2: Test the remaining powers of position The linear expression has a constant derivative $dV/dx = \alpha$, as required. The derivatives of the alternatives containing x^2 , $x^{1/2}$ and $x^{3/2}$ depend on x ; they would describe nonuniform fields for the nonzero potential differences given here. All expressions have the same potential at the origin, so that boundary value alone cannot distinguish them.

Step 3: Conclusion The potential is $V = V_0 + \alpha x$, with constant $\alpha = -E_x$. Hence, the correct option is (A).

Quick Tip to Solve: Differentiate each proposed potential once: for a uniform electric field, its slope must be independent of position.

29(iv)(a). Let E_1, E_2, E_3 and E_4 be the magnitudes of the electric field between the pairs of plates I, II, III and IV respectively. Then: [1 mark]

- (A) $E_1 > E_2 > E_3 > E_4$
- (B) $E_3 > E_4 > E_1 > E_2$
- (C) $E_4 > E_3 > E_2 > E_1$
- (D) $E_2 > E_3 > E_4 > E_1$

Correct Answer: (C) $E_4 > E_3 > E_2 > E_1$

Solution:

Concept:

- The magnitude of a uniform electric field between two plates is $E = |V_R - V_L|/d$.
- Since every pair has the same separation $d = 2.0 \text{ cm} = 0.020 \text{ m}$, the ranking of fields is the ranking of the absolute potential differences.

Step 1: Calculate the four potential differences Subtract the left plate potential from the right and take the magnitude:

$$\begin{aligned} |\Delta V_1| &= |-50 - (-70)| = 20 \text{ V}, \\ |\Delta V_2| &= |150 - (-50)| = 200 \text{ V}, \\ |\Delta V_3| &= |200 - (-20)| = 220 \text{ V}, \\ |\Delta V_4| &= |-400 - (-100)| = 300 \text{ V}. \end{aligned}$$

Step 2: Divide by the common separation and compare The corresponding field magnitudes are $E_1 = 1000$, $E_2 = 10000$, $E_3 = 11000$ and $E_4 = 15000 \text{ V m}^{-1}$. Pair IV has the largest magnitude and pair I the smallest. Option (A) reverses the ordering; (B) wrongly puts III above IV and I above II; (D) wrongly makes II the largest. A negative signed potential difference does not imply a negative field magnitude.

Step 3: Conclusion $E_4 > E_3 > E_2 > E_1$. Hence, the correct option is (C).

Quick Tip to Solve: For equal plate separations, rank the absolute voltage differences directly; there is no need to calculate all four field values.

29(iv)(b). An electron is projected from the right plate of set I directly towards its left plate. It just comes to rest at the plate. The speed with which it was projected is about: (Take $e/m = 1.76 \times 10^{11} \text{ C/kg}$) [1 mark]

- (A) $1.3 \times 10^5 \text{ m/s}$
 (B) $2.6 \times 10^6 \text{ m/s}$
 (C) $6.5 \times 10^5 \text{ m/s}$
 (D) $5.2 \times 10^7 \text{ m/s}$

Correct Answer: (B) $2.6 \times 10^6 \text{ m/s}$

Solution:

Concept:

- Electrostatic energy is conserved: $K_i + qV_i = K_f + qV_f$, where K is kinetic energy and q is the charge.
- An electron has charge $-e$; moving to a lower potential increases its potential energy and can bring it to rest.

Step 1: Find the gain in the electron's potential energy The electron starts at the right plate of pair I, at $V_i = -50 \text{ V}$, and stops at the left plate, at $V_f = -70 \text{ V}$. Hence

$$\Delta U = (-e)[-70 - (-50)] = 20e \text{ V}.$$

Its initial kinetic energy must equal this positive increase because its final kinetic energy is zero.

Step 2: Calculate the required initial speed Using $e/m = 1.76 \times 10^{11} \text{ C kg}^{-1}$,

$$\begin{aligned} \frac{1}{2}mv^2 &= e(20 \text{ V}), \\ v &= \sqrt{2(1.76 \times 10^{11})(20)} \\ &= \sqrt{7.04 \times 10^{12}} = 2.65 \times 10^6 \text{ m s}^{-1}. \end{aligned}$$

The closest stated value is $2.6 \times 10^6 \text{ m s}^{-1}$. The speeds in (A) and (C) supply insufficient kinetic energy to reach the left plate, while (D) would leave substantial kinetic energy there.

Step 3: Conclusion The required projection speed is about $2.6 \times 10^6 \text{ m s}^{-1}$. Hence, the correct option is (B).

Quick Tip to Solve: For an electron stopped by a retarding potential difference, use $v = \sqrt{2(e/m)|\Delta V|}$; calculate the voltage difference before substituting.

30. Diffraction and interference are closely related phenomena that occur together. Diffraction is the phenomenon of bending of light around the edges of the obstacle, while interference is the combination of waves that results in a new wave pattern. In order to get interference, there must be at least two waves that are diffracting. So while diffraction can occur without interference, interference cannot occur without diffraction.

Two slits of width $2\ \mu\text{m}$ each in an opaque material are separated by a distance of $6\ \mu\text{m}$. Monochromatic light of wavelength $450\ \text{nm}$ is incident normally on the slits. One finds a combined interference and diffraction pattern on the screen. [4 marks]

30(i). The number of peaks of the interference fringes formed within the central peak of the envelope of the diffraction pattern will be: [1 mark]

- (A) 2
- (B) 3
- (C) 4
- (D) 6

Correct Answer: No exact option: five bright peaks; (D), six, is the conventional envelope-width/fringe-spacing estimate.

