

CBSE Class 12 Physics Question Paper 2023 with Solution PDF-Set 55/2/3

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 **35** questions. **All** questions are compulsory.
- (ii) Question paper is divided into **FIVE** sections – Section **A, B, C, D** and **E**.
- (iii) In **Section A** : Question number **1** to **18** are Multiple Choice (MCQ) type questions carrying **1** mark each.
- (iv) In **Section B** : Question number **19** to **25** are Short Answer-1 (SA-1) type questions carrying **2** marks each.
- (v) In **Section C** : Question number **26** to **30** are Short Answer-2 (SA-2) type questions carrying **3** marks each.
- (vi) In **Section D** : Question number **31** to **33** are Long Answer (LA) type questions carrying **5** marks each.
- (vii) In **Section E** : Question number **34** and **35** are Case-Based questions carrying **4** marks each.
- (viii) There is no overall choice. However, an internal choice has been provided in **2** questions in Section–**B**, **2** questions in Section–**C**, **3** questions in Section–**D** and **2** questions in Section–**E**.
- (ix) Use of calculators is NOT allowed.

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

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

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

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

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

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

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

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

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

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

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

Section A (18 marks)

1. A long straight wire of radius ' a ' carries a steady current ' I '. The current is uniformly distributed across its area of cross-section. The ratio of magnitude of magnetic field $\vec{B}_1$ at $\frac{a}{2}$ and $\vec{B}_2$ at distance $2a$ is [1 mark]

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

Correct Answer: (B) 1

Solution:

Concept:

- Ampere's law gives $B(2\pi r) = \mu_0 I_{\text{enc}}$, where r is distance from the wire axis and I_{enc} is enclosed current.
- For uniform current density, $I_{\text{enc}} = Ir^2/a^2$ inside the wire; outside, the whole current I is enclosed.

Step 1: Evaluate the interior field At $r = a/2$, only one quarter of the current is enclosed. Therefore,

$$B_1 = \frac{\mu_0 I(a/2)}{2\pi a^2} = \frac{\mu_0 I}{4\pi a}.$$

Step 2: Evaluate the exterior field and compare At $r = 2a$, the field follows the inverse-distance law:

$$B_2 = \frac{\mu_0 I}{2\pi(2a)} = \frac{\mu_0 I}{4\pi a}.$$

Using the exterior formula at both points would wrongly give 4. The options $1/2$ and 2 also fail because the two calculated fields are equal.

Step 3: Conclusion $B_1/B_2 = 1$. Hence, the correct option is (B).

Quick Tip to Solve: First decide whether each observation point is inside or outside the wire; use $B \propto r$ inside and $B \propto 1/r$ outside.

2. The energy of a photon of wavelength 663 nm is [1 mark]

- (A) 6.64×10^{-20} J
(B) 5.18×10^{-19} J
(C) 3.0×10^{-19} J
(D) 2.0×10^{-20} J

Correct Answer: (C) 3.0×10^{-19} J

Solution:

Concept:

- The energy of a photon is $E = h\nu = hc/\lambda$, where h is Planck's constant, c is the speed of light and λ is wavelength.
- Use $h = 6.63 \times 10^{-34}$ J s, $c = 3.0 \times 10^8$ m s $^{-1}$, and convert nanometres into metres.

Step 1: Convert the wavelength The given wavelength must be in SI units before substitution:

$$\lambda = 663 \text{ nm} = 663 \times 10^{-9} \text{ m} = 6.63 \times 10^{-7} \text{ m}.$$

Step 2: Substitute in the photon-energy relation

$$E = \frac{(6.63 \times 10^{-34})(3.0 \times 10^8)}{6.63 \times 10^{-7}} = 3.0 \times 10^{-19} \text{ J}.$$

The power is $-34 + 8 + 7 = -19$. Options A and D have the wrong order of magnitude, while B has an incompatible coefficient.

Step 3: Conclusion The photon energy is $3.0 \times 10^{-19} \text{ J}$. Hence, the correct option is (C).

Quick Tip to Solve: Write 663 nm as $6.63 \times 10^{-7} \text{ m}$; the coefficient then cancels directly with Planck's constant.

3. An electromagnetic wave is produced by a charge

[1 mark]

- (A) moving with a constant velocity
- (B) moving with a constant speed parallel to a magnetic field
- (C) moving with an acceleration
- (D) at rest

Correct Answer: (C) moving with an acceleration

Solution:

Concept:

- An accelerating electric charge emits electromagnetic radiation: the changing electric and magnetic fields propagate away from the source.
- A stationary charge produces an electrostatic field. Uniform straight-line motion does not produce radiation.

Step 1: Identify the radiating motion Acceleration means a change of velocity, either in magnitude or direction. Such motion creates the time-dependent radiation field required for an electromagnetic wave, so the acceleration condition is decisive.

Step 2: Check the other motions A charge at rest has no radiation field, and a charge moving with constant velocity does not radiate. For motion parallel to a magnetic field, $\vec{F} = q\vec{v} \times \vec{B} = 0$; constant-speed parallel motion therefore supplies no magnetic acceleration. Thus options A, B and D do not describe a radiating charge.

Step 3: Conclusion An electromagnetic wave is produced by a charge moving with an acceleration. Hence, the correct option is (C).

Quick Tip to Solve: Look for a change in velocity, including a change in direction; constant speed alone is not enough to rule acceleration out.

4. A semiconductor device is connected in series with a battery, an ammeter and a resistor. A current flows in the circuit. If the polarity of the battery is reversed, the current in the circuit almost becomes zero. The device is a/an [1 mark]

- (A) intrinsic semiconductor
- (B) p-type semiconductor
- (C) n-type semiconductor
- (D) p-n junction diode

Correct Answer: (D) p-n junction diode

Solution:

Concept:

- A p-n junction diode conducts appreciably in forward bias because the junction barrier and depletion width decrease.
- In reverse bias, the barrier increases and only a very small minority-carrier current normally flows, below breakdown.

Step 1: Interpret the initial current The substantial current with the first battery connection indicates forward bias of a junction. Majority carriers can cross the reduced barrier, with the series resistor limiting the circuit current.

Step 2: Interpret the reversed polarity Reversing the battery reverse-biases the junction, so its current falls almost to zero. A homogeneous intrinsic, p-type or n-type semiconductor does not by itself form the rectifying p-n barrier required for this strong directional conduction. Those three options therefore do not explain the observation.

Step 3: Conclusion The device is a p-n junction diode. Hence, the correct option is (D).

Quick Tip to Solve: A large current in one polarity and only a tiny current in the opposite polarity is the signature of a rectifying junction.

5. The formation of depletion region in a p-n junction diode is due to [1 mark]

- (A) movement of dopant atoms
- (B) diffusion of both electrons and holes
- (C) drift of electrons only
- (D) drift of holes only

Correct Answer: (B) diffusion of both electrons and holes

Solution:

Concept:

- Diffusion carries majority carriers from high to low concentration: electrons move from n to p and holes from p to n.
- Recombination near the junction removes mobile carriers and exposes fixed ionised dopants, forming the depletion region.

Step 1: Track the majority carriers On forming the junction, the concentration differences drive electrons and holes across it in opposite directions. They recombine near the interface, leaving a region depleted of free electrons and holes.

Step 2: Distinguish diffusion from drift The exposed positive donor ions on the n side and negative acceptor ions on the p side create an electric field. Its drift current subsequently opposes diffusion; drift of only one carrier is not the formation mechanism. Dopant atoms remain fixed in the crystal, so option A is also incorrect.

Step 3: Conclusion The depletion region forms due to diffusion of both electrons and holes. Hence, the correct option is (B).

Quick Tip to Solve: Remember the order: diffusion and recombination expose fixed ions; the resulting field then drives the opposing drift current.

6. The radius of ${}_{13}^{27}\text{X}$ nucleus is R . The radius of ${}_{53}^{125}\text{Y}$ nucleus will be

[1 mark]

- (A) $\frac{5}{3}R$
(B) $\left(\frac{13}{53}\right)^{1/3}R$
(C) $\left(\frac{5}{3}R\right)^{1/3}$
(D) $\left(\frac{13}{53}R\right)^{1/3}$

Correct Answer: (A) $\frac{5}{3}R$

Solution:

Concept:

- Nuclear radius follows $r = r_0 A^{1/3}$, where A is the mass number and r_0 is approximately the same for all nuclei.
- The superscript gives the mass number; the subscript is atomic number and does not determine the radius ratio in this law.

Step 1: Identify the mass numbers The printed nuclei are ${}_{13}^{27}\text{X}$ and ${}_{53}^{125}\text{Y}$. Thus use $A_X = 27$ and $A_Y = 125$, while $r_X = R$. The atomic numbers 13 and 53 must not replace these mass numbers.

Step 2: Form and simplify the radius ratio

$$\frac{r_Y}{R} = \left(\frac{125}{27}\right)^{1/3} = \frac{5}{3}.$$

Option B uses atomic numbers. Options C and D incorrectly put the dimensional radius R itself inside a cube root; option C also takes an extra cube root after the mass-number ratio has already been simplified.

Step 3: Conclusion The radius is $\frac{5}{3}R$. Hence, the correct option is (A).

Quick Tip to Solve: For perfect-cube mass numbers, take their cube roots first: $\sqrt[3]{125}/\sqrt[3]{27} = 5/3$.

7. An electric dipole of dipole moment $2 \times 10^{-8} \text{ C m}$ in a uniform electric field experiences a maximum torque of $6 \times 10^{-4} \text{ N m}$. The magnitude of electric field is [1 mark]

- (A) $2.2 \times 10^3 \text{ V m}^{-1}$
- (B) $1.2 \times 10^4 \text{ V m}^{-1}$
- (C) $3.0 \times 10^4 \text{ V m}^{-1}$
- (D) $4.2 \times 10^3 \text{ V m}^{-1}$

Correct Answer: (C) $3.0 \times 10^4 \text{ V m}^{-1}$

Solution:

Concept:

- The torque magnitude on an electric dipole is $\tau = pE \sin \theta$, where p is dipole moment and θ is its angle to the electric field.
- The maximum torque occurs at $\theta = 90^\circ$, so $\tau_{\max} = pE$ and $E = \tau_{\max}/p$.

Step 1: Use the maximum-torque condition Because the specified torque is maximum, $\sin \theta = 1$; no unknown angular factor remains. With $p = 2 \times 10^{-8} \text{ C m}$ and $\tau_{\max} = 6 \times 10^{-4} \text{ N m}$, divide torque by dipole moment.

Step 2: Calculate and check the units

$$E = \frac{6 \times 10^{-4}}{2 \times 10^{-8}} = 3.0 \times 10^4 \text{ N C}^{-1}.$$

Since $\text{N C}^{-1} = \text{V m}^{-1}$, this has the required unit. Options A and D have the wrong power of ten, and B does not give the coefficient obtained from $6/2$.

Step 3: Conclusion The field magnitude is $3.0 \times 10^4 \text{ V m}^{-1}$. Hence, the correct option is (C).

Quick Tip to Solve: The word maximum immediately sets $\sin \theta = 1$; subtract the negative exponents carefully when dividing torque by dipole moment.

8. In an extrinsic semiconductor, the number density of holes is $4 \times 10^{20} \text{ m}^{-3}$. If the number density of intrinsic carriers is $1.2 \times 10^{15} \text{ m}^{-3}$, the number density of electrons in it is [1 mark]

- (A) $1.8 \times 10^9 \text{ m}^{-3}$
- (B) $2.4 \times 10^{10} \text{ m}^{-3}$
- (C) $3.6 \times 10^9 \text{ m}^{-3}$
- (D) $3.2 \times 10^{10} \text{ m}^{-3}$

Correct Answer: (C) $3.6 \times 10^9 \text{ m}^{-3}$

Solution:

Concept:

- At thermal equilibrium, the carrier concentrations obey the mass-action law $np = n_i^2$. Here n and p are electron and hole number densities and n_i is the intrinsic carrier density.
- For a given temperature, n_i is fixed; increasing the majority-carrier density decreases the minority-carrier density.

Step 1: Rearrange the carrier-density relation The required electron density is $n = n_i^2/p$, with $p = 4 \times 10^{20} \text{ m}^{-3}$ and $n_i = 1.2 \times 10^{15} \text{ m}^{-3}$. The intrinsic density must be squared before division.

Step 2: Substitute and simplify

$$n = \frac{(1.2 \times 10^{15})^2}{4 \times 10^{20}} = \frac{1.44}{4} \times 10^{10} = 3.6 \times 10^9 \text{ m}^{-3}.$$

The units are $\text{m}^{-6}/\text{m}^{-3} = \text{m}^{-3}$. Only option C satisfies $np = n_i^2$; the coefficients or powers in A, B and D do not reproduce the given intrinsic density.

Step 3: Conclusion The electron number density is $3.6 \times 10^9 \text{ m}^{-3}$. Hence, the correct option is (C).

Quick Tip to Solve: Square both the coefficient and the power in n_i , then divide by the hole density; check that the minority density is much smaller.

9. A point charge q_0 is moving along a circular path of radius a , with a point charge $-Q$ at the centre of the circle. The kinetic energy of q_0 is [1 mark]

- (A) $\frac{q_0 Q}{4\pi\epsilon_0 a}$
(B) $\frac{q_0 Q}{8\pi\epsilon_0 a}$
(C) $\frac{q_0 Q}{4\pi\epsilon_0 a^2}$
(D) $\frac{q_0 Q}{8\pi\epsilon_0 a^2}$

Correct Answer: (B) $\frac{q_0 Q}{8\pi\epsilon_0 a}$

Solution:

Concept:

- Coulomb attraction between charges q_0 and $-Q$, separated by a , has magnitude $F = q_0 Q / (4\pi\epsilon_0 a^2)$.
- For a circular orbit, the radial force supplies mv^2/a , where m and v are the moving particle's mass and speed. Its kinetic energy is $K = mv^2/2$.

