

CBSE Class 12 Physics Question Paper 2026 with Solution PDF-Set 55/4/2



Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

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

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

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

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

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

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

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

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

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

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

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

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

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

Section A (16 marks)

1. A wire is gradually stretched to make it 100% longer. Its resistance will increase by: [1 mark]

- (A) 100%
- (B) 200%
- (C) 300%
- (D) 400%

Correct Answer: (C) 300%

Solution:

Concept:

- The resistance of a uniform wire is $R = \rho l/A$, where ρ is its resistivity, l its length and A its cross-sectional area.
- On stretching a wire without loss of material, its volume Al remains constant. Assume its temperature and resistivity remain unchanged.

Step 1: Relate the new length and area A length increase of 100% means $l' = 2l$. Since $A'l' = Al$, the new cross-sectional area is $A' = A/2$. Both the increased length and the decreased area raise the resistance.

Step 2: Calculate the percentage increase Substitute the new dimensions into the resistance formula:

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

The increase is measured relative to the original resistance:

$$\frac{R' - R}{R} \times 100\% = \frac{4R - R}{R} \times 100\% = 300\%.$$

The value 400% represents the final resistance as a percentage of the original, not its increase. The values 100% and 200% do not account correctly for both dimensional changes.

Step 3: Conclusion The resistance increases by 300%. Hence, the correct option is (C).

Quick Tip to Solve: For a stretched wire of constant volume, use $R'/R = (l'/l)^2$, then subtract one before converting the increase to a percentage.

2. A closely wound long solenoid of self-inductance L is cut into two identical solenoids. The value of self-inductance of each small solenoid will be:

[1 mark]

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

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

Solution:

Concept:

- For a closely wound long solenoid, $L = \mu N^2 A / l$, where N is the number of turns, A the cross-sectional area, l the length and μ the permeability of its medium.
- Equivalently, $L = \mu n^2 A l$, where $n = N/l$ is the number of turns per unit length.

Step 1: Identify the dimensions of each half Cutting the original solenoid into two identical shorter solenoids gives each half $N' = N/2$ turns and length $l' = l/2$. Its cross-sectional area and medium remain unchanged. The turn density is therefore unchanged: $n' = (N/2)/(l/2) = n$.

Step 2: Substitute into the self-inductance formula The self-inductance of either half is

$$L' = \frac{\mu (N/2)^2 A}{l/2} = \frac{1}{2} \frac{\mu N^2 A}{l} = \frac{L}{2}.$$

With unchanged turn density and area, self-inductance is proportional to length. Thus $2L$, $3L$ and $4L$ cannot describe a shorter half; these choices would require an increase rather than the actual decrease.

Step 3: Conclusion Each small solenoid has self-inductance $L/2$. Hence, the correct option is (A).

Quick Tip to Solve: When a uniform solenoid is cut into equal shorter pieces, keep n fixed and use $L \propto l$; do not keep its total turn count fixed.

3. Which of the following characteristics of electrons determines the current in the conductor?

[1 mark]

- (A) Drift velocity only
- (B) Thermal velocity only
- (C) Both drift velocity and thermal velocity
- (D) Neither drift nor thermal velocity

Correct Answer: (A) Drift velocity only

Solution:

Concept:

- Electric current is the net rate of charge flow through a cross-section. Its magnitude in a conductor is $I = neAv_d$, where n is the free-electron number density, e the magnitude of electron charge, A the cross-sectional area and v_d the drift speed.
- Thermal motion is random in direction, whereas drift is the small directed average motion produced by an electric field.

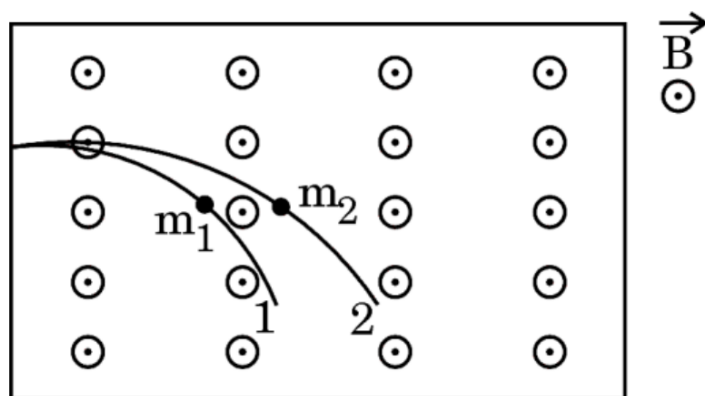
Step 1: Evaluate the contribution of thermal motion In thermal motion, electrons cross any section in both directions. With no preferred direction, their average thermal velocity is zero, and the opposing charge flows cancel. Thermal velocity alone therefore produces no net current, ruling out option (B).

Step 2: Identify the directed motion An applied electric field gives the electrons a nonzero average drift velocity opposite to the field. This produces the net charge transport represented by $I = neAv_d$; conventional current is opposite to electron drift. Option (C) incorrectly includes random thermal motion as an additional net flow, while option (D) ignores the role of drift.

Step 3: Conclusion Of the listed electron characteristics, drift velocity only determines the current. Hence, the correct option is (A).

Quick Tip to Solve: To decide whether a motion contributes to current, average its direction: random thermal velocities cancel, but directed drift survives.

4. Two particles of masses m_1 and m_2 having charges q_1 and q_2 respectively are projected with the same velocity in a region of uniform magnetic field $\vec{B}$ pointing vertically upward. If they describe circular paths as shown in the figure, one may conclude that: [1 mark]



- (A) $\frac{m_1}{m_2} > \frac{q_1}{q_2}$
 (B) $\frac{m_1}{m_2} > \frac{q_2}{q_1}$
 (C) $\frac{m_1}{m_2} < \frac{q_1}{q_2}$
 (D) $\frac{m_1}{m_2} < \frac{q_2}{q_1}$

Correct Answer: (C) $\frac{m_1}{m_2} < \frac{q_1}{q_2}$

Solution:

Concept:

- For a particle moving perpendicular to a uniform magnetic field, the magnetic force supplies the centripetal force: $|q|vB = mv^2/r$. Hence $r = mv/(|q|B)$.
- At equal speed in the same field, the radius is proportional to mass divided by charge magnitude; the sense of bending identifies the sign of charge.

Step 1: Compare the paths in the figure Path 1 bends more sharply than path 2, so $r_1 < r_2$. Both particles enter with the same velocity and bend in the same sense in the given magnetic field, so their charges have the same sign. Consequently $|q_1|/|q_2| = q_1/q_2 > 0$.

Step 2: Express the radius inequality using masses and charges Since the common factors v and B cancel,

$$\frac{r_1}{r_2} = \frac{m_1 |q_2|}{m_2 |q_1|} < 1 \Rightarrow \frac{m_1}{m_2} < \frac{q_1}{q_2}.$$

Option (A) reverses the observed radius inequality. Options (B) and (D) use the reciprocal charge ratio, which does not follow from the magnetic-force equation and cannot be inferred without further charge information.

Step 3: Conclusion The figure implies $m_1/m_2 < q_1/q_2$. Hence, the correct option is (C).

Quick Tip to Solve: First identify the tighter curve, then compare $m/|q|$. Derive the ratio from $r = mv/(|q|B)$ to avoid reversing the charges.

5. Paschen series in spectrum of hydrogen atom lies in:

[1 mark]

- (A) infrared region
- (B) ultraviolet region
- (C) visible region
- (D) partly in ultraviolet region and partly in visible region

Correct Answer: (A) infrared region

Solution:

Concept:

- The Paschen series consists of hydrogen emission transitions from higher levels $n_i \geq 4$ to the final level $n_f = 3$.
- The Rydberg formula is $1/\lambda = R_H(1/n_f^2 - 1/n_i^2)$, where λ is wavelength and R_H is the Rydberg constant.

Step 1: Find the shortest possible Paschen wavelength The shortest wavelength occurs at the series limit, when $n_i \rightarrow \infty$. Using $R_H \simeq 1.097 \times 10^7 \text{ m}^{-1}$,

$$\lambda_{\min} = \frac{9}{R_H} \simeq 8.20 \times 10^{-7} \text{ m} = 820 \text{ nm}.$$

All finite-level Paschen transitions have still longer wavelengths.

Step 2: Identify the spectral region Even the shortest Paschen wavelength lies beyond the red end of the visible spectrum, so the whole series belongs to the infrared region. The Lyman series terminates at $n_f = 1$ and lies in the ultraviolet; the familiar visible hydrogen lines belong to the Balmer series, terminating at $n_f = 2$. Thus neither the ultraviolet nor visible options, including their combination, describes the Paschen series.

Step 3: Conclusion The Paschen series lies in the infrared region. Hence, the correct option is (A).

Quick Tip to Solve: Identify the final level first: Lyman ends at 1, Balmer at 2 and Paschen at 3; Paschen and the higher series are infrared.

6. The kinetic energy of a charged particle is increased to four times of its initial value. The de Broglie wavelength associated with the particle will: [1 mark]

- (A) increase by 100% of its initial value.
- (B) increase by 50% of its initial value.
- (C) decrease by 25% of its initial value.
- (D) decrease by 50% of its initial value.

Correct Answer: (D) decrease by 50% of its initial value.

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p the particle's momentum.
- For a nonrelativistic particle of mass m and kinetic energy K , $p = \sqrt{2mK}$, so $\lambda = h/\sqrt{2mK}$ and $\lambda \propto K^{-1/2}$.

Step 1: Compare the initial and final wavelengths The particle is unchanged, so its mass is constant. When $K' = 4K$, the momentum doubles rather than quadruples. Therefore,

$$\frac{\lambda'}{\lambda} = \sqrt{\frac{K}{K'}} = \sqrt{\frac{K}{4K}} = \frac{1}{2}.$$

Step 2: Calculate the fractional decrease The reduction in wavelength relative to its initial value is

$$\frac{\lambda - \lambda'}{\lambda} \times 100\% = \left(1 - \frac{1}{2}\right) 100\% = 50\%.$$

Options (A) and (B) predict an increase, contrary to the inverse relation between wavelength and momentum. Option (C) predicts a 25% decrease, whereas the square-root dependence leaves exactly half the original wavelength. The particle's charge does not enter this energy-to-wavelength ratio.

Step 3: Conclusion The de Broglie wavelength decreases by 50% of its initial value. Hence, the correct option is (D).

Quick Tip to Solve: For the same nonrelativistic particle, take the square root of the kinetic-energy factor, then invert it to obtain the wavelength factor.

7. In a reversed-biased p-n junction diode, the applied voltage mostly drops across: [1 mark]

- (A) p-region only
- (B) n-region only
- (C) depletion region
- (D) the diode

Correct Answer: (C) depletion region

Solution:

Concept:

- The depletion region of a p-n junction contains ionised donors and acceptors but very few mobile charge carriers, so it offers a much larger resistance than the neutral p- and n-regions.
- Reverse bias increases the junction barrier and widens the depletion region. The largest voltage

drop occurs across the region with the largest resistance.

Step 1: Identify the effect of reverse bias With the p-side connected to the negative terminal and the n-side to the positive terminal, majority carriers are drawn away from the junction. The depletion layer becomes wider and its electric field increases. Only a small reverse current, mainly due to minority carriers before breakdown, flows.

Step 2: Locate the dominant potential drop The neutral p- and n-regions contain many mobile majority carriers and have relatively small resistance, so neither region alone takes most of the applied voltage. The high-resistance depletion region supports most of the reverse voltage. Saying merely that the voltage is across the diode gives its external terminals but does not identify where the potential mainly changes inside it, as the question asks.

Step 3: Conclusion The applied reverse voltage mostly drops across the depletion region. Hence, the correct option is (C).

Quick Tip to Solve: In reverse bias, look for the region depleted of mobile carriers: its high resistance and widened barrier account for most of the voltage drop.

8. A coil having 100 closely wound turns and area of cross-section 300 mm^2 carries a current of 5 mA. The magnitude of the magnetic moment associated with the coil is: [1 mark]

- (A) $6 \times 10^{-4} \text{ A m}^2$
- (B) $3 \times 10^{-5} \text{ A m}^2$
- (C) $1.5 \times 10^{-4} \text{ A m}^2$
- (D) $5 \times 10^{-5} \text{ A m}^2$

Correct Answer: (C) $1.5 \times 10^{-4} \text{ A m}^2$

Solution:

Concept:

- The magnetic moment of a plane coil is $m = NIA$, where N is its number of turns, I its current and A the area enclosed by each turn.
- The SI unit of magnetic moment is A m^2 . Area conversion must be squared: $1 \text{ mm}^2 = 10^{-6} \text{ m}^2$.

Step 1: Convert the current and area to SI units The closely wound turns enclose essentially the same area. The given quantities become

$$N = 100, \quad I = 5 \times 10^{-3} \text{ A}, \quad A = 300 \times 10^{-6} \text{ m}^2.$$

The area is $3 \times 10^{-4} \text{ m}^2$, not $300 \times 10^{-3} \text{ m}^2$.

Step 2: Multiply the moment per turn by the number of turns Each turn contributes IA , and the moments of the closely wound turns add:

$$m = 100(5 \times 10^{-3})(300 \times 10^{-6}) = 1.5 \times 10^{-4} \text{ A m}^2.$$

The values in (A), (B) and (D) do not equal this product. In particular, using only IA would omit the contribution of the other turns.

Step 3: Conclusion The coil's magnetic moment is $1.5 \times 10^{-4} \text{ A m}^2$. Hence, the correct option is (C).

Quick Tip to Solve: Convert square millimetres with 10^{-6} , milliamperes with 10^{-3} , and then include all 100 turns.

9. An ac voltage is given as $v = 14 \sin(314t)$ V. The average and the effective value of the voltage (in V) over a cycle are respectively: [1 mark]

- (A) 14 and 7
- (B) 10 and 14
- (C) 0 and 10
- (D) 10 and 0

Correct Answer: (C) 0 and 10

Solution:

Concept:

- For a sinusoidal voltage $v = V_0 \sin \omega t$, V_0 is the peak voltage and the signed average over a complete cycle is zero.
- The effective voltage is the root mean square value, $V_{\text{rms}} = V_0/\sqrt{2}$; it gives the same heating effect in a resistor as an equal steady voltage.

Step 1: Average the voltage over a complete cycle From $v = 14 \sin(314t)$ V, the peak voltage is $V_0 = 14$ V. The positive and negative half-cycles have equal areas of opposite sign, so

$$V_{\text{av}} = \frac{1}{T} \int_0^T 14 \sin(314t) dt = 0.$$

A half-cycle average or an average of the magnitude would be a different quantity.