Solution:

Concept:

- For slit width a , the central diffraction envelope lies between $a \sin \theta = \pm \lambda$.
- Interference maxima satisfy $d \sin \theta = m\lambda$, where d is slit separation and m is an integer. A maximum coinciding with a diffraction minimum is missing.

Step 1: Find the allowed interference orders Taking the stated separation as $d = 6\ \mu\text{m}$ and the slit width as $a = 2\ \mu\text{m}$, a bright peak inside the central envelope must satisfy

$$|m| < \frac{d}{a} = 3.$$

Thus the surviving orders are $m = -2, -1, 0, 1, 2$. The orders $m = \pm 3$ fall exactly at the first diffraction minima and have zero intensity.

Step 2: Distinguish width ratio from peak count The usual envelope-width to fringe-spacing calculation gives

$$\frac{2\lambda D/a}{\lambda D/d} = \frac{2d}{a} = 6.$$

This is the number of fringe spacings across the envelope, which suggests the intended option (D); it is not the number of surviving bright peaks. The printed alternatives 2, 3, 4 and 6 all omit the exact count 5. Counting the extinguished boundary orders would also be incorrect.

Step 3: Conclusion There are 5 nonzero bright peaks within the central diffraction envelope, so no printed option is exactly correct. Option (D), 6, follows only the conventional width-ratio estimate.

Quick Tip to Solve: When d/a is an integer, exclude the two boundary orders: they coincide with diffraction minima.

30(ii). The number of peaks of the interference formed if the slit width is doubled while keeping the distance between the slits same will be: [1 mark]

- (A) 1
- (B) 2
- (C) 3
- (D) 4

Correct Answer: (C) 3

Solution:

Concept:

- The first diffraction minima satisfy $a \sin \theta = \pm \lambda$, where a is the width of either slit.
- Interference maxima satisfy $d \sin \theta = m\lambda$; thus orders inside the central envelope obey $|m| < d/a$, with d the slit separation.

Step 1: Double the slit width The new width is $a' = 2 \times 2 = 4 \mu\text{m}$, while the separation remains $d = 6 \mu\text{m}$. The diffraction envelope becomes narrower, whereas the interference fringe spacing is unchanged because neither wavelength nor slit separation changes.

Step 2: Count the permitted integer orders Inside the new central envelope,

$$|m| < \frac{d}{a'} = \frac{6}{4} = 1.5.$$

The possible orders are $-1, 0, +1$, giving three peaks including the central one. One peak ignores both side peaks, two omits the central peak, and four would require a further order outside the central envelope. Here the width-ratio estimate $2d/a' = 3$ also agrees with the discrete peak count.

Step 3: Conclusion The central diffraction envelope contains 3 interference peaks. Hence, the correct option is (C).

Quick Tip to Solve: After changing slit width, count the integers satisfying $|m| < d/a$, including the central order $m = 0$.

30(iii)(a). If instead of 450 nm light, another light of wavelength 680 nm is used, number of peaks of the interference formed in the central peak of the envelope of the diffraction pattern will be: [1 mark]

- (A) 2
- (B) 4
- (C) 6
- (D) 9

Correct Answer: No exact option: five bright peaks remain; (C), six, is the wavelength-independent width-ratio estimate.

Solution:

Concept:

- The diffraction envelope has first minima at $a \sin \theta = \pm \lambda$, and interference orders obey $d \sin \theta = m\lambda$.
- Eliminating wavelength gives $|m| < d/a$ for bright orders inside the central envelope. Thus their number depends on slit geometry, not wavelength.

Step 1: Apply the changed wavelength Each sub-question uses the original case-study geometry:

$a = 2 \mu\text{m}$ and $d = 6 \mu\text{m}$. Changing the wavelength from 450 nm to 680 nm broadens both diffraction and interference angular scales by the same factor. It does not change the order bound

$$|m| < \frac{d}{a} = 3.$$

Step 2: Compare the exact count with the options Orders $-2, -1, 0, +1, +2$ survive inside the central envelope. The orders ± 3 coincide with diffraction minima and are absent. The frequently used ratio of central-envelope width to fringe spacing is $2d/a = 6$, unchanged by wavelength, suggesting intended option (C). However, that ratio counts spacings, not the five nonzero peaks. None of the printed values 2, 4, 6 or 9 equals the exact peak count; scaling the count by the wavelength ratio is also unjustified.

Step 3: Conclusion The actual number of bright peaks remains 5, which is absent from the options. Option (C), 6, is the conventional width-ratio estimate and is also wavelength independent.

Quick Tip to Solve: Cancel wavelength before counting orders; changing wavelength expands the envelope and the fringe spacing together.

OR

30(iii)(b). Consider the diffraction of light by a single slit described in this case study. The first minimum falls at an angle θ equal to: [1 mark]

- (A) $\sin^{-1}(0.12)$
- (B) $\sin^{-1}(0.225)$
- (C) $\sin^{-1}(0.32)$
- (D) $\sin^{-1}(0.45)$

Correct Answer: (B) $\sin^{-1}(0.225)$

Solution:

Concept:

- For a single slit of width a , diffraction minima satisfy $a \sin \theta = n\lambda$, with nonzero integer order n .
- The first minimum has $n = 1$, so $\sin \theta = \lambda/a$; θ is measured from the central axis.

