

CBSE Class 12 Physics Question Paper 2025 with Solution PDF-Set 55/5/1



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 metal sheet is inserted between the plates of a parallel plate capacitor of capacitance C . If the sheet partly occupies the space between the plates, the capacitance: [1 mark]

- (A) remains C
- (B) becomes greater than C
- (C) becomes less than C
- (D) becomes zero

Correct Answer: (B) becomes greater than C

Solution:

Concept:

- Capacitance is $C = Q/V$, where Q is the charge on either plate and V is their potential difference.
- The electric field inside a conductor in electrostatic equilibrium is zero, so a metal sheet reduces the thickness of the region across which the potential drops.

Step 1: Compare the effective separation For plate area A and separation d , the initial capacitance is $C = \epsilon_0 A/d$. If an isolated metal sheet of thickness $t < d$ occupies the gap over the plate area, the two remaining air gaps have total thickness $d - t$. Thus

$$C' = \frac{\epsilon_0 A}{d - t}.$$

The sheet does not bridge the plates, so it does not short-circuit the capacitor.

Step 2: Check the direction of change Since $d - t < d$, the same charge produces a smaller potential difference and the capacitance increases. If only part of the plate area is covered, that part has increased capacitance while the uncovered part is unchanged; these parts add in parallel. Neither interpretation leaves the capacitance unchanged, reduces it, or makes it zero, eliminating (A), (C) and (D).

Step 3: Conclusion The capacitance becomes greater than C . Hence, the correct option is (B).

Quick Tip to Solve: For an isolated metal slab in the gap, replace the air-gap thickness d by $d - t$; the smaller denominator means greater capacitance.

2. The electric field at a point in a region is given by $\vec{E} = \alpha \frac{\vec{r}}{|\vec{r}|^3}$, where α is a constant and r is the distance of the point from the origin. The magnitude of potential of the point is: [1 mark]

- (A) $\frac{\alpha}{r}$
 (B) $\frac{\alpha r^2}{2}$
 (C) $\frac{\alpha}{2r^2}$
 (D) $-\frac{\alpha}{r}$

Correct Answer: (A) $\frac{\alpha}{r}$

Solution:

Concept:

- For a radial electric field, $E_r = -dV/dr$. The potential is conventionally taken to vanish at infinity for an inverse-square field.
- The magnitude of the position vector is $|\vec{r}| = r$, so $\vec{E} = \alpha \vec{r}/r^3$ has radial component $E_r = \alpha/r^2$.

Step 1: Integrate the radial field Use a radial path from infinity to the point, keeping the minus sign in the field-potential relation:

$$V(r) - V(\infty) = - \int_{\infty}^r \frac{\alpha}{s^2} ds = \left[\frac{\alpha}{s} \right]_{\infty}^r = \frac{\alpha}{r}.$$

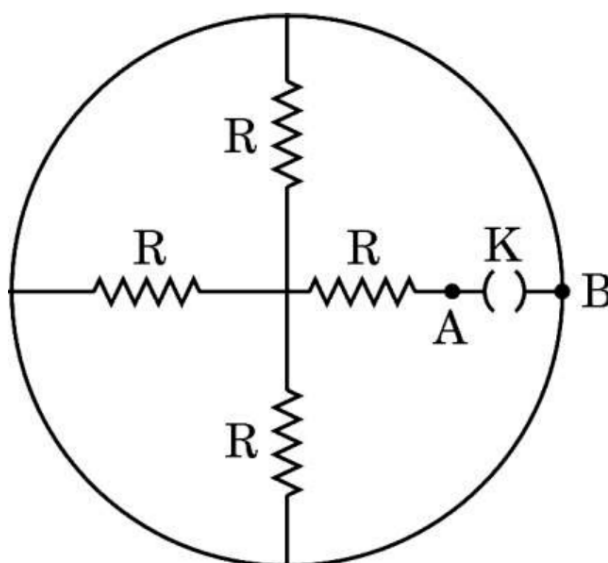
Here s is the integration variable and $V(\infty) = 0$.

Step 2: Compare the printed expressions The expected positive-constant convention gives magnitude α/r ; more generally the magnitude is $|\alpha|/r$. Option (D) reverses the sign of the potential for the stated field. Option (B) has the wrong radial dependence, and option (C) would follow from incorrectly treating the field magnitude as proportional to r^{-3} and forgetting the factor r in $\vec{r}$.

Step 3: Conclusion With the conventional zero at infinity and the intended positive α , the potential magnitude is α/r . Hence, the correct option is (A).

Quick Tip to Solve: First replace $\vec{r}$ by $r\hat{r}$: the field varies as r^{-2} , so its potential varies as r^{-1} .

3. Four resistors, each of resistance R and a key K are connected as shown in the figure. The equivalent resistance between points A and B when key K is open, will be: [1 mark]



- (A) $4R$
- (B) ∞
- (C) $\frac{R}{4}$
- (D) $\frac{4R}{3}$

Correct Answer: (D) $\frac{4R}{3}$

Solution:

Concept:

- Points connected by an ideal wire are at the same potential and form one circuit node.
- Resistors between the same two nodes combine in parallel; a resistor carrying the total current before branching is in series with that combination.