Step 1: Equate the radial forces The negative central charge attracts the positive orbiting charge, so the electric force acts towards the centre and supplies the centripetal force:

$$\frac{mv^2}{a} = \frac{q_0 Q}{4\pi\epsilon_0 a^2}, \quad mv^2 = \frac{q_0 Q}{4\pi\epsilon_0 a}.$$

Step 2: Apply the kinetic-energy factor Kinetic energy is half of mv^2 . Option (A) omits this factor of one-half. Options (C) and (D) retain a^2 in the denominator and therefore have force dimensions, not energy dimensions.

Step 3: Conclusion

$$K = \frac{q_0 Q}{8\pi\epsilon_0 a}.$$

Hence, the correct option is (B).

Quick Tip to Solve: In a Coulomb circular orbit, use $K = Fa/2$; energy varies as $1/a$, while the force varies as $1/a^2$.

10. The curve of binding energy per nucleon as a function of atomic mass number has a sharp peak for helium nucleus. This implies that helium nucleus is [1 mark]

- (A) radioactive
- (B) unstable
- (C) easily fissionable
- (D) more stable nucleus than its neighbours

Correct Answer: (D) more stable nucleus than its neighbours

Solution:

Concept:

- Binding energy is the energy required to separate a nucleus completely into its constituent protons and neutrons.
- Binding energy per nucleon is B/A , where B is total binding energy and A is the mass number. A larger value generally indicates greater nuclear stability.

Step 1: Interpret the helium peak A sharp peak at helium means that its binding energy per nucleon exceeds that of neighbouring light nuclei. More energy per nucleon must therefore be supplied to separate its constituents, showing that helium is particularly tightly bound.

Step 2: Compare the physical interpretations Strong binding supports stability, so the peak does not indicate radioactivity or instability: (A) and (B) reverse its meaning. It also does not imply easy fission; splitting this tightly bound light nucleus is not favoured by a local peak. Thus (C) is unsuitable. The comparison is with nearby nuclei, not a claim that helium has the largest binding energy per nucleon of every nucleus.

Step 3: Conclusion Helium is more stable than its neighbouring nuclei. Hence, the correct option is (D).

Quick Tip to Solve: Read a local upward peak on a binding-energy-per-nucleon graph as enhanced stability relative to nearby mass numbers.

11. The current in a device varies with time t as $I = 6t$, where I is in mA and t is in s. The amount of charge that passes through the device during $t = 0$ s to $t = 3$ s is [1 mark]

- (A) 10 mC
- (B) 18 mC
- (C) 27 mC
- (D) 54 mC

Correct Answer: (C) 27 mC

Solution:

Concept:

- Electric current is the rate of flow of charge: $I = dq/dt$. The charge transferred over an interval is $q = \int I dt$.
- The area under an I -versus- t graph equals charge. Current in mA multiplied by time in s gives charge in mC.

Step 1: Integrate the changing current Since the current grows linearly, a single instantaneous current

cannot be used throughout the interval. With time expressed in seconds, integrate the given numerical relation:

$$q = \int_0^3 6t \, dt = [3t^2]_0^3 = 27 \text{ mC}.$$

Step 2: Check using the average current The endpoint currents are 0 and 18 mA, so their average is 9 mA and the transferred charge is $9 \times 3 = 27 \text{ mC}$. Option (D) incorrectly uses the final current for the whole interval; (B) mistakes the final current's numerical value for charge. Neither (A) nor (B) equals the area under the current graph.

Step 3: Conclusion The charge passing through the device is $27 \text{ mC} = 2.7 \times 10^{-2} \text{ C}$. Hence, the correct option is (C).

Quick Tip to Solve: For a current rising linearly from zero, use the triangular area $q = \frac{1}{2} I_{\text{final}} \Delta t$.

12. A ray of light travels a distance of 12.0 m in a transparent sheet in 60 ns. The refractive index of the sheet is [1 mark]

- (A) 1.33
- (B) 1.50
- (C) 1.65
- (D) 1.75

Correct Answer: (B) 1.50

Solution:

Concept:

- The speed of light in a uniform medium is $v = s/t$, where s is the travelled distance and t is the travel time.
- The absolute refractive index is $n = c/v$, where $c = 3.0 \times 10^8 \text{ m s}^{-1}$ is the vacuum speed. Refractive index is dimensionless.

Step 1: Convert the travel time and find speed A nanosecond is 10^{-9} s , so the specified time is $60 \times 10^{-9} \text{ s}$. The speed inside the transparent sheet is

$$v = \frac{12.0}{60 \times 10^{-9}} = 2.0 \times 10^8 \text{ m s}^{-1}.$$

Step 2: Compare vacuum and medium speeds Divide the vacuum speed by this medium speed:

$$n = \frac{3.0 \times 10^8}{2.0 \times 10^8} = 1.50.$$

The other choices, 1.33, 1.65 and 1.75, do not give the measured speed. Reversing the ratio would incorrectly give an index below unity for this sheet.

Step 3: Conclusion The refractive index of the transparent sheet is 1.50. Hence, the correct option is (B).

Quick Tip to Solve: Combine the two relations as $n = ct/s$, converting nanoseconds to seconds before substitution.

13. A cell of emf E is connected across an external resistance R . When current I is drawn from the cell, the potential difference across the electrodes of the cell drops to V . The internal resistance ' r ' of the cell is [1 mark]

(A) $\left(\frac{E - V}{E}\right) R$

(B) $\left(\frac{E - V}{R}\right)$

(C) $\frac{(E - V) R}{I}$

(D) $\left(\frac{E - V}{V}\right) R$

Correct Answer: (D) $\left(\frac{E - V}{V}\right) R$

Solution:

Concept:

- A cell delivering current I has terminal voltage $V = E - Ir$, where E is its emf and r is its internal resistance.
- The external resistor R is connected across the terminals, so Ohm's law gives $V = IR$. The lost voltage $E - V$ appears across the internal resistance.

Step 1: Express the lost voltage Applying the voltage relation for a discharging cell gives

$$E - V = Ir, \quad r = \frac{E - V}{I}.$$

The external voltage is below the emf because the current also causes a drop inside the cell.

Step 2: Eliminate the current using the external resistor Substitute $I = V/R$, since the voltage across R is V , not E :

$$r = \frac{E - V}{V/R} = \left(\frac{E - V}{V}\right) R.$$

Option (A) uses E in place of the terminal voltage. Option (B) has current dimensions, and (C) has resistance-squared dimensions; neither can represent an internal resistance.

Step 3: Conclusion The internal resistance is $r = \left(\frac{E - V}{V}\right) R$. Hence, the correct option is (D).

Quick Tip to Solve: Compare voltage drops directly: $r/R = (E - V)/V$, because the same current passes through both resistances.

14. A ray of monochromatic light propagating in air, is incident on the surface of water. Which of the following will be the same for the reflected and refracted rays? [1 mark]

- (A) Energy carried
- (B) Speed
- (C) Frequency
- (D) Wavelength

Correct Answer: (C) Frequency

Solution:

Concept:

- The frequency f of monochromatic light is set by its source and remains unchanged during reflection and refraction at a stationary boundary.
- Wave speed and wavelength obey $v = f\lambda$. A change of speed between media changes the wavelength while the frequency stays fixed.

Step 1: Compare the reflected and refracted waves The reflected ray continues through air, whereas the refracted ray travels through water. Both oscillate at the incident light's frequency because the interface responds to the same incident oscillation. Thus their frequencies are equal.

Step 2: Test the remaining quantities Light travels more slowly in water than in air, so the speeds differ and (B) is incorrect. With the same frequency but different speeds, their wavelengths also differ, excluding (D). The incident beam's energy is divided between reflected and transmitted beams and the shares need not be equal, excluding (A). Equal photon energy hf does not imply equal total energy carried by the two rays.

Step 3: Conclusion Frequency is the quantity that remains the same for both rays. Hence, the correct option is (C).

Quick Tip to Solve: At a stationary optical boundary keep f fixed, then use $v = f\lambda$ to compare wavelength and speed in the two media.

15. Beams of electrons and protons move parallel to each other in the same direction. They [1 mark]

- (A) attract each other.
- (B) repel each other.
- (C) neither attract nor repel.
- (D) force of attraction or repulsion depends upon speed of beams.

Correct Answer: (A) attract each other.

Solution:

Concept:

- Electron and proton beams carry opposite charges, so their electric interaction is attractive. Conventional current is opposite to electron motion and along proton motion.
- Oppositely directed currents repel magnetically. For parallel charged beams with speeds v_e and v_p , the force-magnitude ratio is $F_{\text{magnetic}}/F_{\text{electric}} = v_e v_p / c^2$, where c is the speed of light.

Step 1: Identify both contributions Since both beams move in the same direction, their conventional currents are opposite and the magnetic force is repulsive. However, the beams also have opposite

net charges and attract electrically. The printed question does not restrict the interaction to magnetic force, so both contributions must be considered.

Step 2: Compare the force magnitudes For beam separation s and positive line-charge magnitudes λ_e, λ_p , the electric and magnetic forces per length are

$$f_E = \frac{\lambda_e \lambda_p}{2\pi\epsilon_0 s},$$

$$f_B = \frac{\mu_0 \lambda_e \lambda_p v_e v_p}{2\pi s}.$$

Thus $f_B/f_E = v_e v_p/c^2 < 1$ for electrons and protons, whose speeds are below c . Electric attraction exceeds magnetic repulsion. Option (B) describes only the magnetic contribution, (C) would require equal forces, and (D) incorrectly suggests that varying physical beam speeds can reverse the net force.

Step 3: Conclusion The net electromagnetic interaction between the charged beams is attractive. Hence, the correct option is (A).

Quick Tip to Solve: For charged beams include the electric force; the parallel-current rule alone determines only the magnetic contribution.

16. Assertion (A): In Young's double slit experiment all fringes are of equal width.

Reason (R): The fringe width depends upon wavelength of light (λ) used, distance of screen from plane of slits (D) and slits separation (d). [1 mark]

- (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
 (B) Both Assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).
 (C) Assertion (A) is true and Reason (R) is false.
 (D) Assertion (A) is false and Reason (R) is also false.

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

Solution:

Concept:

- In the standard small-angle treatment of Young's double slit experiment, bright fringes occur at $y_n = n\lambda D/d$.
- The fringe width is $\beta = \lambda D/d$, where λ is wavelength, D is the slit-to-screen distance and d is slit separation. It is independent of fringe order n .

Step 1: Evaluate the assertion The separation of consecutive bright fringes is

$$y_{n+1} - y_n = \frac{(n+1)\lambda D}{d} - \frac{n\lambda D}{d} = \frac{\lambda D}{d}.$$

Consecutive dark fringes have the same separation. Therefore all fringe widths are equal in the usual Young's experiment approximation, and Assertion (A) is true.

Step 2: Evaluate the reason The formula $\beta = \lambda D/d$ shows that fringe width depends on precisely the wavelength, screen distance and slit separation stated in Reason (R). Thus the reason is true.

Step 3: Check whether the reason explains the assertion The printed reason merely lists quantities on

which fringe width depends. It does not state the formula or establish that the width is independent of fringe order. That independence, shown in Step 1, is what explains equal widths. Thus the reason is true but is not the stated explanation of the assertion. Option (A) assumes this missing link; (C) and (D) wrongly declare true statements false.

Step 4: Conclusion Both statements are true, but the reason as stated does not correctly explain the assertion. Hence, the correct option is (B).

Quick Tip to Solve: To test equal fringe widths, look for fringe order in β ; its absence means the spacing is constant for fixed λ, D, d .

17. Assertion (A): Diamagnetic substances exhibit magnetism.

Reason (R): Diamagnetic materials do not have permanent magnetic dipole moment. [1 mark]

- (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
(B) Both Assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).
(C) Assertion (A) is true and Reason (R) is false.
(D) Assertion (A) is false and Reason (R) is also false.

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

Solution:

Concept:

- Diamagnetism is the weak magnetisation induced opposite to an applied magnetic field; the susceptibility of a diamagnetic material is negative.
- An atom with paired electrons has no permanent net magnetic dipole moment, but an applied field can induce a magnetic moment.

Step 1: Evaluate the assertion A diamagnetic substance does exhibit magnetism when placed in an external field. Its induced magnetic moment opposes the applied field, producing weak repulsion. Thus Assertion (A) is true; absence of permanent magnetism does not mean absence of a magnetic response.

Step 2: Evaluate the reason In a diamagnetic material the electronic magnetic moments cancel in the absence of an external field, so there is no permanent net magnetic dipole moment. Reason (R) is therefore true.

Step 3: Test the explanatory link The absence of a permanent moment describes the zero-field state. It does not explain how an applied field changes electronic motion and induces a moment opposing that field. Consequently R does not explain A. Option (A) incorrectly asserts that explanatory link, while (C) and (D) incorrectly reject true statements.

Step 4: Conclusion Both A and R are true, but R is not the correct explanation of A. Hence, the correct option is (B).

Quick Tip to Solve: Separate permanent magnetic moment from induced magnetic moment before testing the explanatory link.