Step 1: Use the original case-study values This alternative refers to the original single slit of width $a = 2 \mu\text{m} = 2 \times 10^{-6} \text{ m}$, illuminated with $\lambda = 450 \text{ nm} = 450 \times 10^{-9} \text{ m}$. The wavelength specified in the other alternative does not replace the wavelength in this question.

Step 2: Apply the first-minimum condition Substitute consistent SI units:

$$\sin \theta = \frac{450 \times 10^{-9}}{2 \times 10^{-6}} = 0.225.$$

Therefore the angle is obtained by taking the inverse sine. The slit separation $6 \mu\text{m}$ controls interference and must not be substituted for the slit width. The other proposed sine values, 0.12, 0.32 and

0.45, do not equal λ/a ; 0.45 would correspond to the second diffraction minimum.

Step 3: Conclusion The first minimum is at $\theta = \sin^{-1}(0.225)$. Hence, the correct option is (B).

Quick Tip to Solve: For single-slit minima use the slit width, not the separation between the two slits, and convert nm and micrometres consistently.

30(iv). The number of bright fringes formed due to interference on 1 m of screen placed at $\frac{4}{3}$ m away from the slits is: [1 mark]

- (A) 2
- (B) 3
- (C) 6
- (D) 10

Correct Answer: (D) 10

Solution:

Concept:

- In the usual Young's double-slit approximation, interference fringe spacing is $\beta = \lambda D/d$, where D is screen distance and d is slit separation.
- The standard fringe-count estimate over a screen length L is $N = L/\beta$. This calculation uses the interference spacing without weighting brightness by the diffraction envelope.

Step 1: Substitute the printed screen distance The official paper gives $D = \frac{4}{3}$ m. Use the original wavelength $\lambda = 450 \times 10^{-9}$ m and separation $d = 6 \times 10^{-6}$ m. The resulting interference spacing is

$$\beta = \frac{(450 \times 10^{-9})(4/3)}{6 \times 10^{-6}} = 0.10 \text{ m.}$$

Step 2: Estimate the number across the screen length For the stated screen length $L = 1$ m, the standard interference-fringe calculation gives

$$N = \frac{L}{\beta} = \frac{1}{0.10} = 10.$$

Values 2, 3 and 6 do not match this spacing calculation. In particular, the central diffraction-envelope width is not the screen length asked for here. This estimate treats fringes by their spacing; an exact count of visible peaks would additionally require the screen position, endpoint convention and allowance for missing orders caused by diffraction.

Step 3: Conclusion The intended interference-spacing estimate is 10 bright fringes across 1 m of screen. Hence, the correct option is (D).

Quick Tip to Solve: First compute β in metres, then divide the specified screen length by it; here each fringe spacing is 0.10 m.

Section E (15 marks)

31(a). (i) Obtain the expression for the capacitance of a parallel plate capacitor with a dielectric medium between its plates.

(ii) A charge of $6 \mu\text{C}$ is given to a hollow metallic sphere of radius 0.2 m . Find the potential at (i) the surface and (ii) the centre of the sphere. [5 marks]

Solution:

Concept:

- Capacitance is $C = Q/V$, where Q is the magnitude of charge on either plate and V is the potential difference between the plates.
- A dielectric of relative permittivity K has permittivity $\varepsilon = K\varepsilon_0$. Polarisation reduces the field produced by a fixed free charge.
- A conductor in electrostatic equilibrium is equipotential. For an isolated charged spherical conductor of radius R , its surface potential relative to infinity is $V(R) = Q/(4\pi\varepsilon_0 R)$.

Step 1: (i) Set up the parallel plate capacitor Consider two large parallel conducting plates, each of area A , separated by a small distance d . Their charges are $+Q$ and $-Q$, so the magnitude of free surface charge density on either facing surface is $\sigma = Q/A$. Assume that a homogeneous dielectric of relative permittivity K completely fills the space between the plates, and neglect fringing at the edges.

Step 2: Find the electric field and potential difference The fields of the two oppositely charged plates add between them. In vacuum their resultant field is $E_0 = \sigma/\varepsilon_0$. The dielectric polarises, producing an opposing field; the resultant uniform field for the same free charge is

$$E = \frac{E_0}{K} = \frac{\sigma}{K\varepsilon_0} = \frac{Q}{K\varepsilon_0 A}.$$

The magnitude of the potential difference follows by integrating the uniform field across the separation:

$$V = Ed = \frac{Qd}{K\varepsilon_0 A}.$$

Step 3: Obtain the capacitance Substitute this potential difference into the definition of capacitance:

$$C = \frac{Q}{V} = \frac{Q}{Qd/(K\varepsilon_0 A)} = \frac{K\varepsilon_0 A}{d}.$$

Thus the dielectric increases the capacitance by a factor K compared with the vacuum value $C_0 = \varepsilon_0 A/d$. The result depends on the geometry and permittivity, rather than the particular charge used in the derivation.