Step 1: Identify the connected nodes The entire circular wire, including point B , is one node. The upper, lower and left resistors each connect the central junction to this circular wire. They are therefore three equal resistors in parallel, with resistance

$$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R}, \quad R_p = \frac{R}{3}.$$

Step 2: Trace the path from A to B With key K open, the direct wire route from A to B is broken. Current can still go from A through the right-hand resistor to the central junction and then through the parallel group to B . Thus

$$R_{AB} = R + R_p = R + \frac{R}{3} = \frac{4R}{3}.$$

The circuit is not disconnected, ruling out infinity. The four resistors are neither all in series nor all in

parallel, so $4R$ and $R/4$ also fail.

Step 3: Conclusion The equivalent resistance is $4R/3$. Hence, the correct option is (D).

Quick Tip to Solve: Collapse the circular ideal wire into a single node before combining resistors; its curved shape does not add resistance.

4. A charged particle gains a speed of 10^6 m s^{-1} , when accelerated from rest through a potential difference 10 kV. It enters a region of magnetic field of 0.4 T such that $\vec{v} \perp \vec{B}$. The radius of circular path described by it is: [1 mark]

- (A) 2.5 cm
- (B) 5 cm
- (C) 8 cm
- (D) 10 cm

Correct Answer: (B) 5 cm

Solution:

Concept:

- A particle of mass m and charge magnitude $|q|$, accelerated from rest through potential difference U , gains kinetic energy $|q|U = mv^2/2$.
- With velocity perpendicular to magnetic field B , magnetic force supplies centripetal force: $|q|vB = mv^2/r$, so $r = mv/(|q|B)$.

Step 1: Eliminate the unknown charge-to-mass ratio From the energy equation, $m/|q| = 2U/v^2$. Substitute this in the magnetic-radius relation:

$$r = \frac{m}{|q|} \frac{v}{B} = \frac{2U}{vB}.$$

The particle's charge and mass are unnecessary because its accelerating voltage and acquired speed are both known.

Step 2: Substitute the printed speed in SI units The official question gives $v = 10^6 \text{ m s}^{-1}$, $U = 10 \text{ kV} = 10^4 \text{ V}$ and $B = 0.4 \text{ T}$. Therefore

$$r = \frac{2 \times 10^4}{10^6 \times 0.4} \text{ m} = 0.05 \text{ m} = 5 \text{ cm}.$$

Option (A) loses the factor two from the kinetic-energy equation; (C) and (D) do not satisfy both the energy and magnetic-force relations.

Step 3: Conclusion The radius of the circular path is 5 cm. Hence, the correct option is (B).

Quick Tip to Solve: When speed and accelerating voltage are both given, use $r = 2U/(vB)$; check the printed power of ten before substitution.

5. A current of $\left(\frac{10}{\pi}\right)$ A is maintained in a circular loop of radius 14 cm. The value of dipole moment associated with the loop is: [1 mark]

(A) 0.019 Am^2

(B) 0.14 Am^2

(C) 0.196 Am^2

(D) 0.615 Am^2

Correct Answer: (C) 0.196 Am^2

Solution:

Concept:

- The magnetic dipole moment of a single current loop is $\mu = IA$, where I is the current and A is the enclosed area.
- For a circular loop of radius r , $A = \pi r^2$. The SI unit of magnetic dipole moment is A m^2 .

Step 1: Convert the radius to metres The radius is $r = 14 \text{ cm} = 0.14 \text{ m}$. Squaring the radius gives $r^2 = 0.0196 \text{ m}^2$, and hence the loop area is $A = 0.0196\pi \text{ m}^2$. Using centimetres directly would give an incorrect SI value.

Step 2: Multiply current by area Substitute $I = 10/\pi \text{ A}$ in the dipole-moment formula:

$$\mu = \frac{10}{\pi} \times \pi(0.14)^2 = 10 \times 0.0196 = 0.196 \text{ A m}^2.$$

The factor π cancels exactly. Option (A) is roughly ten times too small, (B) incorrectly resembles the numerical radius, and (D) retains an extra factor approximately equal to π .

Step 3: Conclusion The magnetic dipole moment has magnitude 0.196 A m^2 . Hence, the correct option is (C).

Quick Tip to Solve: Cancel π between the given current and the circular area before calculating, and convert centimetres to metres before squaring.

6. The magnetic flux linked with a coil changes with time t as $\phi = (8t^2 + 5t + 7)$, where t is in seconds and ϕ is in Wb. The value of emf induced in the coil at $t = 4 \text{ s}$ is: [1 mark]

(A) 32 V

(B) 37 V

(C) 64 V

(D) 69 V

Correct Answer: (D) 69 V

Solution:

Concept:

- Faraday's law gives induced emf as $\varepsilon = -d\phi/dt$, where ϕ is the linked magnetic flux and t is time.
- The magnitude is $|\varepsilon| = |d\phi/dt|$; the minus sign expresses Lenz's law, opposing the change of flux.

Step 1: Differentiate the flux expression The linked flux is $\phi = 8t^2 + 5t + 7$, in webers. Differentiate

each term with respect to time:

$$\frac{d\phi}{dt} = 16t + 5.$$

The constant 7 contributes no emf because a constant flux does not induce an emf. The quadratic term supplies the factor two on differentiation.

