

CBSE Class 12 Physics Question Paper 2025 with Solution PDF-Set 55/6/2



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 of resistance R , connected to an ideal battery consumes a power P . If the wire is gradually stretched to double its initial length, and connected across the same battery, the power consumed will be: [1 mark]

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

Correct Answer: (A) $\frac{P}{4}$

Solution:

Concept:

- For a uniform wire, $R = \rho L/A$, where ρ is resistivity, L is length and A is cross-sectional area.
- Stretching conserves the volume AL ; for an ideal battery of fixed voltage V , the power is $P = V^2/R$.

Step 1: Find the resistance after stretching The length becomes $L' = 2L$. At unchanged volume, $A'L' = AL$, so $A' = A/2$. Taking the resistivity as unchanged,

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

Both the increased length and the reduced area increase resistance.

Step 2: Compare the powers at the same voltage The ideal battery maintains the same potential difference. Thus

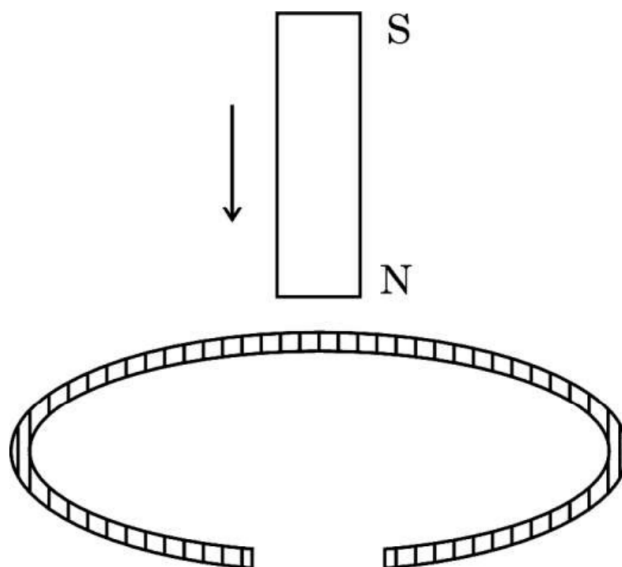
$$\frac{P'}{P} = \frac{V^2/(4R)}{V^2/R} = \frac{1}{4}.$$

Option (B) ignores the reduced area, (C) assumes no resistance change, and (D) would require a decrease in resistance. None describes the stretched wire.

Step 3: Conclusion The new power consumption is $P' = P/4$. Hence, the correct option is (A).

Quick Tip to Solve: For a wire stretched to k times its length at fixed volume, use $R' = k^2R$ and, at fixed voltage, $P' = P/k^2$.

2. A vertically held bar magnet is dropped along the axis of a copper ring having a cut as shown in the diagram. The acceleration of the falling magnet is: [1 mark]



- (A) zero
- (B) less than g
- (C) g
- (D) greater than g

Correct Answer: (C) g

Solution:

Concept:

- A changing magnetic flux induces an emf according to Faraday's law, $\mathcal{E} = -d\Phi_B/dt$, where Φ_B is the magnetic flux.
- A sustained circulating induced current needs a closed conducting path. A cut in the ring interrupts that path.

Step 1: Check whether the induced current can circulate As the magnet approaches the copper ring, the magnetic flux through it changes. An induced emf can therefore exist, but the gap prevents a current from circulating around the ring in the ideal circuit model. Copper being a conductor alone does not make this an electrically closed loop.

Step 2: Apply the equation of motion With no circulating induced current, the ring supplies no magnetic braking force in the stated ideal model. Neglecting air resistance, the force on a magnet of mass m is its weight:

$$ma = mg.$$

Option (B) describes the braking expected for a closed ring; (A) would require complete force balance, while (D) would require an additional downward force.

Step 3: Conclusion The magnet falls with acceleration $a = g$, directed downward. Hence, the correct option is (C).

Quick Tip to Solve: Before applying Lenz's law to a falling magnet, check whether the conducting ring is closed; a cut stops the circulating current.

3. A straight conductor is carrying a current of 2 A in $+x$ direction along it. A uniform magnetic field $\vec{B} = (0.6\hat{j} + 0.8\hat{k})$ T is switched on, in the region. The force acting on 10 cm length of the conductor is: [1 mark]

- (A) $(0.12\hat{j} - 0.16\hat{k})$ N
(B) $(-0.16\hat{j} + 0.12\hat{k})$ N
(C) $(-0.12\hat{j} + 0.16\hat{k})$ N
(D) $(0.16\hat{j} - 0.12\hat{k})$ N

Correct Answer: (B) $(-0.16\hat{j} + 0.12\hat{k})$ N

Solution:

Concept:

- The magnetic force on a straight current-carrying wire is $\vec{F} = I\vec{L} \times \vec{B}$, where $\vec{L}$ points along the conventional current.
- The unit-vector products are $\hat{i} \times \hat{j} = \hat{k}$ and $\hat{i} \times \hat{k} = -\hat{j}$; reversing the order reverses the force.

Step 1: Express the length vector in SI units The wire carries $I = 2$ A along the positive x -axis. The relevant length is 10 cm = 0.10 m, so $\vec{L} = 0.10\hat{i}$ m. Each field component is perpendicular to the wire.

Step 2: Evaluate the cross product Using the right-handed unit-vector relations,

$$\begin{aligned}\vec{F} &= 2(0.10)\hat{i} \times (0.6\hat{j} + 0.8\hat{k}) \\ &= 0.20(0.6\hat{k} - 0.8\hat{j}) \text{ N.}\end{aligned}$$

The $\hat{j}$ coefficient must be negative with magnitude 0.16, and the $\hat{k}$ coefficient positive with magnitude 0.12. Options (A) and (D) have the wrong signs; (C) interchanges the required component magnitudes.

Step 3: Conclusion The force is $\vec{F} = (-0.16\hat{j} + 0.12\hat{k})$ N. Hence, the correct option is (B).

Quick Tip to Solve: For current along $+x$, the B_y component produces $+z$ force and B_z produces $-y$ force; attach coefficients only after fixing directions.

4. An ac source is connected to a resistor and an inductor in series. The voltage across the resistor and inductor are 8 V and 6 V respectively. The voltage of the source is: [1 mark]

- (A) 10 V
(B) 12 V
(C) 14 V
(D) 16 V

Correct Answer: (A) 10 V

Solution:

Concept:

- In a series resistor-inductor circuit, the same alternating current flows through both components.
- The resistor voltage V_R is in phase with current, whereas the ideal inductor voltage V_L leads current by 90° . Their voltage phasors add at right angles.

Step 1: Add the perpendicular voltage phasors The source voltage is the magnitude of the vector

sum of the resistor and inductor voltages. Because their phase difference is 90° ,

$$V_s = \sqrt{V_R^2 + V_L^2}.$$

Adding the magnitudes directly would incorrectly assume that both voltages reach their maxima simultaneously.

Step 2: Substitute the given voltages Using the common voltage convention for both given values,

$$V_s = \sqrt{8^2 + 6^2} \text{ V} = \sqrt{100} \text{ V}.$$

Option (C), 14 V, is the incorrect arithmetic sum. Neither 12 V in (B) nor 16 V in (D) satisfies the perpendicular-phasor relation.

Step 3: Conclusion The source voltage is 10 V. Hence, the correct option is (A).

Quick Tip to Solve: Recognise the 6-8-10 right triangle: perpendicular resistor and inductor voltages use the hypotenuse, not the arithmetic sum.

5. A proton and an α -particle enter with the same velocity $\vec{v}$ in a uniform magnetic field $\vec{B}$ such that $\vec{v} \perp \vec{B}$. The ratio of the radii of their paths is: [1 mark]

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

Correct Answer: (B) $\frac{1}{2}$

Solution:

Concept:

- For motion perpendicular to a uniform magnetic field, magnetic force supplies centripetal force: $|q|vB = mv^2/r$, hence $r = mv/(|q|B)$.
- A proton has mass m_p and charge $+e$; an alpha particle has approximately mass $4m_p$ and charge $+2e$.

Step 1: Compare the mass-to-charge ratios The speeds and the magnetic field are the same, so the radius is proportional to $m/|q|$. For the proton this ratio is m_p/e ; for the alpha particle it is $4m_p/(2e) = 2m_p/e$. The alpha particle therefore follows the larger circle.

Step 2: Form the ratio in the stated order Taking proton first and alpha particle second,

$$\frac{r_p}{r_\alpha} = \frac{m_p/e}{4m_p/(2e)} = \frac{1}{2}.$$

Option (A) reverses this order. Option (C) compares masses alone and omits the alpha particle's doubled charge. Option (D) also fails to use the required mass-to-charge ratio.

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

Quick Tip to Solve: At equal speed in the same magnetic field, compare m/q ; at equal momentum the radius ratio would instead depend only on inverse charge.

6. Two coherent waves, each of intensity I_0 , produce interference pattern on a screen. The average intensity of light on the screen is: [1 mark]

- (A) zero
- (B) I_0
- (C) $2I_0$
- (D) $4I_0$

Correct Answer: (C) $2I_0$

Solution:

Concept:

- For two coherent waves of intensities I_1 and I_2 , the resultant intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \delta$, where δ is the phase difference.
- The spatial average over complete interference fringes has $\langle \cos \delta \rangle = 0$; interference redistributes intensity between bright and dark regions.

Step 1: Write the intensity for equal incident waves For $I_1 = I_2 = I_0$,

$$I = 2I_0(1 + \cos \delta).$$

A bright fringe has $\cos \delta = 1$, giving $4I_0$, while a dark fringe has $\cos \delta = -1$, giving zero. These are local extreme values, not averages over the pattern.

Step 2: Average across the interference pattern Across complete fringe periods, the positive and negative contributions from the cosine term cancel. Therefore

$$\langle I \rangle = 2I_0(1 + \langle \cos \delta \rangle) = 2I_0.$$

Options (A) and (D) describe the minimum and maximum; (B) counts only one of the two incident waves. The average equals their summed incident intensity, as required by energy conservation.

Step 3: Conclusion The average intensity on the screen is $2I_0$. Hence, the correct option is (C).

Quick Tip to Solve: Distinguish spatial average $I_1 + I_2$ from maximum $(\sqrt{I_1} + \sqrt{I_2})^2$; equal waves give $2I_0$ and $4I_0$, respectively.

7. If R_s and R_p are the equivalent resistances of n resistors, each of value R , in series and parallel combinations respectively, then the value of $(R_s - R_p)$ is: [1 mark]

(A) $\left(\frac{n^2 - 1}{n^2}\right) R$

(B) $\left(\frac{n^2 + 1}{n^2 - 1}\right) R$

(C) $\left(\frac{n^2 - 1}{n}\right) R$

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

Correct Answer: (C) $\left(\frac{n^2 - 1}{n}\right) R$

Solution:

Concept:

- For resistors in series, resistances add: $R_s = R_1 + R_2 + \dots + R_n$, where n is the number of resistors.
- For parallel resistors, conductances add: $1/R_p = 1/R_1 + 1/R_2 + \dots + 1/R_n$. Here every resistance is R .

Step 1: Obtain each equivalent resistance With n identical resistors connected in series,

$$R_s = nR.$$

With the same resistors connected in parallel,

$$\frac{1}{R_p} = \frac{n}{R}, \quad R_p = \frac{R}{n}.$$

Thus the series resistance increases with n , whereas the parallel resistance decreases.

Step 2: Subtract with a common denominator The requested difference is

$$R_s - R_p = nR - \frac{R}{n} = \left(\frac{n^2 - 1}{n}\right) R.$$

Option (A) has an extra factor of n in the denominator. Options (B) and (D) contain $n^2 + 1$ instead of the numerator produced by subtraction. As a check, $n = 1$ gives zero difference; for $n = 2$, the difference is $3R/2$.

Step 3: Conclusion The difference is $R_s - R_p = \frac{n^2 - 1}{n} R$. Hence, the correct option is (C).

Quick Tip to Solve: Write $R_s = nR$ and $R_p = R/n$ first, then use denominator n . A single-resistor check should always give zero difference.

8. A galvanometer can be converted into an ammeter of desired range by connecting a: [1 mark]

- (A) small resistance in series
- (B) large resistance in series
- (C) small resistance in parallel
- (D) large resistance in parallel

Correct Answer: (C) small resistance in parallel

Solution:

Concept:

- An ammeter measures the total current and should have a very small effective resistance.
- A shunt resistance S in parallel with a galvanometer of resistance G diverts excess current away from its delicate coil.

Step 1: Apply the parallel-branch condition Let the desired range be I and the galvanometer full-scale current be I_g . The shunt carries $I - I_g$. Equal potential differences across the parallel branches give

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

A small shunt carries most of the current while the coil carries only its safe full-scale current.

Step 2: Test the other connections A series resistance does not divide the current, so neither (A) nor (B) provides the required bypass. A large series resistance is instead used for a voltmeter. A large parallel resistance in (D) carries too little bypass current for the usual ammeter conversion.

Step 3: Conclusion Connect a small resistance in parallel with the galvanometer. Hence, the correct option is (C).

Quick Tip to Solve: Remember the ammeter's shunt as a low-resistance parallel path that carries almost all the measured current.

9. Inside a nucleus, the nuclear forces between proton and proton, proton and neutron, neutron and neutron are F_{pp} , F_{pn} and F_{nn} respectively. Then: [1 mark]

- (A) $F_{pp} > F_{pn} > F_{nn}$
- (B) $F_{pn} > F_{nn} > F_{pp}$
- (C) $F_{nn} > F_{pp} > F_{pn}$
- (D) $F_{pp} = F_{pn} = F_{nn}$

Correct Answer: (D) $F_{pp} = F_{pn} = F_{nn}$

Solution:

Concept:

- The nuclear force is approximately charge independent: it does not distinguish protons from neutrons under comparable conditions.
- Nuclear force and electrostatic force are distinct interactions. The repulsion between two protons is not part of their nuclear force.