18. Assertion (A): Work done in moving a charge around a closed path, in an electric field is always zero.

Reason (R): Electrostatic force is a conservative force.

[1 mark]

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

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

(C) Assertion (A) is true and 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 Assertion (A).

Solution:

Concept:

- The electrostatic force is conservative: work depends only on the initial and final positions.
- Work done by the electrostatic field on charge q is $W = q(V_i - V_f)$, where V_i and V_f are the endpoint potentials.

Step 1: Evaluate the assertion The reference to electrostatic force in R identifies the electrostatic context of the question. On a closed path the charge returns to the same point, so $V_i = V_f$. Therefore

$$W = q(V_i - V_f) = 0.$$

Assertion (A) is true in this context. This result need not apply to a non-conservative electric field induced by a changing magnetic flux.

Step 2: Evaluate the reason Electrostatic force has a single-valued potential energy and does path-independent work. It is a conservative force, so Reason (R) is true.

Step 3: Test the explanatory link Zero work around a closed path is a direct consequence of a conservative force. R therefore gives precisely the reason for A. Option (B) wrongly denies this link; (C) wrongly calls R false; and (D) wrongly calls both statements false in the stated electrostatic context.

Step 4: Conclusion Both A and R are true in electrostatics, and R correctly explains A. Hence, the correct option is (A).

Quick Tip to Solve: For any closed path in an electrostatic field, compare the endpoint potentials: they are identical.

Section B (14 marks)

19. What happens to the interference pattern when two coherent sources are

(a) infinitely close, and

(b) far apart from each other?

[2 marks]

Solution:

Concept:

- For two coherent sources in Young's interference arrangement, fringe width is $\beta = \lambda D/d$, where λ is the wavelength, D the screen distance and d the source separation.

- At fixed wavelength and screen distance, fringe width varies inversely with source separation. Visibility also requires that successive fringes can be resolved.

Step 1: Consider infinitely close sources For part (a), as $d \rightarrow 0$, the relation $\beta = \lambda D/d$ gives $\beta \rightarrow \infty$. Thus the fringes become infinitely broad, and separate alternate bright and dark fringes are not observed over a finite screen. For the usual coherent sources in phase, their path difference becomes zero throughout the screen and the overlapping region appears uniformly bright. A fixed nonzero source phase difference would instead give a different uniform intensity.

Step 2: Consider widely separated sources For part (b), increasing d decreases β , so successive bright and dark fringes come very close together. For a sufficiently large separation the fringes are too fine to resolve and the visible pattern disappears. This is a loss of distinguishable fringes, not a loss of coherence merely because the sources have been moved apart.

Step 3: Conclusion (a) Infinitely close sources give infinitely broad fringes and no distinct fringe pattern; in-phase sources give uniform brightness. (b) Widely separated sources give very narrow, closely spaced fringes, which may become unresolvable.

Quick Tip to Solve: Hold λ and D fixed and use $\beta \propto 1/d$: closer sources widen fringes; farther sources narrow them.

20(a). What is meant by ionisation energy? Write its value for hydrogen atom.

[2 marks]

Solution:

Concept:

- Ionisation energy is the minimum energy needed to remove the most loosely bound electron completely from an isolated gaseous atom in its ground state.
- For hydrogen, $E_n = -13.6/n^2$ eV, where n is the principal quantum number and zero energy corresponds to a free electron at infinity.

Step 1: Specify the ionisation process Removing the electron completely means taking it from the bound ground state to infinity, with no residual kinetic energy at the threshold. The hydrogen atom becomes a positive hydrogen ion and a free electron. Energy must be supplied against the electrostatic attraction between the proton and electron; merely exciting the electron to another finite orbit is not ionisation.

Step 2: Calculate the ground-state energy gap Hydrogen has ground-state energy $E_1 = -13.6$ eV, while the unbound threshold is $E_\infty = 0$. Thus the energy supplied is

$$E_{\text{ion}} = E_\infty - E_1 = 0 - (-13.6) = 13.6 \text{ eV.}$$

Using $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$, this equals approximately $2.18 \times 10^{-18} \text{ J}$ per atom. The positive sign denotes energy absorbed, whereas the negative sign of E_1 denotes a bound state.

Step 3: Conclusion Ionisation energy is the minimum energy required to remove an electron completely from an isolated gaseous atom in its ground state. For hydrogen it is 13.6 eV, or approximately $2.18 \times 10^{-18} \text{ J}$ per atom.

Quick Tip to Solve: Set the final energy to zero at infinity and subtract the negative ground-state energy; ionisation energy is positive.

20(b). Define the term, mass defect. How is it related to stability of the nucleus?

[2 marks]

Solution:

Concept:

- Mass defect is the difference between the sum of the masses of free constituent nucleons and the actual nuclear mass.
- Binding energy is $B = \Delta mc^2$; binding energy per nucleon B/A measures how strongly the nucleons are bound on average.

Step 1: Express the mass defect A nucleus with mass number A and atomic number Z contains Z protons and $A - Z$ neutrons. If m_p , m_n and M denote the proton, neutron and actual nuclear masses, respectively, its mass defect is

$$\Delta m = Zm_p + (A - Z)m_n - M.$$

The bound nucleus has less mass than its separated nucleons because energy is released when the nucleus forms. Here M is the mass of the nucleus, not the neutral atom including its electrons.

Step 2: Relate the missing mass to stability The energy released on formation is the binding energy $B = \Delta mc^2$. The same energy must be supplied to separate the nucleus completely into free nucleons. To compare nuclei of different mass numbers, use

$$\frac{B}{A} = \frac{\Delta mc^2}{A}.$$

Greater binding energy per nucleon generally means stronger binding and greater nuclear stability. Total mass defect alone is not a fair comparison across differently sized nuclei; it is the mass defect per nucleon that gives the relevant measure of relative binding.

Step 3: Conclusion Mass defect is $\Delta m = Zm_p + (A - Z)m_n - M$, corresponding to binding energy $B = \Delta mc^2$. A larger mass defect per nucleon, hence larger binding energy per nucleon, generally indicates a more strongly bound and more stable nucleus.

Quick Tip to Solve: Subtract the bound nuclear mass from the free-nucleon mass sum, then divide the binding energy by A before comparing different nuclei.

21. With the help of a circuit diagram, explain how a full wave rectifier gives output rectified voltage corresponding to both halves of the input ac voltage.

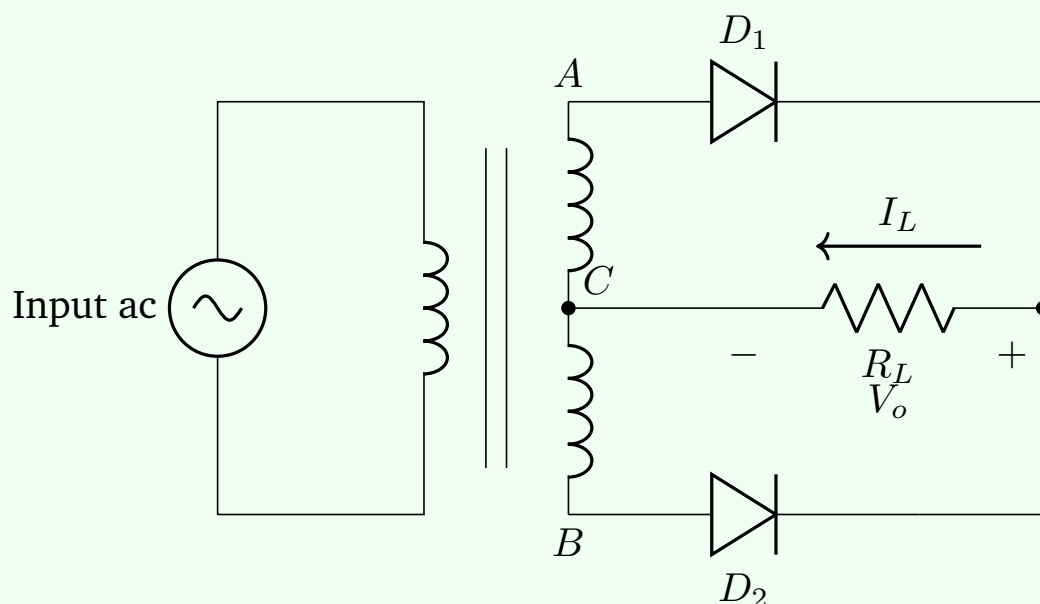
[2 marks]

Solution:

Concept:

- A p-n junction diode conducts appreciably when forward biased and blocks current when reverse biased. Rectification uses this one-way conduction.
- A centre-tapped transformer provides two secondary voltages of opposite instantaneous polarity relative to its centre tap C . Two diodes direct alternate half-cycles through the load R_L in the same direction.

Step 1: Connect the full-wave rectifier Connect the ends A and B of the centre-tapped secondary to the anodes of D_1 and D_2 . Join their cathodes at the positive output terminal and connect the load between this junction and C . Apply the input ac voltage to the primary winding.



Centre-tapped full-wave rectifier; the positive load terminal is at the joined cathodes.

Step 2: Follow both half-cycles When A is positive relative to C , B is negative: D_1 conducts and D_2 is reverse biased. Current follows $A \rightarrow D_1 \rightarrow R_L \rightarrow C$. In the next half-cycle, B becomes positive, so D_2 conducts while D_1 blocks; current follows $B \rightarrow D_2 \rightarrow R_L \rightarrow C$. In both paths the load current flows from the joined cathodes towards C , so its direction does not reverse.

Step 3: Conclusion Both halves of the input ac produce voltage pulses of the same polarity across R_L . The output is full-wave rectified, pulsating dc, with ripple frequency twice the input frequency; it is not a constant voltage without filtering.

Quick Tip to Solve: Track the load-current direction separately for each conducting diode: both paths must enter the same end of the load.

22. Draw energy band diagram for an n-type and p-type semiconductor at $T > 0$ K.

[2 marks]

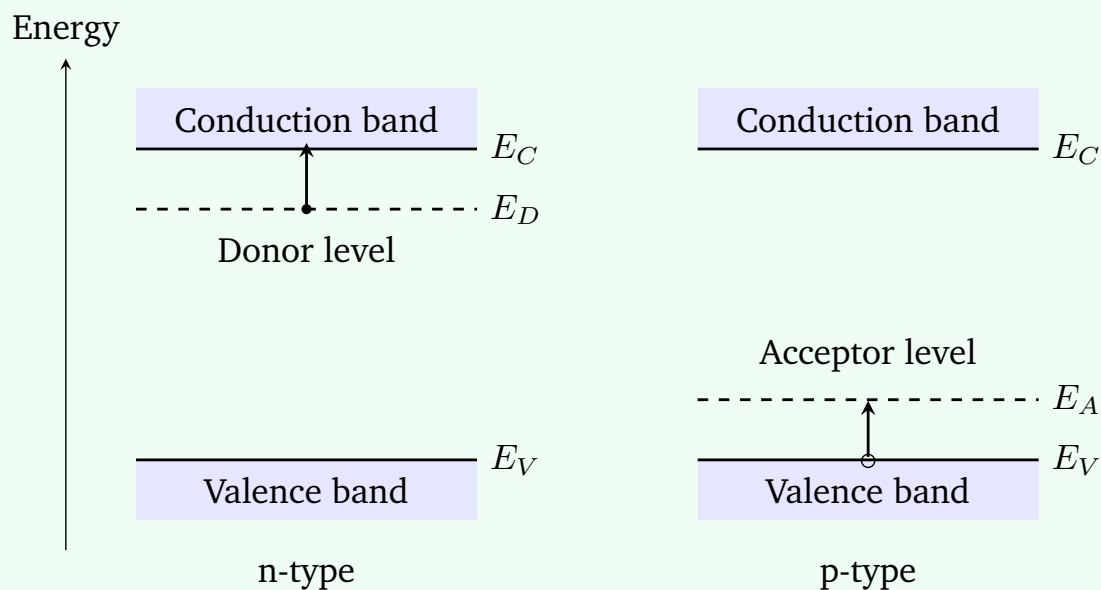
Solution:

Concept:

- The valence-band edge E_V and conduction-band edge E_C bound the forbidden energy gap. Energy increases upwards in a band diagram.
- Pentavalent impurities introduce a donor level E_D just below E_C ; trivalent impurities introduce an acceptor level E_A just above E_V . These impurity levels make thermal excitation easier.

Step 1: Draw the n-type band arrangement Show the donor level close to the conduction band, so $E_C - E_D$ is much smaller than the full band gap. At a nonzero temperature, thermal energy can excite donor electrons into the conduction band, leaving ionised positive donors. Thus electrons are the majority carriers. The upward arrow represents the small energy required for this excitation.

Step 2: Draw the p-type band arrangement Show the acceptor level close to and above the valence band, with $E_A - E_V$ much smaller than the full gap. A valence electron can gain thermal energy and occupy an acceptor state, leaving a mobile hole in the valence band. Holes are therefore the majority carriers. The diagrams are schematic and their energy spacing is not to scale.



Energy-band diagrams at nonzero temperature; arrows show thermal excitation of electrons.

Step 3: Conclusion For n-type material, the donor level lies just below the conduction band. For p-type material, the acceptor level lies just above the valence band; at $T > 0\text{ K}$, thermal excitation supplies majority electrons and holes respectively.

Quick Tip to Solve: Place donors beside the band that receives electrons, and acceptors beside the band from which electrons are accepted.