Step 2: Evaluate the instantaneous emf At $t = 4$ s, the magnitude is

$$|\varepsilon| = 16(4) + 5 = 69 \text{ Wb s}^{-1} = 69 \text{ V}.$$

With a chosen positive flux orientation, the signed emf is -69 V; the positive options ask for its magnitude. Option (C) omits the $5t$ contribution, while (A) and (B) miss the factor two in differentiating $8t^2$.

Step 3: Conclusion The induced emf has magnitude 69 V. Hence, the correct option is (D).

Quick Tip to Solve: Differentiate the flux first and substitute time afterward; the constant flux term disappears and the linear term contributes its coefficient.

7. Which of the following rays coming from the Sun plays an important role in maintaining the Earth's warmth? [1 mark]

- (A) Infrared rays
- (B) γ rays
- (C) UV rays
- (D) Visible light rays

Correct Answer: (A) Infrared rays

Solution:

Concept:

- Infrared radiation lies beyond the red end of the visible spectrum and has a pronounced heating effect when absorbed by matter.
- Absorbed radiant energy increases internal energy. Atmospheric absorption and re-emission of terrestrial infrared radiation also help maintain the Earth's warmth.

Step 1: Identify the heat-associated radiation The Sun emits radiation over a range of wavelengths. In the standard electromagnetic-spectrum classification used here, infrared rays are the heat rays: their absorption by the Earth's surface and other matter contributes to warming. This directly matches the property asked in the question.

Step 2: Distinguish the other choices Gamma rays and ultraviolet rays are higher-frequency radiations and are not the rays identified with maintaining the Earth's warmth in this question. Visible sunlight also supplies energy absorbed by the surface, but infrared is the intended spectrum band associated specifically with heat radiation. Warm surfaces emit infrared, some of which is absorbed and re-emitted by the atmosphere, reducing heat loss to space.

Step 3: Conclusion Infrared rays play the stated role in maintaining the Earth's warmth. Hence, the correct option is (A).

Quick Tip to Solve: For a spectrum question linking a named radiation band with heat or warmth, identify infrared, which lies just beyond visible red.

8. The dimensions of $(\mu\varepsilon)^{-1}$, where ε is permittivity and μ is permeability of a medium, are: [1 mark]

(A) $[M^0 L^1 T^{-1}]$

(B) $[M^0 L^2 T^{-2}]$

(C) $[M^1 L^2 T^{-2}]$

(D) $[M^1 L^{-2} T^{-1}]$

Correct Answer: (B) $[M^0 L^2 T^{-2}]$

Solution:

Concept:

- The speed v of an electromagnetic wave in a medium obeys $v = 1/\sqrt{\mu\varepsilon}$, where μ and ε are its permeability and permittivity.
- Speed has dimensions $[v] = [LT^{-1}]$; numerical powers act on every dimensional exponent.

Step 1: Relate the inverse product to wave speed The printed expression contains the inverse of the product. Squaring the wave-speed relation gives

$$(\mu\varepsilon)^{-1} = v^2.$$

Thus we require the dimensions of speed squared, rather than those of speed or inverse speed squared.

Step 2: Compare all four dimensional expressions Hence $[(\mu\varepsilon)^{-1}] = [L^2 T^{-2}] = [M^0 L^2 T^{-2}]$. Option (A) has the dimensions of speed and misses the square. Options (C) and (D) contain a nonzero mass exponent, although mass cannot occur in the dimensions of v^2 ; option (D) also has incorrect length and time powers.

Step 3: Conclusion The required dimensions are $[M^0 L^2 T^{-2}]$. Hence, the correct option is (B).

Quick Tip to Solve: First notice the exponent -1 : use $(\mu\varepsilon)^{-1} = v^2$ and square the speed dimensions.

9. Which of the following electromagnetic waves has photons of largest momentum?

[1 mark]

- (A) X-rays
- (B) AM radio waves
- (C) Microwaves
- (D) TV waves

Correct Answer: (A) X-rays

Solution:

Concept:

- A photon of frequency ν has energy $E = h\nu$ and momentum $p = E/c = h\nu/c$, where h is Planck's constant and c is the speed of light in vacuum.
- Equivalently, $p = h/\lambda$, so shorter wavelength means larger momentum per photon.

Step 1: Identify what determines photon momentum The question compares individual photons, so wave intensity does not decide the answer. Since h and c are constants, the photon with the greatest frequency, or smallest wavelength, has the greatest momentum.

Step 2: Compare the listed spectral regions X-rays have much shorter wavelengths and higher frequencies than microwaves, TV waves or AM radio waves. Thus the photons in option (A) have greater momentum than those in each of (B), (C) and (D). Increasing the number of radio photons could increase a beam's total momentum, but it would not increase the momentum of each photon.

Step 3: Conclusion X-rays have photons of the largest momentum among the given waves. Hence, the correct option is (A).

Quick Tip to Solve: For momentum per photon, pick the shortest wavelength in the list; do not compare beam intensity.