Step 2: Calculate the effective voltage The cycle average of $\sin^2 \omega t$ is $1/2$. Hence

$$V_{\text{rms}} = \sqrt{\langle v^2 \rangle} = \frac{14}{\sqrt{2}} \text{ V} \simeq 9.90 \text{ V} \simeq 10 \text{ V}.$$

Options (A) and (B) give nonzero signed averages. Option (D) reverses the average and effective values; a nonzero alternating voltage has a positive rms value.

Step 3: Conclusion The average and effective voltages are respectively 0 V and approximately 10 V. Hence, the correct option is (C).

Quick Tip to Solve: For a full sine-wave cycle, write the signed average as zero first, then divide the amplitude by $\sqrt{2}$ for the rms value.

10. The ratio of amplitude of electric field to the amplitude of the magnetic field associated with an electromagnetic wave propagating in glass ($n = 1.5$) is: [1 mark]

- (A) $3 \times 10^8 \text{ m s}^{-1}$
- (B) $2 \times 10^8 \text{ m s}^{-1}$
- (C) $3 \cdot 3 \times 10^{-9} \text{ m s}^{-1}$
- (D) $5 \times 10^{-9} \text{ m s}^{-1}$

Correct Answer: (B) $2 \times 10^8 \text{ m s}^{-1}$

Solution:

Concept:

- In a plane electromagnetic wave, the ratio E_0/B_0 of the electric-field amplitude to the magnetic-field amplitude equals the wave's speed v in the medium.
- Refractive index is $n = c/v$, where $c = 3 \times 10^8 \text{ m s}^{-1}$ is the vacuum speed of light.

Step 1: Find the speed of the wave in glass The given refractive index is $n = 1.5$. Therefore

$$v = \frac{c}{n} = \frac{3 \times 10^8}{1.5} \text{ m s}^{-1} = 2 \times 10^8 \text{ m s}^{-1}.$$

Glass reduces the propagation speed below its vacuum value.

Step 2: Relate the field amplitudes and check the choices For the wave in this medium, $E_0 = vB_0$, giving

$$\frac{E_0}{B_0} = v = 2 \times 10^8 \text{ m s}^{-1}.$$

Option (A) uses the vacuum speed and ignores the glass. The small values in (C) and (D) resemble reciprocals of speeds, which would correspond to B_0/E_0 and would have units s m^{-1} , not the ratio asked for.

Step 3: Conclusion The required ratio is $E_0/B_0 = 2 \times 10^8 \text{ m s}^{-1}$. Hence, the correct option is (B).

Quick Tip to Solve: For E_0/B_0 , first identify the medium: use c/n in glass and c only in vacuum.

11. Radiation of wavelength 331 nm irradiates the following metals:

Metal	Work Function (eV)
Na	1.92
K	2.15
Ca	3.20
Mo	4.17

Which of the following statements is correct?

[1 mark]

- (A) Only Na and K show photoelectric emission.
- (B) Only Mo will not show photoelectric emission.
- (C) All of the given metals show photoelectric emission.
- (D) None of them show photoelectric emission.

Correct Answer: (B) Only Mo will not show photoelectric emission.

Solution:

Concept:

- A photon of wavelength λ carries energy $E = hc/\lambda$, where h is Planck's constant and c is the speed of light.
- Photoelectric emission occurs when the photon energy is at least the metal's work function ϕ ; if $E < \phi$, no electron can escape by absorbing one photon.

Step 1: Calculate the energy of a 331 nm photon Using $h = 6.63 \times 10^{-34} \text{ J s}$, $c = 3 \times 10^8 \text{ m s}^{-1}$ and $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$,

$$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{331 \times 10^{-9}} \simeq 6.01 \times 10^{-19} \text{ J} \simeq 3.76 \text{ eV}.$$

Step 2: Compare the photon energy with every work function The energy 3.76 eV exceeds the tabulated work functions of Na (1.92 eV), K (2.15 eV) and Ca (3.20 eV), so each emits photoelectrons. It is below Mo's 4.17 eV, so Mo does not emit. Option (A) wrongly excludes Ca, (C) wrongly includes Mo, and (D) wrongly excludes the three metals whose thresholds are crossed.

Step 3: Conclusion Only Mo will not show photoelectric emission. Hence, the correct option is (B).

Quick Tip to Solve: Convert the photon energy to eV once, then compare it directly with all four work functions; the threshold lies between Ca and Mo here.

12. In an experiment on photoelectric emission, the intensity of incident radiation is halved keeping its frequency constant. As a result: [1 mark]

- (A) cut-off potential will increase.
- (B) maximum kinetic energy of photoelectrons will remain the same.
- (C) photocurrent will increase.
- (D) cut-off potential will decrease.

Correct Answer: (B) maximum kinetic energy of photoelectrons will remain the same.

Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi$, where ν is the incident frequency and ϕ is the fixed work function of the emitting metal.
- The magnitude of the stopping potential satisfies $eV_s = K_{\max}$. At fixed frequency, intensity controls photon flux and hence the emission rate, rather than the energy of each photon.

Step 1: Hold the energy per photon fixed Halving intensity while retaining the same frequency leaves $h\nu$ unchanged. The same emitting surface also retains the same ϕ . Thus

$$K'_{\max} = h\nu - \phi = K_{\max}, \quad V'_s = V_s.$$

The stopping or cut-off potential therefore neither increases nor decreases, ruling out (A) and (D).

Step 2: Determine what happens to the photocurrent With the same photon energy, halving the incident energy per unit time means half as many photons arrive per unit time. Under unchanged collection conditions, the number of photoelectrons emitted per unit time and the photocurrent decrease; in particular, the saturation photocurrent is halved. Thus the increase claimed by (C) cannot follow from this change.

Step 3: Conclusion The maximum kinetic energy of photoelectrons remains the same. Hence, the correct option is (B).

Quick Tip to Solve: Separate photon energy from photon number: fixed frequency fixes $K_{\max}$ and stopping potential, while intensity changes the emission rate.

13. Assertion (A): The conductivity of an n-type semiconductor is higher than that of a p-type semiconductor at a given temperature.

Reason (R): The electrons being in the conduction band in n-type semiconductor are more mobile than the holes in the valence band in p-type semiconductor. [1 mark]

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

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

Solution:

Concept:

- Semiconductor conductivity is $\sigma = e(n\mu_e + p\mu_h)$, where n, p are electron and hole concentrations, μ_e, μ_h their mobilities, and e the elementary charge.
- Electrons dominate conduction in an n-type semiconductor and holes in a p-type semiconductor. In the usual comparison of the same host material at equal doping and temperature, electron mobility exceeds hole mobility.

Step 1: Evaluate the assertion For comparable majority-carrier concentrations N , neglecting minority carriers gives

$$\sigma_n \simeq eN\mu_e, \quad \sigma_p \simeq eN\mu_h.$$

Since $\mu_e > \mu_h$, the n-type sample has higher conductivity in the standard comparison intended here. Thus the assertion is true under this implicit equal-doping comparison. Temperature alone would not fix conductivity for arbitrarily different doping concentrations.

Step 2: Evaluate the reason Conduction-band electrons have greater mobility than valence-band holes in the usual semiconductor comparison. Mobility measures the drift speed produced per unit electric field. The reason is therefore true.

Step 3: Test the explanatory connection With equal carrier concentrations, $\sigma_n/\sigma_p \simeq \mu_e/\mu_h > 1$. The greater electron mobility directly explains the larger n-type conductivity. Option (B) wrongly denies this link, while (C) and (D) incorrectly declare the reason false.

Step 4: Conclusion Under the standard comparison of equally doped samples, both statements are true and the reason correctly explains the assertion. Hence, the correct option is (A).

Quick Tip to Solve: Compare mobilities only after holding the host, temperature and doping level comparable; conductivity depends on carrier concentration as well as mobility.

14. Assertion (A): The work done, in taking a unit charge around a closed loop of an electric circuit involving cells and resistors in the loop, is zero.

Reason (R): The potential at a point depends on the location of the point in the loop. After completing one round, the charge comes back to the point of start. [1 mark]

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

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

Solution:

Concept:

- Kirchhoff's loop rule states that the algebraic sum of potential changes around a closed steady circuit is zero: $\sum \Delta V = 0$.
- Electrostatic potential is single-valued at each point. The net work per unit charge associated with traversing a closed potential path is zero; energy supplied by cells balances energy transferred in resistors.

Step 1: Evaluate the assertion using the loop rule In a loop with cells and resistors, the signed rises in potential through the sources balance the signed drops through resistors:

$$\sum \mathcal{E} - \sum IR = 0.$$

Thus the algebraic net work per unit charge around the complete loop is zero. The assertion is true. This does not mean that a cell supplies no energy or that a resistor produces no heat; those energy transfers balance.

Step 2: Evaluate the reason using the initial and final points Potential is a function of position in the circuit. After a complete round, the charge returns to precisely its starting point, so $V_{\text{final}} = V_{\text{initial}}$. The reason is true.

Step 3: Check whether the reason explains the assertion The work done by the electrostatic field is

$$W = q(V_{\text{initial}} - V_{\text{final}}) = 0.$$

Returning to the same potential directly explains the zero net loop potential change and hence the assertion. Option (B) overlooks this direct connection; (C) and (D) wrongly reject the true reason.

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

Quick Tip to Solve: In a closed circuit loop, compare the starting and ending potential; zero net change still allows energy supply by cells and dissipation in resistors.

15. Assertion (A): When a ferromagnetic substance is heated to high temperature it becomes paramagnetic in nature.

Reason (R): The disappearance of magnetisation of a ferromagnet is abrupt and not gradual. [1 mark]

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

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

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

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

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

Solution:

Concept:

- A ferromagnet has ordered magnetic moments within domains; thermal agitation weakens this order as temperature rises.
- Above the Curie temperature T_C , spontaneous ferromagnetic magnetisation vanishes and the substance behaves as a paramagnet.

Step 1: Judge Assertion (A) Heating a ferromagnetic substance sufficiently, beyond its Curie temperature, destroys its spontaneous magnetic order. It then responds as a paramagnet to an applied field. Thus Assertion (A) is true.

Step 2: Judge Reason (R) In the standard description, spontaneous magnetisation decreases gradually as temperature increases and reaches zero at the Curie temperature. Therefore the claim that its disappearance is abrupt and not gradual is false.

Step 3: Check the explanatory link A false Reason cannot explain the true Assertion. Options (A) and (B) both require a true Reason, while option (D) requires a false Assertion; each therefore fails the two truth tests.

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

Quick Tip to Solve: Link heating to thermal disorder: magnetisation decreases towards zero at the Curie temperature, above which the material is paramagnetic.

16. Assertion (A): When a convex lens made of glass is immersed in water, its converging power increases.

Reason (R): The focal length of a lens depends only on the radii of curvature of its two faces. [1 mark]

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

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

Solution:

Concept:

- For a thin lens of refractive index n_g in a medium of refractive index n_m , the lens-maker formula is $P = 1/f = (n_g/n_m - 1)(1/R_1 - 1/R_2)$, where R_1, R_2 are the signed radii.
- Converging power is positive; a smaller positive power corresponds to a longer positive focal length.

Step 1: Judge Assertion (A) Water has a greater refractive index than air but a smaller refractive index than ordinary glass. Immersion therefore reduces $n_g/n_m - 1$, while the lens radii remain unchanged. The positive converging power decreases and its focal length increases. Thus Assertion (A) is false.

Step 2: Judge Reason (R) The lens-maker formula contains both the radii of curvature and the refractive index of the lens relative to its surroundings. Hence focal length does not depend only on the two radii; Reason (R) is also false.

Step 3: Check the explanatory link Neither statement is true, so the Reason cannot give a valid explanation of the Assertion. Options (A) and (B) require both statements to be true, and option (C) requires the Assertion to be true; none satisfies the result above.

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

Quick Tip to Solve: For the same lens in a new medium, compare the relative-index factor $n_g/n_m - 1$ before discussing its power or focal length.

Section B (10 marks)

17(a). State Huygens principle. How did Huygens justify the absence of the backwave on a spherical wavefront? [2 marks]

Solution:

Concept:

- A wavefront is a surface of constant phase. Huygens' construction obtains a later wavefront from secondary wavelets emitted by the present one.
- In a homogeneous isotropic medium of wave speed v , each secondary wavelet has radius $v\Delta t$ after time Δt .

Step 1: State Huygens' principle Every point on a given wavefront acts as a source of secondary spherical wavelets that spread through the medium with the speed of the wave. The common forward

envelope, or surface tangent to these wavelets, gives the position of the new wavefront at a later instant. For a spherical wave emitted by a point source, this forward envelope is a larger sphere after time Δt .

Step 2: Explain the absence of a backwave Drawing complete secondary spheres also suggests a backward envelope. Huygens excluded this by assuming that the amplitude of the secondary wavelets is maximum in the forward direction and zero in the backward direction. The backward envelope therefore carries no wave. This was an additional assumption of his construction, rather than a rigorous derivation from the geometrical principle alone.

Step 3: Conclusion The later wavefront is the forward envelope of secondary wavelets. Huygens justified the absence of a backward wave by assuming zero secondary-wavelet amplitude in the backward direction.

Quick Tip to Solve: State both parts of the principle—secondary sources and their forward envelope—then identify the zero-backward-amplitude assumption separately.

OR

17(b). In a single-slit diffraction experiment, light of wavelength λ illuminates the slit of width 'a'. The diffraction pattern is observed on a screen kept at a distance D from the slits.

(i) Depict variation of intensity in the fringe pattern with the angular position of the fringes.

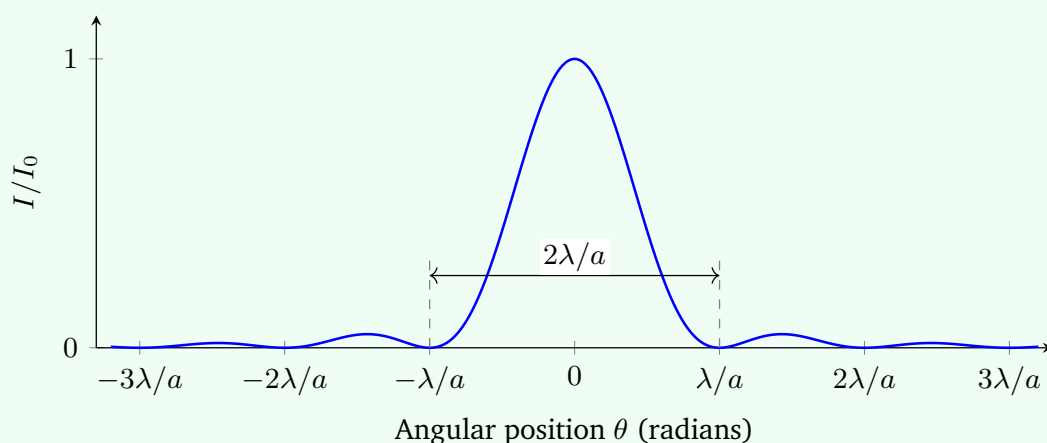
(ii) How is the linear width of central maximum affected when separation between the slit and the screen is decreased? [2 marks]

Solution:

Concept:

- For a slit of width a , single-slit diffraction has intensity $I = I_0(\sin \beta / \beta)^2$, where $\beta = \pi a \sin \theta / \lambda$, θ is measured from the central axis and I_0 is the central intensity.
- Minima occur at $a \sin \theta = m\lambda$, with nonzero integer m . For small angles, the screen position is $y \simeq D\theta$.