23. The power of a thin lens is $+5\text{ D}$. When it is immersed in a liquid, it behaves like a concave lens of focal length 100 cm . Calculate the refractive index of the liquid. Given refractive index of glass $= 1.5$. [2 marks]

Solution:

Concept:

- The lens-maker formula for a thin glass lens in a medium is $P_m = (n_g/n_m - 1)K$, where $K = 1/R_1 - 1/R_2$ depends only on the surface curvatures and n_g, n_m are the refractive indices of glass and medium.
- Power is $P = 1/f$ when focal length is in metres. A diverging lens has negative focal length and negative power; the refractive index of air is taken as unity.

Step 1: Determine the curvature factor in air For the same lens, the radii and therefore K remain unchanged on immersion. Its power in air is $+5\text{ D}$, and $n_g = 1.5$. Thus

$$5 = (1.5 - 1)K, \quad K = 10\text{ m}^{-1}.$$

Step 2: Apply the negative focal length in the liquid Since the immersed lens behaves as a concave, diverging lens, its focal length is $-100\text{ cm} = -1\text{ m}$, giving $P_l = -1\text{ D}$. If n_l is the liquid's refractive

index,

$$-1 = \left(\frac{1.5}{n_l} - 1 \right) 10,$$

$$\frac{1.5}{n_l} = 0.9,$$

$$n_l = \frac{1.5}{0.9} = \frac{5}{3}.$$

This is greater than the glass index, so the change from convergence in air to divergence in liquid is physically consistent.

Step 3: Conclusion The refractive index of the liquid is $n_l = 5/3 \approx 1.67$, a dimensionless quantity.

Quick Tip to Solve: Assign a negative sign to the immersed focal length before taking its reciprocal; a diverging lens has negative power.

24. Briefly explain why and how a galvanometer is converted into an ammeter.

[2 marks]

Solution:

Concept:

- A moving-coil galvanometer is sensitive to small currents. Let its resistance be G and its full-scale deflection current be I_g .
- An ammeter is connected in series with the circuit and should have very low resistance, so that its insertion changes the current as little as possible. Parallel branches share the same potential difference.

Step 1: Explain why conversion is needed A galvanometer alone can measure only a small current; a larger current can damage its coil. Its resistance is also too large for a practical ammeter. To measure larger currents safely with little disturbance of the circuit, most of the current must bypass the sensitive coil.

Step 2: Connect a low-resistance shunt Connect a small resistance S , called a shunt, in parallel with the galvanometer. For a desired full-scale ammeter range I , only I_g flows through the coil, while $I - I_g$ flows through the shunt. Equating the voltage across the two parallel branches gives

$$I_g G = (I - I_g) S, \quad S = \frac{I_g G}{I - I_g}.$$

Calibrate the deflection scale to read the total current I . The combination has resistance $R_A = GS/(G + S)$, which is small because the shunt resistance is small. Connect this complete combination in series with the circuit whose current is to be measured.

Step 3: Conclusion A galvanometer is converted into an ammeter by connecting a suitable low-resistance shunt in parallel with it. This extends its current range, protects the coil, and makes the instrument's effective resistance low.

Quick Tip to Solve: The shunt carries $I - I_g$, not the total current I ; use equal branch voltages to obtain its resistance.

25(a). How are infrared waves produced? Why are these waves referred to as heat waves? Give any two uses of infrared waves. [2 marks]

Solution:

Concept:

- Infrared radiation is electromagnetic radiation with wavelengths longer than visible red light. Hot bodies and molecules undergoing vibrational motion emit infrared waves.
- Absorption transfers radiation energy to the internal energy of matter; an increase in molecular motion can raise its temperature.

Step 1: Explain production and the heating effect Infrared waves are produced by hot bodies and by the vibrational and rotational motion of molecules. For example, an electric heater emits strong infrared radiation even when its element is not visibly glowing. Water and many other materials readily absorb infrared radiation. The absorbed energy increases molecular motion and hence the temperature of the absorbing body, so infrared waves are commonly called heat waves.

Step 2: State two uses (i) Infrared lamps are used in physiotherapy to warm tissues and relieve muscular discomfort. (ii) Infrared radiation is used in television remote controls to transmit control signals to an infrared detector. The first application uses its heating effect, while the second uses it as an electromagnetic signal carrier.

Step 3: Conclusion Infrared waves are emitted by hot bodies and vibrating molecules. Their ready absorption causes heating, which gives them the name heat waves. Two uses are physiotherapy lamps and television remote controls.

Quick Tip to Solve: Link the name heat waves to absorption and increased molecular motion, then give two distinct applications.

OR

25(b). How are X-rays produced? Give any two uses of these. [2 marks]

Solution:

Concept:

- X-rays are high-frequency electromagnetic waves. Accelerated or rapidly decelerated electric charges can emit electromagnetic radiation.
- X-rays penetrate matter, but different materials absorb them by different amounts; their short wavelengths also allow diffraction by crystal planes.

Step 1: Describe production in an X-ray tube Electrons emitted by a heated cathode are accelerated through a large potential difference towards a heavy metal target, such as tungsten. On striking the target they undergo rapid deceleration, producing X-rays. Some of their kinetic energy is converted into electromagnetic radiation; most becomes heat, so the target requires cooling. Inner-shell electronic transitions in target atoms can also produce characteristic X-ray frequencies.

Step 2: Give two uses with their physical basis (i) X-rays are used in medical radiography to detect bone fractures: bones absorb X-rays more strongly than surrounding soft tissues, giving image contrast. (ii) X-rays are used to determine crystal structures by X-ray diffraction: their wavelengths are comparable with atomic spacings, so the diffraction pattern reveals the arrangement of atoms.

Step 3: Conclusion X-rays are produced when fast electrons strike a heavy metal target and are rapidly

decelerated. Two uses are detecting bone fractures and studying crystal structures by diffraction.

Quick Tip to Solve: For production, specify both fast electrons and sudden deceleration at a metal target; name two separate uses.

Section C (15 marks)

26. A ray of light is refracted by a glass prism. Obtain an expression for the refractive index of the glass in terms of the angle of prism A and the angle of minimum deviation δ_m . [3 marks]

Solution:

Concept:

- For a prism of refracting angle A , the internal refraction angles satisfy $r_1 + r_2 = A$. All incidence and refraction angles are measured from the normals to the corresponding faces.
- The deviation is $\delta = i + e - A$, where i is the incidence angle and e is the emergence angle. At minimum deviation the path through the prism is symmetric.
- Snell's law at the first surface gives $\mu = \sin i / \sin r_1$ for glass relative to air, taking the refractive index of air as unity.

Step 1: Relate the angles inside the prism Let a ray enter one refracting face at angle i , refract inside at angle r_1 , and strike the second face internally at angle r_2 , emerging at angle e . The normals to the two faces, together with the internal ray and the prism angle, give

$$r_1 + r_2 = A.$$

The deviations at the first and second surfaces are $i - r_1$ and $e - r_2$. Adding them gives

$$\delta = (i - r_1) + (e - r_2) = i + e - A.$$

Step 2: Apply the minimum-deviation condition At the minimum deviation δ_m , the incident and emergent portions of the ray are symmetric with respect to the prism, so $i = e$ and $r_1 = r_2 = r$. Consequently,

$$2r = A \Rightarrow r = \frac{A}{2}, \quad \delta_m = 2i - A \Rightarrow i = \frac{A + \delta_m}{2}.$$

These equal-angle relations apply at minimum deviation; they need not hold for an arbitrary ray through the prism.

Step 3: Substitute into Snell's law At the air-glass boundary, Snell's law is $1 \times \sin i = \mu \sin r$. Inserting the two angles obtained above therefore gives

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin((A + \delta_m)/2)}{\sin(A/2)}.$$

This relation determines the refractive index at the wavelength of the incident light from the measured prism angle and minimum deviation.

Step 4: Conclusion The refractive index of the glass relative to air is

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

Quick Tip to Solve: First write the symmetric-path equalities at minimum deviation: both internal angles are $A/2$, and incidence is $(A + \delta_m)/2$.

27(a). (i) Distinguish between nuclear fission and fusion giving an example of each.

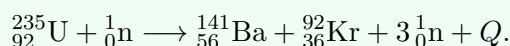
(ii) Explain the release of energy in nuclear fission and fusion on the basis of binding energy per nucleon curve. [3 marks]

Solution:

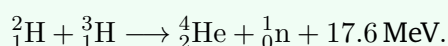
Concept:

- Nuclear fission splits a heavy nucleus, whereas nuclear fusion combines light nuclei. The total nucleon number and total electric charge are conserved in both processes.
- Binding energy per nucleon, B/A , measures the average binding of a nucleon in a nucleus. The curve rises steeply for light nuclei, reaches its broad maximum near iron and nickel, and falls slowly for heavier nuclei.
- The energy released is $Q = (m_{\text{initial}} - m_{\text{final}})c^2 = B_{\text{final}} - B_{\text{initial}}$, using the total binding energies of all nuclei involved.

Step 1: (i) Distinguish fission and fusion with examples In fission, a heavy nucleus splits into two medium-mass nuclei, usually with emission of neutrons. One possible neutron-induced uranium fission reaction is



In fusion, two light nuclei combine to form a heavier nucleus. A typical example is



Fusion requires the nuclei to overcome their electrostatic repulsion; very high temperatures provide the kinetic energy needed for appreciable fusion rates. Neutron-induced fission can be initiated by neutron absorption because the neutron has no electric charge.

Step 2: (ii) Explain energy release in fission Very heavy nuclei such as uranium lie on the slowly declining, heavy-mass side of the binding-energy-per-nucleon curve. Their medium-mass fission fragments lie closer to its broad maximum and have a greater binding energy per nucleon. The total binding energy of the products is therefore greater than that of the initial nucleus. The corresponding decrease in total rest mass appears as released energy, mainly kinetic energy of fragments and emitted particles.

Step 3: (ii) Explain energy release in fusion Light hydrogen isotopes lie on the rising, low-mass side of the curve. When they fuse into a more tightly bound nucleus such as helium, the increase in total binding energy means that the final rest mass is smaller. The difference is released according to $Q = \Delta mc^2$. Thus both energy-releasing processes move towards more tightly bound nuclear

configurations, even though one splits nuclei and the other combines them.

Step 4: Conclusion Fission splits heavy nuclei and fusion combines light nuclei. Both release energy when the products have greater total binding energy, as explained by their positions on the binding-energy-per-nucleon curve.

Quick Tip to Solve: Use the two sides of the binding-energy curve: heavy nuclei release energy by splitting, while suitable light nuclei release it by combining.

OR

27(b). (i) How is the size of a nucleus found experimentally? Write the relation between the radius and mass number of a nucleus.

(ii) Prove that the density of a nucleus is independent of its mass number.

[3 marks]

Solution:

Concept:

- Nuclear size is investigated using scattering of energetic particles. The measured scattering pattern reveals the spatial extent of the nucleus.
- The empirical nuclear radius is $R = R_0 A^{1/3}$, where A is the mass number and $R_0 \simeq 1.2 \times 10^{-15}$ m.
- The nuclear mass is approximately $M = Am_n$, where m_n is the mean nucleon mass; density is mass divided by nuclear volume.

Step 1: (i) Describe the experimental measurement Direct a beam of energetic alpha particles at a thin target and measure the number scattered through different angles. At sufficiently high energies, deviations from scattering by a point-like Coulomb charge provide information about the finite nuclear size. High-energy electron scattering also determines nuclear size from the measured angular distribution; electrons probe the nuclear charge distribution without the strong interaction. Measurements over many nuclei yield

$$R = R_0 A^{1/3}, \quad R_0 \simeq 1.2 \text{ fm.}$$

Thus a nucleus with eight times the mass number has twice the radius, rather than eight times the radius.

Step 2: (ii) Express nuclear volume and mass Approximating the nucleus as a sphere, insert the measured radius relation into its volume:

$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 A.$$

There are A nucleons, whose masses are approximately equal. Neglecting their small mass difference and the binding-energy mass defect for this estimate gives $M \simeq Am_n$.

Step 3: Cancel the mass number in the density Dividing the mass by the volume gives

$$\rho = \frac{Am_n}{(4/3)\pi R_0^3 A} = \frac{3m_n}{4\pi R_0^3}.$$

The factor A cancels because both nuclear mass and nuclear volume grow in the same proportion. Using $m_n \simeq 1.67 \times 10^{-27}$ kg gives an approximate density of 2.3×10^{17} kg m⁻³.

Step 4: Conclusion (i) Energetic-particle scattering determines nuclear size, with $R = R_0 A^{1/3}$. (ii) $\rho = 3m_n/(4\pi R_0^3)$, so nuclear density is approximately independent of mass number.

Quick Tip to Solve: Cube the radius law first: $R^3 \propto A$. Nuclear mass also scales as A , so their ratio cannot depend on A .

28(a). Two charged conducting spheres of radii a and b are connected to each other by a wire. Find the ratio of the electric fields at their surfaces. [3 marks]

Solution:

Concept:

- Conductors joined by a conducting wire reach the same electrostatic potential: otherwise charge continues to flow through the wire.
- For a spherical conductor of radius r carrying charge Q , $V = kQ/r$ and the field just outside its surface is $E = kQ/r^2$, where $k = 1/(4\pi\epsilon_0)$.

Step 1: Use the common final potential Let the final charges on the spheres of radii a and b be Q_a and Q_b , respectively. In the usual textbook treatment, the spheres are sufficiently separated that each can be treated as a spherical conductor and the wire's effect is negligible. At equilibrium their potentials are equal:

$$V_a = V_b, \quad \frac{kQ_a}{a} = \frac{kQ_b}{b}.$$

Therefore $Q_a/Q_b = a/b$. Equal potential does not mean equal charge: the larger sphere must hold proportionately more charge to have the same potential.