10. A compound microscope has an objective and an eyepiece of focal lengths f_o and f_e , respectively. To obtain a large magnification of a small object, the microscope should have:

[1 mark]

- (A) f_o and f_e small, and $f_e > f_o$
- (B) f_o and f_e small, and $f_o > f_e$
- (C) f_o and f_e large, and $f_e > f_o$
- (D) f_o and f_e large, and $f_o > f_e$

Correct Answer: (A) f_o and f_e small, and $f_e > f_o$

Solution:

Concept:

- A compound microscope first forms a magnified real image with the objective and then magnifies that image angularly using the eyepiece.
- For normal adjustment, the magnitude of magnifying power is approximately $M = (L/f_o)(D/f_e)$, where L is tube length, D is the least distance of distinct vision and f_o, f_e are objective and eyepiece focal lengths.

Step 1: Choose focal lengths that increase magnification For fixed L and D , the product $f_o f_e$ occurs in the denominator. Both lenses should therefore have small focal lengths. Large focal lengths, as in (C) and (D), reduce the microscope's magnifying power.

Step 2: Apply the standard microscope arrangement The objective is the shorter-focal-length lens, placed close to the small object to produce a strongly enlarged intermediate image. The eyepiece also has a short focal length, but one greater than the objective's: $f_e > f_o$. Thus (B) reverses the usual objective-eyepiece relation, while (A) combines the required small focal lengths and correct order.

Step 3: Conclusion Both f_o and f_e should be small, with $f_e > f_o$. Hence, the correct option is (A).

Quick Tip to Solve: Remember the compound microscope objective has the shortest focal length; both lenses must be short-focus.

11. Two coherent light waves, each having amplitude 'a', superpose to produce an interference pattern on a screen. The intensity of light as seen on the screen varies between: [1 mark]

- (A) 0 and $2a^2$
- (B) 0 and $4a^2$
- (C) a^2 and $2a^2$
- (D) $2a^2$ and $4a^2$

Correct Answer: (B) 0 and $4a^2$

Solution:

Concept:

- Coherent waves have a constant phase relationship. Their displacement amplitudes add before the resultant intensity is calculated.
- For amplitudes a_1, a_2 and phase difference ϕ , intensity in the amplitude-squared convention is $I = a_1^2 + a_2^2 + 2a_1a_2 \cos \phi$.

Step 1: Substitute the equal amplitudes With $a_1 = a_2 = a$, the intensity at a point is

$$I = 2a^2(1 + \cos \phi).$$

The phase difference varies with position on the screen, producing alternate maxima and minima.

Step 2: Evaluate the two limiting phase differences For destructive interference, $\cos \phi = -1$, so $I_{\min} = 0$. For constructive interference, $\cos \phi = 1$, so $I_{\max} = 4a^2$. Option (A) incorrectly treats $2a^2$, the sum of the individual intensities, as the maximum. Options (C) and (D) omit complete cancellation, which is possible because the amplitudes are equal.

Step 3: Conclusion The intensity varies between 0 and $4a^2$, in the convention used by the options. Hence, the correct option is (B).

Quick Tip to Solve: Square the extreme resultant amplitudes: $(a - a)^2 = 0$ and $(a + a)^2 = 4a^2$.

12. The kinetic energy of an alpha particle is four times the kinetic energy of a proton. The ratio $\frac{\lambda_\alpha}{\lambda_p}$ of de Broglie wavelengths associated with them will be: [1 mark]

- (A) $\frac{1}{16}$
- (B) $\frac{1}{8}$
- (C) $\frac{1}{4}$
- (D) $\frac{1}{2}$

Correct Answer: (C) $\frac{1}{4}$

Solution:

Concept:

- For a nonrelativistic particle of mass m and kinetic energy K , momentum is $p = \sqrt{2mK}$ and de Broglie wavelength is $\lambda = h/\sqrt{2mK}$.
- An alpha particle contains two protons and two neutrons, so its mass is approximately four times the proton mass: $m_\alpha = 4m_p$.

Step 1: Form the wavelength ratio before substitution The factors h and 2 cancel in the ratio, giving

$$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p K_p}{m_\alpha K_\alpha}}.$$

The heavier particle and its larger kinetic energy both increase momentum and decrease wavelength.

Step 2: Include both factors of four The question gives $K_\alpha = 4K_p$, while $m_\alpha = 4m_p$. Thus

$$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{1}{4 \times 4}} = \frac{1}{4}.$$

Option (A) omits the square root of the product. Option (D) includes only one factor of four, and (B) has no basis in the mass and energy ratios given.

Step 3: Conclusion The wavelength ratio is $\lambda_\alpha/\lambda_p = 1/4$. Hence, the correct option is (C).

Quick Tip to Solve: Use $\lambda \propto (mK)^{-1/2}$: multiply the mass ratio by the energy ratio before taking the square root.

13. Assertion (A): The impurities in p-type Si are not pentavalent atoms.

Reason (R): The hole density in valance band in p-type semiconductor is almost equal to the acceptor density. [1 mark]

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

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

Solution:

Concept:

- Trivalent acceptor impurities create holes in silicon and produce p-type material; pentavalent donor impurities supply extra electrons and produce n-type material.
- For a p-type sample with ionised acceptors of density N_A , negligible donor compensation and negligible minority-electron density, the hole density is approximately $p = N_A$.

Step 1: Evaluate the assertion Assertion (A) is true. Silicon has four valence electrons, whereas a trivalent dopant has only three. The missing bonding electron creates a hole. A pentavalent dopant instead supplies an extra electron and therefore does not serve as the acceptor impurity used to make p-type silicon.