Step 1: Compare the three nucleon pairs For the same separation and comparable nuclear states, replacing a proton with a neutron does not change the nuclear interaction in the Class 12 description.

Thus the proton-proton, proton-neutron and neutron-neutron nuclear forces have equal strength.

Step 2: Exclude an electric-charge ranking Options (A), (B) and (C) each rank the nuclear forces by the identity of the two nucleons. Such rankings contradict charge independence. Although two protons also repel electrically, the question asks only about nuclear forces, so that extra Coulomb interaction must not be included in the comparison.

Step 3: Conclusion $F_{pp} = F_{pn} = F_{nn}$. Hence, the correct option is (D).

Quick Tip to Solve: When comparing nucleon pairs, check whether the question asks for nuclear force alone or the total force including Coulomb repulsion.

10. The de Broglie wavelength associated with an electron moving with energy 5 eV is: [1 mark]

- (A) 0.75 nm
- (B) 1.2 nm
- (C) 2.4 nm
- (D) 0.55 nm

Correct Answer: (D) 0.55 nm

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p is momentum.
- For a nonrelativistic electron of mass m_e and kinetic energy K , $p = \sqrt{2m_e K}$. Also, $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$.

Step 1: Convert the kinetic energy The given electron energy is its kinetic energy. It is sufficiently small for the nonrelativistic expression:

$$K = 5(1.6 \times 10^{-19}) = 8.0 \times 10^{-19} \text{ J}.$$

Step 2: Calculate and compare the wavelength Using $m_e = 9.1 \times 10^{-31} \text{ kg}$ and $h = 6.63 \times 10^{-34} \text{ J s}$,

$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2(9.1 \times 10^{-31})(8.0 \times 10^{-19})}} = 5.49 \times 10^{-10} \text{ m}.$$

Since $1 \text{ nm} = 10^{-9} \text{ m}$, this is about 0.55 nm. The values 0.75, 1.2 and 2.4 nm do not match; 1.2 nm is approximately the value for a 1 eV electron.

Step 3: Conclusion The de Broglie wavelength is 0.55 nm. Hence, the correct option is (D).

Quick Tip to Solve: For an electron, use $\lambda(\text{nm}) \simeq 1.227/\sqrt{K(\text{eV})}$; divide by $\sqrt{5}$, not by 5.

11. A piece of a diamagnetic material, free to move when placed in a uniform magnetic field: [1 mark]

- (A) moves along the field
- (B) moves opposite to the field
- (C) moves perpendicular to the field
- (D) does not move at all

Correct Answer: (D) does not move at all

Solution:

Concept:

- A diamagnetic material develops magnetisation opposite to the applied magnetic field; its magnetic susceptibility is negative.
- A net translational magnetic force requires a spatial variation of field strength. A uniform field has no field gradient.

Step 1: Identify the role of uniformity The field has the same magnitude and direction throughout the piece of material. Opposing magnetic forces balance, so there is no net force to translate the piece. Being free to move does not itself provide a driving force.

Step 2: Distinguish magnetisation from motion Magnetisation opposite to the field does not mean motion opposite to the field. A diamagnetic sample moves from stronger to weaker field only in a nonuniform field. Hence (A), (B) and (C), which prescribe translational motion along, opposite to or perpendicular to this uniform field, are all unsuitable.

Step 3: Conclusion The piece has no translational motion due to the uniform magnetic field. Hence, the correct option is (D), does not move at all.

Quick Tip to Solve: Underline the word uniform: the rule that diamagnets move towards weaker fields applies only when field strength varies with position.

12. The momentum (in kg m/s) of a photon of frequency 6.0×10^{14} Hz is:

[1 mark]

- (A) 6.63×10^{-25}
- (B) 1.326×10^{-27}
- (C) 2.652×10^{-26}
- (D) 3.978×10^{-24}

Correct Answer: (B) 1.326×10^{-27}

Solution:

Concept:

- A photon has energy $E = h\nu$, where h is Planck's constant and ν is its frequency.
- For a photon, $E = pc$, so its momentum is $p = h\nu/c$, where c is the speed of light.

Step 1: Calculate the photon energy Substitute $h = 6.63 \times 10^{-34}$ J s and the given frequency:

$$E = (6.63 \times 10^{-34})(6.0 \times 10^{14}) = 3.978 \times 10^{-19} \text{ J.}$$

Step 2: Divide by the speed of light With $c = 3.0 \times 10^8 \text{ m s}^{-1}$,

$$p = \frac{3.978 \times 10^{-19}}{3.0 \times 10^8} = 1.326 \times 10^{-27} \text{ kg m s}^{-1}.$$

Dividing by 10^8 changes the exponent from -19 to -27 . None of the values in (A), (C) or (D) equals this quotient; photon momentum must not be confused with photon energy.

Step 3: Conclusion The momentum is $1.326 \times 10^{-27} \text{ kg m s}^{-1}$. Hence, the correct option is (B).

Quick Tip to Solve: First calculate $h\nu$, then divide by c ; track the power as $-34 + 14 - 8 = -28$ before normalising the coefficient.

13. Assertion (A): A hole is an apparent free particle with effective positive electronic charge.

Reason (R): A hole is not necessarily a vacancy left behind by an electron in the valence band.

Select the correct answer from the codes given below:

[1 mark]

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

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

Solution:

Concept:

- A hole is an unoccupied electron state in an otherwise nearly filled valence band of a semiconductor.
- Motion of valence electrons to fill successive vacancies makes the vacancy behave as a mobile carrier of effective charge $+e$, where e is the magnitude of electronic charge.

Step 1: Judge the assertion When a valence electron fills a neighbouring vacancy, it leaves a new vacancy at its original position. The vacancy therefore appears to move opposite to the electron. This effective carrier has positive electronic charge, so the assertion is true; it is not an actual free proton.

Step 2: Judge the reason In the semiconductor description used here, a hole is precisely the vacancy of an electron in the valence band. The printed reason denies that necessary identification by saying not necessarily. Hence the reason is false.

Step 3: Check the explanatory link A false reason cannot explain the true assertion. Options (A) and (B) wrongly treat the reason as true, while (D) wrongly treats the assertion as false. The effective positive charge follows from the missing negative charge and the motion of the vacancy.

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

Quick Tip to Solve: Treat a hole as a moving valence-band vacancy; a statement denying the vacancy description is false in this semiconductor context.

14. Assertion (A): In a reflecting telescope, the image does not have chromatic aberration.

Reason (R): Chromatic aberration occurs only due to refraction of light through an optical medium.

Select the correct answer from the codes given below:

[1 mark]

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

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

Solution:

Concept:

- Chromatic aberration is the failure of different colours to focus at the same point because a refracting medium has a wavelength-dependent refractive index.
- A reflecting telescope uses a curved mirror as its objective. The law of reflection and the mirror's focal length are independent of the colour of light.

Step 1: Judge the assertion The reflecting objective focuses different colours at the same focal point. It therefore forms an image without the chromatic aberration associated with a refracting objective. In this standard telescope comparison, the assertion is true.

Step 2: Judge the reason In geometrical optics, chromatic aberration arises when refraction through a dispersive optical medium bends different colours by different amounts. This makes a lens's focal length depend on colour. The reason correctly identifies that origin, so it is true.

Step 3: Check the explanatory link The mirror objective forms its image by reflection, so the colour-dependent refraction identified in the reason is absent. The reason therefore explains the assertion. Option (B) incorrectly denies this link; (C) and (D) incorrectly declare one or both statements false.

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

Quick Tip to Solve: For chromatic aberration, identify the objective first: a lens disperses colours by refraction, while a mirror reflects them to the same focus.

15. Assertion (A): The binding energy per nucleon is practically constant for mass number in the range ($30 < A < 170$).

Reason (R): Nuclear forces between the nucleons for mass numbers in the range ($30 < A < 170$) are not short-range.

Select the correct answer from the codes given below:

[1 mark]

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

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

Solution:

Concept:

- Binding energy per nucleon is B/A , where B is the total binding energy and A is the number of nucleons.
- Nuclear forces are short-range and show saturation: each nucleon interacts strongly mainly with nearby nucleons.

Step 1: Evaluate the assertion For medium-mass nuclei in the range $30 < A < 170$, the binding-energy-per-nucleon curve is nearly flat, with values around 8 MeV. It is not exactly constant, but the word practically makes the assertion true.

Step 2: Evaluate the reason Nuclear forces remain short-range in these nuclei, acting effectively over distances of a few femtometres. The statement that these forces are not short-range is therefore false.

Step 3: Check the explanation and the codes Short range and saturation mean that adding nucleons adds approximately the same binding energy per nucleon. Thus the actual explanation uses the opposite of the stated reason. Codes (A) and (B) require a true reason, while (D) requires a false assertion; none fits.

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

Quick Tip to Solve: Associate a nearly flat B/A curve with saturation of short-range nuclear forces; watch for the word “not” in the reason.

16. Assertion (A): X-rays are produced when slow moving electrons are stopped by a metal target of high atomic number.

Reason (R): X-rays consist of low-energy photons.

Select the correct answer from the codes given below:

[1 mark]

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

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

Solution:

Concept:

- In an X-ray tube, fast electrons accelerated through a large potential difference strike a high-atomic-number target and lose energy rapidly.
- Photon energy is $E_\gamma = h\nu = hc/\lambda$, where h is Planck's constant, ν the frequency and λ the wavelength.

Step 1: Evaluate the assertion The target material in the assertion is suitable, but the description of the incident electrons is wrong. Standard X-ray production requires fast, high-energy electrons. Slow-moving electrons do not provide the kinetic energy required for X-ray photons. Thus the assertion is false.

Step 2: Evaluate the reason X-rays have very short wavelengths and high frequencies, so $E_\gamma = hc/\lambda$ is large. They consist of high-energy photons compared with visible or infrared radiation. Calling these photons low-energy makes the reason false.

Step 3: Check the logical connection Since both statements are false, the reason cannot explain the assertion. Codes (A) and (B) incorrectly treat both statements as true, and code (C) incorrectly treats the assertion as true.

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

Quick Tip to Solve: For X-ray production, pair fast incident electrons with short-wavelength, high-energy emitted photons.

Section B (10 marks)

17. A cell of emf E and internal resistance r is connected to an external variable resistance R . Plot a graph showing the variation of terminal voltage V of the cell as a function of current I , supplied by the cell. Explain how the emf of the cell and its internal resistance can be found from it. [2 marks]

Solution:

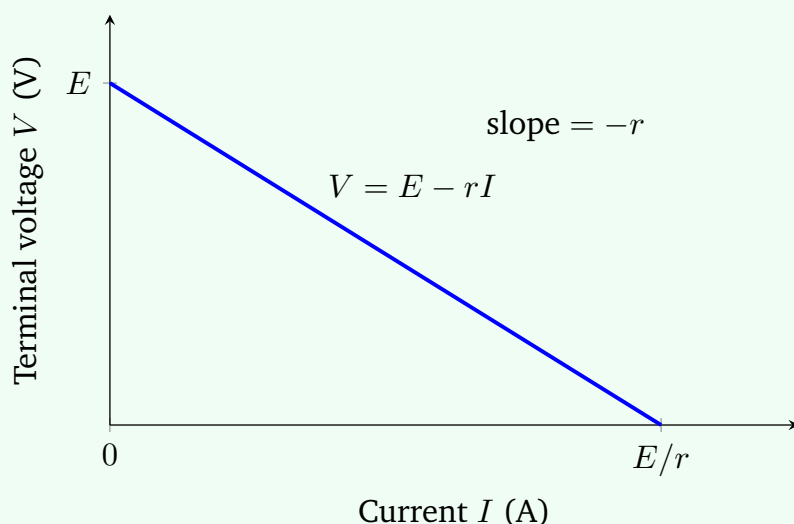
Concept:

- For a cell supplying current I , its emf E equals the terminal voltage V plus the internal voltage drop Ir , where r is its internal resistance.
- A straight line $y = c + mx$ has vertical intercept c and slope m . Apply this form with $y = V$ and $x = I$.

Step 1: Obtain the graph equation The same current flows through the internal resistance and the external resistance. Using the loop equation and $V = IR$,

$$E = IR + Ir = V + Ir \Rightarrow V = E - rI.$$

Varying R changes I ; for constant E and r , a plot of terminal voltage on the vertical axis against current on the horizontal axis is a straight line sloping downward.



Terminal voltage decreases linearly as the supplied current increases.

Step 2: Read the emf and internal resistance At $I = 0$, the internal voltage drop is zero and $V = E$. Therefore the voltage-axis intercept gives the emf in volts. Choose two well-separated points (I_1, V_1) and (I_2, V_2) on the line. Its slope is negative:

$$\frac{\Delta V}{\Delta I} = \frac{V_2 - V_1}{I_2 - I_1} = -r, \quad r = \frac{V_1 - V_2}{I_2 - I_1}.$$

The magnitude of the slope gives r in ohms. The extrapolated current-axis intercept is E/r , corresponding to the ideal short-circuit limit.

Step 3: Conclusion The graph is the straight line $V = E - rI$. Its voltage intercept gives E , and the magnitude of its negative slope gives r .

Quick Tip to Solve: Put V vertically and I horizontally before taking the slope; resistance is $-\Delta V/\Delta I$, not the reciprocal.

18. In an n -type semiconductor electron-hole combination is a continuous process at room temperature. Yet the electron concentration is always greater than the hole concentration in it. Explain.