Step 4: (ii) Calculate the potential at the surface The given charge and radius are $Q = 6 \times 10^{-6} \text{ C}$ and $R = 0.2 \text{ m}$. With zero potential at infinity, the exterior field is that of a point charge at the centre, giving

$$\begin{aligned} V(R) &= \frac{1}{4\pi\varepsilon_0} \frac{Q}{R} \\ &= \frac{(9 \times 10^9)(6 \times 10^{-6})}{0.2} \\ &= 2.7 \times 10^5 \text{ V}. \end{aligned}$$

The potential is positive because the charge supplied to the sphere is positive.

Step 5: Determine the potential at the centre No charge is present in the hollow cavity. The electric field is zero throughout the interior, so there is no potential change from the surface to the centre:

$$V(0) - V(R) = - \int_R^0 \vec{E} \cdot d\vec{r} = 0.$$

Hence the centre has the same potential as the surface. Zero electric field means constant potential; it does not require that constant to be zero.

Step 6: Conclusion (i) The capacitance is $C = K\epsilon_0 A/d$ when the dielectric completely fills the gap.
(ii) Both the surface and the centre are at $+2.7 \times 10^5 \text{ V}$ relative to infinity.

Quick Tip to Solve: Use the outer radius in the potential formula for every point inside a charged hollow conductor; never substitute the centre's radial coordinate into kQ/r .

OR

31(b). (i) A charge $+Q$ is placed on a thin conducting spherical shell of radius R . Use Gauss's theorem to derive an expression for the electric field at a point lying (i) inside and (ii) outside the shell.
(ii) Show that the electric field for same charge density (σ) is twice in case of a conducting plate or surface than in a nonconducting sheet. [5 marks]

Solution:

Concept:

- Gauss's theorem states $\oint \vec{E} \cdot d\vec{A} = Q_{\text{enc}}/\epsilon_0$, where Q_{enc} is the net charge enclosed by the closed Gaussian surface.
- Spherical symmetry makes the electric field radial and its magnitude constant on a concentric sphere. The field inside a conductor in electrostatic equilibrium is zero.
- A large uniformly charged nonconducting sheet has equal outward fields on its two sides. Just outside a conducting surface the field is normal to it, while the field just inside the conductor vanishes.

Step 1: (i) Choose a Gaussian surface for the shell Let r be the distance of the observation point from the centre of the isolated thin conducting spherical shell. The positive charge Q spreads uniformly over its surface by spherical symmetry. Choose a concentric Gaussian sphere of radius r . The field is radial, parallel to the outward area vector, and has the same magnitude $E(r)$ at every point on that sphere. Therefore,

$$\oint \vec{E} \cdot d\vec{A} = E(r) 4\pi r^2.$$

Step 2: Derive the field inside the shell For $r < R$, all the charge lies outside the Gaussian sphere, so $Q_{\text{enc}} = 0$. Gauss's theorem, together with spherical symmetry, gives

$$E(r) 4\pi r^2 = 0 \implies E(r) = 0.$$

Thus the field vanishes everywhere in the empty interior, including the centre. Zero enclosed charge alone would imply only zero net flux; spherical symmetry is what allows the local field to be deduced here.

Step 3: Derive the field outside the shell For $r > R$, the Gaussian sphere encloses the full charge $+Q$.

Hence

$$E(r) 4\pi r^2 = \frac{Q}{\epsilon_0}, \quad \vec{E}(r) = \frac{Q}{4\pi\epsilon_0 r^2} \hat{r}.$$

The field is directed radially outward and is identical to that of a point charge $+Q$ placed at the centre. Just outside the surface, its magnitude is $Q/(4\pi\epsilon_0 R^2)$; just inside it is zero.

Step 4: (ii) Apply Gauss's theorem at a conducting surface Take a small cylindrical pillbox of face area a , with one face just outside the conductor and the other just inside. Here σ denotes the charge per unit area on the particular conducting surface crossed by the pillbox. The enclosed charge is σa . The inner face contributes no flux because the interior field vanishes; the curved side contributes none in the thin-pillbox limit. For positive σ ,

$$E_{\text{conductor}} a = \frac{\sigma a}{\epsilon_0} \implies E_{\text{conductor}} = \frac{\sigma}{\epsilon_0}.$$

The field is normal to and outward from the positively charged surface.

Step 5: Compare with a nonconducting sheet Consider an effectively infinite, uniformly charged non-conducting sheet carrying the same surface charge density σ , with vacuum on both sides. Symmetry gives equal field magnitudes on the two sides, directed away from the positively charged sheet. A pillbox straddling the sheet now has flux through both plane faces:

$$2E_{\text{sheet}} a = \frac{\sigma a}{\epsilon_0} \implies E_{\text{sheet}} = \frac{\sigma}{2\epsilon_0}.$$

Therefore $E_{\text{conductor}}/E_{\text{sheet}} = 2$. The comparison uses charge density on one conducting surface; it must not be confused with total charge per projected area shared between both faces of an isolated conducting plate.

Step 6: Conclusion (i) $\vec{E} = 0$ ($r < R$), while $\vec{E} = Q\hat{r}/(4\pi\epsilon_0 r^2)$ ($r > R$). (ii) At equal surface charge density, $E_{\text{conductor}} = 2E_{\text{sheet}}$, since their field magnitudes are $|\sigma|/\epsilon_0$ and $|\sigma|/(2\epsilon_0)$, respectively.

Quick Tip to Solve: Count the pillbox faces that carry flux: only the outer face contributes for a conductor, whereas both faces contribute for a symmetric nonconducting sheet.

32(a). (i) (1) What is meant by current sensitivity of a galvanometer? Mention the factors on which it depends.