Step 1: Depict the angular intensity pattern The central maximum is the brightest and is centred at $\theta = 0$. The first minima lie at $\theta \simeq \pm\lambda/a$; weaker secondary maxima appear symmetrically on either side, with decreasing intensities. The central maximum has angular width $2\lambda/a$, approximately twice the width between successive minima on either side. The graph shows the small-angle pattern, with intensity normalised to I_0 .



Single-slit diffraction: a broad central maximum and weaker secondary maxima.

Step 2: Find how the central width changes The first dark fringes are at $y_1 \simeq D\lambda/a$ and $-y_1$. Their separation is the linear width of the central maximum:

$$W = 2y_1 = \frac{2D\lambda}{a}.$$

At fixed wavelength and slit width, W is directly proportional to D . Thus reducing the slit-screen separation from D to D' gives $W'/W = D'/D$, as long as the usual far-field diffraction conditions hold.

Step 3: Conclusion The pattern has a broad bright central peak and successively weaker side peaks. Decreasing the slit-screen separation decreases the linear central width $W = 2D\lambda/a$; its angular width is unchanged.

Quick Tip to Solve: Mark the first minima at $\pm\lambda/a$, then multiply their angular separation by D to obtain the linear central width.

18. The hole concentration in an intrinsic semiconductor is $5 \times 10^8 \text{ m}^{-3}$. When it is doped with certain impurity, the electron concentration becomes $4 \times 10^{12} \text{ m}^{-3}$. Find the new value of the hole concentration. Also identify the type of new semiconductor formed after doping. [2 marks]

Solution:

Concept:

- In an intrinsic semiconductor the electron and hole concentrations are equal: $n_i = p_i$, where n_i is the intrinsic carrier concentration.
- At a fixed temperature in thermal equilibrium, the mass-action law is $np = n_i^2$, where n and p are the electron and hole concentrations after doping.

Step 1: Identify the intrinsic concentration The printed intrinsic hole concentration is $p_i = 5 \times 10^8 \text{ m}^{-3}$. Because the material is initially intrinsic, its electron concentration has the same value. Hence

$$n_i^2 = (5 \times 10^8)^2 = 2.5 \times 10^{17} \text{ m}^{-6}.$$

Step 2: Apply the mass-action law after doping The electron concentration after doping is $n = 4 \times 10^{12} \text{ m}^{-3}$. Assuming the temperature is unchanged, divide the fixed product n_i^2 by this new

electron concentration:

$$p = \frac{n_i^2}{n} = \frac{2.5 \times 10^{17}}{4 \times 10^{12}} \text{ m}^{-3} \\ = 0.625 \times 10^5 \text{ m}^{-3} = 6.25 \times 10^4 \text{ m}^{-3}.$$

Step 3: Identify the majority carriers The doped electron concentration $4 \times 10^{12} \text{ m}^{-3}$ is much larger than the new hole concentration. Electrons are therefore majority carriers and holes are minority carriers; the doping is donor type. The decrease in holes is consistent with the fixed equilibrium carrier product.

Step 4: Conclusion The new hole concentration is $6.25 \times 10^4 \text{ m}^{-3}$, and the doped semiconductor is n-type.

Quick Tip to Solve: Square the intrinsic concentration before dividing by the doped electron concentration; identify the semiconductor from whichever carrier is more abundant.

19. A concave mirror of radius of curvature 16 cm produces two-times enlarged real image of an object kept in front of it. Find the position of the object. [2 marks]

Solution:

Concept:

- For a spherical mirror, the focal length is half its radius of curvature: $f = R/2$. In the Cartesian sign convention, a concave mirror has negative focal length.
- The mirror formula is $1/f = 1/v + 1/u$, and the linear magnification is $m = -v/u$, where u and v are the signed object and image distances from the pole.

Step 1: Use the image nature to set the signs The radius of curvature has magnitude 16 cm, so the focal length is $f = -8$ cm. A real image formed by a concave mirror is inverted. Therefore, a two-times enlarged real image has magnification $m = -2$, rather than $+2$.

$$-\frac{v}{u} = -2 \Rightarrow v = 2u.$$

Step 2: Substitute into the mirror formula Use centimetres consistently and replace v by $2u$:

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

The corresponding image distance is $v = -24$ cm, which is negative as required for a real image in front of the mirror. The object lies between the focus at 8 cm and the centre of curvature at 16 cm, the correct region for an enlarged real image.

Step 3: Conclusion The object must be placed 12 cm in front of the concave mirror, i.e. $u = -12$ cm in the Cartesian sign convention.

Quick Tip to Solve: For an enlarged real mirror image, put the negative sign into magnification first; here $m = -2$ immediately gives $v = 2u$.

20. Prove that the density of nuclear matter is same for all nuclei.

[2 marks]

Solution:

Concept:

- A nucleus of mass number A contains A nucleons. Since proton and neutron masses are nearly equal, its mass is approximately $M = Am_N$, where m_N is the mean nucleon mass.
- The empirical nuclear-radius relation is $R = R_0 A^{1/3}$, where R_0 is a constant. The mean density of a spherical nucleus is $\rho = M/V$, with $V = (4/3)\pi R^3$.

Step 1: Express the nuclear volume in terms of mass number Cube the nuclear-radius relation and substitute it into the volume of a sphere:

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

Thus, although the radius increases only as $A^{1/3}$, the nuclear volume increases directly in proportion to the number of nucleons.

Step 2: Divide the nuclear mass by its volume The nuclear mass also increases in direct proportion to A . Hence,

$$\rho = \frac{M}{V} = \frac{Am_N}{(4/3)\pi R_0^3 A} = \frac{3m_N}{4\pi R_0^3}.$$

The factor A cancels completely. Both m_N and R_0 are independent of the chosen nucleus in this standard nuclear model, so the expression contains no dependence on its mass number. Small mass differences and binding-energy corrections are neglected in this approximation.

Step 3: Conclusion $\rho = \frac{3m_N}{4\pi R_0^3}$ is independent of A . Therefore, the mean density of nuclear matter is approximately the same for all nuclei.

Quick Tip to Solve: Cube $R \propto A^{1/3}$ before finding density: both nuclear mass and nuclear volume are proportional to A , so their ratio is constant.

21. An electric dipole consists of two point charges $+1 \mu\text{C}$ and $-1 \mu\text{C}$, held 10 cm apart. It is subjected to a uniform electric field of 100 N/C. Calculate the amount of work done in turning the dipole from its position of stable equilibrium to the position of unstable equilibrium, in the field.

[2 marks]

Solution:

Concept:

- An electric dipole made of charges $\pm q$, separated by distance s , has dipole-moment magnitude $p = qs$, directed from the negative to the positive charge.
- Its potential energy in a uniform field is $U = -pE \cos \theta$, where θ is the angle between the dipole moment and the field. The external work needed for a slow rotation equals ΔU .

Step 1: Convert the separation and find the dipole moment The given 10 cm is the full separation of the charges, so it is used directly in $p = qs$. With $q = 1 \times 10^{-6} \text{ C}$ and $s = 0.10 \text{ m}$,

$$p = (1 \times 10^{-6})(0.10) = 1 \times 10^{-7} \text{ C m}.$$

Step 2: Evaluate the increase in potential energy Stable equilibrium occurs when the dipole moment is parallel to the field, at $\theta_i = 0$, so $U_i = -pE$. Unstable equilibrium occurs at $\theta_f = \pi$, when it is antiparallel, so $U_f = +pE$. Therefore the work supplied against the electric torque is

$$\begin{aligned} W_{\text{ext}} &= U_f - U_i = pE - (-pE) = 2pE, \\ &= 2(1 \times 10^{-7})(100) = 2 \times 10^{-5} \text{ J}. \end{aligned}$$

The positive sign shows that energy must be supplied to raise the dipole from its minimum-energy orientation to its maximum-energy orientation. The work done by the electric field itself has the opposite sign.

Step 3: Conclusion The required external work is $2 \times 10^{-5} \text{ J}$, or $20 \mu\text{J}$. The field does $-2 \times 10^{-5} \text{ J}$ of work during this rotation.

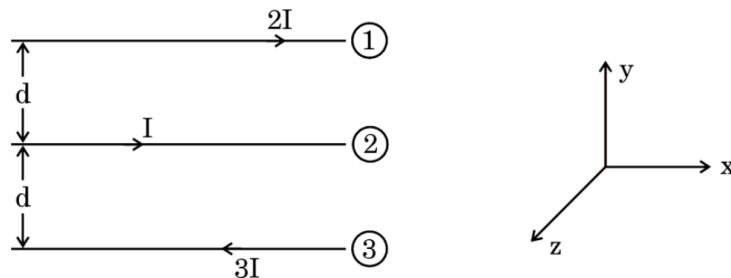
Quick Tip to Solve: For stable-to-unstable rotation, use $W = 2pE$; the dipole energy changes from $-pE$ to $+pE$, and the stated charge separation is used only once.

Section C (21 marks)

22(a). The figure given below shows three straight long parallel conductors (1), (2) and (3) kept in x-y plane, carrying currents $2I$, I and $3I$ respectively as shown in figure.

Find the magnitude and direction of:

- net magnetic field at a point on conductor (1) and
- net magnetic force acting on unit length of conductor (1), due to conductors (2) and (3). [3 marks]



Solution:

Concept:

- The magnetic field at a perpendicular distance r from a long straight wire carrying current I_w has magnitude $B = \mu_0 I_w / (2\pi r)$. Its direction follows the right-hand thumb rule.
- Fields add vectorially. The magnetic force per unit length on a straight conductor is $\vec{F}/L = I_w \hat{\ell} \times \vec{B}_{\text{ext}}$, where $\hat{\ell}$ points along its current and $\vec{B}_{\text{ext}}$ is the field due to the other conductors.

Step 1: Identify the distances and field directions In the given axes, conductors (1) and (2) carry currents $2I$ and I along $+x$, while conductor (3) carries $3I$ along $-x$. Conductor (1) is d above (2), and $2d$ above (3). By the right-hand rule, their fields at (1) point along $+z$ and $-z$, respectively. We use only these external fields.

Step 2: Add the magnetic fields at conductor (1) The contributions have opposite directions, so

subtract their magnitudes with their signs retained:

$$\begin{aligned}\vec{B}_2 &= \frac{\mu_0 I}{2\pi d} \hat{z}, \\ \vec{B}_3 &= -\frac{\mu_0 (3I)}{2\pi (2d)} \hat{z} = -\frac{3\mu_0 I}{4\pi d} \hat{z}, \\ \vec{B}_{\text{net}} &= \left(\frac{2\mu_0 I}{4\pi d} - \frac{3\mu_0 I}{4\pi d} \right) \hat{z} = -\frac{\mu_0 I}{4\pi d} \hat{z}.\end{aligned}$$

The field due to (3) is larger and sets the resultant direction.

Step 3: Find the force on unit length of conductor (1) The current in conductor (1) is $2I$ along $+x$. Therefore,

$$\begin{aligned}\frac{\vec{F}_1}{L} &= 2I \hat{x} \times \left(-\frac{\mu_0 I}{4\pi d} \hat{z} \right) \\ &= \frac{\mu_0 I^2}{2\pi d} \hat{y},\end{aligned}$$

using $\hat{x} \times (-\hat{z}) = \hat{y}$. The upward repulsion due to (3) exceeds the downward attraction due to (2), confirming this direction.

Step 4: Conclusion (i) The net magnetic field has magnitude $\mu_0 I / (4\pi d)$, directed along $-z$. (ii) The net magnetic force per unit length has magnitude $\mu_0 I^2 / (2\pi d)$, directed along $+y$, away from the other two conductors. With I in amperes and d in metres, these are in tesla and N m^{-1} , respectively.

Quick Tip to Solve: Measure each separation from conductor (1): they are d and $2d$. Use current divided by distance to compare opposing fields before applying $I\hat{\ell} \times \vec{B}$.

OR

22(b). A rectangular loop of sides l and b and resistance 'R' is kept in a region in which the magnetic field varies as $B = B_0 \sin \omega t$.

(i) Derive expression for the emf induced in the loop.

(ii) Find the effective value of current that flows in the loop.

[3 marks]

Solution:

Concept:

- The magnetic flux through a stationary loop is $\Phi = BA \cos \theta$, where $A = lb$ and θ is the angle between the field and the normal to the loop.
- Faraday's law gives the induced emf as $\varepsilon = -d\Phi/dt$.
- For a resistive loop, $i = \varepsilon/R$. The effective current is $I_{\text{rms}} = \sqrt{\langle i^2 \rangle}$.

Step 1: (i) Write the magnetic flux Take the usual intended arrangement in which the uniform magnetic field is perpendicular to the plane of the loop. The area and orientation of the loop remain constant, so its time-dependent flux is

$$\Phi(t) = lbB(t) = B_0 lb \sin \omega t.$$

Here B_0 is the peak field and ω is its angular frequency.

Step 2: Differentiate the flux to obtain the emf Applying Faraday's law to the varying field gives

$$\begin{aligned}\varepsilon(t) &= -\frac{d}{dt}(B_0 lb \sin \omega t) \\ &= -B_0 lb \omega \cos \omega t.\end{aligned}$$

Thus the peak magnitude of the emf is $\varepsilon_0 = B_0 lb \omega$. The sign follows Lenz's law and the chosen circulation convention.

Step 3: (ii) Calculate the effective current Neglecting self-inductance, as in the stated resistive-loop model, the instantaneous current is

$$i(t) = -\frac{B_0 lb \omega}{R} \cos \omega t = -I_0 \cos \omega t.$$

Over one period $T = 2\pi/\omega$, the mean value of $\cos^2 \omega t$ is $1/2$. Therefore

$$I_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} = \frac{I_0}{\sqrt{2}} = \frac{B_0 lb \omega}{\sqrt{2}R}.$$

The printed question does not specify the orientation. For any fixed angle θ to the normal, multiply the emf by $\cos \theta$ and its rms magnitude by $|\cos \theta|$.

Step 4: Conclusion For a field normal to the loop, $\varepsilon(t) = -B_0 lb \omega \cos \omega t$ and $I_{\text{rms}} = B_0 lb \omega / (\sqrt{2}R)$. The emf is measured in volts and the effective current in amperes.

Quick Tip to Solve: Differentiate the sinusoidal field first; then divide the peak emf by $R\sqrt{2}$ to obtain the rms current, not by R alone.