[2 marks]

Solution:

Concept:

- An n -type semiconductor is formed by adding pentavalent donor impurities to an intrinsic semiconductor such as silicon. Ionised donors supply extra conduction electrons.
- Electron-hole recombination removes one electron and one hole together, while thermal generation creates them in pairs. Donor ionisation supplies electrons without creating valence-band holes.

Step 1: Identify the source of excess electrons Four valence electrons of a donor atom form covalent bonds with neighbouring semiconductor atoms. Its fifth electron is weakly bound and is readily released into the conduction band at room temperature. The donor becomes a fixed positive ion. This release does not leave a mobile hole in the valence band, so donors add electrons without an equal addition of holes.

Step 2: Account for continuous recombination Recombination consumes equal numbers of electrons and holes; it cannot by itself remove the excess of electrons over holes. At thermal equilibrium, thermal generation and recombination balance. For an uncompensated material, charge neutrality gives

$$n = p + N_D^+,$$

where n and p are the electron and hole concentrations and N_D^+ is the concentration of ionised donors. Thus the negative charge of the excess mobile electrons balances the fixed positive donor charge, and the material remains electrically neutral.

Step 3: Conclusion Donor impurities provide extra electrons without corresponding holes. Consequently $n > p$: electrons remain majority carriers and holes remain minority carriers despite continuous recombination.

Quick Tip to Solve: Distinguish donor ionisation from electron-hole pair generation: only pair generation creates a mobile hole with every added electron.

19. A laser beam of wavelength 500 nm and power 5 mW strikes normally on a perfectly reflecting surface of area 1 mm^2 of a body. It rebounds back from the surface. Find the force exerted by the laser beam on the body.

[2 marks]

Solution:

Concept:

- A photon of wavelength λ has energy $E_\gamma = hc/\lambda$ and momentum magnitude $p = h/\lambda$, where c is the speed of light.

- Force is the rate of momentum transfer. On normal reflection from a perfect reflector, the photon's momentum reverses, so the surface gains momentum $2p$ per photon.

Step 1: Relate beam power to photon arrival rate Let $\dot{N}$ be the number of photons striking the surface per second. All of the stated beam power P reaches the reflecting surface. Since power is energy delivered per second,

$$\dot{N} = \frac{P}{E_\gamma} = \frac{P\lambda}{hc}.$$

Here $P = 5 \times 10^{-3} \text{ W}$ and $\lambda = 500 \times 10^{-9} \text{ m}$.

Step 2: Calculate the momentum transferred per second Take the incoming beam direction as positive. A photon changes momentum from $+p$ to $-p$, so the body receives $+2p$. Therefore,

$$F = \dot{N} \frac{2h}{\lambda} = \frac{P\lambda}{hc} \frac{2h}{\lambda} = \frac{2P}{c}.$$

Substituting $c = 3 \times 10^8 \text{ m s}^{-1}$,

$$F = \frac{2(5 \times 10^{-3})}{3 \times 10^8} = 3.33 \times 10^{-11} \text{ N}.$$

Wavelength cancels between photon momentum and photon arrival rate. The given area 1 mm^2 would be needed for radiation pressure F/A , but is not needed for force when total incident power is given.

Step 3: Conclusion The force is $3.33 \times 10^{-11} \text{ N}$, normal to the reflecting surface and in the direction of the incident beam.

Quick Tip to Solve: For total incident power P , use $F = 2P/c$ for perfect normal reflection; the factor two comes from reversal of photon momentum.

20. A ray of light is incident on face AB of a prism ABC with angle of prism A and emerges out from face AC . The prism is set in the position of minimum deviation with angle of deviation δ . Find (i) the angle of incidence and (ii) the angle of refraction on face AB . [2 marks]

Solution:

Concept:

- For a prism of angle A , the internal refraction angles satisfy $r_1 + r_2 = A$, where the angles are measured from the normals to the two faces.
- The deviation is $\delta = i + e - A$, with i the angle of incidence and e the angle of emergence. At minimum deviation the ray travels symmetrically: $i = e$ and $r_1 = r_2$.

Step 1: Use the minimum-deviation condition to find incidence Since the prism is already set for minimum deviation, substitute $e = i$ into the deviation relation. The given δ is therefore the minimum deviation itself:

$$\delta = i + i - A = 2i - A, \quad i = \frac{A + \delta}{2}.$$

This is the angle between the incident ray and the normal to face AB , not the angle with the face.

Step 2: Apply the prism-angle relation inside the glass The symmetric path also makes the two

internal angles equal. Calling the angle of refraction on face AB r_1 , we obtain

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

No refractive-index value is required because the question asks only for the geometrical angles at this special position.

Step 3: Conclusion (i) The angle of incidence is $i = (A + \delta)/2$. (ii) The angle of refraction on face AB is $r_1 = A/2$.

Quick Tip to Solve: At minimum deviation first write $i = e$ and $r_1 = r_2$; the deviation and prism-angle equations then each reduce to a factor of two.

21(a). Find the intensity at a point on the screen in Young's double slit experiment, at which the interfering waves of intensity I_0 each, have a path difference of (i) $\frac{\lambda}{3}$ and (ii) $\frac{\lambda}{2}$. [2 marks]

Solution:

Concept:

- For two coherent waves of intensities I_1 and I_2 , the resultant intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$, where ϕ is their phase difference.
- A path difference Δx corresponds to $\phi = 2\pi\Delta x/\lambda$, where λ is the wavelength. Here each wave has intensity I_0 , so $I = 2I_0(1 + \cos \phi)$.

Step 1: Calculate the intensity for the first path difference For the printed value $\Delta x = \lambda/3$, convert path difference into phase difference before adding the waves:

$$\phi = \frac{2\pi \lambda}{\lambda} \frac{1}{3} = \frac{2\pi}{3}.$$

Since $\cos(2\pi/3) = -1/2$, the interference term reduces the sum of the separate intensities:

$$I = 2I_0 \left(1 - \frac{1}{2}\right) = I_0.$$

Step 2: Calculate the intensity for the second path difference For $\Delta x = \lambda/2$, the phase difference is

$$\phi = \frac{2\pi \lambda}{\lambda} \frac{1}{2} = \pi.$$

The waves have equal amplitudes and opposite phases, so their displacements cancel completely. Substitution gives

$$I = 2I_0(1 + \cos \pi) = 2I_0(1 - 1) = 0.$$

Step 3: Conclusion The resultant intensities are I_0 for (i) $\Delta x = \lambda/3$, and 0 for (ii) $\Delta x = \lambda/2$, a dark fringe.

Quick Tip to Solve: For equal source intensities, use $I = 4I_0 \cos^2(\pi\Delta x/\lambda)$; a half-wavelength path difference immediately gives zero.

21(b). A point source of light in air is kept at a distance of 12 cm in front of a convex spherical surface of glass of refractive index 1.5 and radius of curvature 30 cm. Find the nature and position of the image formed. [2 marks]

Solution:

Concept:

- Refraction at a spherical surface obeys $n_2/v - n_1/u = (n_2 - n_1)/R$ for paraxial rays, where u , v and R are signed distances from the surface pole.
- With the positive direction along incident light, a real object before the surface has $u < 0$. For a convex glass surface facing the object, its centre lies inside the glass, so $R > 0$.

Step 1: Assign signs and substitute the optical data Light passes from air into glass. Therefore $n_1 = 1$, $n_2 = 1.5$, $u = -12$ cm and $R = +30$ cm. Using centimetres consistently in the spherical-refraction equation gives

$$\frac{1.5}{v} - \frac{1}{-12} = \frac{1.5 - 1}{30}, \quad \frac{1.5}{v} + \frac{1}{12} = \frac{1}{60}.$$

Step 2: Solve for the image distance and interpret its sign Rearranging the equation without changing the Cartesian signs,

$$\frac{1.5}{v} = \frac{1}{60} - \frac{1}{12} = -\frac{1}{15}, \quad v = -22.5 \text{ cm}.$$

The negative image distance puts the image on the incident side of the surface, in air. The actual refracted rays in glass diverge, and their backward extensions meet at this image position; it is therefore virtual.

Step 3: Conclusion The image is **virtual**, formed **22.5 cm** in front of the spherical surface on the same side as the source ($v = -22.5$ cm).

Quick Tip to Solve: Assign $u = -12$ cm and $R = +30$ cm before substitution; the negative value of v then directly identifies the virtual image in air.

Section C (21 marks)

22. (a) Define the term ‘drift velocity’ of conduction electrons in a conductor.

(b) A conductor of length l and area of cross-section A is connected across an ideal battery of emf V . Derive the formula for the current density in terms of relaxation time τ . [3 marks]

Solution:

Concept:

- Drift velocity $\vec{v}_d$ is the average velocity acquired by conduction electrons under an applied electric field, superposed on their random thermal motion.
- An electron of charge $-e$ and mass m has acceleration $\vec{a} = -e\vec{E}/m$. The relaxation time τ is the mean time between successive collisions that randomise its motion.
- For electron number density n , conventional current density is $\vec{J} = -ne\vec{v}_d$. Its magnitude is current per cross-sectional area: $J = I/A$.

Step 1: Define drift velocity and its direction (a) Drift velocity is the average velocity with which free conduction electrons drift through a conductor when an electric field is applied. Since electrons are

negatively charged, their drift is opposite to $\vec{E}$. Without an applied field their thermal velocities are randomly directed and have zero average, even though individual electrons keep moving.

Step 2: Express the average drift using relaxation time (b) For the uniform conductor of length l connected across an ideal battery, the potential difference is V , giving field magnitude $E = V/l$. Between collisions each electron accelerates under the electric force. Averaging over the time since its last collision gives

$$\vec{v}_d = \vec{a}\tau = -\frac{e\tau}{m}\vec{E}, \quad v_d = \frac{e\tau V}{ml}.$$

The random velocity immediately after a collision contributes zero to the ensemble average. Here v_d without an arrow denotes the positive drift-speed magnitude.

Step 3: Obtain the current per unit area In time Δt , electrons within a cylinder of length $v_d\Delta t$ cross a section of area A . Their number is $nAv_d\Delta t$, so the magnitude of charge crossing is $\Delta Q = neAv_d\Delta t$. Therefore

$$I = \frac{\Delta Q}{\Delta t} = neAv_d, \quad J = \frac{I}{A} = nev_d = \frac{ne^2\tau V}{ml}.$$

The area cancels because current density measures current per unit area. Conventional current flows opposite to electron drift, hence along the electric field.

Step 4: Conclusion Drift velocity is the field-induced average velocity of conduction electrons, opposite to the field. The required current density is

$$J = \frac{ne^2\tau V}{ml}, \quad \vec{J} = \frac{ne^2\tau}{m}\vec{E},$$

in $A\ m^{-2}$, with n the number of conduction electrons per unit volume.

Quick Tip to Solve: Derive in the order $E = V/l$, $v_d = eE\tau/m$, $J = nev_d$; use magnitudes for the algebra and state electron drift is opposite to conventional current.

23(a). State Lenz's law. A rod MN of length L is rotated about an axis passing through its end M perpendicular to its length, with a constant angular velocity $\vec{\omega}$ in a uniform magnetic field $\vec{B}$ parallel to the axis. Obtain an expression for emf induced between its ends. [3 marks]

Solution:

Concept:

- Lenz's law states that the induced current has a direction such that its magnetic effect opposes the change in magnetic flux that produces it. It is represented by the negative sign in Faraday's law, $\mathcal{E} = -d\Phi_B/dt$.
- A conductor moving in a magnetic field experiences charge separation through the magnetic force $q(\vec{v} \times \vec{B})$. An element perpendicular to both its velocity and the field develops a motional emf of magnitude $d\mathcal{E} = Bv\,dx$.

Step 1: Find the speed of an element of the rod Take a small element of length dx at distance x from the fixed end M . All points have the same angular speed ω , but their linear speeds differ:

$$v(x) = \omega x.$$

The velocity is tangential to the circular path, while $\vec{B}$ is along the rotation axis. Thus the velocity is

perpendicular to the field, and $\vec{v} \times \vec{B}$ lies along the rod. The speed rises from zero at M to ωL at N .

Step 2: Add the emfs of the successive elements The elemental emf is

$$d\mathcal{E} = B\omega x \, dx.$$

Since the elements lie in series along the rod, integrate from the axis to the free end:

$$\mathcal{E} = \int_0^L B\omega x \, dx = B\omega \left[\frac{x^2}{2} \right]_0^L.$$

For $\vec{\omega}$ and $\vec{B}$ in the same direction, the magnetic force on positive charges is radially outward, so positive charge accumulates at N . Reversing the field or rotation reverses the polarity. If a closed conducting path is provided, the induced current produces a magnetic torque opposing the rotation, in accordance with Lenz's law.

Step 3: Conclusion The magnitude of the emf between the ends is $\boxed{\mathcal{E} = \frac{1}{2}B\omega L^2}$. For parallel, same-sense $\vec{\omega}$ and $\vec{B}$, $V_N - V_M = \frac{1}{2}B\omega L^2$; the outer end N is positive relative to M .

Quick Tip to Solve: The rod does not move at one speed: use $v = \omega x$ and integrate. Using the free-end speed throughout incorrectly doubles the emf.

OR

23(b). Define 'self-inductance' of a coil. Derive an expression for self-inductance of a long solenoid of cross-sectional area A and length l , having n turns per unit length. [3 marks]

Solution:

Concept:

- The self-inductance L of a coil is its magnetic flux linkage per unit current: $L = N\Phi/I$, where N is the number of turns and Φ is the flux through each turn. This definition assumes a linear magnetic medium.
- A change in the coil's current induces an opposing emf $\mathcal{E} = -L \, dI/dt$. Its self-inductance is one henry if a current change of $1 \, \text{A s}^{-1}$ induces an emf of magnitude 1 V.
- Inside a long air-core solenoid, the magnetic field is approximately uniform: $B = \mu_0 nI$, where n is the number of turns per unit length and end effects are neglected.