(2) A galvanometer of resistance G is converted into a voltmeter of range $(0 - V)$ by using a resistance R . Find the resistance, in terms of R and G , required to convert it into a voltmeter of range $\left(0 - \frac{V}{2}\right)$.

(ii) The magnetic flux through a coil of resistance 5Ω increases with time as: $\phi = (2.0t^3 + 5.0t^2 + 6.0t)$ mWb. Find the magnitude of induced current through the coil at $t = 2$ s. [5 marks]

Solution:

Concept:

- In a moving-coil galvanometer with a radial magnetic field, the magnetic torque is $NIAB$. At equilibrium it balances the restoring torque $k\theta$, where k is the torsional constant of the suspension.
- A galvanometer of resistance G and full-scale current I_g becomes a voltmeter by adding a series resistance. Its range is the full-scale current multiplied by the total resistance.
- Faraday's law gives the induced emf as $\varepsilon = -d\phi/dt$; the current magnitude in a resistive coil is

$|\varepsilon|/R_c$, where R_c denotes the coil resistance.

Step 1: (i)(1) Define and obtain current sensitivity Current sensitivity is the angular deflection produced per unit current through the galvanometer. If the coil has N turns, area A , and lies in a radial field of magnitude B , equilibrium gives

$$NIAB = k\theta \Rightarrow S_I = \frac{\theta}{I} = \frac{NAB}{k}.$$

Its SI unit is rad A^{-1} . Thus sensitivity increases with the number of turns, coil area and magnetic field strength, and decreases with the torsional constant. A suspension with a smaller restoring torque per unit twist therefore produces a larger deflection for the same current.

Step 2: (i)(2) Relate both ranges to the same full-scale current Let R' be the new external series resistance. The galvanometer itself is unchanged, so both ranges correspond to the same full-scale current I_g :

$$V = I_g(G + R), \quad \frac{V}{2} = I_g(G + R').$$

Dividing these equations eliminates I_g . The total resistance must halve, so

$$G + R' = \frac{G + R}{2} \Rightarrow R' = \frac{R - G}{2}.$$

This is the required series resistance, not simply $R/2$, because the internal resistance G also contributes to the original range. A non-negative external series resistance requires $R \geq G$; if $R = G$, no extra series resistance is needed.

Step 3: (ii) Differentiate the flux and calculate the current Convert the given flux from milliweber to weber before calculating the emf:

$$\phi = (2.0t^3 + 5.0t^2 + 6.0t) \times 10^{-3} \text{ Wb}.$$

Differentiating with respect to time gives

$$|\varepsilon| = (6.0t^2 + 10.0t + 6.0) \times 10^{-3} \text{ V}.$$

At $t = 2 \text{ s}$, this becomes

$$|\varepsilon| = (24 + 20 + 6) \times 10^{-3} = 50 \times 10^{-3} \text{ V}.$$

Hence, for $R_c = 5 \Omega$, Ohm's law gives

$$|I| = \frac{50 \times 10^{-3}}{5} = 1.0 \times 10^{-2} \text{ A}.$$

The negative sign in Faraday's law specifies opposition to the flux increase; only the magnitude is requested here.

Step 4: Conclusion (i)(1) $S_I = \theta/I = NAB/k$: it increases with N , A , B and decreases with k . (i)(2) The new series resistance is $R' = (R - G)/2$. (ii) The induced current magnitude is 10 mA .

Quick Tip to Solve: When changing a voltmeter range, scale the total resistance $G + R$, then subtract G . For the flux polynomial, differentiate first and retain the 10^{-3} conversion from mWb to Wb.

32(b). (i) A rectangular coil of N turns and area of cross-section A is rotated at a steady angular speed ω in a uniform magnetic field. Obtain an expression for the emf induced in the coil at any instant of time.

(ii) Two coplanar and concentric circular loops L_1 and L_2 are placed coaxially with their centres coinciding. The radii of L_1 and L_2 are 1 cm and 100 cm respectively. Calculate the mutual inductance of the loops. (Take $\pi^2 = 10$) [5 marks]

Solution:

Concept:

- The magnetic flux through one plane turn is $\phi = BA \cos \theta$, where θ is the angle between the magnetic field and the area normal. For N turns, Faraday's law is $\varepsilon = -d(N\phi)/dt$.
- Mutual inductance is the flux linkage in one circuit per unit current in the other: $M = \Phi_{12}/I_2$ for a single receiving turn. It is reciprocal, so $M_{12} = M_{21}$.
- At the centre of a circular loop of radius r_2 carrying current I_2 , the magnetic field is $B_2 = \mu_0 I_2 / (2r_2)$. It is approximately uniform over a much smaller concentric loop.

Step 1: (i) Express the rotating coil's flux linkage Let the coil rotate about an axis in its plane perpendicular to the uniform field $\vec{B}$, as in an AC generator. Choose $t = 0$ when the area normal is parallel to the field. At constant angular speed ω , the angle between the normal and the field is $\theta = \omega t$. The flux through each turn, and hence the flux linkage of all N turns, are

$$\phi(t) = BA \cos \omega t, \quad N\phi(t) = NBA \cos \omega t.$$

The factor $\cos \omega t$ accounts for the changing area projected perpendicular to the field even though B and the actual coil area remain constant.