23. With the help of a circuit diagram, explain the working of a full wave rectifier. Depict the input and output waveforms.

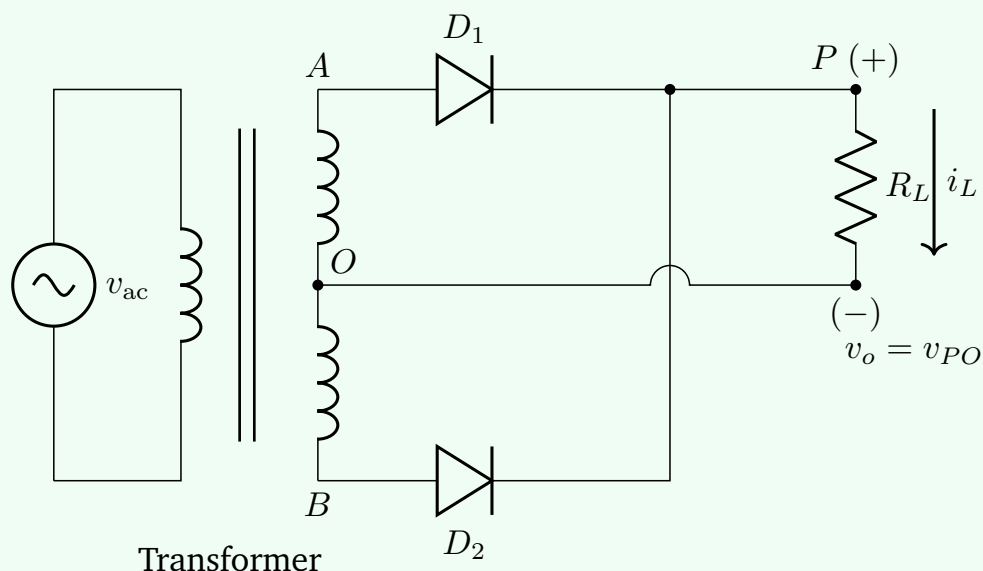
[3 marks]

Solution:

Concept:

- A junction diode conducts when forward biased and blocks current when reverse biased. A rectifier uses this property to convert alternating voltage into unidirectional output.
- A centre-tapped secondary provides equal voltages of opposite phase: $v_{AO} = V_m \sin \omega t$ and $v_{BO} = -V_m \sin \omega t$, relative to the centre tap O .

Step 1: Connect the full-wave rectifier Connect the anodes of diodes D_1 and D_2 to ends A and B of a centre-tapped transformer secondary. Join their cathodes at P , the positive output terminal. Connect the load resistance R_L between P and the centre tap O . The crossing with a bridge in the circuit is not a junction. Assume ideal diodes for the waveforms.



Centre-tapped full-wave rectifier; the bridged wire crossing has no electrical connection.

Step 2: Follow the positive half-cycle When A is positive relative to O , B is negative. Diode D_1 is forward biased and conducts, while D_2 is reverse biased. The current path is

$$A \longrightarrow D_1 \longrightarrow P \longrightarrow R_L \longrightarrow O.$$

Current returns through the upper half of the secondary; it flows downwards through the load, from its positive terminal towards O .

Step 3: Follow the negative half-cycle On reversal of the input, B becomes positive and A negative relative to O . Now D_2 conducts and D_1 is reverse biased. The conducting path is

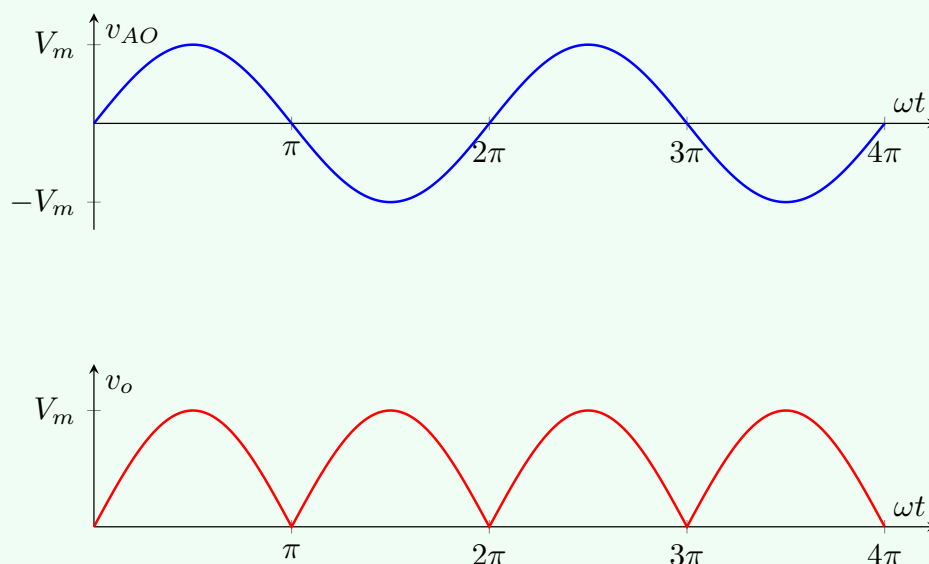
$$B \longrightarrow D_2 \longrightarrow P \longrightarrow R_L \longrightarrow O,$$

returning through the lower half of the secondary. The load current has the same direction as in the previous half-cycle, so both halves of the input are used.

Step 4: Relate the input and output waveforms The input alternates above and below zero, whereas the output has a positive pulse in each half-cycle. For an ideal circuit,

$$v_o = V_m |\sin \omega t|, \quad i_L = \frac{V_m}{R_L} |\sin \omega t|.$$

There are two output pulses per input cycle, so the ripple frequency is $2f$ for an input frequency f . This is pulsating direct current; a smoothing filter would be required to obtain an approximately steady output.



Input voltage across one half of the secondary and the full-wave rectified output; ωt is in radians.

Step 5: Conclusion The two diodes conduct alternately, maintaining the same direction of current through R_L during both half-cycles. Thus the circuit gives full-wave rectification with positive pulsating output and ripple frequency $2f$.

Quick Tip to Solve: In each half-cycle, identify the secondary end positive relative to the centre tap; its diode conducts, but the load-current arrow stays unchanged.

24. In Bohr model of hydrogen atom, calculate:

- (a) the radius of the innermost electron orbit, and
(b) the speed of electron in this orbit.

[3 marks]

Solution:

Concept:

- In the Bohr model, the electrostatic attraction between the proton and electron supplies the centripetal force: $ke^2/r^2 = m_e v^2/r$, where $k = 1/(4\pi\epsilon_0)$.
- The allowed orbits satisfy angular-momentum quantisation, $m_e v r = nh/(2\pi)$. The innermost orbit is the ground state with $n = 1$; hydrogen has nuclear charge $+e$.

Step 1: (a) Derive the ground-state radius For the innermost orbit, angular-momentum quantisation gives $v = h/(2\pi m_e r)$. Insert this into the force equation:

$$\begin{aligned}\frac{ke^2}{r^2} &= \frac{m_e}{r} \left(\frac{h}{2\pi m_e r} \right)^2, \\ ke^2 r &= \frac{h^2}{4\pi^2 m_e}, \\ r_1 &= \frac{h^2}{4\pi^2 m_e k e^2}.\end{aligned}$$

The nucleus is treated as stationary in the usual school-level Bohr model.

Step 2: Substitute the physical constants Use $h = 6.63 \times 10^{-34} \text{ J s}$, $m_e = 9.1 \times 10^{-31} \text{ kg}$, $e =$

$1.6 \times 10^{-19} \text{ C}$, and $k = 9 \times 10^9 \text{ N m}^2\text{C}^{-2}$. Hence

$$r_1 = \frac{(6.63 \times 10^{-34})^2}{4\pi^2(9.1 \times 10^{-31})(9 \times 10^9)(1.6 \times 10^{-19})^2} \\ \simeq 5.3 \times 10^{-11} \text{ m} = 0.053 \text{ nm}.$$

This is the Bohr radius, approximately $0.53 \text{ \AA}$.

Step 3: (b) Calculate the electron speed Combine $m_e v_1 r_1 = h/(2\pi)$ with $m_e v_1^2 r_1 = k e^2$. Dividing the second relation by the first eliminates both m_e and r_1 :

$$v_1 = \frac{2\pi k e^2}{h} \\ = \frac{2\pi(9 \times 10^9)(1.6 \times 10^{-19})^2}{6.63 \times 10^{-34}} \\ \simeq 2.18 \times 10^6 \text{ m s}^{-1}.$$

The result is a speed, so it is positive. It is about $0.0073c$, consistent with the nonrelativistic treatment used here.

Step 4: Conclusion (a) The innermost-orbit radius is $r_1 \simeq 5.3 \times 10^{-11} \text{ m}$. (b) The electron speed is $v_1 \simeq 2.18 \times 10^6 \text{ m s}^{-1}$.

Quick Tip to Solve: Set $n = 1$ for the innermost orbit, then combine the force and angular-momentum equations; dividing them gives the speed without reusing a rounded radius.

25. (a) Explain how the dual aspect of matter is evident in the de Broglie relation.

(b) Radiation of wavelength λ is incident on a photosensitive surface. Find the de Broglie wavelength of electrons emitted from the surface. Assume that the work function of the surface is negligible.

[3 marks]

Solution:

Concept:

- The de Broglie relation is $\lambda_e = h/p$, where λ_e is the matter-wave wavelength, p is the particle momentum and h is Planck's constant.
- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi = hc/\lambda - \phi$, where λ is the incident radiation wavelength, c is the speed of light and ϕ is the work function.
- For a nonrelativistic electron of mass m_e , kinetic energy and momentum obey $K = p^2/(2m_e)$.

Step 1: (a) Identify the wave and particle quantities In $\lambda_e = h/p$, wavelength λ_e is a characteristic of a wave, while momentum p is a characteristic of a moving particle. The same relation therefore connects the wave behaviour of matter with its particle behaviour. A moving material particle has an associated matter wave; increasing its momentum decreases its wavelength. Thus the dual aspect of matter is explicitly present in one equation.

Step 2: (b) Obtain the photoelectron kinetic energy Each incident photon has energy hc/λ . Neglecting the work function as instructed, Einstein's equation gives

$$K_{\max} = \frac{hc}{\lambda}.$$

This is the maximum kinetic energy of the emitted electrons. Electrons that lose energy before emerging can have smaller kinetic energies.

Step 3: Express the electron momentum and wavelength Apply $p^2 = 2m_e K$ to the fastest photoelectrons, then substitute in the de Broglie relation:

$$p_{\max} = \sqrt{\frac{2m_e h c}{\lambda}},$$

$$\lambda_{e,\min} = \frac{h}{p_{\max}} = \frac{h}{\sqrt{2m_e h c / \lambda}} = \sqrt{\frac{h \lambda}{2m_e c}}.$$

In the idealised energy-transfer model of the question, this is the required electron wavelength. The incident wavelength λ and electron wavelength λ_e describe different waves and must not be equated.

Step 4: Conclusion (a) The relation $\lambda_e = h/p$ links a wave quantity, wavelength, with a particle quantity, momentum, demonstrating matter-wave duality. (b) The required de Broglie wavelength is $\lambda_e = \sqrt{h\lambda/(2m_e c)}$; more precisely, it is the minimum wavelength associated with the maximum-energy photoelectrons.

Quick Tip to Solve: First convert the photon wavelength to electron kinetic energy using $K_{\max} = hc/\lambda$, then use $\lambda_e = h/\sqrt{2m_e K_{\max}}$; do not set the two wavelengths equal.

26. What are microwaves? How are they produced? Give any two uses of microwaves.

[3 marks]

Solution:

Concept:

- Microwaves form a part of the electromagnetic spectrum between ordinary radio waves and infrared radiation. Like other electromagnetic waves, they consist of oscillating electric and magnetic fields and travel in vacuum with speed c .
- Wavelength λ and frequency ν satisfy $c = \nu\lambda$. Their short wavelengths allow microwaves to be transmitted as narrow, directional beams.

Step 1: Define microwaves Microwaves are electromagnetic waves of short wavelength in the radio-wave region, typically from millimetres to tens of centimetres. A commonly used range is approximately 1 mm to 0.3 m, corresponding to frequencies of about 300 GHz down to 1 GHz. These boundaries are conventional rather than sharp physical divisions.

Step 2: State how they are produced Microwaves are generated by special vacuum tubes such as **klystrons** and **magnetrons**. These devices use controlled electron motion to sustain high-frequency electromagnetic oscillations. The resulting radiation is extracted and guided to an antenna or to an oven cavity. Semiconductor microwave oscillators, such as Gunn diodes, can also be used.

Step 3: Explain two applications **Radar:** A microwave beam is sent towards a distant object, and the reflected signal is detected. The short wavelength makes a narrow beam possible, which helps determine the object's direction. If the echo returns after time Δt , its distance is $d = c\Delta t/2$, since the wave travels to the object and back.

Microwave ovens: Food absorbs microwave energy, mainly through dielectric heating involving polar water molecules. The rapidly varying electric field drives molecular motion, and the absorbed energy becomes thermal energy, heating the food. A magnetron commonly supplies the microwaves used for this purpose.

Step 4: Conclusion Microwaves are short-wavelength electromagnetic radio waves, produced using devices such as klystrons and magnetrons. Two uses are **radar detection and ranging** and **heating food in microwave ovens**.

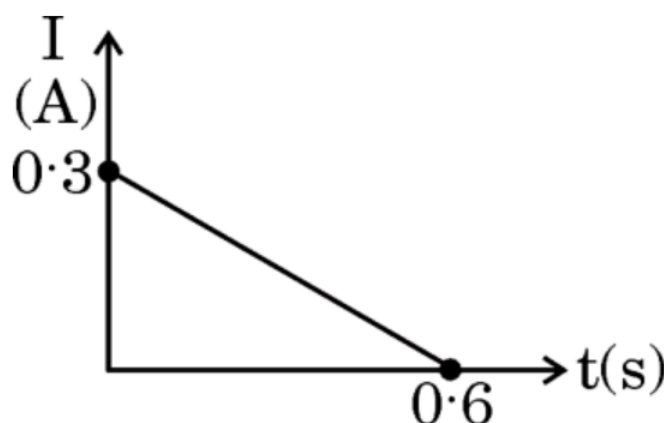
Quick Tip to Solve: Pair each use with a property: short wavelength gives a narrow radar beam, while absorption by polar water molecules enables microwave heating.

27. A conducting rectangular loop of area 5 cm^2 and resistance 4Ω is removed from a region of uniform magnetic field, acting normal to the plane of the loop. The value of induced current I in the loop varies with time t , as shown in the figure.