Step 1: Calculate the flux through one turn Let the current in the solenoid be I , its length be l , and its cross-sectional area be A . For a long solenoid, the internal field is parallel to its axis and perpendicular to the plane of every turn. Therefore the magnetic flux through each turn is

$$\Phi = BA \cos 0 = \mu_0 nIA.$$

The common flux approximation is valid away from the ends; the external magnetic field is negligible in this idealisation.

Step 2: Obtain the total flux linkage and inductance The total number of turns is $N = nl$. Each turn links approximately the same flux, so the total flux linkage is

$$N\Phi = (nl)(\mu_0 nIA) = \mu_0 n^2 AlI.$$

Substitute into the definition of self-inductance:

$$L = \frac{N\Phi}{I} = \frac{\mu_0 n^2 Al I}{I}.$$

Thus the inductance depends on the solenoid's geometry and medium, and is independent of current for a linear medium. For a uniform core of relative permeability μ_r , replace μ_0 by $\mu_0\mu_r$.

Step 3: Conclusion The self-inductance of the long air-core solenoid is $L = \mu_0 n^2 Al = \mu_0 N^2 A/l$, measured in henry (H). With a linear magnetic core it becomes $L = \mu_0\mu_r n^2 Al$.

Quick Tip to Solve: Use total flux linkage $N\Phi$, not flux through one turn. Substitute $N = nl$ only after accounting for all the turns.

24. A ray of light is incident at an angle i on a parallel sided glass slab of thickness ' d ' and gets refracted into the slab at angle r . Draw a ray diagram to show its path as it emerges out of the slab. Hence, obtain an expression for the lateral shift of the ray. Under what condition will the shift be minimum? [3 marks]

Solution:

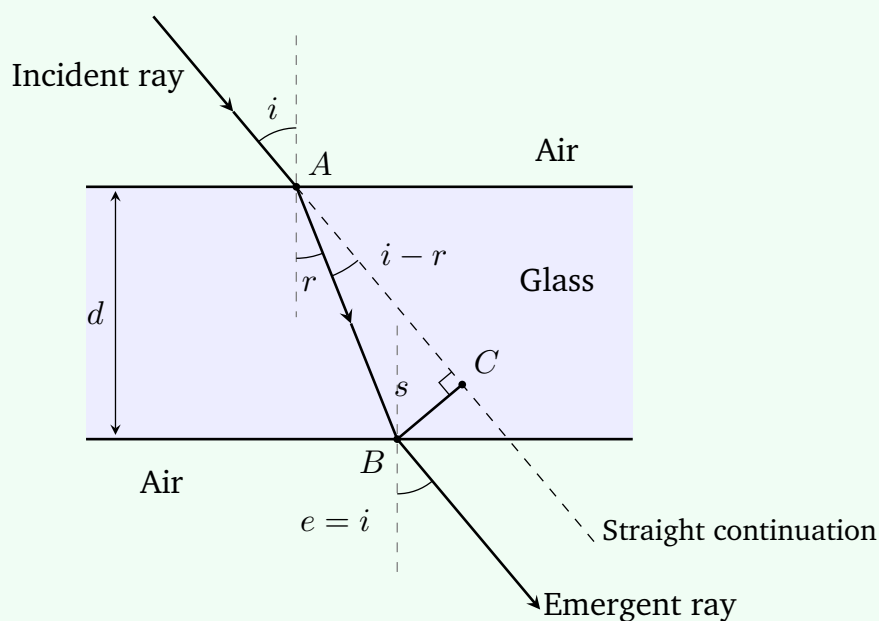
Concept:

- At each plane refracting surface, Snell's law gives $n_1 \sin i = n_2 \sin r$. A ray passing through a parallel-sided slab into the same surrounding medium emerges parallel to its original direction.
- Lateral shift s is the perpendicular separation between the emergent ray and the straight-line continuation of the incident ray. Slab thickness d is measured normal to its parallel faces.

Step 1: Trace the ray through the parallel faces The incident ray enters the glass at A , bending towards the normal from angle i to r . It travels along AB and emerges into air at B , bending away from the normal. Since the faces are parallel, the incidence angle at the second face is r . If μ is the refractive index of glass relative to air and e is the emergence angle, Snell's law gives

$$\sin i = \mu \sin r, \quad \mu \sin r = \sin e.$$

Thus $e = i$. The incident and emergent rays are parallel, but the emergent ray is displaced sideways. In the diagram, AC lies on the undeviated continuation of the incident ray, and $BC \perp AC$.



Refraction through a parallel glass slab; $BC = s$ is the perpendicular lateral shift.

Step 2: Relate the sideways separation to the slab thickness The component of AB normal to the slab is its thickness, so

$$AB \cos r = d, \quad AB = \frac{d}{\cos r}.$$

The angle between the original direction AC and the refracted path AB is $i - r$. In right triangle ABC , the perpendicular separation is $s = BC$, giving

$$\sin(i - r) = \frac{BC}{AB}, \quad s = AB \sin(i - r).$$

The perpendicular measurement is essential: the horizontal separation of the rays at the lower face is not the lateral shift.

Step 3: Identify the condition for minimum shift At normal incidence, $i = 0$. Snell's law then gives $r = 0$, so the ray passes straight through both surfaces along their normals. The lateral shift is zero, the smallest possible magnitude for a glass slab of fixed nonzero thickness in air.

Step 4: Conclusion The emergent ray is parallel to the incident ray, and its lateral shift is $s = d \sin(i - r) / \cos r$. The minimum shift is $s_{\min} = 0$, obtained at normal incidence $i = r = 0$.

Quick Tip to Solve: Draw a perpendicular from the emergence point to the incident ray's straight continuation. That segment, not the separation along a slab face, is the lateral shift.

25. Describe briefly Geiger-Marsden scattering experiment. Depict the graph showing the variation of number of scattered particles detected with the scattering angle. How did this graph lead to the discovery of the nucleus? [3 marks]

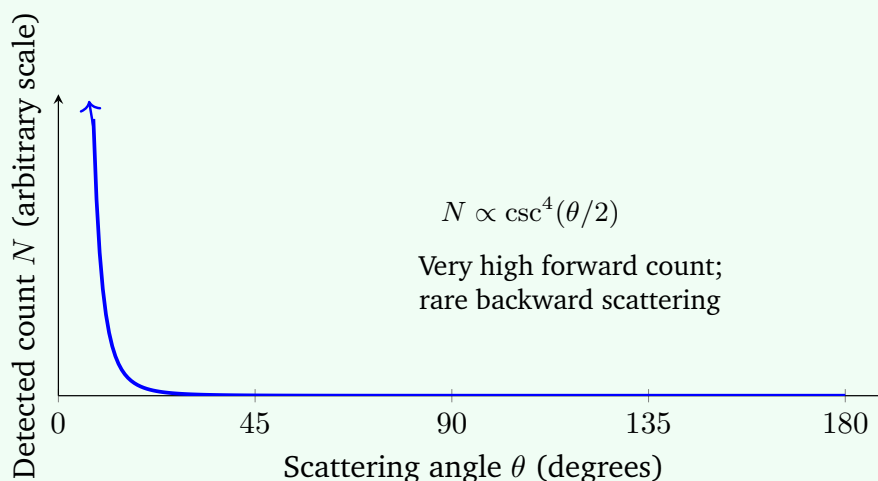
Solution:

Concept:

- An alpha particle is a massive, positively charged projectile. Its deflection by an atom tests how the atom's positive charge and mass are distributed.
- For fixed incident energy, foil and detector solid angle, Rutherford scattering gives $N(\theta) \propto 1/\sin^4(\theta/2)$, where N is the number detected in a fixed time and θ is the deflection from the incident direction.

Step 1: Describe the arrangement and measurement Geiger and Marsden directed a narrow, collimated beam of alpha particles from a radioactive source onto a very thin gold foil. The apparatus was evacuated to reduce scattering by air. A movable zinc sulphide screen, viewed through a microscope, detected the particles through scintillations. Moving the detector around the foil allowed the number of scintillations in equal time intervals to be measured at different scattering angles.

Step 2: State the observations and plot the variation Most alpha particles passed through the foil with practically no deflection. A much smaller number suffered appreciable deflections, and a very small fraction were scattered through angles greater than 90° , sometimes nearly back along their incident path. Thus the count is strongly concentrated near the forward direction and decreases steeply as the scattering angle increases. The graph below is schematic, with an arbitrary vertical scale: even near 180° , the count is small but nonzero. The ideal scattering formula is applied away from exactly 0° , where the direct transmitted beam dominates the measurement.



Schematic alpha-particle count versus scattering angle (arbitrary vertical scale).

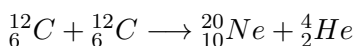
Step 3: Infer the nuclear structure The large forward count shows that most of the atomic volume is empty space. Large-angle and backward scattering of heavy, fast alpha particles requires a very strong repulsive electric field concentrated in a tiny region; a diffuse positive charge could not produce such deflections. The rarity of these encounters shows that this region occupies only a minute fraction of

the atomic volume. Rutherford therefore concluded that essentially all the positive charge and most of the mass reside in a small, dense central nucleus, with electrons occupying the surrounding space.

Step 4: Conclusion The rapidly decreasing scattering count, together with rare but definite backward scattering, establishes a tiny, massive, positively charged nucleus inside an otherwise mostly empty atom.

Quick Tip to Solve: Link each observation to its inference: forward transmission means empty space, while rare backward scattering means a small, dense positive nucleus.

26. Find the Q value of the following nuclear reaction:



Is this reaction exothermic or endothermic?

Given:

$$m({}^{12}_6\text{C}) = 12.000000 \text{ u}$$

$$m({}^{20}_{10}\text{Ne}) = 19.992439 \text{ u}$$

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

$$1 \text{ u} = 931 \text{ MeV}/c^2$$

[3 marks]

Solution:

Concept:

- The reaction energy is $Q = (m_{\text{initial}} - m_{\text{final}})c^2$. A positive Q means rest-mass energy is released; a negative Q means energy must be supplied.
- With masses in atomic mass units, multiply the mass difference by 931 MeV/u to obtain Q . Here $1 \text{ u } c^2 = 931 \text{ MeV}$.

Step 1: Check the reaction and add the initial masses Two carbon-12 nuclei combine to produce neon-20 and helium-4. The mass numbers balance as $12 + 12 = 20 + 4$, and the charge numbers balance as $6 + 6 = 10 + 2$. Thus the given reaction conserves nucleon number and electric charge. The total initial mass is

$$m_{\text{initial}} = 2(12.000000) = 24.000000 \text{ u.}$$

If the tabulated values are atomic masses, they may still be used: the two sides contain the same total number of electrons, so their electron rest masses cancel in this calculation.

Step 2: Calculate the final mass and mass difference Add the masses of both products before taking the difference:

$$m_{\text{final}} = 19.992439 + 4.002603 = 23.995042 \text{ u.}$$

Therefore,

$$\Delta m = 24.000000 - 23.995042 = 0.004958 \text{ u.}$$

The products have a smaller total rest mass. The positive sign must be retained because it determines whether this reaction releases or absorbs energy.

Step 3: Convert the mass difference into reaction energy Using the supplied conversion factor rather than a rounded alternative,

$$Q = (0.004958)(931) \text{ MeV} = 4.615898 \text{ MeV}.$$

This energy is the net increase in the kinetic energy available to the products relative to the incident kinetic energy. It comes from the decrease in the total rest-mass energy, so Q is positive.

Step 4: Conclusion The reaction has $Q \simeq +4.62 \text{ MeV}$ and is **exothermic**.

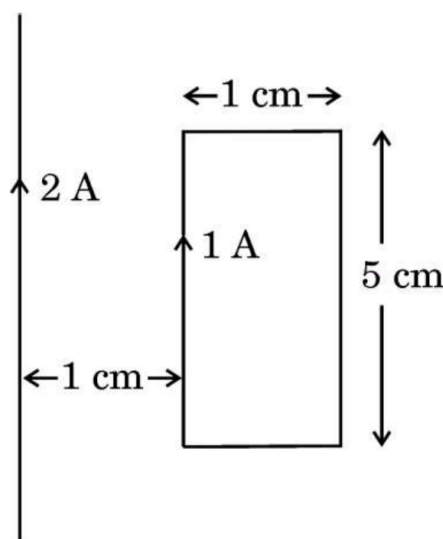
Quick Tip to Solve: Add both product masses first and subtract from 24 u; a positive initial-minus-final difference identifies energy release immediately.

27. A rectangular loop carries a current of 1 A. A straight long wire carrying 2 A current is kept near the loop in the same plane as shown in the figure.

Find:

- (i) the torque acting on the loop, and
- (ii) the magnitude and direction of the net force on the loop.

[3 marks]



Solution:

Concept:

- A long straight wire carrying current I_w produces $B(r) = \mu_0 I_w / (2\pi r)$ at perpendicular distance r . Its direction follows the right-hand thumb rule.
- The force on a current element is $d\vec{F} = I d\vec{l} \times \vec{B}$. Parallel currents attract and antiparallel currents repel; forces must be added as vectors when the field varies across a loop.

Step 1: Identify the geometry and magnetic field Here $I_w = 2 \text{ A}$, loop current $I = 1 \text{ A}$, and the vertical side length is $l = 5 \text{ cm} = 0.05 \text{ m}$. The near side is at $a = 0.01 \text{ m}$; the far side is at $b = 0.02 \text{ m}$, since the loop width is 1 cm. The straight-wire current is upward, so its field throughout the loop points into the page. The loop current is upward on the near side and downward on the far side.