Step 2: Compare the surface fields The electric fields immediately outside the two surfaces are normal to the surfaces, with magnitudes

$$E_a = \frac{k|Q_a|}{a^2}, \quad E_b = \frac{k|Q_b|}{b^2}.$$

Use the charge ratio found from the equilibrium condition:

$$\frac{E_a}{E_b} = \frac{|Q_a|}{|Q_b|} \frac{b^2}{a^2} = \frac{a}{b} \frac{b^2}{a^2} = \frac{b}{a}.$$

Equivalently, eliminating charge gives $E = |V|/r$. Thus, for a common nonzero potential, the smaller sphere has the stronger surface field. If $a = b$, the result correctly reduces to equal fields.

Step 3: Conclusion The required ratio is $E_a : E_b = b : a$, where the subscripts refer to the spheres of radii a and b , respectively.

Quick Tip to Solve: For connected spheres, first set potentials equal, then use $E = |V|/r$: the surface fields are inversely proportional to the radii.

28(b). A parallel plate capacitor (A) of capacitance C is charged by a battery to voltage V . The battery is disconnected and an uncharged capacitor (B) of capacitance $2C$ is connected across A. Find the ratio of

(i) final charges on A and B.

(ii) total electrostatic energy stored in A and B finally and that stored in A initially.

[3 marks]

Solution:

Concept:

- For a capacitor, $Q = CV$. Parallel-connected capacitors have the same potential difference in the final equilibrium state.
- After the battery is disconnected, charge is conserved during redistribution. Stored electrostatic energy is $U = \frac{1}{2}CV^2$; it need not remain conserved during charge sharing.

Step 1: Find the common final voltage Initially capacitor A has charge magnitude $Q_0 = CV$, while B is uncharged. Connecting B across A joins corresponding plates, so the charge on each connected set of plates is conserved. Let the final common potential difference be V_f . Then

$$CV = CV_f + 2CV_f = 3CV_f, \quad V_f = \frac{V}{3}.$$

The battery cannot maintain the original voltage because it has been disconnected.

Step 2: (i) Calculate the final charges Using the same final voltage for both capacitors gives

$$Q_{A,f} = C \frac{V}{3} = \frac{CV}{3}, \quad Q_{B,f} = 2C \frac{V}{3} = \frac{2CV}{3}.$$

Hence their final charge magnitudes are in the ratio 1 : 2. Their sum is CV , as required by charge conservation.

Step 3: (ii) Compare final and initial energies Initially only A stores electrostatic energy:

$$U_i = \frac{1}{2}CV^2.$$

Finally, add the energies of A and B:

$$\begin{aligned} U_f &= \frac{1}{2}C \left(\frac{V}{3}\right)^2 + \frac{1}{2}(2C) \left(\frac{V}{3}\right)^2 \\ &= \frac{CV^2}{18} + \frac{CV^2}{9} = \frac{CV^2}{6}, \\ \frac{U_f}{U_i} &= \frac{CV^2/6}{CV^2/2} = \frac{1}{3}. \end{aligned}$$

The missing stored energy is dissipated as heat and radiation during charge redistribution.

Step 4: Conclusion (i) $Q_{A,f} : Q_{B,f} = 1 : 2$. (ii) $U_f : U_i = 1 : 3$, with U_f the total final energy in both capacitors.

Quick Tip to Solve: After disconnecting the battery, conserve charge to find the shared voltage. For parallel capacitors the final charge ratio equals their capacitance ratio.

29. A potential difference V is applied across a conductor of length l and cross-sectional area A . Briefly explain how the current density j in the conductor will be affected if

(a) the potential difference V is doubled,

(b) the conductor were gradually stretched to reduce its cross-sectional area to $\frac{A}{2}$ and then the same potential difference V is applied across it. [3 marks]

Solution:

Concept:

- For a uniform ohmic conductor, $R = \rho l/A$ and $j = I/A = V/(\rho l)$, where ρ is resistivity, l is length and A is cross-sectional area.
- During uniform stretching the conductor's volume is conserved: $Al = A'l'$. Assume temperature and hence resistivity remain unchanged.

Step 1: Express the initial current density Apply Ohm's law to the original conductor:

$$I = \frac{V}{R} = \frac{VA}{\rho l}, \quad j = \frac{I}{A} = \frac{V}{\rho l}.$$

For a given resistivity it depends on the electric field $E = V/l$, through $j = E/\rho$; this also helps distinguish changes in current from changes in current density.

Step 2: (a) Double the potential difference The length and cross-sectional area are unchanged in this part. Replacing V by $2V$ gives

$$j_a = \frac{2V}{\rho l} = 2j.$$

The field inside the conductor doubles, so its current and current density both double under the stated constant-temperature assumption.

Step 3: (b) Find the new length after stretching The area is reduced to $A' = A/2$. Since stretching does not remove material, conservation of volume gives

$$Al = \frac{A}{2}l', \quad l' = 2l.$$

Apply the original voltage V across this doubled length:

$$j_b = \frac{V}{\rho l'} = \frac{V}{2\rho l} = \frac{j}{2}.$$

As a check, the resistance becomes

$$R' = \rho \frac{2l}{A/2} = 4R, \quad I' = \frac{I}{4}.$$

Hence $I'/A' = (I/4)/(A/2) = j/2$, confirming the result.

Step 4: Conclusion (a) The current density doubles: $j_a = 2j$. (b) For the final area $A/2$, the length doubles and the current density halves: $j_b = j/2$.

Quick Tip to Solve: Use $Al = \text{constant}$ before applying $j = V/(\rho l)$. Stretching changes both the length and area.

30. A resistor of $50\ \Omega$, a capacitor of $\left(\frac{25}{\pi}\right)\ \mu\text{F}$ and an inductor of $\left(\frac{4}{\pi}\right)\ \text{H}$ are connected in series across an ac source whose voltage (in volt) is given by $V = 70 \sin(100\pi t)$. Calculate:

- the net reactance of the circuit,
- the impedance of the circuit,
- the effective value of current in the circuit.

[3 marks]

Solution:

Concept:

- In a series LCR circuit the same current flows through all components. The inductive and capacitive reactances are $X_L = \omega L$ and $X_C = 1/(\omega C)$, where ω is the angular frequency.
- The signed net reactance is $X = X_L - X_C$, and the impedance is $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Reactances subtract because the inductor and capacitor voltages have opposite phases.
- For a sinusoidal voltage $V = V_0 \sin \omega t$, the effective voltage is $V_{\text{rms}} = V_0/\sqrt{2}$, and the effective current is $I_{\text{rms}} = V_{\text{rms}}/Z$.

Step 1: Identify the angular frequency and convert capacitance Comparing $V = 70 \sin(100\pi t)$ with $V_0 \sin \omega t$ gives $V_0 = 70\ \text{V}$ and $\omega = 100\pi\ \text{rad s}^{-1}$. The given component values are

$$R = 50\ \Omega, \quad L = \frac{4}{\pi}\ \text{H}, \quad C = \frac{25}{\pi} \times 10^{-6}\ \text{F}.$$

The coefficient of time in the sine is angular frequency, so no additional factor of 2π is needed.

Step 2: (a) Calculate the two reactances Substituting the values in their respective expressions,

$$X_L = (100\pi) \frac{4}{\pi} = 400\ \Omega,$$

$$X_C = \frac{1}{(100\pi)(25/\pi)10^{-6}} = 400\ \Omega.$$

Therefore $X = X_L - X_C = 400 - 400 = 0\ \Omega$. The circuit is at series resonance: the two nonzero reactances cancel in the net voltage relation.

Step 3: (b) Calculate the impedance Since the net reactance vanishes,

$$Z = \sqrt{50^2 + (400 - 400)^2} = 50\ \Omega.$$

The impedance is purely resistive at this frequency; it is not the sum of the magnitudes of the individual reactances.

Step 4: (c) Obtain the effective current The stated 70 V is the peak voltage. Hence

$$I_{\text{rms}} = \frac{70/\sqrt{2}}{50} = \frac{1.4}{\sqrt{2}}\ \text{A} \simeq 0.990\ \text{A}.$$

The value $70/50 = 1.4\ \text{A}$ would be the peak current, whereas the question asks for the effective value.

Step 5: Conclusion $X = 0\ \Omega, \quad Z = 50\ \Omega, \quad I_{\text{rms}} \simeq 0.99\ \text{A}.$

Quick Tip to Solve: Read angular frequency directly from the sine argument and convert microfarads to farads before testing whether the reactances cancel.

Section D (15 marks)

31(a). (i) Define coefficient of self-induction. Obtain an expression for self-inductance of a long solenoid of length l , area of cross-section A having N turns.

(ii) Calculate the self-inductance of a coil using the following data obtained when an AC source of frequency $\left(\frac{200}{\pi}\right)$ Hz and a DC source is applied across the coil.

AC Source		
S.No.	V (Volts)	I (A)
1	3.0	0.5
2	6.0	1.0
3	9.0	1.5

DC Source		
S.No.	V (Volts)	I (A)
1	4.0	1.0
2	6.0	1.5
3	8.0	2.0

[5 marks]

Solution:

Concept:

- Self-inductance L is the magnetic flux linkage per unit current: $N\Phi = LI$, where N is the number of turns and Φ is the flux through each turn, for a linear magnetic medium.
- The self-induced emf is $\varepsilon = -L dI/dt$. The minus sign expresses opposition to the change in current, as required by Lenz's law.
- For a long solenoid of permeability μ and turn density $n = N/l$, the internal field is $B = \mu nI$. In air or vacuum, $\mu = \mu_0$.
- A coil has both resistance and inductance. At steady DC, $V/I = R$; for AC at angular frequency ω , $V_{\text{rms}}/I_{\text{rms}} = Z = \sqrt{R^2 + (\omega L)^2}$.

Step 1: (i) Define the coefficient of self-induction The coefficient of self-induction of a coil is the total magnetic flux linked with it per unit current flowing through it:

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

Equivalently, it is the magnitude of the emf induced in the coil when its current changes at unit rate. A coil has self-inductance 1 H if an emf of magnitude 1 V is induced for a current change of 1 A s⁻¹. Thus 1 H = 1 V s A⁻¹.

Step 2: (i) Determine the flux linkage of the long solenoid Consider a solenoid of length l , cross-sectional area A and N closely wound turns carrying current I . Neglecting end effects, its nearly uniform internal magnetic field is

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

for an air core. The field is parallel to the area vector of each turn, so the magnetic flux through one turn is

$$\Phi = BA = \mu_0 \frac{N}{l} IA.$$

Each of the N turns links approximately the same flux; hence the total flux linkage is

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

Step 3: (i) Identify the self-inductance Comparing the flux-linkage expression with $N\Phi = LI$ gives

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

If the solenoid is filled with a linear magnetic medium of relative permeability μ_r , replace μ_0 by $\mu = \mu_0 \mu_r$. The result assumes that flux leakage and end effects are negligible. The squared dependence on the number of turns arises because more turns both strengthen the field and increase the linked flux.

Step 4: (ii) Extract the resistance and impedance from the data Under steady DC, the current is constant and the self-induced emf is zero. All three DC measurements therefore yield the winding resistance:

$$R = \frac{4.0}{1.0} = \frac{6.0}{1.5} = \frac{8.0}{2.0} = 4.0 \, \Omega.$$

For the AC measurements, the voltage-to-current ratio gives the impedance:

$$Z = \frac{3.0}{0.5} = \frac{6.0}{1.0} = \frac{9.0}{1.5} = 6.0 \, \Omega.$$

Consistency of the three ratios in each set supports treating the coil as a series resistance and inductance.

Step 5: (ii) Calculate the inductance from the reactance The angular frequency corresponding to the given frequency is

$$\omega = 2\pi f = 2\pi \left(\frac{200}{\pi} \right) = 400 \, \text{rad s}^{-1}.$$

Since the resistive and inductive voltage drops are perpendicular in phase,

$$X_L = \sqrt{Z^2 - R^2} = \sqrt{6^2 - 4^2} = \sqrt{20} \, \Omega,$$

$$L = \frac{X_L}{\omega} = \frac{\sqrt{20}}{400} \, \text{H} \simeq 0.01118 \, \text{H}.$$

Subtracting R directly from Z would be incorrect because these voltage contributions add as phasors.

Step 6: Conclusion The coefficient of self-induction is flux linkage per unit current, measured in henry. For a long air-core solenoid, $L = \mu_0 N^2 A / l$. For the given coil, $L \simeq 1.12 \times 10^{-2} \, \text{H} = 11.2 \, \text{mH}$.

Quick Tip to Solve: Use the DC data to find resistance first; then use the squared difference of AC impedance and resistance to isolate inductive reactance.

31(b). (i) With the help of a labelled diagram, describe the principle and working of an ac generator. Hence, obtain an expression for the instantaneous value of the emf generated.