Step 2: Evaluate the reason Reason (R) is true in the usual extrinsic-semiconductor approximation. Each ionised acceptor corresponds to one hole, and charge neutrality gives $p = n + N_A$. Since the minority-electron density n is very small, $p \simeq N_A$.

Step 3: Check the explanatory connection The reason states the approximate number of holes after acceptor doping. It does not explain why the dopant is not pentavalent: that requires comparing the impurity's valence electrons with silicon's four valence electrons. Thus both statements are true, but R is not the correct explanation of A. This excludes (A), while the truth of R excludes (C) and (D).

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

Quick Tip to Solve: Separate dopant valency from carrier counting: trivalent versus pentavalent explains type; $p \simeq N_A$ counts holes.

14. Assertion (A): During formation of a nucleus, the mass defect produced is the source of the binding energy of the nucleus.

Reason (R): For all nuclei, the value of binding energy per nucleon increases with mass number.

[1 mark]

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

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

Solution:

Concept:

- The mass defect of a nucleus is $\Delta m = Zm_p + (A - Z)m_n - M$, where Z and A are its atomic and mass numbers and M is its nuclear mass.
- Binding energy is $B = \Delta mc^2$. Binding energy per nucleon, B/A , measures the average energy needed to remove nucleons and does not increase monotonically with A .

Step 1: Evaluate the assertion using mass-energy equivalence A bound nucleus has less mass than its separated constituent protons and neutrons. The decrease in rest energy, Δmc^2 , is released when the nucleus forms and equals the energy required to separate it completely. Hence the mass defect accounts for the binding energy, so Assertion (A) is true.

Step 2: Test the reason against the binding-energy curve Binding energy per nucleon rises rapidly for light nuclei and reaches its broad maximum near the iron-nickel region, around mass number 56 to 62. It then decreases gradually for heavier nuclei. Consequently, the claim that it increases with mass number for all nuclei is false.

Step 3: Apply the assertion-reason code A false reason cannot explain a true assertion. Both (A) and (B) require R to be true, and (D) requires A to be false, so all three are excluded. The mass-energy explanation of binding energy remains valid irrespective of the non-monotonic variation of binding energy per nucleon.

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

Quick Tip to Solve: Check the word 'all': the binding-energy-per-nucleon curve falls beyond the iron-nickel region.

15. Assertion (A): The Balmer series in hydrogen atom spectrum is formed when the electron jumps from higher energy state to the ground state.

Reason (R): In Bohr's model of hydrogen atom, the electron can jump between successive orbits only. [1 mark]

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

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

Solution:

Concept:

- A hydrogen spectral series is identified by its final principal quantum number n_f : Lyman ends at $n_f = 1$, while Balmer ends at $n_f = 2$.
- A transition emits a photon of energy $h\nu = E_i - E_f$. The initial and final allowed Bohr orbits need not be adjacent.

Step 1: Evaluate the assertion Balmer lines arise from transitions $n_i = 3, 4, 5, \dots$ to $n_f = 2$, the first excited state. Transitions to the ground state $n_f = 1$ belong to the Lyman series. Therefore Assertion (A) is false.

Step 2: Evaluate the reason Bohr's frequency condition requires the photon energy to equal the energy difference between the two stationary states. It does not require successive orbits: for example, the Balmer transition $n = 4 \rightarrow n = 2$ skips an orbit. Therefore Reason (R) is false.

Step 3: Check the explanation and options Since both statements are false, the reason cannot explain the assertion. Options (A) and (B) incorrectly declare both statements true, and option (C) incorrectly declares the assertion true.

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

Quick Tip to Solve: Identify a hydrogen series by its ending orbit: ground state means Lyman, while Balmer ends at $n = 2$.

16. Assertion (A): In Rutherford's alpha particle scattering experiment, the presence of only few alpha particles at angle of scattering π led him to the discovery of nucleus.

Reason (R): The size of nucleus is approximately 10^{-5} times the size of an atom and therefore only few alpha particles are rebounded. [1 mark]

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

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

Solution:

Concept:

- Rutherford scattering is due to electrostatic repulsion between positively charged alpha particles and the concentrated positive charge of a nucleus.
- The nuclear radius is of order 10^{-15} m, compared with an atomic radius of order 10^{-10} m, giving a size ratio of about 10^{-5} .

Step 1: Evaluate the assertion An alpha particle scattered through π radians reverses its direction. Such rare, nearly head-on encounters showed that a very strong repulsive electric field and most of the atomic mass are concentrated in a tiny central region. This led to the nuclear model, so Assertion (A) is true.

Step 2: Evaluate the reason The printed ratio 10^{-5} is the approximate ratio of nuclear to atomic linear sizes. The nucleus occupies a very small region of the atom, so only a few incident particles approach its centre closely enough to undergo backward scattering. Most pass through with little or no deflection. Reason (R) is true.

Step 3: Test the explanatory link The tiny spatial extent of the concentrated positive charge explains why rebounds are rare. Thus the reason explains the observation in the assertion. Option (B) denies this link, while options (C) and (D) incorrectly reject the reason.

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

Quick Tip to Solve: Link the rarity of backscattering to the tiny nucleus; link the large deflection to its concentrated positive charge.