Step 2: Determine the torque about the loop centre Forces on the two vertical sides are horizontal. Each side's resultant acts at its midpoint, along the horizontal line through the loop centre, and hence

gives zero torque about that centre. The top side experiences an upward force and the bottom side a downward force. At each distance r from the wire, the paired elements on the top and bottom have equal and opposite forces on the same vertical line, so their torques cancel as well. Thus the nonuniform field exerts no turning effect: $\tau = 0$. This symmetry argument remains valid even though the field strength is greater at the nearer side.

Step 3: Calculate and combine the forces The near vertical side carries current parallel to the wire and is attracted towards it:

$$F_{\text{near}} = \frac{\mu_0 I_w I l}{2\pi a} = \frac{(2 \times 10^{-7})(2)(1)(0.05)}{0.01} = 2.0 \times 10^{-6} \text{ N}.$$

The far vertical side carries antiparallel current and is repelled:

$$F_{\text{far}} = \frac{\mu_0 I_w I l}{2\pi b} = \frac{(2 \times 10^{-7})(2)(1)(0.05)}{0.02} = 1.0 \times 10^{-6} \text{ N}.$$

The equal and opposite forces on the horizontal sides cancel. The vertical-side forces oppose each other, so the resultant magnitude is

$$F_{\text{net}} = F_{\text{near}} - F_{\text{far}} = 1.0 \times 10^{-6} \text{ N}.$$

Step 4: Conclusion (i) The torque about the loop centre is 0 N m . (ii) The net force is $1.0 \times 10^{-6} \text{ N}$, directed horizontally **towards the straight wire**.

Quick Tip to Solve: Use distances 1 cm and 2 cm for the parallel sides; the closer side has twice the force, so its attraction decides the net direction.

28. Name the electromagnetic wave used (i) in radar, (ii) in eye surgery and (iii) as diagnostic tool in medicine. Write their wavelength range also. [3 marks]

Solution:

Concept:

- Electromagnetic waves are classified by wavelength λ or frequency ν , related in vacuum by $c = \nu\lambda$. Different regions are selected for applications according to their interaction with matter.
- The conventional wavelength ranges of adjacent spectral bands are approximate. The ranges below use the usual Class 12 electromagnetic-spectrum classification.

Step 1: Identify the waves used in radar Radar uses microwaves. A directional microwave pulse is transmitted towards an object, and the reflected pulse is detected. Their relatively short wavelength permits a narrow beam, while the time delay of the echo gives the object's distance. The usual wavelength range is

$$10^{-3} \text{ m} \lesssim \lambda \lesssim 10^{-1} \text{ m},$$

that is, approximately 1 mm to 10 cm.

Step 2: Identify the waves used in eye surgery Ultraviolet radiation is used in the eye-surgery application of this spectrum question, for example precise corneal reshaping with an ultraviolet laser. Its high photon energy allows controlled removal of a thin layer of tissue. The ultraviolet wavelength range is approximately

$$10^{-9} \text{ m} \lesssim \lambda \lesssim 4 \times 10^{-7} \text{ m},$$

or 1 nm to 400 nm. The surgical laser uses a particular wavelength within this band, not the whole band simultaneously.

Step 3: Identify the diagnostic radiation X-rays are used as a diagnostic tool in medicine. Different tissues absorb them by different amounts, so a detector can form an image showing internal structures such as bones. Their usual wavelength range is approximately

$$10^{-12} \text{ m} \lesssim \lambda \lesssim 10^{-9} \text{ m},$$

or 0.001 nm to 1 nm.

Step 4: Conclusion (i) Radar: microwaves, approximately 10^{-3} to 10^{-1} m. (ii) Eye surgery: ultraviolet rays, approximately 10^{-9} to 4×10^{-7} m. (iii) Medical diagnosis: X-rays, approximately 10^{-12} to 10^{-9} m.

Quick Tip to Solve: Recall the application chain: radar–microwaves, corneal surgery–ultraviolet, bone imaging–X-rays; their wavelengths decrease in that order.

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. Case Study (Extrinsic Semiconductors): Extrinsic semiconductors are made by doping pure or intrinsic semiconductors with suitable impurity. There are two type of dopants used in doping, Si or Ge, and using them p-type and n-type semiconductors can be obtained. A p-n junction is the basic building block of many semiconductor devices. Two important processes occur during the formation of a p-n junction: diffusion and drift. When such a junction is formed, a ‘depletion layer’ is created consisting of immobile ion-cores. This is responsible for a junction potential barrier. The width of a depletion layer and the height of potential barrier changes when a junction is forward-biased or reverse-biased. A semiconductor diode is basically a p-n junction with metallic contacts provided at the ends for application of an external voltage. Using diodes, alternating voltages can be rectified.

[4 marks]

29(i). Which of the following is a donor impurity atom for Ge?

[1 mark]

- (A) Boron
- (B) Antimony
- (C) Aluminium
- (D) Indium

Correct Answer: (B) Antimony

Solution:

Concept:

- Germanium is tetravalent: each Ge atom contributes four valence electrons to covalent bonds with its four nearest neighbours.
- A pentavalent impurity is a donor because it supplies one weakly bound extra electron to the crystal, producing an n-type semiconductor.

Step 1: Count the valence electrons of the dopant Antimony has five valence electrons. When

it substitutes for a Ge atom, four electrons participate in covalent bonds. The fifth can become a conduction electron, leaving an immobile positively charged donor ion behind.

Step 2: Compare the remaining choices Boron, aluminium and indium are trivalent. Each lacks one electron needed to complete four covalent bonds and behaves as an acceptor, producing a hole. Therefore choices (A), (C) and (D) are acceptors rather than donors.

Step 3: Conclusion Antimony is the donor impurity for Ge. Hence, the correct option is (B).

Quick Tip to Solve: For Si or Ge, count dopant valence electrons: five gives a donor and three gives an acceptor.

29(ii). When a pentavalent atom occupies the position of an atom in the crystal lattice of Si, four of its electrons form covalent bonds with four silicon neighbours, while the fifth remains bound to the parent atom. The energy required to set this electron free is about: [1 mark]

- (A) 0.5 eV
- (B) 0.1 eV
- (C) 0.05 eV
- (D) 0.01 eV

Correct Answer: (C) 0.05 eV

Solution:

Concept:

- A pentavalent donor in silicon contributes four electrons to covalent bonds. Its fifth electron occupies a donor level very close to the conduction band.
- Donor ionisation requires the small energy difference between the donor level and the conduction-band edge, not the full forbidden energy gap of silicon.

Step 1: Use the donor ionisation energy for silicon The standard approximate energy needed to release the fifth electron of a pentavalent impurity in Si is 0.05 eV. This weak binding explains why donor electrons can readily contribute to conduction at ordinary temperatures.

Step 2: Distinguish the alternatives The values 0.5 eV and 0.1 eV exceed the approximate donor binding energy quoted for silicon. The smaller value 0.01 eV is the usual corresponding estimate for germanium; the printed question specifically names Si.

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

Quick Tip to Solve: Associate donor ionisation with 0.05 eV for Si and 0.01 eV for Ge; first check which host crystal is named.

29(iii). During formation of a p-n junction:

[1 mark]

- (A) a layer of negative charge on n-side and a layer of positive charge on p-side appear.
- (B) a layer of positive charge on n-side and a layer of negative charge on p-side appear.
- (C) the electrons on p-side of the junction move to n-side initially.
- (D) initially diffusion current is small and drift current is large.

Correct Answer: (B) a layer of positive charge on n-side and a layer of negative charge on p-side appear.

Solution:

Concept:

- Immediately after a p-n junction is formed, majority carriers diffuse down their concentration gradients: electrons from n to p and holes from p to n.
- Recombination near the junction removes mobile carriers and exposes fixed ionised donors on the n-side and fixed ionised acceptors on the p-side.

Step 1: Determine the sign on each side Electrons leaving the n-side uncover positively charged donor ions. Holes leaving the p-side uncover negatively charged acceptor ions. These immobile charges form the depletion region and establish an electric field directed from the n-side towards the p-side.

Step 2: Test the other statements Choice (A) reverses the two signs. Choice (C) reverses the initial majority-electron diffusion direction. Choice (D) is also incorrect: initially diffusion dominates, whereas the drift current develops as the barrier field builds up. At equilibrium the opposing diffusion and drift currents balance.

Step 3: Conclusion A positive-charge layer appears on the n-side and a negative-charge layer on the p-side. Hence, the correct option is (B).

Quick Tip to Solve: Track what remains after diffusion: departing electrons leave positive donors on n; departing holes leave negative acceptors on p.

29(iv)(a). In reverse-biased p-n junction:

[1 mark]

- (A) the drift current is of the order of few mA.
- (B) the applied voltage mostly drops across the depletion region.
- (C) the depletion region width decreases.
- (D) the current increases with increase in applied voltage.

Correct Answer: (B) the applied voltage mostly drops across the depletion region.

Solution:

Concept:

- Reverse bias raises the potential barrier and widens the depletion region of a p-n junction.
- The depletion region has very few mobile charge carriers and offers high resistance. The small reverse current is due mainly to minority-carrier drift.

Step 1: Locate the main voltage drop In reverse bias, majority carriers are pulled away from the junction. The depletion region becomes wider and has much higher resistance than the neutral p and n regions, so it takes most of the applied voltage. This establishes the physical basis of option (B).

Step 2: Test the remaining statements Option (A) is incorrect: the normal reverse drift current is very small, typically of the order of microamperes or less, rather than a few milliamperes. Option

(C) reverses the effect of reverse bias: the depletion width increases. Option (D) is incorrect in the usual pre-breakdown operating region, where the reverse current remains approximately saturated as reverse voltage increases. The sharp rise at breakdown is a separate regime.

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

Quick Tip to Solve: For reverse bias, remember the linked changes: wider depletion layer, higher barrier and a tiny nearly saturated reverse current.

OR

29(iv)(b). The output frequency of a full-wave rectifier with 50 Hz as input frequency is: [1 mark]

- (A) 25 Hz
- (B) 50 Hz
- (C) 100 Hz
- (D) 200 Hz

Correct Answer: (C) 100 Hz

Solution:

Concept:

- A full-wave rectifier converts both half-cycles of an alternating input into output pulses of the same polarity.
- Its output repeats after half the input period: $T_{\text{out}} = T_{\text{in}}/2$, so $f_{\text{out}} = 2f_{\text{in}}$.

Step 1: Count pulses in one input cycle The positive and negative input half-cycles each produce a pulse across the load. Thus there are two output pulses for each complete input cycle, and the time between successive identical output pulses is half the input period.

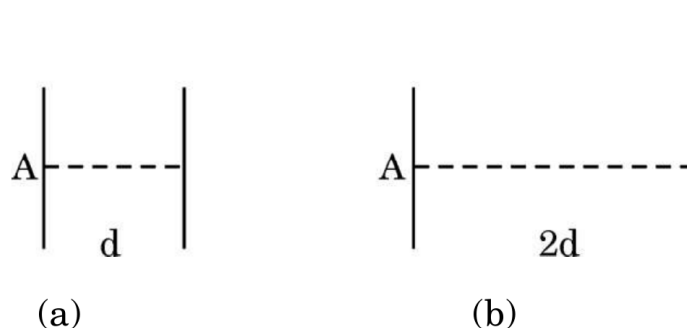
Step 2: Substitute the input frequency and compare options With $f_{\text{in}} = 50$ Hz, the input period is $1/50 = 0.020$ s. The output period is therefore 0.010 s, corresponding to $2 \times 50 = 100$ Hz. Option (A) incorrectly halves the frequency; option (B) would be the pulse frequency for a half-wave rectifier; option (D) assumes four pulses per cycle instead of two.

Step 3: Conclusion The full-wave rectifier output frequency is 100 Hz. Hence, the correct option is (C).

Quick Tip to Solve: Count the rectified pulses per input cycle: two pulses mean twice the input frequency, even though current through the load keeps one direction.

30. Case Study (Capacitors): A capacitor is a system of two conductors separated by an insulator. In practice, the two conductors have charges Q and $-Q$ with potential difference $V = V_1 - V_2$ between them. The ratio $\frac{Q}{V}$ is a constant, denoted by C and is called the capacitance of the capacitor. It is independent of Q or V . It depends only on the geometrical configuration (shape, size, separation) of the two conductors and the medium separating the conductors. When a parallel plate capacitor is charged, the electric field E_0 is localised between the plates and is uniform throughout. When a slab of a dielectric is inserted between the charged plates (charge density σ), the dielectric is polarised by the field. Consequently opposite charges appear on the faces of the slab, near the plates, with surface charge density of magnitude σ_p . For a linear dielectric σ_p is proportional to $\vec{E}_0$. Introduction of a dielectric changes the electric field, and hence, the capacitance of a capacitor, and hence, the energy stored in the capacitor. Like resistors, capacitors can also be arranged in series or in parallel or in a combination of series and parallel. [4 marks]

30(i). Consider a capacitor of capacitance C , with plate area A and plate separation d , filled with air [Fig. (a)]. The distance between the plates is increased to $2d$ and one of the plates is shifted as shown in Fig. (b). The capacitance of the new system now is: [1 mark]



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

Correct Answer: (A) $\frac{C}{4}$

Solution:

Concept:

- Neglecting edge effects, an air-filled parallel-plate capacitor has capacitance $C = \epsilon_0 A/d$, where A is the overlapping plate area and d is the separation.
- When plates are displaced parallel to themselves, only their facing overlap contributes to the area in this formula.

Step 1: Read the new geometry In Fig. (b), the vertical shift reduces the overlap to half of the original area, so $A' = A/2$. The stated new separation is $d' = 2d$. Both changes reduce the capacitance and must be included.

Step 2: Compare the capacitances Taking the ratio cancels the permittivity and original dimensions:

$$\frac{C'}{C} = \frac{A' d}{A d'} = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}.$$

Choice (B) would result from doubling the separation while ignoring the reduced overlap. Choices

(C) and (D) predict an increase, inconsistent with both geometric changes.