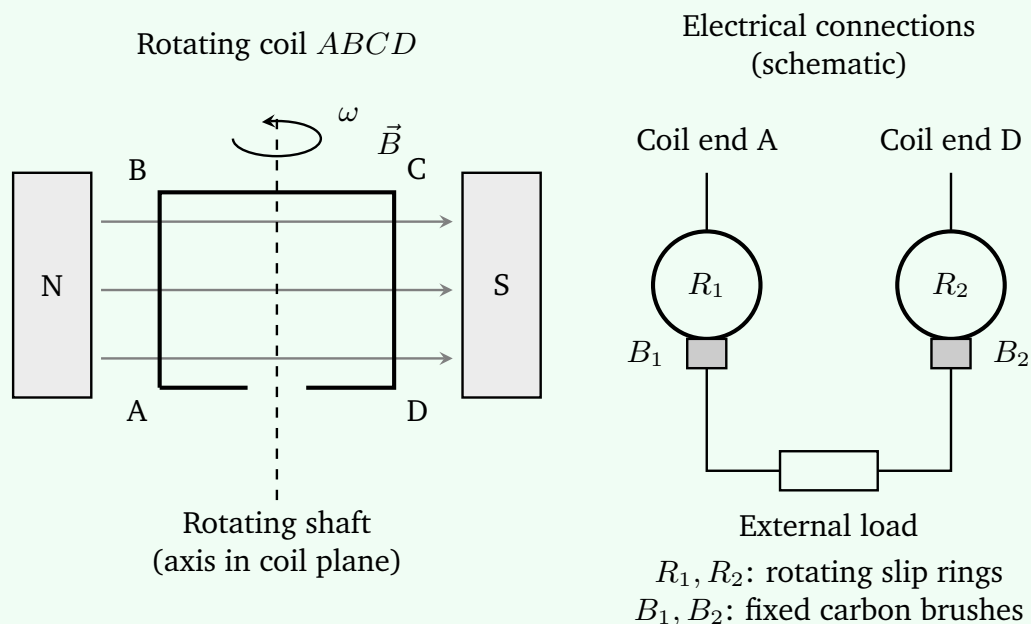
(ii) The coil of an ac generator consists of 100 turns of wire, each of area 0.5 m^2 . The resistance of the wire is 100Ω . The coil is rotating in a magnetic field of 0.8 T perpendicular to its axis of rotation, at a constant angular speed of $60 \text{ radian per second}$. Calculate the maximum emf generated and power dissipated in the coil. [5 marks]

Solution:

Concept:

- An ac generator converts mechanical energy into electrical energy by electromagnetic induction. Faraday's law gives $e = -d(N\Phi)/dt$, where $N\Phi$ is the total magnetic flux linkage.
- For a plane coil of N turns and area A rotating in a uniform field B , the flux linkage is $NBA \cos \theta$, where θ is the angle between the field and the coil's normal.
- In a resistive coil, $p(t) = e^2(t)/R$. For sinusoidal emf of amplitude E_0 , $E_{\text{rms}} = E_0/\sqrt{2}$ and the average heating power is $E_0^2/(2R)$.

Step 1: (i) Describe the construction and principle A rectangular insulated coil $ABCD$ is mounted on a rotating shaft between the north and south poles of a magnet. The axis of rotation lies in the plane of the coil and is perpendicular to the magnetic field. The two ends of the coil connect separately to two insulated slip rings R_1 and R_2 , which rotate with the shaft. Stationary carbon brushes B_1 and B_2 touch the rings and connect the coil to an external circuit. The diagram shows the rotating coil and, separately, its electrical connections. The rings remain electrically isolated from one another.



Rotating coil between magnet poles; separate connection schematic of insulated slip rings and stationary brushes.

Step 2: Explain the working through one revolution Mechanical rotation changes the magnetic flux linked with the coil and therefore induces an emf. During the next half-revolution, the direction in which each active side cuts the magnetic field reverses, so the polarity of the induced emf reverses. The slip rings maintain contact with the same coil ends throughout the rotation, delivering an alternating emf to the external circuit. The emf is zero when the coil's normal is parallel to the field and has maximum magnitude when the normal is perpendicular to the field. Mechanical work supplied to

maintain the rotation provides the electrical energy, in accordance with Lenz's law.

Step 3: Derive the instantaneous emf Choose $t = 0$ when the coil's normal is parallel to $\vec{B}$. If its constant angular speed is ω , then $\theta = \omega t$. The total flux linkage and induced emf are

$$\begin{aligned} N\Phi(t) &= NBA \cos(\omega t), \\ e(t) &= -\frac{d}{dt}\{NBA \cos(\omega t)\} \\ &= NBA\omega \sin(\omega t) = E_0 \sin(\omega t), \\ E_0 &= NBA\omega. \end{aligned}$$

Thus the emf is sinusoidal, with frequency $f = \omega/(2\pi)$. A different initial position changes only the phase of the sine function, not its amplitude.

Step 4: (ii) Calculate the maximum emf The given area is the area of each turn, so it must be multiplied by the number of turns. Substituting $N = 100$, $A = 0.5 \text{ m}^2$, $B = 0.8 \text{ T}$ and $\omega = 60 \text{ rad s}^{-1}$,

$$E_0 = 100 \times 0.5 \times 0.8 \times 60 = 2400 \text{ V}.$$

For the phase choice above, the instantaneous emf is therefore $e(t) = 2400 \sin(60t) \text{ V}$, with t in seconds.

Step 5: Calculate the power dissipated in the coil Taking the stated coil resistance $R = 100 \Omega$ as the resistance of the closed circuit, with inductive effects neglected in this calculation, the rms current and mean heating power are

$$\begin{aligned} I_{\text{rms}} &= \frac{E_0}{\sqrt{2}R} = 12\sqrt{2} \text{ A}, \\ P_{\text{av}} &= I_{\text{rms}}^2 R = \frac{E_0^2}{2R} \\ &= \frac{2400^2}{2 \times 100} = 28800 \text{ W}. \end{aligned}$$

Here power dissipated denotes the cycle-average heating power. For clarity, the instantaneous power is $p(t) = 57600 \sin^2(60t) \text{ W}$, and its peak value is 57600 W . Using the peak emf directly in E^2/R would give this peak power, rather than the average power.

Step 6: Conclusion The generator works by electromagnetic induction, producing $e(t) = NBA\omega \sin(\omega t)$. Its maximum emf is $\boxed{2400 \text{ V}}$, and the average power dissipated is $\boxed{2.88 \times 10^4 \text{ W}}$ (peak power $5.76 \times 10^4 \text{ W}$).

Quick Tip to Solve: Use the area of one turn in $E_0 = NBA\omega$; for average heating, first divide the peak emf by $\sqrt{2}$, or use $P = E_0^2/(2R)$ directly.

32(a). (i) State Huygen's principle. With the help of a diagram, show how a plane wave is reflected from a surface. Hence verify the law of reflection.

(ii) A concave mirror of focal length 12 cm forms a three times magnified virtual image of an object. Find the distance of the object from the mirror. [5 marks]

Solution:

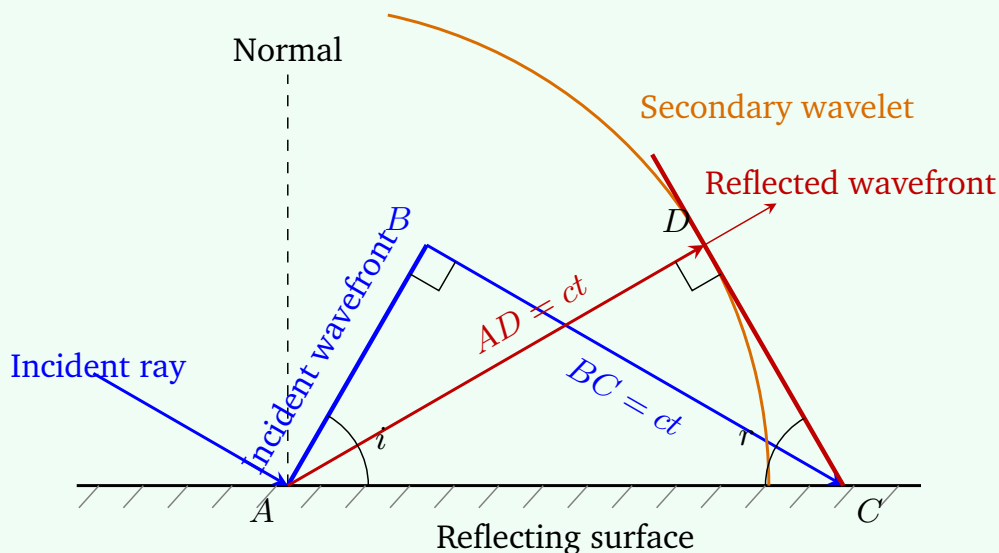
Concept:

- Huygens' principle: every point of a wavefront acts as a source of secondary wavelets which spread through the medium with the speed of the wave. The forward envelope of these wavelets at a later instant gives the new wavefront.
- Rays are perpendicular to wavefronts. For reflection in the same medium, incident and reflected disturbances travel with the same speed c .
- For a spherical mirror, $1/f = 1/v + 1/u$ and linear magnification $m = -v/u$, where f , u and v are signed focal, object and image distances measured from the pole.

Step 1: (i) Construct the reflected wavefront Let AB be a plane incident wavefront meeting the plane reflecting surface AC first at A . The incident rays are normal to AB ; hence $BC \perp AB$. In the time t taken by the disturbance at B to reach C , the secondary wavelet originating at A has radius

$$BC = ct, \quad AD = ct.$$

Draw the tangent CD from C to this wavelet. This tangent is the reflected plane wavefront, the common forward envelope of the secondary wavelets emitted by the points of the reflecting surface. The radius AD is perpendicular to CD and gives the reflected-ray direction. The diagram shows a section perpendicular to the reflecting surface; the dashed line at A is its normal.



Huygens' construction: AB incident wavefront, CD reflected wavefront, and $BC = AD = ct$.

Step 2: Verify the laws of reflection Triangles ABC and ADC are right-angled at B and D , respectively. They have the same hypotenuse AC , and $BC = AD = ct$. Thus, by right-angle-hypotenuse-side congruence,

$$\angle BAC = \angle ACD.$$

Because the incident ray is perpendicular to AB and the normal is perpendicular to AC , $\angle BAC$ equals the angle of incidence i . Similarly, $\angle ACD$ equals the angle of reflection r . Therefore $i = r$.

The incident ray, reflected ray and surface normal all lie in the plane of this construction, establishing the coplanarity law as well.

Step 3: (ii) Apply the magnification and mirror formulae Use the Cartesian sign convention, with the incident light travelling towards the mirror. A concave mirror has $f = -12$ cm. Its virtual image is erect, so the stated threefold magnification means $m = +3$, not -3 . Therefore

$$-\frac{v}{u} = 3 \Rightarrow v = -3u.$$

Substitute this relation into the mirror formula:

$$\begin{aligned} \frac{1}{-12} &= \frac{1}{-3u} + \frac{1}{u} = \frac{2}{3u}, \\ 3u &= -24 \text{ cm}, \\ u &= -8 \text{ cm}, \quad v = +24 \text{ cm}. \end{aligned}$$

The object is between the pole and the focus, since $|u| < |f|$, consistent with an erect, enlarged virtual image behind the mirror.

Step 4: Conclusion Huygens' construction gives $i = r$, with the incident ray, reflected ray and normal coplanar. The object must be placed 8 cm in front of the concave mirror ($u = -8$ cm).

Quick Tip to Solve: In Huygens' reflection construction compare the equal distances $BC = AD = ct$. For an erect virtual mirror image, take magnification as positive before using $m = -v/u$.

OR

32(b). (i) Draw a labelled ray diagram showing the image formation by a refracting telescope. Define its magnifying power. Write two limitations of a refracting telescope over a reflecting telescope.

(ii) The focal lengths of the objective and the eye-piece of a compound microscope are 1.0 cm and 2.5 cm respectively. Find the tube length of the microscope for obtaining a magnification of 300.

[5 marks]

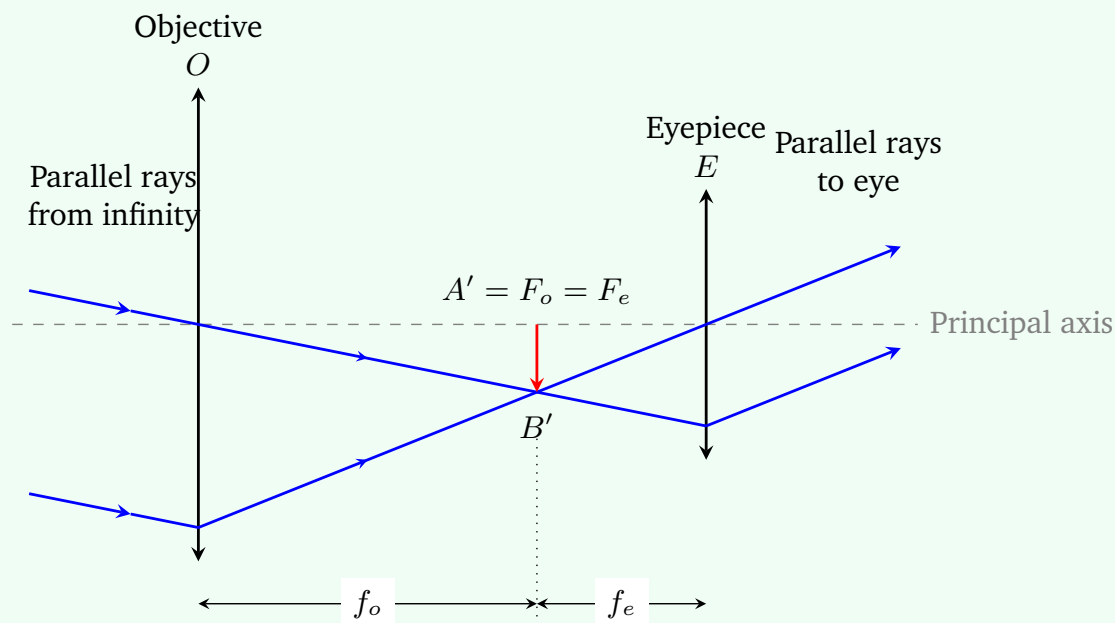
Solution:

Concept:

- A refracting astronomical telescope uses a long-focal-length objective and a short-focal-length eyepiece. The objective forms a real, inverted intermediate image; the eyepiece magnifies its angular size.
- Angular magnifying power is $M = \beta/\alpha$, where β is the angle subtended at the eye by the final image and α is the angle subtended by the distant object at the unaided eye. For normal adjustment, $M = -f_o/f_e$.
- For a compound microscope, $|M| \simeq (L/f_o)m_e$, where L is the effective tube length and m_e the eyepiece magnification. With the least distance of distinct vision $D = 25$ cm, $m_e = D/f_e$ for a relaxed eye and $m_e = 1 + D/f_e$ for a final image at the near point.