Find:

- (a) total charge that passed through the loop
- (b) change in magnetic flux through the loop
- (c) magnitude of magnetic field in the region

[3 marks]



Solution:

Concept:

- Charge passing through a circuit is $Q = \int I dt$, so the area under a current-time graph gives the total charge when the current remains in one direction.
- Faraday's law for a single loop gives $\mathcal{E} = -d\Phi/dt$. With constant resistance R , Ohm's law implies $Q = |\Delta\Phi|/R$ when the flux changes monotonically.
- Magnetic flux is $\Phi = BA \cos \theta$, where θ is the angle between the magnetic field and the area normal. Here the field is normal to the loop, so the initial flux magnitude is BA .

Step 1: (a) Calculate the area under the current-time graph The printed graph shows current decreasing linearly from 0.3 A at $t = 0$ to zero at $t = 0.6 \text{ s}$. The region under the graph is a triangle with height 0.3 A and base 0.6 s . Thus

$$Q = \frac{1}{2} \times 0.6 \times 0.3 = 0.09 \text{ C}.$$

No current is indicated after the loop has been removed, so this is the total charge transferred during removal.

Step 2: (b) Determine the change in magnetic flux Integrate Faraday's law over the interval of

removal. Taking magnitudes and using $\mathcal{E} = IR$,

$$|\Delta\Phi| = \int |\mathcal{E}| dt = R \int I dt = RQ = 4 \times 0.09 = 0.36 \text{ Wb}.$$

The magnetic flux decreases to zero. If the area normal is chosen along the initial field, the signed change $\Phi_f - \Phi_i$ is -0.36 Wb ; its magnitude is 0.36 Wb .

Step 3: (c) Calculate the magnetic field magnitude Initially the whole loop is in the uniform field; finally it is outside, so $|\Delta\Phi| = BA$. Convert the area before substitution:

$$A = 5 \text{ cm}^2 = 5 \times 10^{-4} \text{ m}^2.$$

Therefore

$$B = \frac{|\Delta\Phi|}{A} = \frac{0.36}{5 \times 10^{-4}} = 720 \text{ T}.$$

This large value follows directly from the printed current scale and the small loop area; the graph axes are in amperes and seconds.

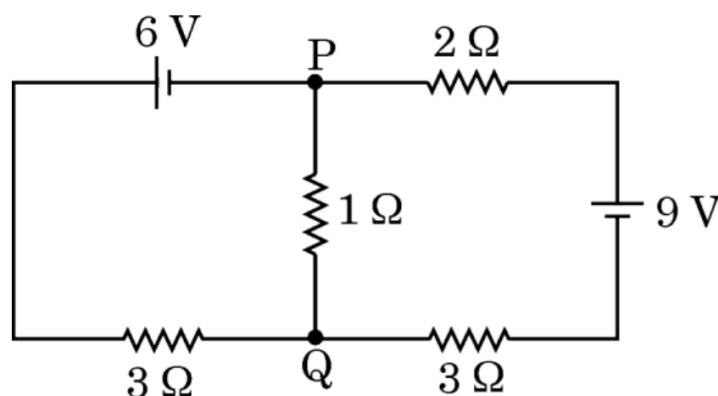
Step 4: Conclusion (a) Total charge $Q = 0.09 \text{ C}$. (b) The flux decreases by 0.36 Wb , or $\Delta\Phi = -0.36 \text{ Wb}$ with the initial flux positive. (c) The field magnitude is $B = 720 \text{ T}$.

Quick Tip to Solve: Use the chain area under $I-t \rightarrow Q \rightarrow RQ = |\Delta\Phi| \rightarrow |\Delta\Phi|/A = B$, and remember that $1 \text{ cm}^2 = 10^{-4} \text{ m}^2$.

28. (a) The two Kirchhoff's rules are based on law of conservation of two physical quantities. Name the quantities.

(b) Find magnitude and direction of current in 1Ω resistor in the given circuit.

[3 marks]



Solution:

Concept:

- Kirchhoff's junction rule conserves electric charge: the algebraic sum of currents leaving a junction is zero.
- Kirchhoff's loop rule conserves energy: potential changes sum to zero around a closed loop. A resistor has drop IR along its current; a cell gives rise E from negative to positive.

Step 1: Identify the conserved quantities in part (a) Charge cannot accumulate at a junction in steady state, so incoming and outgoing currents balance. Around a closed loop a charge returns to the same potential energy. The conserved quantities are therefore electric charge and energy, respectively.

Step 2: Express the branch currents in part (b) Let $V = V_P - V_Q$, counting each branch current as positive from P to Q. In the left branch, the 6 V cell has its positive terminal on the left: traversing from P to Q gives a cell rise and a resistor drop. In the right branch, the 9 V cell is positive at the top: the same traversal gives a cell drop and total resistance $2 + 3 = 5 \Omega$. Hence

$$I_L = \frac{V + 6V}{3\Omega}, \quad I_R = \frac{V - 9V}{5\Omega}, \quad I_C = \frac{V}{1\Omega}.$$

Step 3: Apply the junction rule and interpret the sign At P, $I_L + I_R + I_C = 0$. Taking numerical voltages in volts and currents in amperes,

$$\begin{aligned} \frac{V + 6}{3} + \frac{V - 9}{5} + V &= 0, \\ 5V + 30 + 3V - 27 + 15V &= 0, \\ 23V &= -3. \end{aligned}$$

Thus $V_P - V_Q = -3/23 \text{ V}$ and the assumed P-to-Q current is $I_C = -3/23 \text{ A}$. Its negative sign reverses the assumed direction. The check $I_L = 45/23 \text{ A}$, $I_R = -42/23 \text{ A}$ satisfies the junction equation.

Step 4: Conclusion (a) The conserved quantities are electric charge and energy. (b) The current through 1Ω is $3/23 \text{ A} \approx 0.130 \text{ A}$, upwards from Q to P .

Quick Tip to Solve: Mark each cell's long plate as positive first; a negative assumed P-to-Q current means that the actual current flows from Q to P.

Section D (8 marks)

Questions number 29 and 30 are Case Study-based questions. Read the following paragraphs and answer the questions that follow.

29. An astronomical telescope consists of two converging lenses. One of them of large aperture and large focal length is called objective lens and the other one, of smaller focal length and smaller aperture is called the eyepiece. It is used to see distant objects which are not seen clearly with naked eyes. The image formed by the objective lens acts as an object for the eyepiece and the final image produced by the eyepiece is magnified. [4 marks]

29(i). The images formed by the objective lens and the eyepiece are respectively: [1 mark]

- (A) virtual, real
- (B) real, virtual
- (C) virtual, virtual
- (D) real, real

Correct Answer: (B) real, virtual

Solution:

Concept:

- A converging objective focuses the nearly parallel rays from a distant object to form a real image near its principal focal plane.
- The eyepiece acts as a magnifier: it presents a virtual final image of the objective's real intermediate image to the eye.

Step 1: Determine the image formed by the objective Light from the distant object actually converges after passing through the objective. Its intermediate image can be received on a screen, so it is real and inverted. Options (A) and (C), which call this first image virtual, are therefore incorrect.

Step 2: Determine the final image formed by the eyepiece In normal adjustment the intermediate image lies in the eyepiece's first focal plane and the emerging rays are parallel; the eye sees the virtual final image at infinity. For viewing at the least distance of distinct vision, the intermediate image is placed within the eyepiece's focal length and the final image is again virtual. Thus (D), which describes the final image as real, is unsuitable for normal telescope viewing.

Step 3: Conclusion The objective forms a real image and the eyepiece forms a virtual final image. Hence, the correct option is (B).

Quick Tip to Solve: Follow the light in two stages: the objective first forms a screen-receivable image, and the eyepiece then magnifies that image for the eye.

29(ii). The magnification produced by the telescope does not depend upon the:

[1 mark]

- (A) colour of light
- (B) focal length of objective lens
- (C) focal length of eyepiece
- (D) apertures of objective lens and eyepiece

Correct Answer: (D) apertures of objective lens and eyepiece

Solution:

Concept:

- In normal adjustment, the magnitude of the angular magnification of an astronomical telescope is $|M| = f_o/f_e$, where f_o and f_e are the focal lengths of the objective and eyepiece.
- Aperture determines the amount of light admitted and affects resolving ability; it does not occur in the geometrical formula for angular magnification.

Step 1: Inspect the magnification formula The angular magnification increases with objective focal length and decreases with eyepiece focal length. Thus the magnification explicitly depends on both quantities in options (B) and (C). If the final image is at the near point D , the expression becomes $|M| = (f_o/f_e)(1 + f_e/D)$; aperture remains absent.

Step 2: Distinguish aperture from optical dispersion The refractive index of lens material varies with the colour of light, and hence the lens focal lengths can vary with colour. Colour cannot therefore be asserted to have no effect in general, whereas changing the clear apertures while retaining the same focal lengths changes brightness or resolution without changing the geometrical angular magnification. This identifies the quantity in option (D).

Step 3: Conclusion The magnification does not depend on the apertures of the objective lens and eyepiece. Hence, the correct option is (D).

Quick Tip to Solve: Use $|M| = f_o/f_e$ to separate magnification from brightness and resolution: focal lengths set the former, while aperture controls the latter properties.

29(iii). Which of the following statements is not correct for this telescope?

[1 mark]

- (A) The focal length of objective lens (f_o) is larger than the focal length of eyepiece (f_e).
- (B) Its magnifying power can be increased by increasing the focal length of objective lens (f_o).
- (C) The distance between two lenses is more than $(f_o + f_e)$.
- (D) The magnifying power can be decreased by increasing the focal length of eyepiece.

Correct Answer: (C) The distance between two lenses is more than $(f_o + f_e)$.

Solution:

Concept:

- An astronomical telescope uses an objective with focal length f_o much greater than eyepiece focal length f_e ; its angular magnification magnitude in normal adjustment is $|M| = f_o/f_e$.
- Normal adjustment places the objective's real image at the eyepiece's first focus, giving lens separation $L = f_o + f_e$.

Step 1: Check the statements about focal lengths and magnification The objective has the longer focal length, so (A) is correct. At fixed f_e , increasing f_o increases $|M|$, making (B) correct. At fixed

f_o , increasing f_e decreases $|M|$, making (D) correct. These statements agree with the ratio of focal lengths.

Step 2: Check the statement about lens separation In normal adjustment the lens separation is exactly $f_o + f_e$, not greater. If the virtual final image is instead formed at the near point D , the object distance magnitude for the eyepiece is $f_e D / (D + f_e) < f_e$. The separation is then $f_o + f_e D / (D + f_e)$, which is smaller than $f_o + f_e$. Thus (C) is incorrect in both standard viewing arrangements.

Step 3: Conclusion The incorrect statement is that the distance between the lenses is more than $f_o + f_e$. Hence, the correct option is (C).

Quick Tip to Solve: For a telescope, remember that normal adjustment gives the sum of focal lengths; bringing the final virtual image to the near point shortens the tube.

29(iv)(a). An astronomical telescope has objective lens and eyepiece of focal lengths 80 cm and 4 cm respectively. To view the image in normal adjustment, the lenses must be separated by a distance of: [1 mark]

- (A) 84 cm
- (B) 76 cm
- (C) 20 cm
- (D) 320 cm

Correct Answer: (A) 84 cm

Solution:

Concept:

- In normal adjustment, the final image produced by an astronomical telescope is at infinity and the rays emerging from its eyepiece are parallel.
- The objective's second focal plane coincides with the eyepiece's first focal plane, so the separation of two converging lenses is $L = f_o + f_e$.

Step 1: Apply the condition for normal adjustment The distant object forms its intermediate image $f_o = 80$ cm behind the objective. For the eyepiece to send out parallel rays, that intermediate image must lie $f_e = 4$ cm in front of the eyepiece. Both these positive distances contribute to the space between the lenses.

Step 2: Calculate the required separation Add the two focal lengths:

$$L = 80 \text{ cm} + 4 \text{ cm} = 84 \text{ cm}.$$

The difference 76 cm in (B) does not place the shared focal plane between two converging lenses. The number 20 comes from a focal-length ratio and describes magnification, while 320 comes from a product of focal lengths and is not the required length. Hence (C) and (D) also fail.

Step 3: Conclusion The lenses must be separated by 84 cm. Hence, the correct option is (A).

Quick Tip to Solve: With two converging lenses in normal telescope adjustment, add their focal lengths for tube length and divide them for magnification.

29(iv)(b). Consider the telescope described in question (iv) (a). Its magnifying power in normal adjustment will be: [1 mark]

- (A) 320
- (B) 84
- (C) 76
- (D) 20

Correct Answer: (D) 20

Solution:

Concept:

- An astronomical telescope in normal adjustment has angular magnification $M = -f_o/f_e$, with f_o and f_e the focal lengths of its objective and eyepiece.
- The minus sign signifies the inverted final image. When positive numerical magnifying powers are listed, compare the magnitude $|M| = f_o/f_e$, which has no unit.

Step 1: Use the focal lengths of the specified telescope Part (iv)(a) gives objective focal length $f_o = 80$ cm and eyepiece focal length $f_e = 4$ cm. Normal adjustment means that the final image is at infinity, so no near-point correction factor is needed.

Step 2: Evaluate the focal-length ratio and compare options The magnitude of angular magnification is

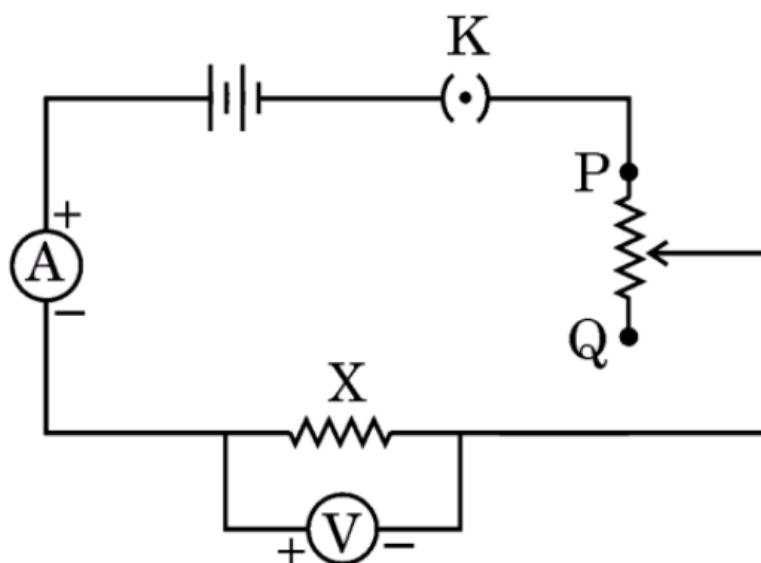
$$|M| = \frac{80 \text{ cm}}{4 \text{ cm}} = 20.$$

The units cancel, as required for a ratio of angles. The value 320 in (A) is the product of the numerical focal lengths; 84 in (B) is their sum, giving the tube length in centimetres; and 76 in (C) is their difference. None of those operations gives the magnifying power.