Step 3: Conclusion The new capacitance is $C' = C/4$. Hence, the correct option is (A).

Quick Tip to Solve: For a shifted capacitor, multiply the overlap-area ratio by the inverse separation ratio: here $(1/2)(1/2)$.

30(ii). A slab (area A and thickness d_1) of a linear dielectric of dielectric constant K is inserted between charged plates (charge density σ) of a parallel plate capacitor [plate area A and plate separation $d (> d_1)$] and opposite charges with charge density of magnitude σ_p appear on the faces of the slab. The dielectric constant K is given by: [1 mark]

- (A) $\frac{\sigma + \sigma_p}{\sigma}$
(B) $\frac{\sigma}{\sigma - \sigma_p}$
(C) $\frac{\sigma + \sigma_p}{\sigma_p}$
(D) $\frac{\sigma}{\sigma_p}$

Correct Answer: (B) $\frac{\sigma}{\sigma - \sigma_p}$

Solution:

Concept:

- Free plate charges of surface density magnitude σ produce the field $E_0 = \sigma/\epsilon_0$. Polarisation produces an opposing field of magnitude $E_p = \sigma_p/\epsilon_0$ inside the slab.
- For a linear dielectric, its dielectric constant is $K = E_0/E$, where E is the resultant electric field within the dielectric.

Step 1: Find the field inside the slab The bound charges oppose the applied field, so their contribution is subtracted:

$$E = E_0 - E_p = \frac{\sigma - \sigma_p}{\epsilon_0}.$$

This is the field inside the dielectric even though air gaps remain outside the slab; the slab thickness is not needed for this local relation.

Step 2: Form the dielectric-constant ratio Substitute the two fields into the definition:

$$K = \frac{\sigma/\epsilon_0}{(\sigma - \sigma_p)/\epsilon_0} = \frac{\sigma}{\sigma - \sigma_p}.$$

A plus sign would incorrectly make the polarisation field reinforce the original field. Choice (C) and choice (D) also fail the no-polarisation limit $\sigma_p = 0$, in which K must equal one.

Step 3: Conclusion $K = \frac{\sigma}{\sigma - \sigma_p}$. Hence, the correct option is (B).

Quick Tip to Solve: First subtract the opposing polarisation field, then divide the original field by the reduced field; K should exceed one.

30(iii). An electric field E is established between the plates of an air filled parallel plate capacitor, with charges Q and $-Q$. V is the volume of the space enclosed between the plates. The energy stored in the capacitor is: [1 mark]

- (A) $\frac{1}{2}\epsilon_0 E^2$
- (B) $\epsilon_0 Q^2 E$
- (C) $\frac{1}{2}\epsilon_0 E^2 V$
- (D) $\epsilon_0 EQV$

Correct Answer: (C) $\frac{1}{2}\epsilon_0 E^2 V$

Solution:

Concept:

- The energy density of a uniform electrostatic field in air is $u = \frac{1}{2}\epsilon_0 E^2$, where ϵ_0 is the vacuum permittivity.
- Total field energy is energy density multiplied by the field-filled volume: $U = uV$. Here V denotes volume, not potential difference.

Step 1: Relate capacitor energy to the electric field Write the potential difference as $\Delta\phi$ to avoid confusing it with volume. For plate area A and separation d , $C = \epsilon_0 A/d$ and $\Delta\phi = Ed$. Therefore,

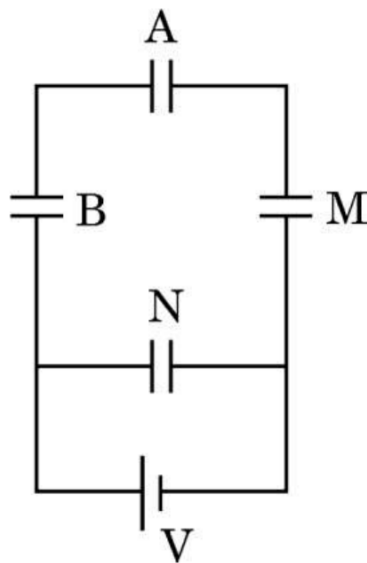
$$U = \frac{1}{2}C(\Delta\phi)^2 = \frac{1}{2}\frac{\epsilon_0 A}{d}(Ed)^2 = \frac{1}{2}\epsilon_0 E^2 Ad.$$

Step 2: Identify the enclosed volume and compare the options The space between the plates has volume $V = Ad$. Option (A) gives energy per unit volume, so it lacks the required volume factor. Options (B) and (D) introduce extra charge factors and do not have the dimensions of energy. The expression in option (C) is the field energy density integrated over the uniform-field region.

Step 3: Conclusion The stored energy is $U = \frac{1}{2}\epsilon_0 E^2 V$. Hence, the correct option is (C).

Quick Tip to Solve: When V means volume, multiply $\epsilon_0 E^2/2$ by V ; reserve a different symbol for voltage.

30(iv)(a). Three capacitors A , B and M , each of capacitance C are connected to a capacitor N of capacitance $2C$ and a battery as shown in the figure. If the charges on A and N are Q and Q' respectively, then $\frac{Q'}{Q}$ is: [1 mark]



- (A) $\frac{1}{6}$
- (B) $\frac{1}{3}$
- (C) 3
- (D) 6

Correct Answer: (D) 6

Solution:

Concept:

- Capacitors in series carry equal charge; their equivalent capacitance satisfies $1/C_s = 1/C_1 + 1/C_2 + 1/C_3$.
- A capacitor directly across a battery of voltage V carries charge $q = C_{\text{cap}}V$; parallel branches have the same voltage.

Step 1: Identify the two parallel branches Trace the outer path from one battery terminal to the other: it contains B , A and M in series. Each has capacitance C , so their equivalent capacitance is

$$C_s = \left(\frac{1}{C} + \frac{1}{C} + \frac{1}{C} \right)^{-1} = \frac{C}{3}.$$

The charge on each series capacitor, including A , is therefore $Q = CV/3$.

Step 2: Compare the charges in the branches Capacitor N , of capacitance $2C$, is directly across the battery, so $Q' = 2CV$. The comparison is

$$\frac{Q'}{Q} = \frac{2CV}{CV/3}.$$

Option (A) reverses the requested ratio. Options (B) and (C) miss either the factor of two in N 's capacitance or the series-branch voltage division; none equals this quotient.

Step 3: Conclusion The charge ratio is $\boxed{Q'/Q = 6}$. Hence, the correct option is (D).

Quick Tip to Solve: Trace the battery-to-battery paths first: the three equal capacitors form one series branch, while the larger capacitor gets the full battery voltage.

OR

30(iv)(b). A slab (area A and thickness $\frac{d}{2}$) of dielectric constant K is inserted in a parallel plate capacitor of plate area A and plate separation d . If C and C_0 are the capacitances of the capacitors with and without the dielectric, then $\frac{C}{C_0}$ is: [1 mark]

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

Correct Answer: (B) $\frac{2K}{K+1}$

Solution:

Concept:

- A dielectric slab spanning the full plate area creates layers along the electric field; these layers act as capacitors in series.
- A layer of thickness t , area A and relative permittivity K has capacitance $K\varepsilon_0 A/t$. The original air capacitor has $C_0 = \varepsilon_0 A/d$.

Step 1: Find the capacitance of each layer The dielectric occupies thickness $d/2$, leaving total air thickness $d/2$. The corresponding layer capacitances are

$$C_{\text{air}} = \frac{\varepsilon_0 A}{d/2} = 2C_0, \quad C_{\text{dielectric}} = \frac{K\varepsilon_0 A}{d/2} = 2KC_0.$$

Both layers carry the same normal electric displacement, and their potential differences add.

Step 2: Combine the layers in series Add the inverse capacitances because the layers lie successively between the plates:

$$\frac{1}{C} = \frac{1}{2C_0} + \frac{1}{2KC_0} = \frac{K+1}{2KC_0}.$$

Option (A) is the inverse of the requested enhancement ratio. Options (C) and (D) contain an incorrect difference: the air and dielectric voltage drops add. Also, at $K = 1$ the ratio must be unity; (C) and (D) fail this check.

Step 3: Conclusion Thus $\boxed{C/C_0 = 2K/(K+1)}$. Hence, the correct option is (B).

Quick Tip to Solve: For a slab filling half the gap, replace the effective air separation by $d/2 + d/(2K)$, then divide the original separation by this value.

Section E (15 marks)

31(a). (i) Draw a ray diagram to show the image formation by a compound microscope. Obtain the expression for the total magnification of the microscope when the final image is formed at infinity.

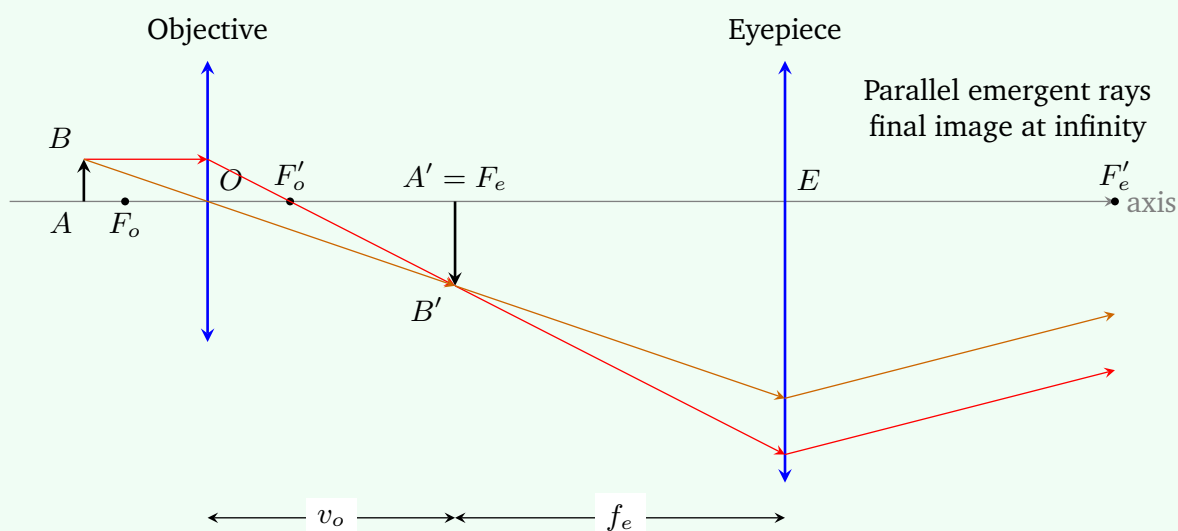
(ii) In a compound microscope, an object is placed at a distance of 1.5 cm from the objective of focal length 1.25 cm. The eyepiece has a focal length of 5 cm. The final image is formed at infinity. Calculate the distance between the objective and the eyepiece. [5 marks]

Solution:

Concept:

- The objective produces a real, inverted and enlarged intermediate image. The eyepiece acts as a magnifying glass; for a relaxed eye, this intermediate image is at its first focal plane and the final image is at infinity.
- With Cartesian signs, the lens formula is $1/f = 1/v - 1/u$. The objective's linear magnification is $m_o = v_o/u_o$.
- For normal adjustment the eyepiece's angular magnification is $M_e = D/f_e$, where $D = 25$ cm is the least distance of distinct vision. Total magnification is $M = m_o M_e$.

Step 1: (i) Construct the image formation diagram Place the object AB just beyond the first focus F_o of the objective. A ray from B parallel to the principal axis passes through F'_o after refraction, while a ray through the objective's optical centre O is undeviated. They meet at B' , forming the real inverted image $A'B'$. Adjust the eyepiece so that A' coincides with its first focus F_e . Rays from B' then emerge parallel from the eyepiece and the final image lies at infinity. The schematic shows this normal adjustment; its distances are not to scale.



Compound microscope in normal adjustment: the intermediate image is at the eyepiece focal plane and emergent rays are parallel.

Step 2: Derive the magnifying power Let the object height be h and the magnitude of the intermediate-image height be h' . The objective produces $h'/h = v_o/|u_o|$. Viewed directly at the near point, the object subtends the small angle $\alpha \simeq h/D$. Through the eyepiece, the intermediate image at its focal plane subtends $\beta \simeq h'/f_e$. Hence,

$$|M| = \frac{\beta}{\alpha} = \frac{h'}{h} \frac{D}{f_e} = \frac{v_o}{|u_o|} \frac{D}{f_e}.$$

Since the final image is inverted relative to the original object, the signed expression is

$$M = \frac{v_o}{u_o} \frac{D}{f_e}.$$

In the usual microscope approximation, $|u_o| \simeq f_o$ and $v_o \simeq L$, where L represents the effective optical tube length. Thus $M \simeq -LD/(f_o f_e)$, or magnifying power $|M| \simeq (L/f_o)(D/f_e)$. Use the exact lens formula, rather than this approximation, for the numerical lens separation below.

Step 3: (ii) Find the objective image distance The real object lies to the left of the objective, so $u_o = -1.5$ cm, while $f_o = +1.25$ cm. Substitution gives

$$\begin{aligned} \frac{1}{v_o} &= \frac{1}{f_o} + \frac{1}{u_o} = \frac{1}{1.25} - \frac{1}{1.5} \\ &= \frac{4}{5} - \frac{2}{3} = \frac{2}{15} \text{ cm}^{-1}, \\ v_o &= 7.5 \text{ cm}. \end{aligned}$$

The positive image distance confirms that the intermediate image is real and lies on the eyepiece side of the objective.