Step 1: (i) Construct the telescope ray diagram Show the telescope in normal adjustment. Parallel rays from a distant off-axis object enter the objective O and meet at B' in its focal plane. The real inverted image $A'B'$ lies at the first focal plane of the eyepiece E , so rays emerging from the eyepiece are parallel and the final image is at infinity. The common focal point on the axis is $F_o = F_e = A'$; the

lens separation is $f_o + f_e$. The diagram traces two rays from the same distant object point.



Refracting telescope in normal adjustment: the intermediate image lies in the common focal plane and emergent rays are parallel.

Step 2: Define and obtain the telescope magnifying power Magnifying power is the ratio of the angular size of the final image seen through the telescope to the angular size of the object seen directly. If the intermediate image has height of magnitude h , the small-angle approximation gives $|\alpha| \simeq h/f_o$ and $|\beta| \simeq h/f_e$. Hence,

$$|M| = \frac{|\beta|}{|\alpha|} = \frac{f_o}{f_e}, \quad M = -\frac{f_o}{f_e}.$$

The minus sign indicates that the final image is inverted relative to the distant object.

Step 3: State two limitations of a refracting telescope First, its objective lens suffers from chromatic aberration: different wavelengths are refracted by different amounts and focus at different positions. A reflecting telescope's mirror does not disperse light in this way. Second, making and supporting a large objective lens is difficult: it is heavy and can be supported only at its rim, so it may deform. A large mirror can be supported from behind, permitting a larger practical aperture and greater light-gathering power.

Step 4: (ii) Calculate the microscope tube length Use $f_o = 1.0$ cm, $f_e = 2.5$ cm, $|M| = 300$ and the standard value $D = 25$ cm. Under normal adjustment, the final image is at infinity and the eyepiece magnification is $25/2.5 = 10$. Thus, using the usual CBSE tube-length approximation,

$$300 = \frac{L}{1.0 \text{ cm}} \frac{25}{2.5}, \quad L = \frac{300(1.0)(2.5)}{25} \text{ cm} = 30 \text{ cm}.$$

The printed question does not specify the final-image position. If the microscope is instead adjusted for maximum magnification with its final image at the near point, the eyepiece magnification is $1 + 25/2.5 = 11$, giving

$$L = \frac{|M|f_o}{1 + D/f_e} = \frac{300(1.0)}{11} \text{ cm} \simeq 27.3 \text{ cm}.$$

These values refer to the effective tube length in the standard approximate microscope formula; the viewing condition must accompany the result.

Step 5: Conclusion The telescope in normal adjustment has $M = -f_o/f_e$; chromatic aberration and difficulty constructing and supporting a large objective are two limitations. The microscope requires $L = 30 \text{ cm}$ for normal adjustment, or $L \simeq 27.3 \text{ cm}$ for a final image at the near point, which the printed question leaves unspecified.

Quick Tip to Solve: For the microscope, calculate the eyepiece factor first: it is 10 for a relaxed eye and 11 at the near point. State the viewing condition before finding the tube length.

33(a). (i) Use Gauss' law to obtain an expression for the electric field due to an infinitely long thin straight wire with uniform linear charge density λ .

(ii) An infinitely long positively charged straight wire has a linear charge density λ . An electron is revolving in a circle with a constant speed v such that the wire passes through the centre, and is perpendicular to the plane, of the circle. Find the kinetic energy of the electron in terms of magnitudes of its charge and linear charge density λ on the wire.

(iii) Draw a graph of kinetic energy as a function of linear charge density λ .

[5 marks]

Solution:

Concept:

- Gauss' law states that $\oint \vec{E} \cdot d\vec{S} = Q_{\text{enc}}/\epsilon_0$, where Q_{enc} is the enclosed charge and ϵ_0 is the permittivity of free space.
- Cylindrical symmetry makes the field of an infinite uniformly charged wire radial, with a magnitude depending only on the perpendicular distance r from the wire.
- For a circular orbit, the inward force is mv^2/r , and the kinetic energy is $K = mv^2/2$. The magnitude of the electron's charge is denoted by e .

Step 1: (i) Choose a cylindrical Gaussian surface Take a closed cylinder of radius r and length L , coaxial with the wire. The electric field has the same magnitude at every point on the curved surface and is parallel to its outward normal for positive λ . On the two plane ends, the field is perpendicular to the area vectors, so the flux through each end is zero. The charge inside the cylinder is $Q_{\text{enc}} = \lambda L$.

Step 2: Apply Gauss' law to the curved surface Only the curved surface, of area $2\pi rL$, contributes to the flux. Therefore,

$$E(2\pi rL) = \frac{\lambda L}{\epsilon_0}, \quad E = \frac{\lambda}{2\pi\epsilon_0 r} \quad (\lambda > 0).$$

In vector form, $\vec{E} = \lambda\hat{r}/(2\pi\epsilon_0 r)$. Thus the field points radially outward for a positively charged wire and inward for a negatively charged wire; its magnitude is $|\lambda|/(2\pi\epsilon_0 r)$. The arbitrary length L cancels, as required for an infinite wire.

Step 3: (ii) Equate the electric force to the centripetal force Let the electron's orbital radius be r and its mass be m . Since the wire is positively charged, the force on the electron is directed towards the wire. It supplies the required centripetal force, while remaining perpendicular to the instantaneous velocity:

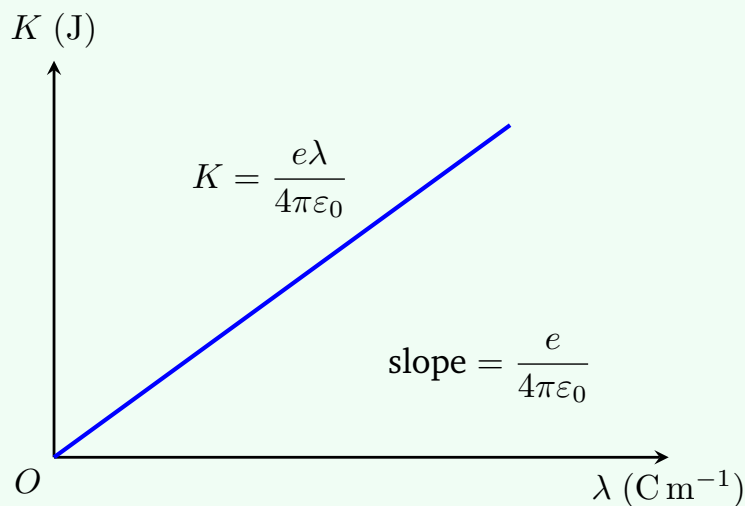
$$\frac{mv^2}{r} = eE = \frac{e\lambda}{2\pi\epsilon_0 r}.$$

Cancelling r and multiplying by $1/2$ gives

$$mv^2 = \frac{e\lambda}{2\pi\epsilon_0}, \quad K = \frac{1}{2}mv^2 = \frac{e\lambda}{4\pi\epsilon_0}.$$

Hence, in the stated classical model, the kinetic energy depends on the linear charge density and is independent of the orbital radius and the electron's mass.

Step 4: (iii) Plot kinetic energy against linear charge density The equation $K = [e/(4\pi\epsilon_0)]\lambda$ has the form $y = sx$, with a positive constant slope $s = e/(4\pi\epsilon_0)$. For the positive linear charge densities considered here, the graph is a straight line in the first quadrant. Its extrapolation passes through the origin; at zero charge density there is no electrostatic force to sustain a nonzero-speed circular orbit.



Kinetic energy increases linearly with positive linear charge density.

Step 5: Conclusion The wire's field is $\vec{E} = \lambda\hat{r}/(2\pi\epsilon_0 r)$. The revolving electron has kinetic energy $K = e\lambda/(4\pi\epsilon_0)$, where e and λ are magnitudes. The K -versus- λ graph is a straight line through the origin with slope $e/(4\pi\epsilon_0)$.

Quick Tip to Solve: Cancel the common $1/r$ in the electric and centripetal forces before finding the kinetic energy; this immediately reveals why the orbital radius disappears.

33(b). (i) Consider two identical point charges located at points $(0, 0)$ and $(a, 0)$.

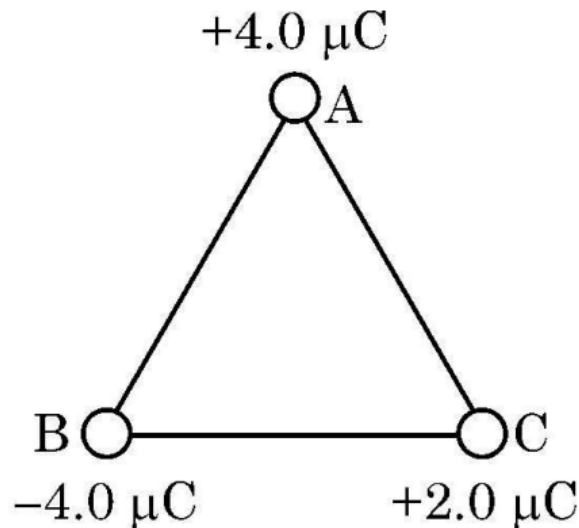
(1) Is there a point on the line joining them at which the electric field is zero?

(2) Is there a point on the line joining them at which the electric potential is zero?

Justify your answers for each case.

(ii) State the significance of negative value of electrostatic potential energy of a system of charges.

Three charges are placed at the corners of an equilateral triangle ABC of side 2.0 m as shown in figure. Calculate the electric potential energy of the system of three charges. [5 marks]



Solution:

Concept:

- Electric fields add vectorially, whereas electric potentials add algebraically: $\vec{E} = \sum_i \vec{E}_i$ and $V = \sum_i kq_i/r_i$, with $k = 1/(4\pi\epsilon_0)$.
- Taking zero potential at infinity, the electrostatic energy of a system of point charges is $U = \sum_{i < j} kq_i q_j / r_{ij}$. Each distinct pair contributes once.
- Negative electrostatic potential energy means that the configuration lies below the energy of charges infinitely separated at rest; positive external work is required to separate the charges quasistatically to infinity.

Step 1: (i)(1) Locate the point where the fields cancel Denote each identical nonzero charge by q . Between the charges, at $(x, 0)$ with $0 < x < a$, the two electric fields have opposite directions. Their magnitudes are equal when

$$\frac{k|q|}{x^2} = \frac{k|q|}{(a-x)^2} \Rightarrow x = a - x = \frac{a}{2}.$$

Thus the net field is zero at the midpoint $(a/2, 0)$, whether both charges are positive or both are negative. Outside the segment joining the charges, the fields have the same direction and cannot cancel. At either charge itself the point-charge field is undefined.

Step 2: (i)(2) Check whether the potentials can cancel At any finite point on the line other than the

charge positions, the distances r_1 and r_2 are positive, so

$$V = kq \left(\frac{1}{r_1} + \frac{1}{r_2} \right).$$

Both contributions have the sign of q ; they cannot cancel. There is therefore no finite point on the line at which the potential is zero, taking the conventional reference $V = 0$ at infinity. At the midpoint, for example, $V = 4kq/a \neq 0$, despite the electric field there being zero. The potential tends to zero only in the limit of infinite distance.

Step 3: (ii) Interpret a negative system energy With the energy of infinitely separated charges chosen as zero, a negative value of U means that energy is released when the system is assembled from infinity. Conversely, an external agent must supply net work $W_{\text{ext}} = 0 - U = |U|$ to separate all the charges quasistatically to infinity. The configuration is energetically bound relative to complete separation; a negative total energy by itself does not imply that every pair attracts or that the given arrangement is a stable mechanical equilibrium.

Step 4: Add the three pair energies of the triangle From the figure, $q_A = +4.0 \times 10^{-6} \text{ C}$, $q_B = -4.0 \times 10^{-6} \text{ C}$, and $q_C = +2.0 \times 10^{-6} \text{ C}$. Each separation is $r = 2.0 \text{ m}$. Hence

$$\begin{aligned} U &= \frac{k}{r} (q_A q_B + q_B q_C + q_C q_A) \\ &= \frac{9 \times 10^9}{2.0} [(-16 - 8 + 8) \times 10^{-12}] \\ &= -7.2 \times 10^{-2} \text{ J}. \end{aligned}$$

The BC attractive pair contributes -0.036 J , and the CA repulsive pair contributes $+0.036 \text{ J}$. These cancel, leaving the AB pair contribution of -0.072 J . This also checks the sign and arithmetic of the total.

Step 5: Conclusion The electric field vanishes at $(a/2, 0)$, but the potential is nonzero at every finite point where it is defined. Negative system energy indicates that work must be supplied for complete separation to infinity. For the given triangle, $U = -7.2 \times 10^{-2} \text{ J}$; the net work needed for quasistatic complete separation is $+7.2 \times 10^{-2} \text{ J}$.