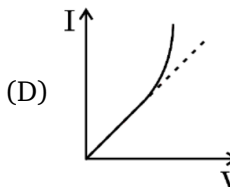
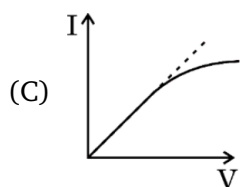
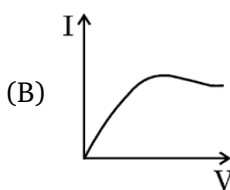
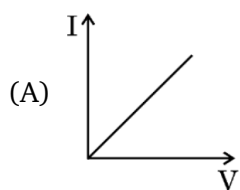
Step 3: Conclusion The magnifying power is $\boxed{20}$. The signed angular magnification is -20 , indicating inversion. Hence, the correct option is (D).

Quick Tip to Solve: Put both focal lengths in the same unit before dividing, and distinguish the dimensionless magnifying power from the tube length in centimetres.

30. A student sets up the circuit as shown in the figure to find the value of unknown resistance X and records a set of readings of the voltmeter and the ammeter by using the rheostat. [4 marks]



30(i). If resistor X were made of manganin and readings for V and I are taken without switching off the circuit, the graph between V and I will be as: [1 mark]



Correct Answer: (A)

Solution:

Concept:

- Ohm's law gives $V = IR$, where V is the potential difference, I the current and R the resistance of the wire.
- Manganin has a very small temperature coefficient of resistance. Its resistance stays approximately constant over the temperature change in this experiment.

Step 1: Account for heating of the resistor Leaving the circuit switched on can heat the wire. For manganin, however, this produces negligible change in resistance, so the ratio V/I remains nearly constant as readings are taken.

Step 2: Match the plotted axes and shape The printed graphs have I on the vertical axis and V on the horizontal axis. Therefore $I = V/R$ gives a straight line through the origin with constant positive slope $1/R$. The curved graphs in (B), (C) and (D) require a varying resistance and do not represent the approximately ohmic manganin wire.

Step 3: Conclusion The graph is the straight line through the origin. Hence, the correct option is (A).

Quick Tip to Solve: Check the axes first: an I -versus- V graph has slope $1/R$; nearly constant manganin resistance gives a straight line.

30(ii). Error in the value of X obtained from different sets of voltmeter and ammeter readings, is: [1 mark]

- (A) due to error in voltmeter reading only.
- (B) due to error in ammeter reading only.
- (C) equal to the sum of error in voltmeter reading and error in ammeter reading.
- (D) equal to error in voltmeter reading divided by the error in ammeter reading.

Correct Answer: (C) equal to the sum of error in voltmeter reading and error in ammeter reading.

Solution:

Concept:

- The measured resistance is $X = V/I$, where V and I are the voltmeter and ammeter readings.
- For a quotient, the maximum fractional errors add: $\Delta X/X = \Delta V/V + \Delta I/I$, to first order in small measurement uncertainties.

Step 1: Include uncertainty in both readings Since the resistance depends on both measured quantities, uncertainty in either instrument changes the calculated value. Options (A) and (B), which include only one instrument, omit part of the error.

Step 2: Apply the error rule for a quotient The largest resistance estimate occurs when the voltage is overestimated and the current is underestimated. Thus the maximum relative error is the sum of their relative errors:

$$\frac{\Delta X}{X} = \frac{\Delta V}{V} + \frac{\Delta I}{I}.$$

Option (C) uses the usual intended meaning of fractional or percentage error. It must not mean adding the absolute errors in volts and amperes, which have different units. Option (D) is incorrect because dividing measured quantities does not mean dividing their uncertainties.

Step 3: Conclusion The maximum fractional (or percentage) error in X is the sum of the corresponding errors in V and I . Hence, the correct option is (C).

Quick Tip to Solve: For $X = V/I$, add percentage uncertainties; never add an uncertainty in volts directly to one in amperes.

30(iii). If the movable end of rheostat is moved towards P, then:

[1 mark]

- (A) reading in ammeter decreases and reading in voltmeter increases.
- (B) readings in both voltmeter and ammeter increase.
- (C) reading in ammeter increases and reading in voltmeter decreases.
- (D) readings in both voltmeter and ammeter decrease.

Correct Answer: (B) readings in both voltmeter and ammeter increase.

Solution:

Concept:

- In a rheostat, the resistance in the circuit is proportional to the length of resistance wire between the connected fixed end and the slider.
- For a fixed source emf $\mathcal{E}$, the series current is $I = \mathcal{E}/R_{\text{total}}$. Across a constant resistance X , the voltage is $V_X = IX$.

Step 1: Identify the active part of the rheostat The circuit uses the fixed end P and the sliding contact; Q is not externally connected. Moving the contact towards P shortens the included wire and reduces the rheostat resistance. Consequently the total circuit resistance decreases.

Step 2: Determine both meter readings With the source unchanged, the smaller total resistance increases the current, so the ammeter reading increases. The voltmeter is connected across the same resistor X ; therefore its reading IX also increases. Options (A) and (C) incorrectly predict opposite changes for the two readings, while (D) would require an increase in series resistance.

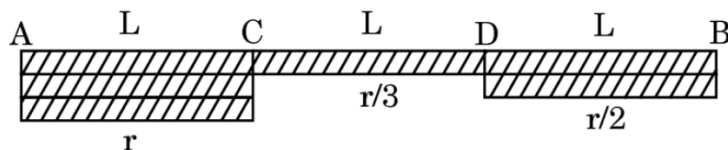
Step 3: Conclusion Readings in both the voltmeter and the ammeter increase. Hence, the correct option is (B).

Quick Tip to Solve: Trace the two connected rheostat terminals: moving the slider towards the connected fixed end shortens the active wire and raises current.

30(iv)(a). Suppose the unknown resistance X is replaced by a wire made of the same metal. This wire consists of three parts, of the same length L but has radii r , $r/3$ and $r/2$ as shown in the figure.

For a particular setting of the rheostat, let v_1 , v_2 and v_3 be the value of drift velocities in parts AC, CD and DB. Then:

[1 mark]



(A) $v_1 > v_2 > v_3$

(B) $v_2 > v_3 > v_1$

(C) $v_3 > v_2 > v_1$

(D) $v_1 = v_2 = v_3$

Correct Answer: (B) $v_2 > v_3 > v_1$

Solution:

Concept:

- A steady current has the same value through every cross-section of a wire connected in series; charge cannot accumulate continuously at a junction.
- The magnitude of drift velocity is $v_d = I/(neA)$, where n is the free-electron number density, e the electron charge magnitude and A the cross-sectional area.

Step 1: Compare the cross-sectional areas All three parts are made of the same metal, so n is the same, and the current I is common. Their radii give

$$A_1 = \pi r^2, \quad A_2 = \frac{\pi r^2}{9}, \quad A_3 = \frac{\pi r^2}{4}.$$

Step 2: Use the inverse-area dependence For fixed I and n , drift speed is inversely proportional to area. Taking $v_1 = I/(ne\pi r^2)$, the other speeds are $v_2 = 9v_1$ and $v_3 = 4v_1$. Thus the narrowest part CD requires the fastest drift and the widest part AC the slowest. Equal current does not imply equal speed, so (D) fails; (A) and (C) also conflict with the inverse-area dependence.

Step 3: Conclusion $v_1 : v_2 : v_3 = 1 : 9 : 4$, so $v_2 > v_3 > v_1$. Hence, the correct option is (B).

Quick Tip to Solve: For series portions of the same metal, compare $1/r^2$: radii $r, r/3, r/2$ give drift-speed ratios $1 : 9 : 4$.

30(iv)(b). Consider the same wire, as shown in figure in question (iv) (a) connected in place of X. For a particular setting of rheostat, let E_1 , E_2 and E_3 be the value of electric fields in part AC, CD and DB. Then: [1 mark]

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

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

Solution:

Concept:

- In steady state, the same current I passes through the three parts of the series wire, but current density $J = I/A$ depends on cross-sectional area A .
- The microscopic form of Ohm's law is $E = \rho J = \rho I/A$. Here E is electric-field magnitude and ρ is resistivity, common to the parts of the same metal under the stated conditions.

Step 1: Express each field in terms of its area The radii of AC, CD and DB are $r, r/3, r/2$, respectively. Their areas are $\pi r^2, \pi r^2/9, \pi r^2/4$. With the same current and resistivity in every part,

$$E_1 = \frac{\rho I}{\pi r^2}, \quad E_2 = 9E_1, \quad E_3 = 4E_1.$$

Step 2: Compare the field strengths The narrowest part CD has the largest current density and therefore the strongest field. The widest part AC has the weakest field. Equal lengths do not make the fields equal, so (A) fails. The orderings in (B) and (D) are also inconsistent with the inverse-area dependence, since CD must have the largest field.

Step 3: Conclusion $E_1 : E_2 : E_3 = 1 : 9 : 4$, and hence $E_2 > E_3 > E_1$. Hence, the correct option is (C).

Quick Tip to Solve: In series sections of one metal, both electric field and drift speed vary as $1/A$, so the smallest radius gives the largest field.

Section E (15 marks)

31(a). (i) Explain the following statements giving reason:

(I) An equipotential surface through a point is normal to the electric field at that point.

(II) When a dielectric is placed in an external electric field, the electric field inside the dielectric is less than that outside it.

(III) The potential difference between the plates of a charged parallel plate capacitor decreases when its plates are brought closer.

(ii) Obtain an expression for the work done to dissociate the system of three charges q , $-4q$ and $2q$ placed at the vertices A, B and C respectively of an equilateral triangle of side 'a'. [5 marks]

Solution:

Concept:

- The potential change in a displacement $d\vec{l}$ is $dV = -\vec{E} \cdot d\vec{l}$. An equipotential surface has the same potential at every point.
- A dielectric is polarised by an external field: its induced bound charges produce an opposing field inside the material.
- For an isolated parallel plate capacitor, charge Q remains fixed, $C = \epsilon_0 A/d$, and $V = Q/C$, where A is plate area and d is separation.
- The electrostatic potential energy of point charges is the sum over distinct pairs, $U = \sum_{i < j} k q_i q_j / r_{ij}$, where $k = 1/(4\pi\epsilon_0)$. External work in a quasistatic process equals the change in potential energy.

Step 1: (i)(I) Relate the field to a tangential displacement Take an infinitesimal displacement $d\vec{l}$ along the equipotential surface. Since both its endpoints have the same potential, $dV = 0$. Therefore,

$$\vec{E} \cdot d\vec{l} = E dl \cos \theta = 0.$$

At a point where the field is nonzero, $\theta = 90^\circ$. This is true for every tangent direction on the surface, so the electric field has no tangential component and points along the normal to the surface. Otherwise moving a charge tangentially would require nonzero work despite zero potential difference.

Step 2: (i)(II) Account for dielectric polarisation The external field slightly separates the positive and negative bound charges in nonpolar molecules, and tends to align permanent dipoles in polar molecules. Bound charges consequently appear on opposite faces of the dielectric. Their electric field $\vec{E}_p$ inside the dielectric opposes the applied field $\vec{E}_0$. Thus the resultant field has magnitude

$$E = E_0 - E_p < E_0.$$

For the usual uniform-field arrangement with a linear dielectric of relative permittivity $K > 1$, this is expressed as $E = E_0/K$. The reduction results from polarisation, without free conduction of charge through the dielectric.

Step 3: (i)(III) Keep the capacitor charge fixed The stated decrease applies to a charged capacitor isolated from a voltage source, so no charge can enter or leave its plates. Neglecting edge effects,

$$V = \frac{Q}{C} = \frac{Qd}{\epsilon_0 A}.$$

Bringing the plates closer decreases d , increases C , and hence decreases V , since Q and A stay unchanged. Equivalently, the field $E = Q/(\epsilon_0 A)$ remains constant while $V = Ed$ decreases. If a

battery were kept connected, it would instead maintain the potential difference; the fixed-charge condition is essential here.

Step 4: (ii) Sum the three pair energies All three separations in the equilateral triangle are a . With $q_A = q$, $q_B = -4q$, and $q_C = 2q$, include each pair once:

$$\begin{aligned} U_i &= \frac{k}{a} (q_A q_B + q_B q_C + q_C q_A) \\ &= \frac{k}{a} (-4q^2 - 8q^2 + 2q^2) \\ &= -\frac{10kq^2}{a}. \end{aligned}$$

Complete dissociation means taking all charges infinitely far apart, where their mutual potential energy is $U_f = 0$. For slow separation with no net change in kinetic energy, the external work is

$$W_{\text{ext}} = U_f - U_i = \frac{10kq^2}{a}.$$

Its positive sign means energy must be supplied to separate this initially negative-energy system; the work done by the electric field has the opposite sign.

Step 5: Conclusion The field is normal to an equipotential surface; dielectric polarisation opposes and reduces the applied field; and decreasing plate separation reduces V at fixed charge. The work required to dissociate the three-charge system is $W_{\text{ext}} = 10q^2/(4\pi\epsilon_0 a)$.

Quick Tip to Solve: For the capacitor, identify whether charge or voltage is fixed before using $V = Q/C$. For three charges, list AB, BC and CA once and reverse the sign of their total energy to obtain the dissociation work.

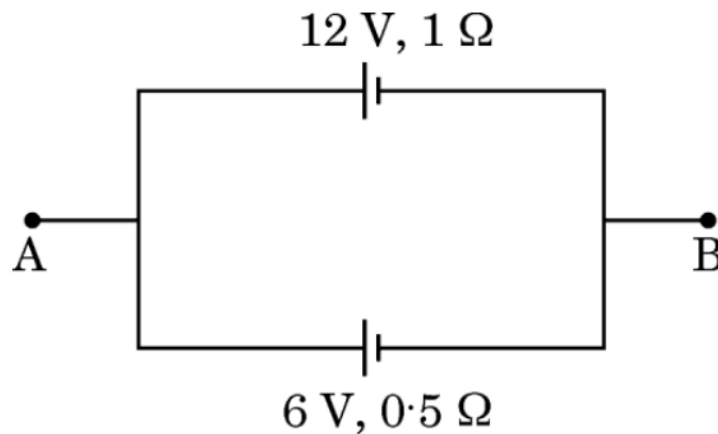
31(b). (i) Answer the following giving reason:

(I) The electron drift speed is estimated to be only a few mm/s for currents in the range of a few amperes. How, then, is the current established almost the instant a circuit is closed?

(II) A low voltage supply from which one needs high currents must have very low internal resistance. Why?

(III) The assertion that $V = IR$ is a statement of Ohm's law is not true. Why?