Step 2: (i) Apply Faraday's law Differentiating the flux linkage gives

$$\begin{aligned} \varepsilon(t) &= -\frac{d}{dt}(NBA \cos \omega t) \\ &= NBA\omega \sin \omega t = \varepsilon_0 \sin \omega t, \end{aligned}$$

where $\varepsilon_0 = NBA\omega$ is the peak emf. It vanishes when the flux is maximum or minimum and reaches its greatest magnitude when the flux is zero and changing fastest. Its sign reverses every half-revolution. If the initial normal makes angle θ_0 with the field, the same derivation gives $\varepsilon = NBA\omega \sin(\omega t + \theta_0)$; thus the choice of time origin only changes the phase.

Step 3: (ii) Calculate the flux through the smaller loop Put a current I_2 in the larger loop L_2 . Convert the radii to SI units:

$$r_1 = 1 \text{ cm} = 10^{-2} \text{ m}, \quad r_2 = 100 \text{ cm} = 1 \text{ m}.$$

Since $r_1/r_2 = 0.01$, the field of L_2 is nearly uniform over the small loop L_1 and perpendicular to its plane. Its flux linkage is therefore approximately

$$\Phi_{12} = B_2 \pi r_1^2 = \frac{\mu_0 I_2 \pi r_1^2}{2r_2}.$$

Only one turn is present in each loop; no additional turn factor is needed.

Step 4: (ii) Obtain the mutual inductance Divide the flux linkage by the current producing it, then

use $\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$:

$$\begin{aligned} M &= \frac{\Phi_{12}}{I_2} = \frac{\mu_0 \pi r_1^2}{2r_2} \\ &= \frac{4\pi \times 10^{-7} \times \pi \times (10^{-2})^2}{2 \times 1} \text{ H} \\ &= 2\pi^2 \times 10^{-11} \text{ H}. \end{aligned}$$

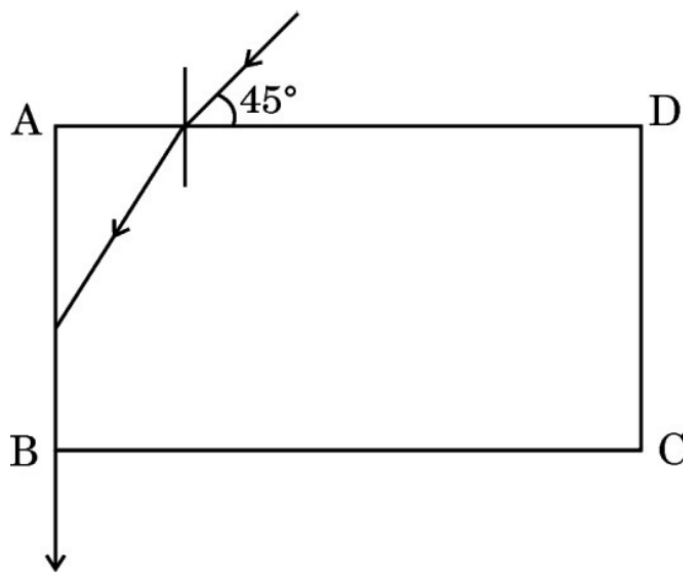
With the prescribed $\pi^2 = 10$, this gives $M \approx 2.0 \times 10^{-10} \text{ H}$. By reciprocity, the same mutual inductance describes flux in the larger loop produced by current in the smaller one.

Step 5: Conclusion (i) The induced emf is $\varepsilon(t) = NBA\omega \sin \omega t$, with the normal initially parallel to the field and peak value $NBA\omega$. (ii) The mutual inductance is $M \approx 2.0 \times 10^{-10} \text{ H}$, using the nearly uniform field over the small loop.

Quick Tip to Solve: For concentric loops with very different radii, put the imaginary source current in the larger loop and calculate flux through the smaller loop. Use its area πr_1^2 , but the larger radius in the field denominator.

33(a). (i) Trace the path of a ray of light showing refraction through a triangular prism and hence obtain an expression for angle of deviation (δ) in terms of A , i and e , where symbols have their usual meanings. Draw a graph showing the variation of angle of deviation with the angle of incidence.

(ii) In the figure, a ray of light is incident on a transparent liquid contained in a thin glass box at an angle of 45° with its one face. The emergent ray passes along the face AB . Find the refractive index of the liquid. [5 marks]



Solution:

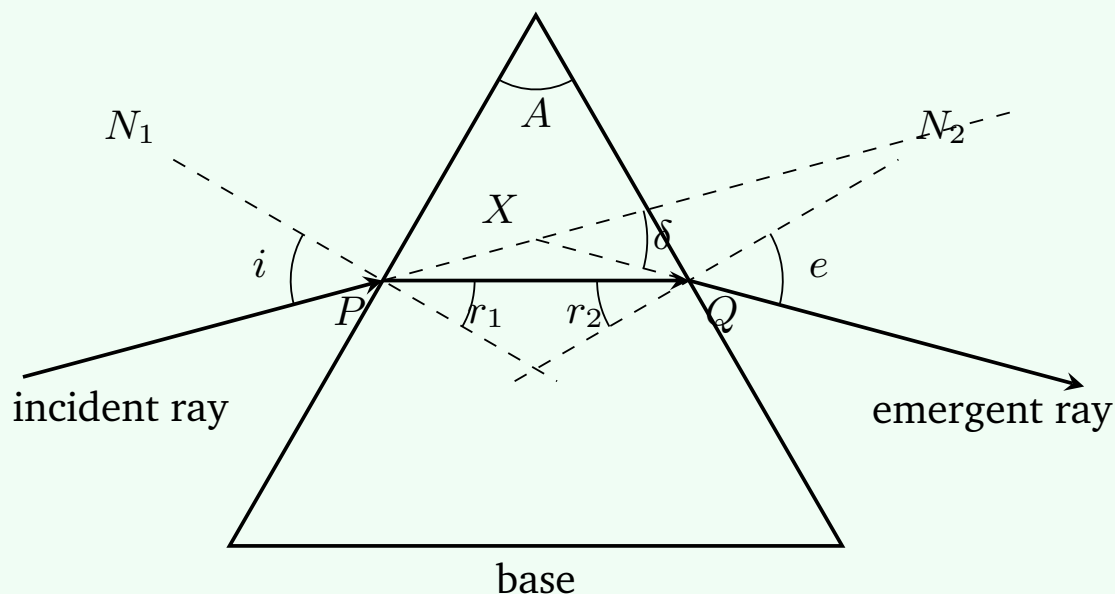
Concept:

- For a prism, the internal refraction angles satisfy $r_1 + r_2 = A$, where A is the prism angle. Incidence i , emergence e and refraction angles are measured from the corresponding normals.
- Snell's law at an air-liquid boundary is $\sin i = \mu \sin r$, where μ is the liquid's refractive index relative to air.
- At the critical angle c , light emerging from liquid into air grazes the surface: $\mu \sin c = 1$.

Step 1: (i) Trace refraction through the prism Let the incident ray enter the first refracting face at P , travel inside the prism along PQ , and emerge from the second face at Q . Draw normals to both faces. At P , the ray bends towards the normal, making internal angle r_1 ; at Q , it bends away from the normal, making emergence angle e . The deviation is towards the base of the prism. The normals to the faces enclose a supplementary angle $180^\circ - A$. Applying the angle sum to the triangle formed by the two normals and PQ gives

$$r_1 + r_2 + (180^\circ - A) = 180^\circ, \quad r_1 + r_2 = A.$$

In the ray sketch, the dashed continuations of the incident and emergent directions meet at X ; their angle is the total deviation δ .



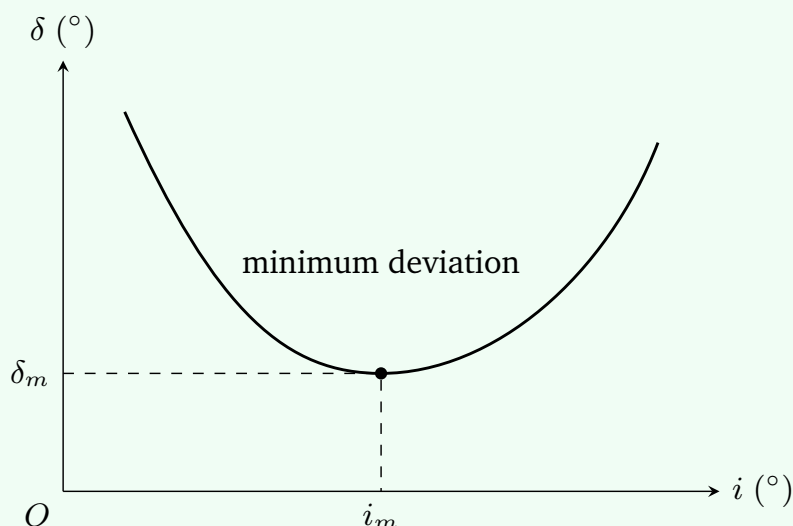
Refraction through a triangular prism; dashed lines are normals or ray continuations.

Step 2: Add the deviations at the two faces At the first face the change of direction is $i - r_1$, and at the second face it is $e - r_2$. Both bend the ray towards the prism's base, so they add:

$$\begin{aligned} \delta &= (i - r_1) + (e - r_2) \\ &= i + e - (r_1 + r_2) \\ &= i + e - A. \end{aligned}$$

This relation applies to a ray transmitted through the two refracting faces; it does not require the minimum-deviation condition.

Step 3: Sketch deviation versus incidence As i increases over the range for which a ray emerges, δ first decreases, reaches a minimum δ_m , and then increases. At minimum deviation the path is symmetric: $i = e = i_m$ and $r_1 = r_2 = A/2$. Therefore $\delta_m = 2i_m - A$. The graph below is schematic; its turning point represents the minimum, not zero deviation.



Schematic variation of deviation with incidence for a prism.

Step 4: (ii) Relate the angles inside the liquid The incident ray makes 45° with the top face AD . Hence its angle with that face's normal is also $i = 90^\circ - 45^\circ = 45^\circ$. Let the angle of refraction in the liquid, measured from the vertical normal to AD , be r . The normals to adjacent faces AD and AB are perpendicular. Thus the angle of incidence at AB is $90^\circ - r$. Since the emerging ray runs along AB , this latter incidence angle equals the critical angle:

$$c = 90^\circ - r.$$

The thin, parallel glass walls introduce no net change to the air–liquid angular relation, so Snell's law may be applied between air and liquid.