Quick Tip to Solve: Keep charge signs in each product and count the three pairs only once. Here the BC and CA energies cancel because their distances are equal and their charge products are opposite.

Section E (8 marks)

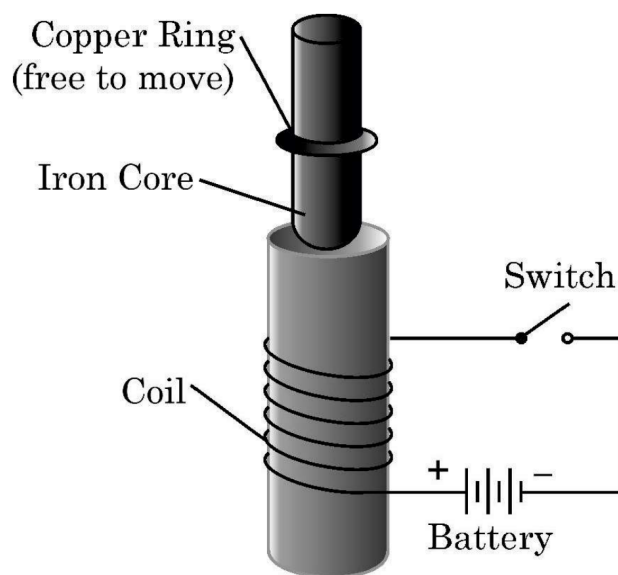
Note : Questions number 34 and 35 are case study based questions. Read the following paragraph and answer the questions.

34(a). Consider the experimental set up shown in the figure. This jumping ring experiment is an outstanding demonstration of some simple laws of Physics. A conducting non-magnetic ring is placed over the vertical core of a solenoid. When current is passed through the solenoid, the ring is thrown off.

Answer the following questions:

- Explain the reason of jumping of the ring when the switch is closed in the circuit.
- What will happen if the terminals of the battery are reversed and the switch is closed? Explain.
- Explain the two laws that help us understand this phenomenon.

[4 marks]



Solution:

Concept:

- Faraday's law states that a changing magnetic flux through a closed conducting loop produces an induced emf: $\mathcal{E} = -d\Phi_B/dt$ for a single-turn ring, where Φ_B is the magnetic flux through it.
- Lenz's law fixes the direction of the induced current: its magnetic effect opposes the change in magnetic flux which produces it.
- A conducting ring can carry induced current even though its material is non-magnetic. The current-carrying ring interacts with the solenoid's non-uniform magnetic field near its end.

Step 1: (i) Explain the jump when the switch closes Initially the solenoid carries no current. On closing the switch, its current grows from zero, so the magnetic flux through the copper ring increases. Faraday's law therefore produces an emf and a current in the closed ring. By Lenz's law, the ring's magnetic field opposes this increasing flux. The ring and solenoid consequently behave as opposing coaxial magnetic dipoles; their adjacent faces have like magnetic polarity. The resulting repulsive force pushes the freely movable ring upward, away from the solenoid, causing it to jump. The energy for this motion comes from the battery. With a steady direct current, the flux becomes constant and this induction effect ceases; the jump is associated with the switching transient.

Step 2: (ii) Reverse the battery connections Reversing the battery reverses the direction of the

solenoid's increasing magnetic field at switch-on. The induced emf and current in the ring also reverse, because they must still oppose the new increase of flux. Thus both magnetic polarities reverse together: the adjacent faces remain like poles and the interaction is again repulsive. The ring therefore jumps upward again, assuming the same initial conditions and current magnitude. Reversing the battery does not turn the switch-on repulsion into attraction.

Step 3: (iii) State the two laws and their roles Faraday's law of electromagnetic induction states that an emf is induced whenever the magnetic flux linked with a circuit changes, and its magnitude equals the rate of change of flux linkage:

$$|\mathcal{E}| = N \left| \frac{d\Phi_B}{dt} \right|.$$

Here N is the number of turns and Φ_B is the flux per turn; the ring has $N = 1$. This law explains why a current is induced at switch-on. Lenz's law states that the direction of the induced current is such that its magnetic effect opposes the change in flux producing it. The minus sign in $\mathcal{E} = -N d\Phi_B/dt$ expresses this law. It determines the direction of the ring current and explains why the switch-on force is repulsive in either battery orientation.

Step 4: Conclusion The ring jumps because the increasing solenoid flux induces a current whose magnetic effect opposes that increase, giving an upward repulsive force. It also jumps with the battery reversed. Faraday's law explains the induction, and Lenz's law explains its direction.

Quick Tip to Solve: At switch-on, track the change in flux, not just its direction: reversing the source reverses both currents, so the repulsion persists.

OR

34(b). Briefly explain various ways to increase the strength of magnetic field produced by a given solenoid. [4 marks]

Solution:

Concept:

- The magnetic field well inside a long solenoid is approximately $B = \mu n I = \mu_0 \mu_r (N/L) I$, where I is current, N is the number of turns, L is the winding length, and $n = N/L$ is the number of turns per unit length.
- The permeability $\mu = \mu_0 \mu_r$ describes the magnetic response of the core. An air core has μ_r approximately equal to one, whereas soft iron can provide much greater permeability.

Step 1: Relate the field to the controllable quantities Ampere's circuital law applied to a long, closely wound solenoid gives $HL = NI$, with H the magnetising field strength. Hence

$$H = \frac{NI}{L} = nI, \quad B = \mu H = \mu n I.$$

The field therefore depends on the current, the turn density and the material placed inside the solenoid. For a given unchanged winding, N and L are fixed, so current and core material are the directly adjustable factors.

Step 2: Increase the current through the solenoid Pass a larger current through the winding, for example by raising the applied potential difference or reducing the external series resistance. Keeping turn density and core permeability fixed gives $B \propto I$: doubling the current approximately doubles the

magnetic field in the linear regime. The current should remain within the winding's heating limit, since the dissipated power is I^2R , with R the wire resistance.

Step 3: Insert a suitable magnetic core Place a soft-iron core inside the solenoid, replacing the air core. Soft iron becomes strongly magnetised in the coil's field, and its magnetisation adds to that field. Its much larger permeability therefore increases B for the same winding and current. This enhancement is limited by magnetic saturation: the proportionality to an assumed constant μ_r cannot be extended to arbitrarily large fields.

Step 4: Increase the turn density if the winding can be modified More turns per unit length increase the magnetic effects that add along the solenoid's axis. Thus, if modification of the winding is allowed, add turns over the same length, or bring the existing turns closer together while retaining a solenoid geometry. Since $n = N/L$, either change raises n , and consequently raises B when the current is maintained. Merely increasing the total number of turns while increasing the length in the same ratio leaves n unchanged and does not provide this increase.

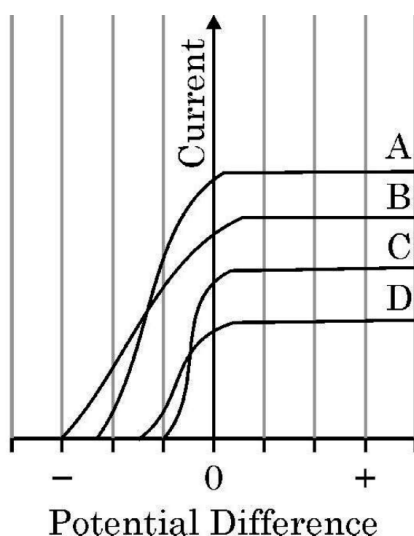
Step 5: Conclusion Increase the current and insert a soft-iron core to strengthen the field of the given solenoid. If its winding may be modified, increasing the number of turns per unit length also strengthens the field, as described by $B = \mu nI$.

Quick Tip to Solve: Start from $B = \mu nI$ and vary one factor at a time; for an unchanged winding, turn density is fixed, so adjust current or core material.

35(a). Figure shows the variation of photoelectric current measured in a photo cell circuit as a function of the potential difference between the plates of the photo cell when light beams A, B, C and D of different wavelengths are incident on the photo cell. Examine the given figure and answer the following questions:

- (i) Which light beam has the highest frequency and why?
- (ii) Which light beam has the longest wavelength and why?
- (iii) Which light beam ejects photoelectrons with maximum momentum and why?

[4 marks]



Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi = eV_s$, where ν is incident frequency, ϕ the work function of the common photocathode and $V_s > 0$ the magnitude of stopping potential.
- Light wavelength and frequency obey $\lambda = c/\nu$. The largest emitted electron momentum obeys $p_{\max} = \sqrt{2m_e K_{\max}}$, where m_e is electron mass.
- The negative voltage where photocurrent vanishes gives $-V_s$. Saturation current measures the rate of collection of emitted electrons; its height does not determine their maximum kinetic energy.

Step 1: Trace the curves to their stopping points Follow each labelled plateau back to the negative-potential axis, taking care where curves cross. Curve B meets the axis farthest to the left; then come A, D and C. Thus the stopping-potential magnitudes satisfy

$$V_{s,B} > V_{s,A} > V_{s,D} > V_{s,C}.$$

Although A has the greatest saturation current, B requires the strongest retarding potential to stop its fastest electrons. The intercept, rather than the plateau height, is the relevant observation.

Step 2: Compare the incident frequencies for part (i) The same photocell has the same work function for all four beams. Rearranging Einstein's equation gives

$$\nu = \frac{\phi + eV_s}{h}.$$

A larger stopping-potential magnitude therefore requires a greater photon frequency. Use the leftmost intercept identified above to rank the frequencies.

Step 3: Compare the wavelengths for part (ii) The intercept nearest the origin belongs to C, so C gives the smallest V_s and hence the smallest incident frequency. Since $\lambda = c/\nu$, wavelength varies inversely with frequency. Equivalently,

$$\lambda = \frac{hc}{\phi + eV_s},$$

showing directly that the smallest stopping potential gives the longest wavelength.

Step 4: Compare maximum electron momenta for part (iii) The stopping potential measures the largest electron kinetic energy, not the average kinetic energy. Combining the energy and momentum relations gives

$$p_{\max} = \sqrt{2m_e eV_s}.$$

All emitted particles have the same mass and charge magnitude. Therefore the beam with the largest stopping-potential magnitude also produces the largest maximum electron momentum.

Step 5: Conclusion (i) Beam B has the highest frequency because it has the largest stopping-potential magnitude. (ii) Beam C has the longest wavelength because it has the smallest stopping-potential magnitude and lowest frequency. (iii) Beam B ejects electrons with the maximum momentum because $p_{\max} = \sqrt{2m_e eV_s}$ is largest for B.

Quick Tip to Solve: Trace each plateau back through curve crossings to its negative-axis intercept: farther left means higher frequency and greater maximum electron momentum, while nearer zero means longer wavelength.

35(b). What is the effect on threshold frequency and stopping potential on increasing the frequency of incident beam of light? Justify your answer. [4 marks]

Solution:

Concept:

- The work function ϕ is the minimum energy needed to remove an electron from the emitting metal. Its threshold frequency is $\nu_0 = \phi/h$, where h is Planck's constant.
- Above threshold, Einstein's photoelectric equation gives $K_{\max} = h\nu - \phi = h(\nu - \nu_0)$. Here ν is the incident frequency and $K_{\max}$ the greatest photoelectron kinetic energy.
- Stopping potential magnitude V_s is determined by $eV_s = K_{\max}$, with e the positive elementary charge. The actual collector potential required to stop emission current is negative relative to the emitter.

Step 1: Examine the threshold frequency For a fixed emitting material and unchanged surface, the binding energy of electrons, and therefore the work function, remains the same. Increasing the frequency changes the energy $h\nu$ of the incident photons, but does not change this minimum energy requirement. Hence

$$\nu_0 = \frac{\phi}{h}$$

has no dependence on the incident beam frequency. Threshold frequency is a property of the emitter, not a quantity set by the colour of the illuminating light.

Step 2: Relate stopping potential to frequency Each absorbed photon supplies $h\nu$. After the electron spends energy ϕ escaping the surface, the remaining energy is its maximum kinetic energy. A retarding potential must remove this energy to stop even the fastest electrons:

$$eV_s = h\nu - \phi, \quad V_s = \frac{h}{e}(\nu - \nu_0).$$

For two incident frequencies $\nu_2 > \nu_1$, both producing photoemission, subtraction gives

$$V_{s,2} - V_{s,1} = \frac{h}{e}(\nu_2 - \nu_1) > 0.$$

Thus the stopping-potential magnitude increases linearly with frequency, with slope h/e . The corresponding signed retarding voltage becomes more negative.

Step 3: Check the emission condition The stopping-potential relation applies when $\nu \geq \nu_0$. At the threshold, the ideal maximum kinetic energy and stopping-potential magnitude are zero. If the incident frequency remains below threshold, no photoelectric emission occurs and no stopping potential for an emitted photocurrent can be measured. Increasing frequency past threshold initiates emission; additional photon energy then increases electron kinetic energy.

Step 4: Conclusion Increasing the incident frequency leaves the threshold frequency $\nu_0 = \phi/h$ unchanged for the same emitter. In the photoemission regime, the stopping-potential magnitude increases according to $\Delta V_s = (h/e)\Delta\nu$, because the emitted electrons have greater maximum kinetic energy.

Quick Tip to Solve: Separate the material property $\nu_0 = \phi/h$ from the beam-dependent quantity $V_s = (h/e)(\nu - \nu_0)$; increasing frequency changes only the latter for a fixed photocathode.