(ii) Two cells of emfs 12 V and 6 V are connected in parallel as shown in the figure. Their internal resistances are $1\ \Omega$ and $0.5\ \Omega$ respectively. Calculate the emf and internal resistance of the equivalent cell between points A and B. [5 marks]



Solution:

Concept:

- Drift speed describes the slow average motion of charge carriers; the electromagnetic signal that establishes the electric field travels through a circuit much faster.
- A source of emf $\mathcal{E}$ and internal resistance r supplying current I has terminal voltage $V = \mathcal{E} - Ir$ and internal power loss I^2r .
- Ohm's law requires $V \propto I$, so $R = V/I$ is constant when the conductor's temperature and other physical conditions remain unchanged.
- Cells connected in parallel have a common terminal voltage. Their equivalent emf is the open-circuit terminal voltage, and their equivalent internal resistance is the parallel combination of their internal resistances.

Step 1: (i)(I) Distinguish signal propagation from drift Free electrons are already present throughout every part of the conducting circuit. When the switch is closed, the change in electric field propagates around the circuit at a very high speed, of the order of the speed of light in the surrounding medium. Electrons in each segment respond to their local field, acquiring a small average drift velocity on top of their random motion. The circuit therefore does not wait for an electron to travel from the battery through the entire wire. The field is established throughout an ordinary circuit in a very short time, even though an individual electron's drift speed is only a few mm s^{-1} . Establishment is rapid but is not literally instantaneous.

Step 2: (i)(II) Limit the internal voltage drop The source's internal resistance consumes part of its emf as an internal drop Ir . To obtain a large load current while retaining nearly the full, already

small, supply voltage, we need

$$Ir \ll \mathcal{E}, \quad r \ll \frac{\mathcal{E}}{I}.$$

For large I and small $\mathcal{E}$, this requires very small r . A substantial internal resistance would greatly reduce the terminal voltage $V = \mathcal{E} - Ir$ and also waste power as internal heating $I^2 r$.

Step 3: (i)(III) Identify the extra condition in Ohm's law Writing $V = IR$ alone can merely express the definition $R = V/I$ at a chosen operating point. This ratio can be defined even for a non-ohmic device, where it changes with the applied voltage or current. Ohm's law adds the experimentally testable requirement that, at constant temperature and other unchanged physical conditions, R is independent of V and I . Its voltage-current graph is then a straight line through the origin. Thus the bare equation without the constant-resistance condition is not a complete statement of the law.

Step 4: (ii) Calculate the common open-circuit voltage In the printed figure, the long plate of each cell is on the A side: both positive terminals are connected to A. Let $V = V_A - V_B$. For cell j , take I_j positive when it supplies current to terminal A. Then $I_j = (\mathcal{E}_j - V)/r_j$. With no external load, Kirchhoff's junction rule gives $I_1 + I_2 = 0$, so

$$\begin{aligned} \frac{\mathcal{E}_1 - V}{r_1} + \frac{\mathcal{E}_2 - V}{r_2} &= 0, \\ V &= \frac{\mathcal{E}_1/r_1 + \mathcal{E}_2/r_2}{1/r_1 + 1/r_2} \\ &= \frac{12/1 + 6/0.5}{1/1 + 1/0.5} = 8 \text{ V}. \end{aligned}$$

This open-circuit terminal voltage is $\mathcal{E}_{\text{eq}}$. As a check, the 12 V cell supplies $(12 - 8)/1 = 4$ A, while the 6 V cell has supplying current $(6 - 8)/0.5 = -4$ A: it receives the same circulating current.

Step 5: (ii) Combine the internal resistances To find the resistance seen between A and B, replace each ideal emf by a short circuit while retaining its internal resistance. The two resistances then lie in parallel:

$$r_{\text{eq}} = \frac{r_1 r_2}{r_1 + r_2} = \frac{1 \times 0.5}{1 + 0.5} = \frac{1}{3} \Omega.$$

This is less than either individual internal resistance, as a parallel combination must be. The equivalent emf lies between the two original emfs; it is not their sum.

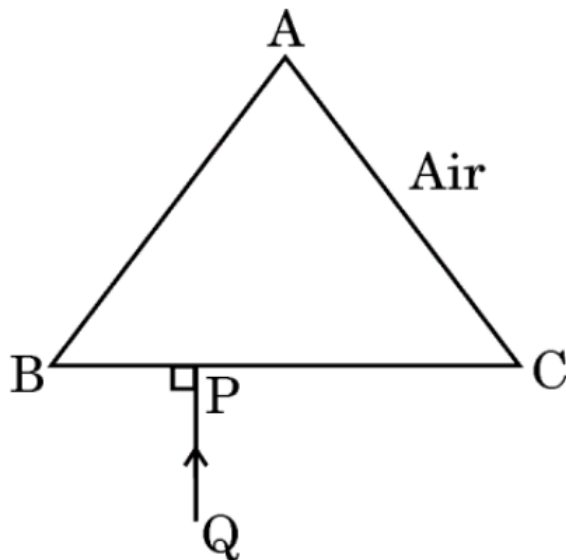
Step 6: Conclusion Current begins rapidly because the electric-field signal travels fast; high-current low-voltage supplies need a small internal drop; and Ohm's law additionally requires constant R . The equivalent cell has $\mathcal{E}_{\text{eq}} = 8 \text{ V}$, with A positive relative to B, and $r_{\text{eq}} = 1/3 \Omega \approx 0.33 \Omega$.

Quick Tip to Solve: Check the long plates to fix the cell polarities. For like-polarity cells in parallel, average the emfs with weights $1/r$, and combine the internal resistances in parallel.

32(a). (i) Define refractive index of a medium in terms of speed of light.

(ii) Derive the relation for the refractive index (μ) of a prism in terms of angle of minimum deviation (δ_m) and angle of prism (A).

(iii) A ray of light QP is incident normally on the face BC of a triangular prism ABC of refractive index 1.5 kept in air, as shown in the figure. Trace the path of the ray as it passes through the prism and give relevant explanation. [5 marks]



Solution:

Concept:

- Absolute refractive index is $\mu = c/v$, where c is the speed of light in vacuum and v is its speed in the medium.
- For a prism in air, Snell's law gives $\sin i = \mu \sin r_1$ and $\sin e = \mu \sin r_2$. Here i, e are external angles and r_1, r_2 are internal angles, all measured from the respective normals.
- Prism geometry gives $r_1 + r_2 = A$ and total deviation $\delta = i + e - A$. At minimum deviation the ray path is symmetric.
- At a prism-air boundary, total internal reflection occurs only when incidence exceeds the critical angle θ_c , with $\sin \theta_c = 1/\mu$.

Step 1: (i) Define refractive index using the speed of light The absolute refractive index of a medium is the ratio of the speed of light in vacuum to its speed in that medium:

$$\mu = \frac{c}{v}.$$

It is dimensionless because both speeds have the same units. For a transparent medium with $\mu = 1.5$, light travels at $v = c/1.5$; taking $c = 3.0 \times 10^8 \text{ m s}^{-1}$ gives $v = 2.0 \times 10^8 \text{ m s}^{-1}$.

Step 2: (ii) Relate the refraction angles to the prism angle Let a ray enter one refracting face at incidence i , refract inside through angle r_1 , reach the second face at internal incidence r_2 , and emerge at angle e . The normals to the two faces form an angle $180^\circ - A$ inside the quadrilateral containing the prism apex and the two points of refraction. Its angle sum gives

$$r_1 + r_2 = A.$$

The changes in direction at the first and second faces are respectively $i - r_1$ and $e - r_2$. Their sum is

the deviation:

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

Step 3: Apply the symmetric minimum-deviation condition When deviation is minimum, reversibility of light gives a symmetric path: $i = e$ and $r_1 = r_2$. Thus

$$r_1 = r_2 = \frac{A}{2}, \quad \delta_m = 2i - A, \quad i = \frac{A + \delta_m}{2}.$$

Applying Snell's law at the first face, with the refractive index of air taken as unity, yields

$$\mu = \frac{\sin i}{\sin r_1} = \frac{\sin[(A + \delta_m)/2]}{\sin(A/2)}.$$

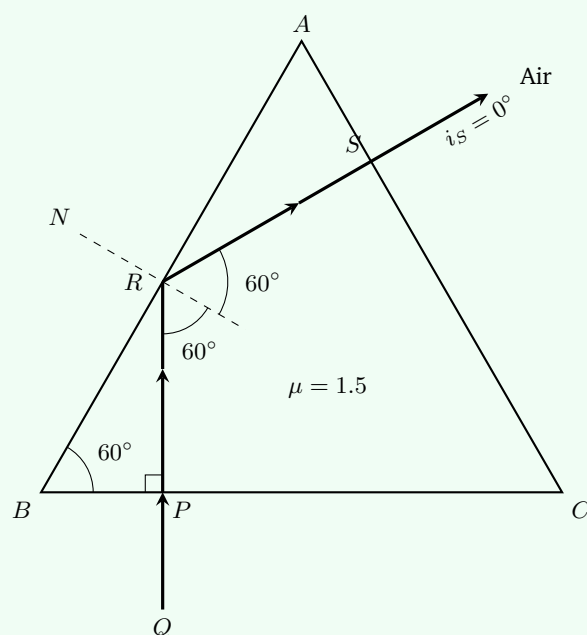
This relation uses the minimum value of deviation; an arbitrary measured deviation cannot replace δ_m .

Step 4: (iii) Determine entry and the condition for internal reflection At P , the incident ray QP is normal to BC , so $i = 0$. Snell's law therefore gives $r = 0$: the ray enters undeviated and reaches face AB . For the prism of refractive index 1.5 in air,

$$\theta_c = \sin^{-1}\left(\frac{1}{1.5}\right) = \sin^{-1}\left(\frac{2}{3}\right) \simeq 41.8^\circ.$$

If $B = \angle ABC$, the ray's incidence on AB , measured from that face's normal, equals B . Hence it undergoes total internal reflection there when $B > 41.8^\circ$. For $B < 41.8^\circ$ it instead has a transmitted ray obeying $\sin r = 1.5 \sin B$; at equality the refracted ray grazes the face.

Step 5: Trace the conventional equilateral-prism interpretation The printed diagram supplies no prism angles or equal-side markings, so an exact numerical ray path is not uniquely specified. Under the conventional equilateral interpretation, $A = B = C = 60^\circ$, the requested path is as drawn below. The ray reaches AB at R with incidence $60^\circ > 41.8^\circ$, so it is totally internally reflected. Its reflection angle is also 60° , measured from the normal at R . The reflected ray RS then meets face AC normally at S and emerges undeviated into air. Thus this interpretation gives the path $Q \rightarrow P \rightarrow R \rightarrow S$, followed by straight emergence through AC . The 60° angles and normal emergence depend on the stated equilateral assumption; normal entry at BC and the critical angle do not.



Ray path under the explicitly stated equilateral-prism assumption; dashed lines are normals.

Step 6: Conclusion $\mu = \frac{c}{v} = \frac{\sin[(A + \delta_m)/2]}{\sin(A/2)}$ for a prism in air at minimum deviation. The ray enters BC normally. For an equilateral prism it undergoes total internal reflection at AB and emerges normally through AC ; without specified prism angles, that complete path is conditional.

Quick Tip to Solve: Measure incidence from the normal, then compare it with 41.8° . Do not infer a numerical prism angle merely from an unlabelled sketch.

OR

32(b). (i) What is the difference between a ray and a wavefront?

(ii) A plane wave is incident on a reflecting surface. Using Huygens principle, show how it is reflected from the surface. Hence, verify the law of reflection.

(iii) Depict refraction of a plane wave by a convex lens.

[5 marks]

Solution:

Concept:

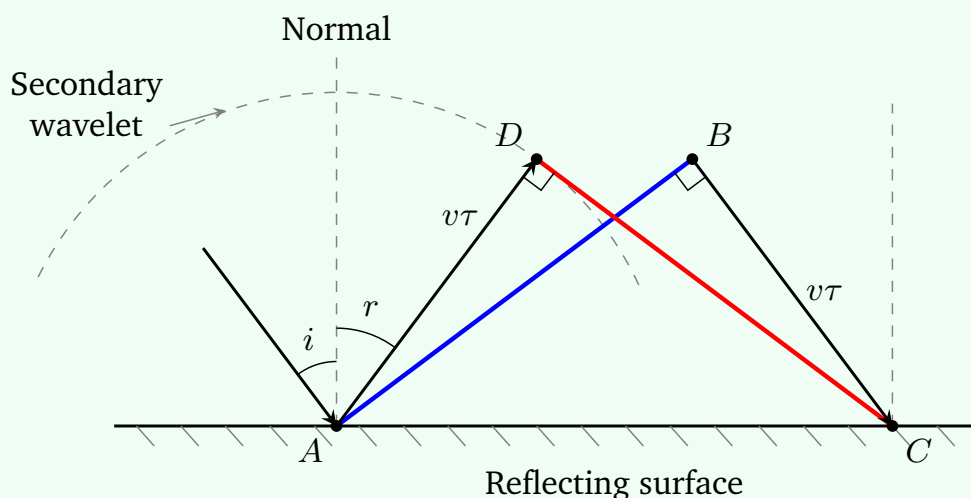
- A wavefront is the locus of points vibrating in the same phase. In an isotropic medium, a ray gives the direction of propagation and is normal to the wavefront.
- Huygens' principle: every point on a wavefront acts as a source of secondary wavelets; their forward envelope gives the subsequent wavefront. A wavelet travels a distance $v\tau$ in time τ , where v is the wave speed.
- The angles of incidence i and reflection r are measured between the respective rays and the normal to the reflecting surface. A thin convex lens converts an axial plane wavefront into a converging spherical wavefront, in the paraxial approximation.

Step 1: (i) Distinguish a ray from a wavefront A **ray** is an imaginary directed line showing the path along which light energy propagates. A **wavefront** is a surface joining points of a wave that have the same phase at a given instant. Thus a ray specifies a propagation direction, whereas a wavefront

specifies a surface of equal phase. In a homogeneous isotropic medium the rays are perpendicular to the wavefront: parallel rays correspond to a plane wavefront, while rays directed towards a common point are normal to a converging spherical wavefront. The lines used for wavefronts in the figures are cross-sections of these surfaces.

Step 2: (ii) Construct the reflected wavefront Let AB be the incident plane wavefront and AC the reflecting surface. Point A reaches the surface first. During the next time interval τ , the disturbance at B travels along the incident ray BC and reaches C , so $BC = v\tau$.

Meanwhile, the secondary wavelet originating at A spreads in the incident medium with radius $AD = v\tau$. Draw the tangent CD from C to this wavelet. The line CD , which is also the envelope of the secondary wavelets emitted by the intervening surface points, is the reflected wavefront at that instant. The reflected ray AD is perpendicular to CD , and BC is perpendicular to AB . The dashed circular arc shows the wavelet from A .