Section B (10 marks)

17. The threshold frequency for a given metal is 3.6×10^{14} Hz. If monochromatic radiations of frequency 6.8×10^{14} Hz are incident on this metal, find the cut-off potential for the photoelectrons.

[2 marks]

Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi = h(\nu - \nu_0)$, where ν_0 is the threshold frequency and $\phi = h\nu_0$ is the work function.
- The magnitude of the cut-off or stopping potential V_0 obeys $eV_0 = K_{\max}$, since the retarding field just stops the fastest emitted electrons.

Step 1: Find the frequency above threshold The incident frequency exceeds the threshold frequency, so photoemission occurs. Only the energy above the work function is available as kinetic energy:

$$\nu - \nu_0 = (6.8 - 3.6) \times 10^{14} = 3.2 \times 10^{14} \text{ Hz.}$$

Step 2: Calculate the stopping potential Using $h = 6.63 \times 10^{-34}$ J s and $e = 1.6 \times 10^{-19}$ C,

$$\begin{aligned} K_{\max} &= (6.63 \times 10^{-34})(3.2 \times 10^{14}) \\ &= 2.1216 \times 10^{-19} \text{ J,} \\ V_0 &= \frac{2.1216 \times 10^{-19}}{1.6 \times 10^{-19}} = 1.326 \text{ V.} \end{aligned}$$

The collector is made negative relative to the emitting metal to oppose the motion of the photoelectrons; the quoted stopping potential is its magnitude.

Step 3: Conclusion The cut-off potential has magnitude $V_0 \simeq 1.33$ V, corresponding to a collector potential of approximately -1.33 V relative to the emitter.

Quick Tip to Solve: Subtract the threshold frequency before multiplying by h/e ; the full photon energy is not the emitted electron's kinetic energy.

18(a). A point object is placed in air at a distance $R/3$ in front of a convex surface of radius of curvature R , separating air from a medium of refractive index n (< 4). Find the nature and position of the image formed.

[2 marks]

Solution:

Concept:

- For paraxial refraction at a spherical surface, $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$, where distances are measured from the pole.
- Use the Cartesian convention: distances along the incident light are positive. A negative image distance represents a virtual image on the incident side of the surface.

Step 1: Assign the signed distances Let light travel from the object in air towards the medium. The object is in front of the surface, so $u = -R/3$. The surface is convex as seen from the object, placing its centre of curvature inside the second medium and giving a positive radius $+R$. The refractive

indices are $n_1 = 1$ and $n_2 = n$.

Step 2: Substitute in the refraction formula With these signed quantities,

$$\begin{aligned}\frac{n}{v} - \frac{1}{-R/3} &= \frac{n-1}{R}, \\ \frac{n}{v} + \frac{3}{R} &= \frac{n-1}{R}, \\ \frac{n}{v} &= \frac{n-4}{R}, \\ v &= \frac{nR}{n-4} = -\frac{nR}{4-n}.\end{aligned}$$

Since the given ordinary refractive index is positive and less than 4, $v < 0$. The refracted rays diverge and their backward extensions meet on the air side. Also, the lateral magnification is $m = n_1 v / (n_2 u) = 3 / (4 - n) > 0$, so the image is erect.

Step 3: Conclusion The image is virtual and erect, on the air side at a distance $\frac{nR}{4-n}$ in front of the surface; its signed position is $v = -\frac{nR}{4-n}$.

Quick Tip to Solve: For a convex refracting surface use $R > 0$ but keep the real object's distance negative; the sign of v then gives the image's nature.

OR

18(b). In Young's double slit experimental set-up, the intensity of the central maximum is I_0 . Calculate the intensity at a point where the path difference between two interfering waves is $\lambda/3$. [2 marks]

Solution:

Concept:

- In the usual Young's double slit arrangement, the two coherent waves have equal individual intensity I_s . Their resultant intensity is $I_P = 2I_s(1 + \cos \phi) = 4I_s \cos^2(\phi/2)$.
- A path difference Δ corresponds to phase difference $\phi = 2\pi\Delta/\lambda$, where λ is the wavelength. At the central maximum $\Delta = 0$, so the given intensity is $I_0 = 4I_s$.

Step 1: Convert path difference to phase difference The specified path difference is one-third of a wavelength. The phase difference between the waves reaching this point is therefore

$$\phi = \frac{2\pi}{\lambda} \left(\frac{\lambda}{3} \right) = \frac{2\pi}{3}.$$

This lies between a central bright fringe, where the phase difference is zero, and the first dark fringe, where it is π .

Step 2: Express the intensity using the central maximum Eliminate the single-slit intensity by using

$4I_s = I_0$. The required intensity is

$$\begin{aligned} I_P &= I_0 \cos^2 \left(\frac{\phi}{2} \right) \\ &= I_0 \cos^2 \left(\frac{\pi}{3} \right) \\ &= I_0 \left(\frac{1}{2} \right)^2. \end{aligned}$$

The amplitude factor is squared because intensity is proportional to the square of resultant amplitude, not to amplitude itself.

Step 3: Conclusion The intensity at path difference $\lambda/3$ is $I_P = I_0/4$, one-quarter of the central maximum intensity.