Step 4: Position the eyepiece for parallel emergent rays The final image is at infinity only when the intermediate image lies one eyepiece focal length to the left of the eyepiece. Thus the eyepiece must be 5 cm beyond that image. The separation ℓ of the two lenses is therefore found from

$$\ell = v_o + f_e = (7.5 + 5.0) \text{ cm}.$$

Adding the distances is essential: both segments lie consecutively between the objective and the eyepiece.

Step 5: Conclusion For the final image at infinity, $M = (v_o/u_o)(D/f_e) \simeq -LD/(f_o f_e)$; the minus sign denotes inversion. The required objective-to-eyepiece distance is 12.5 cm.

Quick Tip to Solve: First find v_o with the signed lens formula, then add f_e for normal adjustment; do not substitute the approximate tube-length formula for this exact separation.

OR

31(b). (i) Using Huygens' principle, explain the refraction of a plane wavefront, propagating in air, at a plane interface between air and glass. Hence verify Snell's law.

(ii) Use mirror formula to deduce that a convex mirror always produces a virtual image of an object kept in front of it. [5 marks]

Solution:

Concept:

- Huygens' principle: every point of a wavefront emits secondary wavelets; their forward envelope gives the new wavefront. Rays are normal to wavefronts.
- The refractive index is $n = c/v$, where v is light's speed in the medium. Snell's law is $n_1 \sin i = n_2 \sin r$, with angles measured from the interface normal.
- The mirror formula is $1/f = 1/v + 1/u$, where u , v and f are signed object distance, image distance

and focal length in the Cartesian convention.

Step 1: (i) Construct the refracted wavefront Let a plane wavefront AB travel in air towards a plane air-glass interface. Point A reaches the interface first. Let B reach a point C on the interface after time t , so AC lies along the interface. If the speeds in air and glass are v_1 and v_2 , respectively, the incident ray travels $BC = v_1 t$. During the same time, the secondary wavelet from A travels into glass through a radius $AD = v_2 t$. Draw the tangent CD from C to this wavelet. Since the interface is plane and all its points obey the same construction, CD is the refracted plane wavefront. The radius AD is perpendicular to CD and gives the refracted ray direction.

Step 2: (i) Use the two right triangles to verify Snell's law Since $BC \perp AB$, triangle ABC is right angled at B . The angle between AB and AC equals the incidence angle i , because the corresponding rays and normal are perpendicular to these lines. Similarly, triangle ADC is right angled at D , and the angle between CD and CA equals the refraction angle r . Hence

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}, \quad \sin r = \frac{AD}{AC} = \frac{v_2 t}{AC}.$$

Dividing and using $n_1 = c/v_1$, $n_2 = c/v_2$,

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{n_2}{n_1} \implies n_1 \sin i = n_2 \sin r.$$

For air to glass, $v_2 < v_1$, so $r < i$: the ray bends towards the normal. At normal incidence both angles are zero and the ray remains undeviated.

Step 3: (ii) Apply the mirror formula with signed distances For any real object in front of a convex mirror, write $u = -a$, where $a > 0$. The convex mirror has its principal focus behind the mirror, so $f > 0$. Rearranging the mirror formula gives

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{f} + \frac{1}{a} = \frac{a+f}{af},$$
$$v = \frac{af}{a+f} > 0.$$

A positive image distance places the image behind the mirror. Reflected rays do not actually meet there; only their backward extensions meet, which establishes that the image is virtual for every finite positive object distance a . Also $v/f = a/(a+f) < 1$, so the image lies between the pole and focus. The limiting image for an infinitely distant object is at the focus behind the mirror.

Step 4: Conclusion (i) Huygens' construction gives $n_{\text{air}} \sin i = n_{\text{glass}} \sin r$, verifying Snell's law. (ii) For $u = -a < 0$ and $f > 0$, $v = af/(a+f) > 0$; thus a convex mirror always forms a virtual image of a real object in front of it.

Quick Tip to Solve: In Huygens' proof compare distances travelled in the same time; for a convex mirror set $u = -a$ and $f > 0$ before deciding the image's nature.

32(a). (i) The electric field in a region is given by $\vec{E} = 40x\hat{i}$ N/C. Find the amount of work done in taking a unit positive charge from a point (0, 3 m) to the point (5 m, 0).

(ii) A charge Q is distributed over two concentric hollow spheres of radii r and $R (> r)$ such that their surface charge densities are equal. Find:

(I) the electric field, and

(II) the potential

at their common centre.

[5 marks]

Solution:

Concept:

- The work done by an electric field is $W_{\text{field}} = q \int_A^B \vec{E} \cdot d\vec{l}$. The potential difference is $V_B - V_A = - \int_A^B \vec{E} \cdot d\vec{l}$.
- In moving a charge without changing its kinetic energy, the external work is $W_{\text{ext}} = q(V_B - V_A) = -W_{\text{field}}$. This distinguishes the two possible work conventions.
- A uniformly charged spherical shell of radius a and charge q_s has zero electric field inside and constant potential $q_s/(4\pi\epsilon_0 a)$, with zero potential at infinity. Fields and potentials obey superposition.

Step 1: (i) Evaluate the field integral between the endpoints The unit positive charge is $q = 1$ C. Since $\vec{E} = 40x\hat{i}$ N/C has only an x -component, $\vec{E} \cdot d\vec{l} = 40x dx$. The change of the y -coordinate from 3 m to zero contributes no work. The field depends only on x , so the integral is independent of the route:

$$\int_A^B \vec{E} \cdot d\vec{l} = \int_0^5 40x dx = [20x^2]_0^5 = 500 \text{ V}.$$

Thus the final point has a lower potential by 500 V. We must integrate the varying field; multiplying the final field by the full displacement would overestimate the work.

Step 2: (i) State the work and its sign convention The usual electrostatic work required to take the charge slowly from A to B , meaning work by an external agent, is

$$W_{\text{ext}} = q(V_B - V_A) = (1 \text{ C})(-500 \text{ V}) = -500 \text{ J}.$$

The negative sign means the external agent removes energy while restraining the charge, because the electric field favours this motion. The work done by the electric field itself is $W_{\text{field}} = +500 \text{ J}$. Thus the magnitude is 500 J; specifying the agent resolves the sign in the printed phrase “work done in taking”.

Step 3: (ii) Divide the total charge using equal surface densities Let the charges on the shells of radii r and R be q_r and q_R , respectively, and let their common uniform surface charge density be σ . Their charges are proportional to surface areas:

$$\begin{aligned} q_r &= 4\pi r^2 \sigma, & q_R &= 4\pi R^2 \sigma, \\ Q &= 4\pi \sigma (r^2 + R^2), \\ q_r &= \frac{Qr^2}{r^2 + R^2}, & q_R &= \frac{QR^2}{r^2 + R^2}. \end{aligned}$$

Equal densities therefore do not mean equal charges: the larger shell carries the larger share in proportion to the square of its radius.

Step 4: (ii)(I) Superpose the electric fields at the centre The common centre lies inside both spherical shells. For each uniformly charged shell, diametrically opposite surface elements give equal and opposite field contributions there. Equivalently, the shell theorem gives zero field everywhere inside

an individual shell. Thus

$$\vec{E}_{\text{centre}} = \vec{E}_r + \vec{E}_R = \vec{0}.$$

Step 5: (ii)(II) Add the scalar potentials at the centre Every element of the inner shell is at distance r from the centre and every element of the outer shell is at distance R . Potentials are scalars, so they add rather than cancelling like the field vectors:

$$\begin{aligned} V_{\text{centre}} &= \frac{1}{4\pi\epsilon_0} \left(\frac{q_r}{r} + \frac{q_R}{R} \right) \\ &= \frac{Q}{4\pi\epsilon_0(r^2 + R^2)}(r + R). \end{aligned}$$

Zero field implies a spatially constant potential in the central cavity, not zero potential. Its value is fixed by the chosen zero at infinity.

Step 6: Conclusion (i) External work is -500 J , whereas the electric field does $+500 \text{ J}$ of work. (ii) At the common centre,

$$\vec{E} = \vec{0}, \quad V = \frac{Q(r + R)}{4\pi\epsilon_0(r^2 + R^2)}.$$

Quick Tip to Solve: Integrate $40x$ over the endpoint x -coordinates and specify whose work is meant. For equal shell densities use $q_r : q_R = r^2 : R^2$, then add their potentials.

OR

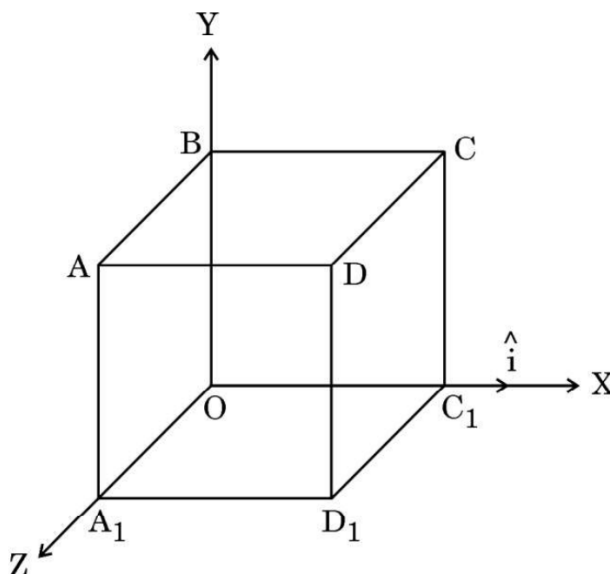
32(b). (i) Obtain an expression for the electric field $\vec{E}$ due to a dipole of dipole moment $\vec{p}$ at a point on its equatorial plane and specify its direction. Hence, find the value of electric field:

(I) at the centre of the dipole ($r = 0$), and

(II) at a point $r \gg a$,

where $2a$ is the length of the dipole.

(ii) An electric field $\vec{E} = (10x + 5)\hat{i} \text{ N/C}$ exists in a region in which a cube of side L is kept as shown in the figure. Here x and L are in metres. Calculate the net flux through the cube. [5 marks]



Solution:

Concept:

- A dipole consists of charges $-q$ and $+q$ separated by $2a$. Its moment $\vec{p}$ points from $-q$ to $+q$, with magnitude $p = 2qa$.
- Electric fields add vectorially. Each point charge produces a field of magnitude $E_q = kq/d^2$ at distance d , where $k = 1/(4\pi\epsilon_0)$.
- Electric flux through a closed surface is $\Phi = \oint \vec{E} \cdot d\vec{A}$, where $d\vec{A}$ points outward. A face perpendicular to a uniform field contributes $\pm EA$; a face parallel to the field contributes zero.

Step 1: (i) Resolve the two fields on the equatorial plane Choose the dipole axis as the x -axis, with $-q$ at $(-a, 0)$ and $+q$ at $(a, 0)$. Let P be a point at distance r from the centre on a perpendicular axis. Both charges are at the same distance $d = \sqrt{r^2 + a^2}$ from P . The field due to $+q$ points away from that charge, whereas the field due to $-q$ points towards it.

$$\begin{aligned}\vec{E}_+ &= \frac{kq}{(r^2 + a^2)^{3/2}}(-a\hat{i} + r\hat{j}), \\ \vec{E}_- &= \frac{kq}{(r^2 + a^2)^{3/2}}(-a\hat{i} - r\hat{j}).\end{aligned}$$

The components perpendicular to the dipole axis cancel, while the axial components add towards the negative charge. Hence, using $\vec{p} = 2qa\hat{i}$,

$$\vec{E}_{\text{eq}} = \vec{E}_+ + \vec{E}_- = -\frac{1}{4\pi\epsilon_0} \frac{\vec{p}}{(r^2 + a^2)^{3/2}}.$$

Rotational symmetry about the dipole axis makes this expression valid at every point on the equatorial plane. Its direction is opposite to $\vec{p}$.

Step 2: (i)(I) Put the observation point at the centre Substitute $r = 0$ into the exact finite-dipole expression:

$$\vec{E}(0) = -\frac{\vec{p}}{4\pi\epsilon_0 a^3}, \quad E(0) = \frac{2kq}{a^2}.$$

At the midpoint, each charge contributes kq/a^2 , and both fields point from $+q$ towards $-q$. Thus the field is finite and nonzero; symmetry does not cancel it.

Step 3: (i)(II) Apply the far-field approximation When $r \gg a$, the ratio a^2/r^2 is negligible. Therefore

$$(r^2 + a^2)^{3/2} = r^3 \left(1 + \frac{a^2}{r^2}\right)^{3/2} \simeq r^3,$$

giving

$$\vec{E}_{\text{eq}} \simeq -\frac{\vec{p}}{4\pi\epsilon_0 r^3}.$$

The direction remains opposite to the dipole moment, and the magnitude falls as r^{-3} . This approximation must not be used at the centre.

Step 4: (ii) Add the outward fluxes through the cube faces In the printed figure the left face $ABOA_1$ lies at $x = 0$, and the opposite right face DCC_1D_1 lies at $x = L$. Each has area L^2 . The field is along $+\hat{i}$ and is constant over either of these faces because x is fixed. Their outward normals are $-\hat{i}$ and $+\hat{i}$,

respectively.

$$\begin{aligned}\Phi_{x=0} &= -E(0)L^2 = -5L^2, \\ \Phi_{x=L} &= E(L)L^2 = (10L + 5)L^2.\end{aligned}$$

These expressions give flux in $\text{N m}^2/\text{C}$ when L is entered in metres. On the remaining four faces, the field lies parallel to the surface, so $\vec{E} \cdot d\vec{A} = 0$. Adding all six contributions gives

$$\Phi_{\text{net}} = [(10L + 5) - 5]L^2 = 10L^3 \text{ N m}^2/\text{C}.$$

The constant term contributes equal inward and outward flux and cancels. The positive net flux results from the field increasing along x .