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

Step 3: Verify the law of reflection In right triangles ABC and ADC , the common hypotenuse is AC , and the distances travelled during the same time interval satisfy

$$BC = AD = v\tau.$$

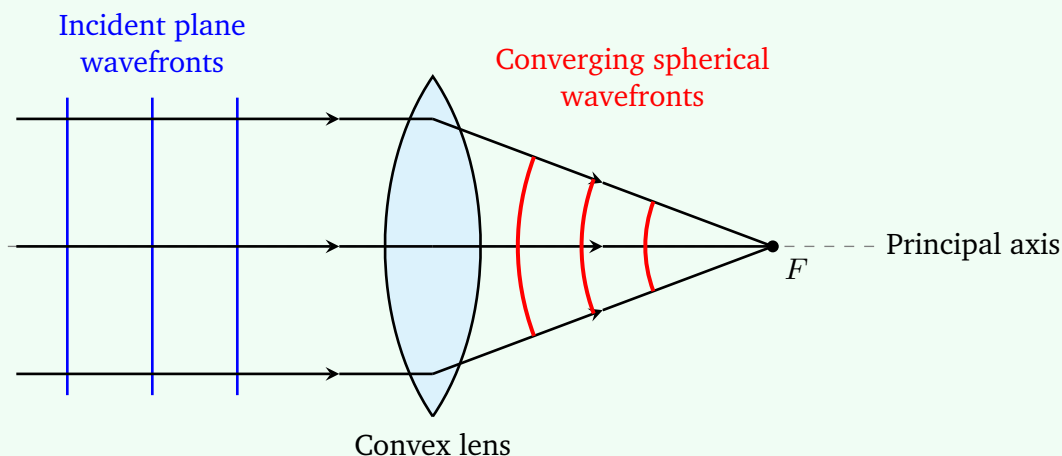
The angle $\angle BAC$ between the incident wavefront and the surface equals i , since their respective perpendiculars are the incident ray and surface normal. Similarly, $\angle DCA = r$. Hence,

$$\begin{aligned}\sin i &= \frac{BC}{AC} = \frac{v\tau}{AC}, \\ \sin r &= \frac{AD}{AC} = \frac{v\tau}{AC}.\end{aligned}$$

Therefore $\sin i = \sin r$. Both angles lie between 0° and 90° , giving $i = r$. The construction places the incident ray, reflected ray and surface normal in the same plane. Thus it verifies both laws of reflection.

Step 4: (iii) Depict the wavefront emerging from a convex lens Take the incident plane wavefront perpendicular to the principal axis of a thin convex lens. Its incident rays are parallel to that axis. The lens is thicker at the centre, so the central portion of the wave suffers a greater optical delay than the portions near the edges. Refraction consequently changes the plane wavefront into a converging spherical wavefront whose centre is the principal focus F , neglecting spherical aberration.

The diagram shows successive incident plane wavefronts and successive emerging spherical wavefronts. The emerging rays are normal to these curved wavefronts and meet at F ; as the wave travels towards F , the radius of curvature decreases. Beyond the focus the wavefront would be divergent.



A convex lens transforms plane wavefronts into spherical wavefronts converging at F (schematic, paraxial approximation).

Step 5: Conclusion A ray represents the direction of propagation, while a wavefront is a surface of equal phase. Huygens' construction gives a reflected plane wavefront and verifies $i = r$, with the incident ray, reflected ray and normal coplanar. A convex lens transforms an axial incident plane wavefront into a spherical wavefront converging towards its principal focus.

Quick Tip to Solve: In the reflection construction, mark the two equal distances $BC = AD = v\tau$ first and draw the tangent from C . For a convex lens, draw curved wavefronts centred on F , with rays perpendicular to them.

33(a). (i) Define the terms (I) resonant frequency, and (II) power factor of a series LCR circuit. For what value of the power factor will the power dissipated in the circuit be maximum?

(ii) An inductor of $\frac{5}{\pi}$ H, a capacitor of $\frac{50}{\pi} \mu\text{F}$ and a resistor of 400Ω are connected in series across an ac voltage $v = 140 \sin(100\pi t)$ V. Calculate:

(I) impedance of the circuit, and

(II) rms value of current that flows in the circuit.

(Take $\sqrt{2} = 1.4$)

[5 marks]

Solution:

Concept:

- In a series LCR circuit, resonance occurs when the inductive reactance $X_L = \omega L$ equals the capacitive reactance $X_C = 1/(\omega C)$. Here L is the inductance, C the capacitance and $\omega = 2\pi f$ the angular frequency.
- The impedance magnitude is $Z = \sqrt{R^2 + (X_L - X_C)^2}$, where R is the resistance. The power factor is $\cos \phi = R/Z$, with ϕ the phase difference between the applied voltage and the current.
- For sinusoidal alternating voltage, $V_{\text{rms}} = V_0/\sqrt{2}$ and $I_{\text{rms}} = V_{\text{rms}}/Z$. The average power dissipated is $P = V_{\text{rms}} I_{\text{rms}} \cos \phi$.

Step 1: (i)(I) Define the resonant frequency The resonant frequency is the frequency of the applied

alternating voltage at which the inductive and capacitive reactances of a series LCR circuit are equal. The net reactance then vanishes, the impedance is minimum and, for a fixed applied rms voltage, the current is maximum. Setting the two reactances equal gives

$$\omega_0 L = \frac{1}{\omega_0 C} \Rightarrow \omega_0 = \frac{1}{\sqrt{LC}}, \quad f_0 = \frac{1}{2\pi\sqrt{LC}}.$$

At this frequency, the circuit behaves as a pure resistance and the applied voltage and current are in phase.

Step 2: (i)(II) Define the power factor and find its value for maximum power The power factor is the cosine of the phase difference between the applied voltage and the circuit current. Equivalently, it is the ratio of average power to the product of rms voltage and rms current:

$$\cos \phi = \frac{P}{V_{\text{rms}} I_{\text{rms}}} = \frac{R}{Z}.$$

For a series circuit with fixed resistance and fixed applied rms voltage,

$$P = I_{\text{rms}}^2 R = \frac{V_{\text{rms}}^2 R}{R^2 + (X_L - X_C)^2}.$$

This expression is greatest when $X_L = X_C$, so that $Z = R$ and $\phi = 0$. Thus maximum power dissipation corresponds to unity power factor.

Step 3: (ii)(I) Read the source frequency and calculate the reactances Comparing the given source $v = 140 \sin(100\pi t)$ V with $v = V_0 \sin(\omega t)$, we obtain $V_0 = 140$ V and $\omega = 100\pi$ rad s⁻¹. Use the printed component values $L = 5/\pi$ H and $C = (50/\pi) \times 10^{-6}$ F. Therefore,

$$X_L = \omega L = (100\pi) \frac{5}{\pi} = 500 \Omega,$$

$$X_C = \frac{1}{\omega C} = \frac{1}{(100\pi)(50/\pi) \times 10^{-6}} = 200 \Omega.$$

The net reactance is $X_L - X_C = 300 \Omega$, so the circuit is inductive at the supplied frequency. The resistance and net reactance combine as perpendicular components in the impedance triangle, not by direct addition.

Step 4: (ii)(I) Evaluate the impedance With $R = 400 \Omega$, the impedance magnitude is

$$Z = \sqrt{400^2 + 300^2} \Omega$$

$$= \sqrt{160000 + 90000} \Omega = \sqrt{250000} \Omega = 500 \Omega.$$

As a consistency check, the power factor of this particular circuit is $R/Z = 400/500 = 0.8$, below unity because the source frequency is not the resonant frequency.

Step 5: (ii)(II) Calculate the rms current The coefficient 140 V in the sine expression is the peak voltage. Convert it to the rms value using the value of $\sqrt{2}$ specified in the question:

$$V_{\text{rms}} = \frac{140}{1.4} = 100 \text{ V}.$$

Ohm's law for the rms quantities then gives

$$I_{\text{rms}} = \frac{V_{\text{rms}}}{Z} = \frac{100}{500} = 0.20 \text{ A}.$$

Alternatively, the peak current is $140/500 = 0.28 \text{ A}$, whose rms value is $0.28/1.4 = 0.20 \text{ A}$, confirming the calculation.

Step 6: Conclusion The resonant frequency is $f_0 = 1/(2\pi\sqrt{LC})$, where $X_L = X_C$. The power factor is $\cos \phi = R/Z$, and maximum power dissipation occurs at $\cos \phi = 1$. For the given circuit, $Z = 500 \Omega$ and $I_{\text{rms}} = 0.20 \text{ A}$.

Quick Tip to Solve: Retain the printed factors of $1/\pi$ in both L and C : they cancel against $\omega = 100\pi$. Then use the 300-400-500 impedance triangle and convert peak voltage to rms before finding rms current.

OR

33(b). (i) Draw a labelled diagram of a step-up transformer. Obtain the ratio of secondary voltage to primary voltage in terms of number of turns in the two coils.

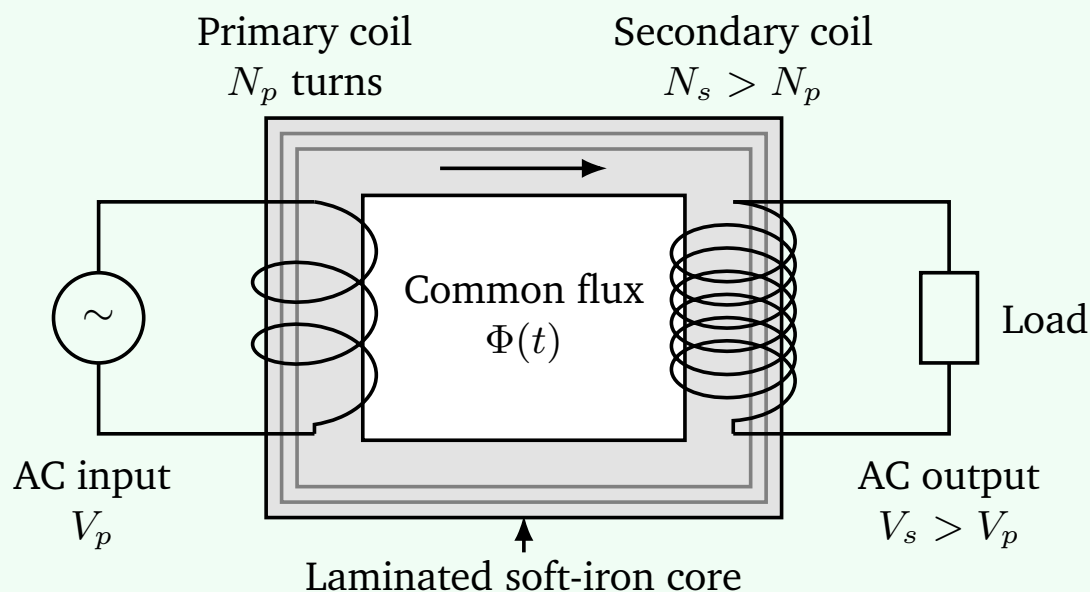
(ii) The number of turns in the primary and the secondary coil of an ideal transformer are 100 and 5000 respectively. If 3.3 kW power is supplied to the transformer at 220 V, find (I) current in the primary coil, and (II) output voltage. [5 marks]

Solution:

Concept:

- A transformer works by mutual induction: an alternating primary current produces a changing magnetic flux in a common iron core, inducing an emf in the secondary coil.
- Faraday's law gives the induced emf in a coil of N turns as $e = -N d\Phi/dt$, where Φ is the magnetic flux through each turn.
- For an ideal transformer, both coils link the same flux and $V_s/V_p = N_s/N_p$, where V_p, V_s are rms voltages and N_p, N_s are the primary and secondary turns. A step-up transformer has $N_s > N_p$.
- An ideal transformer has no power loss. For the usual resistive-load numerical, $P_{\text{in}} = V_p I_p = P_{\text{out}}$, where I_p is the rms primary current.

Step 1: (i) Draw and explain the step-up transformer Wind two insulated coils on a common laminated soft-iron core, with more turns in the secondary coil than in the primary coil. Connect the primary to an alternating-voltage source and connect the secondary to a load. The closed core guides the changing magnetic flux through both coils; its laminations reduce eddy-current loss. The drawing shows the relative numbers of turns schematically. The coils are electrically separate, while energy is transferred through their common alternating magnetic flux.



Step-up transformer: the secondary has more turns and links the same alternating core flux as the primary.

Step 2: (i) Derive the voltage ratio using Faraday's law Let the instantaneous common flux through each turn be $\Phi(t)$. Neglect flux leakage, winding resistance and losses for an ideal transformer. The induced emfs in the two windings, measured using consistent winding orientations, are

$$e_p = -N_p \frac{d\Phi}{dt}, \quad e_s = -N_s \frac{d\Phi}{dt}.$$

Both expressions contain the same flux-change factor. Dividing their magnitudes therefore gives $|e_s|/|e_p| = N_s/N_p$. The applied primary voltage balances the primary induced emf, and the secondary terminal voltage equals its induced emf in the ideal case. The rms magnitudes thus obey

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

Equivalently, for $\Phi = \Phi_m \sin \omega t$, the rms induced emf is $N\omega\Phi_m/\sqrt{2}$ in either winding, giving the same ratio. Since $N_s > N_p$, the secondary voltage exceeds the primary voltage. The frequency is unchanged.

Step 3: (ii)(I) Calculate the primary current The input power and primary voltage are

$$P_{\text{in}} = 3.3 \text{ kW} = 3300 \text{ W}, \quad V_p = 220 \text{ V}.$$

Using the standard ideal-transformer power relation for this numerical, $P_{\text{in}} = V_p I_p$, divide the supplied power by the input voltage:

$$I_p = \frac{P_{\text{in}}}{V_p} = \frac{3300}{220} = 15 \text{ A}.$$

Use the primary voltage here because the given power is supplied at the input. The voltage and current in this calculation are rms values.

Step 4: (ii)(II) Calculate the output voltage Substitute $N_p = 100$ and $N_s = 5000$ into the turns ratio:

$$\frac{N_s}{N_p} = \frac{5000}{100} = 50, \quad V_s = 50V_p = 50(220) = 11000 \text{ V}.$$

As a consistency check, conservation of power gives a secondary current of $3300/11000 = 0.30 \text{ A}$. Thus the fiftyfold voltage increase is accompanied by a fiftyfold current decrease, leaving the ideal output power equal to the input power.

Step 5: Conclusion The labelled step-up transformer has $N_s > N_p$, and its voltage ratio is $V_s/V_p = N_s/N_p$. The required primary current is $I_p = 15 \text{ A}$, and the output voltage is $V_s = 11000 \text{ V} = 11 \text{ kV}$.

Quick Tip to Solve: First calculate the turns multiplier $5000/100 = 50$: multiply the input voltage by 50 for the output voltage. Find the input current separately from $3300/220$; convert kW to W first.