Quick Tip to Solve: When the maximum intensity is given, use $I_P/I_0 = \cos^2(\pi\Delta/\lambda)$ directly and remember to square the cosine.

19. A voltmeter of resistance 1000Ω can measure up to 25 V. How will you convert it so that it can read up to 250 V? [2 marks]

Solution:

Concept:

- A voltmeter reaches its maximum reading when its full-scale current I_v flows through its internal resistance R_v : $V_v = I_v R_v$.
- To increase the voltage range, connect a high resistance R_s in series, so the same full-scale current flows at the new maximum voltage V : $V = I_v(R_v + R_s)$.

Step 1: Find the full-scale current of the original meter The meter has $R_v = 1000 \Omega$ and reads its maximum value at $V_v = 25 \text{ V}$. Therefore,

$$I_v = \frac{25}{1000} = 0.025 \text{ A}.$$

The range must be increased without making the current through the meter exceed this value.

Step 2: Calculate the required series resistance At the new full-scale voltage of 250 V, the total resistance must be

$$R_v + R_s = \frac{250}{0.025} = 10000 \Omega.$$

The voltmeter already supplies 1000Ω , so the external resistance is

$$R_s = 10000 - 1000 = 9000 \Omega.$$

This series resistor drops 225 V at full scale, leaving 25 V across the original meter. Calibrate the combined instrument's scale for the new range; each old reading is multiplied by ten.

Step 3: Conclusion Connect a $9000 \Omega = 9 \text{ k}\Omega$ resistance in series with the voltmeter and multiply its original scale readings by 10. The combined instrument measures up to 250 V.

Quick Tip to Solve: For an n -fold voltage range, add $(n - 1)R_v$ in series: here $(10 - 1) \times 1000 = 9000 \Omega$.

20. When a neutron collides with ${}^{235}_{92}\text{U}$, the nucleus gives ${}^{140}_{54}\text{Xe}$ and ${}^{94}_{38}\text{Sr}$ as fission products and two neutrons are ejected. Calculate the mass defect and the energy released (in MeV) in the process. Given:

$$m({}^{235}_{92}\text{U}) = 235.04393 \text{ u}, m({}^{140}_{54}\text{Xe}) = 139.92164 \text{ u}$$

$$m({}^{94}_{38}\text{Sr}) = 93.91536 \text{ u}, m_n = 1.00866 \text{ u}$$

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

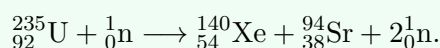
[2 marks]

Solution:

Concept:

- The mass defect in a reaction is the total initial rest mass minus the total final rest mass: $\Delta m = m_i - m_f$.
- A positive mass defect releases energy $Q = \Delta mc^2$. The given conversion is $1 \text{ u } c^2 = 931 \text{ MeV}$.

Step 1: Write the balanced fission reaction Include the incident neutron among the reactants and both emitted neutrons among the products:



The mass numbers balance as $235 + 1 = 140 + 94 + 2 = 236$, and the atomic numbers balance as $92 = 54 + 38$. If the supplied masses are atomic masses, the electron masses cancel because the total atomic number is unchanged.

Step 2: Evaluate the initial and final masses Using all the supplied values in atomic mass units,

$$m_i = 235.04393 + 1.00866 = 236.05259 \text{ u},$$

$$m_f = 139.92164 + 93.91536 + 2(1.00866)$$

$$= 235.85432 \text{ u},$$

$$\Delta m = 236.05259 - 235.85432 = 0.19827 \text{ u}.$$

The products have less rest mass; this difference is converted into energy.

Step 3: Convert the mass defect into energy Multiply the mass defect by the stated mass-energy conversion factor:

$$Q = 0.19827 \times 931 = 184.58937 \text{ MeV}.$$

This is the energy released per fission event, rather than per mole of uranium.

Step 4: Conclusion The mass defect is $\boxed{0.19827 \text{ u}}$, and the energy released is $\boxed{184.59 \text{ MeV}}$ per fission.

Quick Tip to Solve: Count neutrons on both sides before subtracting masses: one enters and two leave, so one neutron mass remains in the net final-mass subtraction.

21. The resistance of a wire at 25°C is $10.0\ \Omega$. When heated to 125°C , its resistance becomes $10.5\ \Omega$. Find (i) the temperature coefficient of resistance of the wire, and (ii) the resistance of the wire at 425°C . [2 marks]

Solution:

Concept:

- For linear temperature dependence, $R_T = R_{\text{ref}}[1 + \alpha_{\text{ref}}(T - T_{\text{ref}})]$, where α_{ref} is the fractional resistance increase per degree relative to the chosen reference resistance.
- Here take the given 25°C state as the reference: $R_{25} = 10.0\ \Omega$. A temperature interval of 1°C equals $1\ \text{K}$.

Step 1: Calculate the temperature coefficient The resistance increases by $10.5 - 10.0 = 0.5\ \Omega$ over $125 - 25 = 100^{\circ}\text{C}$. Thus the coefficient referred to 25°C is

$$\alpha_{25} = \frac{R_{125} - R_{25}}{R_{25}(125 - 25)} = \frac{0.5}{10.0 \times 100} = 5.0 \times 10^{-4}\ \text{K}^{-1}.$$

Its positive sign means the resistance rises with temperature. The corresponding resistance slope is $0.005\ \Omega\ \text{K}^{-1}$.