Step 5: Conclusion The exact equatorial field is $\vec{E} = -\vec{p}/[4\pi\epsilon_0(r^2 + a^2)^{3/2}]$, opposite to $\vec{p}$. At the centre it is $-\vec{p}/(4\pi\epsilon_0 a^3)$; for $r \gg a$ it is approximately $-\vec{p}/(4\pi\epsilon_0 r^3)$. The net outward flux through the cube is $10L^3 \text{ N m}^2/\text{C}$, with L in metres.

Quick Tip to Solve: Use the exact finite-dipole formula before substituting $r = 0$. For the cube, only the two faces normal to the field matter: subtract the entry field from the exit field, then multiply by L^2 .

33(a). (i) Write the principle of working of an ac generator. Draw its labelled diagram and explain its working.

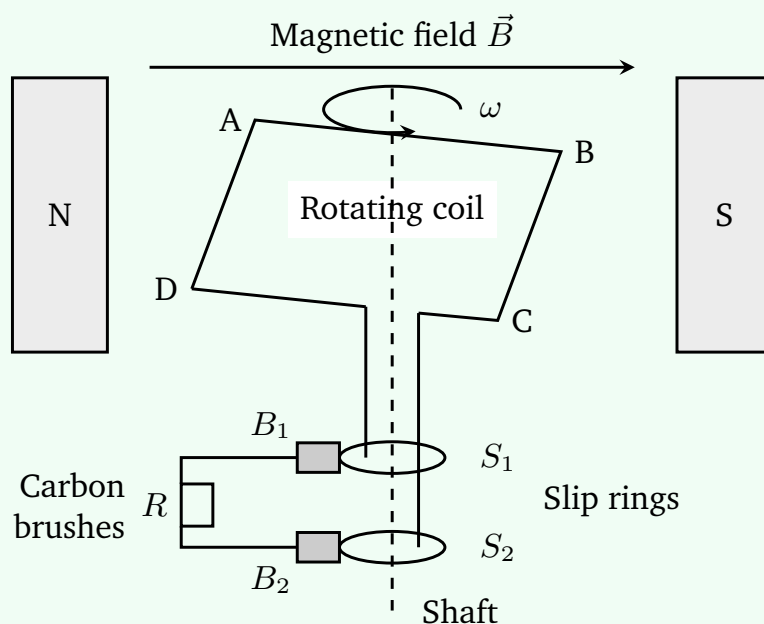
(ii) A resistor of 400Ω , an inductor of $\left(\frac{5}{\pi}\right) \text{ H}$ and a capacitor of $\left(\frac{50}{\pi}\right) \mu\text{F}$ are joined in series across an ac source $v = 140 \sin(100\pi t) \text{ V}$. Find the rms voltages across these three circuit elements. The algebraic sum of these voltages is more than the rms voltage of source. Explain. [5 marks]

Solution:

Concept:

- An ac generator uses electromagnetic induction: the induced emf is $e = -d(N\Phi)/dt$, where $N\Phi$ is the magnetic flux linkage of the rotating coil.
- In a series RLC circuit the same rms current I flows through all elements. Reactances are $X_L = \omega L$ and $X_C = 1/(\omega C)$, and impedance is $Z = \sqrt{R^2 + (X_L - X_C)^2}$.
- The rms voltage of a sinusoidal source is $V = V_0/\sqrt{2}$. Element voltages are $V_R = IR$, $V_L = IX_L$ and $V_C = IX_C$; they must be added as phasors.

Step 1: (i) State the principle and identify the parts When a coil rotates in a magnetic field, its magnetic flux linkage changes and an emf is induced according to Faraday's law. Thus an ac generator converts mechanical energy into electrical energy. A rectangular armature coil ABCD is rotated by a shaft between the north and south poles of a magnet. Its two ends connect separately to two continuous slip rings S_1, S_2 , insulated from each other and the shaft. Stationary carbon brushes B_1, B_2 touch the rings and connect the rotating coil to the external load.



AC generator: rotating coil, separate continuous slip rings, stationary brushes and external load (schematic).

Step 2: (i) Explain the alternating output Let the coil have N turns and area A , in a uniform field of magnitude B . If its normal makes angle $\theta = \omega t$ with the field, its flux linkage and induced emf are

$$N\Phi = NBA \cos \omega t, \quad e = -\frac{d(N\Phi)}{dt} = NBA\omega \sin \omega t.$$

The peak emf is $e_0 = NBA\omega$. It is zero when the coil's normal is parallel to the field and maximum in magnitude when the normal is perpendicular to the field. After every half rotation the motion of each side relative to the field reverses, so the induced emf reverses. The continuous slip rings preserve the connection of each coil end to its own brush; hence the external current also reverses every half cycle for a resistive load. Mechanical work supplied against the magnetic torque provides the electrical energy.

Step 3: (ii) Calculate the reactances and circuit current From $v = 140 \sin(100\pi t)$ V, the peak voltage is 140 V and the angular frequency is $100\pi \text{ rad s}^{-1}$. Use the printed inductance $L = 5/\pi \text{ H}$ and convert the capacitance to farads:

$$\begin{aligned} C &= \frac{50}{\pi} \times 10^{-6} \text{ F}, \\ X_L &= 100\pi \times \frac{5}{\pi} = 500 \Omega, \\ X_C &= \frac{1}{100\pi(50/\pi) \times 10^{-6}} = 200 \Omega, \\ Z &= \sqrt{400^2 + (500 - 200)^2} = 500 \Omega, \\ V &= \frac{140}{\sqrt{2}} = 70\sqrt{2} \text{ V}, \\ I &= \frac{V}{Z} = \frac{70\sqrt{2}}{500} = 0.14\sqrt{2} \text{ A}. \end{aligned}$$

Step 4: (ii) Obtain the rms element voltages and explain their sum Multiplying the common rms

current by the corresponding resistance or reactance gives

$$V_R = (0.14\sqrt{2})(400) = 56\sqrt{2} \text{ V},$$

$$V_L = (0.14\sqrt{2})(500) = 70\sqrt{2} \text{ V},$$

$$V_C = (0.14\sqrt{2})(200) = 28\sqrt{2} \text{ V}.$$

Their arithmetic sum is $154\sqrt{2} \text{ V}$, which exceeds the source rms voltage. These rms magnitudes are not in phase: V_R is in phase with current, V_L leads current by 90° , and V_C lags it by 90° . Thus the inductive and capacitive voltages oppose each other, and their resultant is perpendicular to the resistive voltage. The correct phasor sum is

$$V = \sqrt{V_R^2 + (V_L - V_C)^2} = \sqrt{(56\sqrt{2})^2 + (42\sqrt{2})^2} = 70\sqrt{2} \text{ V}.$$

Kirchhoff's voltage law still holds for the signed instantaneous voltages; adding positive rms magnitudes ignores their phase differences.

Step 5: Conclusion The ac generator works by electromagnetic induction and produces $e = NBA\omega \sin \omega t$. The rms voltages are $V_R \approx 79.2 \text{ V}$, $V_L \approx 99.0 \text{ V}$ and $V_C \approx 39.6 \text{ V}$. Their phasor sum equals the source rms voltage 99.0 V , although their arithmetic sum is larger.

Quick Tip to Solve: Read 140 V as the peak value, convert microfarads to farads, and subtract the reactances before finding impedance. Add element voltages as phasors.

OR

33(b). (i) Write the principle of working of a transformer. With the help of a labelled diagram, explain the working of a step-up transformer.

(ii) An ideal transformer is designed to convert 50 V into 250 V . It draws 200 W power from an ac source whose instantaneous voltage is given by $v_i = 20 \sin(100\pi)t \text{ V}$.

Find:

(I) rms value of input current.

(II) expression for instantaneous output voltage.

(III) expression for instantaneous output current.

[5 marks]

Solution:

Concept:

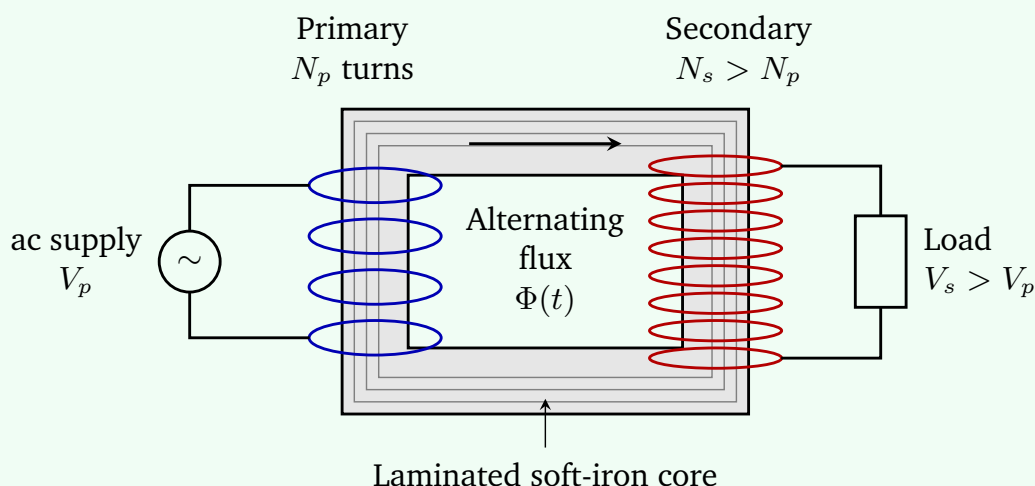
- A transformer works by mutual induction: an alternating current in the primary produces changing magnetic flux linked with the secondary, inducing an emf there.
- For an ideal transformer, both windings link the same flux Φ . Thus $e_p = -N_p d\Phi/dt$, $e_s = -N_s d\Phi/dt$, and the voltage-magnitude ratio is $V_s/V_p = N_s/N_p$.
- For a sinusoid, rms value equals peak value divided by $\sqrt{2}$. An ideal transformer conserves average power; for a resistive load, $P = V_p I_p = V_s I_s$, where the voltages and currents are rms values.

Step 1: (i) Explain the construction and working The insulated primary and secondary windings are wound on a common laminated soft-iron core. The primary is connected to an ac supply; the secondary is connected to the load. The core provides a path for magnetic flux linking both coils. Laminations reduce eddy-current losses. Alternating primary current produces alternating flux in the

core. By Faraday's law, this induces an alternating emf in each turn of both windings. The emf per turn is the same for perfect magnetic coupling, so

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

In a step-up transformer, $N_s > N_p$, hence $V_s > V_p$. On loading, the secondary current is smaller than the primary current in the inverse turns ratio, so the voltage increase does not create extra power. The frequency remains unchanged. A steady dc supply cannot sustain the changing flux needed for transformer action.



Step-up transformer: a common laminated core links the primary and the secondary, with $N_s > N_p$.

Step 2: (ii) Establish the turns ratio and operating input voltage The design voltages specify the ratio, rather than the actual input used in this numerical:

$$k = \frac{N_s}{N_p} = \frac{250}{50} = 5.$$

Reading the printed sinusoidal source as $v_i = 20 \sin(100\pi t)$ V, its peak is 20 V, angular frequency is $100\pi \text{ rad s}^{-1}$, and frequency is 50 Hz. Therefore,

$$V_{i,\text{rms}} = \frac{20}{\sqrt{2}} = 10\sqrt{2} \text{ V}.$$

For the requested numerical currents, use the usual textbook assumption of a resistive load (unity power factor). Ideal efficiency alone does not specify the load power factor; this assumption is needed for the quoted current values and phases.

Step 3: (I) Calculate the rms input current The given 200 W is average input power. With unity power factor,

$$I_{i,\text{rms}} = \frac{P}{V_{i,\text{rms}}} = \frac{200}{10\sqrt{2}} = 10\sqrt{2} \text{ A}.$$

The corresponding peak primary current is

$$I_{i0} = \sqrt{2} I_{i,\text{rms}} = 20 \text{ A}.$$

Step 4: (II) Obtain the instantaneous output voltage Every instantaneous voltage magnitude is multiplied by the turns ratio; the angular frequency is unchanged. Choose corresponding terminal

polarities so that input and output voltages have the same phase. Then

$$v_o(t) = kv_i(t) = 100 \sin(100\pi t) \text{ V.}$$

Reversing the chosen secondary terminal polarity reverses the sign of this expression, with no change in the physical voltage amplitude.

Step 5: (III) Obtain the instantaneous output current For an ideal transformer the current magnitudes scale inversely with turns ratio:

$$I_{o,\text{rms}} = \frac{I_{i,\text{rms}}}{5} = 2\sqrt{2} \text{ A},$$
$$I_{o0} = \sqrt{2} I_{o,\text{rms}} = 4 \text{ A.}$$

Taking positive output current as delivered to the resistive load, current and load voltage are in phase:

$$i_o(t) = 4 \sin(100\pi t) \text{ A.}$$

A power check gives $V_{o,\text{rms}} I_{o,\text{rms}} = (100/\sqrt{2})(4/\sqrt{2}) = 200 \text{ W}$, as required. If a load phase angle ϕ were allowed, the data would instead give $I_{i,\text{rms}} = 10\sqrt{2}/\cos \phi \text{ A}$ and $i_o = (4/\cos \phi) \sin(100\pi t - \phi) \text{ A}$; the printed question supplies no such angle.

Step 6: Conclusion The transformer uses mutual induction, with $N_s > N_p$ for step-up action. Under the usual unity-power-factor assumption, (I) $I_{i,\text{rms}} = 10\sqrt{2} \text{ A} \approx 14.14 \text{ A}$; (II) $v_o = 100 \sin(100\pi t) \text{ V}$; and (III) $i_o = 4 \sin(100\pi t) \text{ A}$, using corresponding voltage polarities and current delivered to the load.

Quick Tip to Solve: Use 250/50 only to find the turns ratio. For power calculations, use the rms value of the actual 20 V peak source, then convert rms currents back to peaks for their instantaneous expressions.