Step 5: Apply Snell's law and eliminate the internal angle At the entry face,

$$\mu \sin r = \sin 45^\circ = \frac{1}{\sqrt{2}}.$$

At the exit face, the angle in air is 90° ; therefore

$$\mu \sin c = 1, \quad \mu \cos r = 1.$$

Squaring these two relations and adding eliminates r :

$$\begin{aligned} \mu^2(\sin^2 r + \cos^2 r) &= \frac{1}{2} + 1, \\ \mu^2 &= \frac{3}{2}. \end{aligned}$$

As a consistency check, division gives $\tan r = 1/\sqrt{2}$, so $r \approx 35.3^\circ$ and $c \approx 54.7^\circ$; the entry ray bends towards the normal as expected.

Step 6: Conclusion (i) The prism deviation is $\delta = i + e - A$, with a minimum δ_m at $i = e$. (ii) The liquid has refractive index $\mu = \sqrt{3/2} \approx 1.225$, a dimensionless quantity.

Quick Tip to Solve: For entry and grazing exit through perpendicular faces, the internal angles are complementary. Square and add $\mu \sin r = \sin i$ and $\mu \cos r = 1$ to obtain $\mu^2 = 1 + \sin^2 i$.

33(b). (i) The displacement of two light waves, each of amplitude ' a ' and frequency ω , emanating from two coherent sources of light, are given by $y_1 = a \cos \omega t$ and $y_2 = a \cos(\omega t + \phi)$. ϕ is the phase difference between the two waves. These light waves superpose at a point. Obtain the expression for the resultant intensity at that point.

(ii) In Young's double slit experiment, find the ratio of intensities at two points on a screen when waves emanating from two slits reaching these points have path differences (i) $\frac{\lambda}{6}$ and (ii) $\frac{\lambda}{12}$. [5 marks]

Solution:

Concept:

- Superposition adds the instantaneous displacements: $y = y_1 + y_2$. Coherent sources have a fixed phase difference ϕ , so their interference pattern is stable.
- In the same medium, intensity is proportional to the square of amplitude. Write $I_0 = K a^2$ for the intensity from either wave alone, where K is the common proportionality constant.
- A path difference Δ produces phase difference $\phi = 2\pi\Delta/\lambda$, where λ is the wavelength. Equal-amplitude waves give $I = 4I_0 \cos^2(\phi/2)$.

Step 1: (i) Add the two displacements At the observation point, apply the principle of superposition to the two given waves. Use the identity $\cos A + \cos B = 2 \cos[(A+B)/2] \cos[(A-B)/2]$:

$$\begin{aligned} y &= a \cos \omega t + a \cos(\omega t + \phi) \\ &= 2a \cos\left(\frac{\phi}{2}\right) \cos\left(\omega t + \frac{\phi}{2}\right). \end{aligned}$$

The resultant remains harmonic with the same angular frequency. Its amplitude magnitude is $A = 2a |\cos(\phi/2)|$; the absolute value ensures a non-negative amplitude and does not affect its square.

Step 2: (i) Relate the resultant amplitude to intensity Squaring the resultant amplitude and using $I_0 = K a^2$ gives

$$\begin{aligned} I &= K A^2 = 4K a^2 \cos^2\left(\frac{\phi}{2}\right) \\ &= 4I_0 \cos^2\left(\frac{\phi}{2}\right) = 2I_0(1 + \cos \phi). \end{aligned}$$

Thus the total intensity includes the interference term $2I_0 \cos \phi$ in addition to the sum $2I_0$ of the individual intensities. As checks, in-phase waves give $4I_0$, while waves with phase difference π cancel and give zero intensity.

Step 3: (ii) Evaluate the intensity at each path difference In the usual equal-slit Young's experiment, take the individual slit intensities to be equal. Denote the resultant intensities at the two specified points by I_P and I_Q . For $\Delta_P = \lambda/6$,

$$\phi_P = \frac{2\pi \lambda}{\lambda} \frac{\lambda}{6} = \frac{\pi}{3}, \quad I_P = 2I_0 \left(1 + \frac{1}{2}\right) = 3I_0.$$

For the printed second path difference $\Delta_Q = \lambda/12$,

$$\phi_Q = \frac{2\pi \lambda}{\lambda} \frac{\lambda}{12} = \frac{\pi}{6}, \quad I_Q = 2I_0 \left(1 + \frac{\sqrt{3}}{2}\right) = (2 + \sqrt{3})I_0.$$

The second point lies closer in phase to the central bright fringe and therefore has the larger intensity, consistent with these expressions.

Step 4: (ii) Form the ratio in the stated order Divide the intensity for path difference $\lambda/6$ by that for $\lambda/12$. The common single-slit intensity cancels:

$$\frac{I_P}{I_Q} = \frac{3I_0}{(2 + \sqrt{3})I_0} = \frac{3}{2 + \sqrt{3}} = 3(2 - \sqrt{3}).$$

This ratio is dimensionless, as required for a comparison of two intensities.

Step 5: Conclusion (i) The resultant intensity is $I = 4I_0 \cos^2(\phi/2) = 2I_0(1 + \cos \phi)$, where I_0 is the intensity of either wave alone. (ii) In the order asked, $I(\lambda/6) : I(\lambda/12) = 3 : (2 + \sqrt{3})$.

Quick Tip to Solve: Convert each path difference to phase with $2\pi\Delta/\lambda$, then use $2I_0(1 + \cos \phi)$; it avoids evaluating $\cos^2 15^\circ$ for $\lambda/12$.