Step 2: Extrapolate to the requested temperature Assuming the same linear law remains valid, the temperature increase from the reference state is $425 - 25 = 400^{\circ}\text{C}$. Therefore,

$$\begin{aligned} R_{425} &= 10.0 [1 + (5.0 \times 10^{-4})(400)] \\ &= 10.0(1.20) = 12.0\ \Omega. \end{aligned}$$

The rise is four times the original 100°C interval, so the resistance increase is four times $0.5\ \Omega$, independently confirming the calculation.

Step 3: Conclusion (i) The temperature coefficient referred to the given initial temperature is $\alpha_{25} = 5.0 \times 10^{-4}\ \text{K}^{-1}$. (ii) The resistance at 425°C is $12.0\ \Omega$.

Quick Tip to Solve: Keep the reference temperature with its resistance: using $10.0\ \Omega$ means subtracting 25°C from every final temperature.

Section C (21 marks)

22. (a) Draw the energy-band diagrams for conductors, semiconductors and insulators at $T = 0\ \text{K}$. How is an electron-hole pair formed in a semiconductor at room temperature?

(b) Carbon and silicon both, are members of IV group of periodic table and have the same lattice structure. Carbon is an insulator whereas silicon is a semiconductor. Explain. [3 marks]

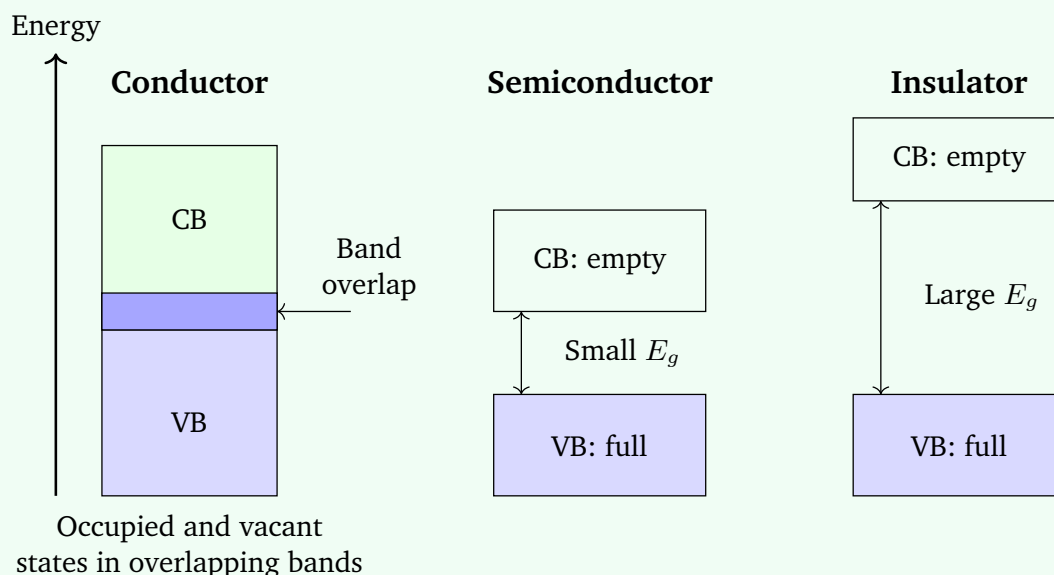
Solution:

Concept:

- The valence band (VB) contains the outer-electron states; the conduction band (CB) contains higher states in which mobile electrons can conduct. The forbidden energy gap is $E_g = E_C - E_V$.
- At $0\ \text{K}$, an intrinsic semiconductor or insulator has a full VB and an empty CB. A conductor has a partially filled band or overlapping valence and conduction bands, with accessible vacant states.

Step 1: Draw and compare the bands at zero temperature (a) The diagrams below show a conductor

with overlapping bands, a semiconductor with a small forbidden gap, and an insulator with a large gap. The energy axis points upward. In the conductor there is no forbidden gap separating the relevant occupied and vacant states. In the other two materials, thermal excitation is absent at 0 K, so the CB is empty and the VB is full; neither has thermally generated mobile carriers at this temperature. The different gap widths control their behaviour when heated.



Schematic energy bands at $T = 0\text{ K}$; the gap widths are qualitative.

Step 2: Explain electron-hole pair formation At room temperature, some valence electrons in a semiconductor acquire sufficient thermal energy to cross its small forbidden gap. An electron promoted into the CB can move through the crystal. Its departure leaves a vacancy in the VB, called a hole, which behaves as a positive charge carrier. Thus every excitation creates one conduction electron and one hole simultaneously. In an intrinsic semiconductor, the generated electron and hole concentrations are equal.

Step 3: Compare carbon and silicon (b) Carbon here means diamond, the form having the stated lattice structure. Although diamond and silicon both have four valence electrons per atom, their band gaps differ because their bonding energies differ. Diamond has a large gap, about 5.5 eV, so room-temperature thermal excitation produces a negligible carrier population and it is an insulator. Silicon has a much smaller gap, about 1.1 eV, so an appreciable number of electron-hole pairs can be thermally generated and it is a semiconductor. Equal valence-electron counts and similar crystal structures therefore do not imply equal electrical conductivity.

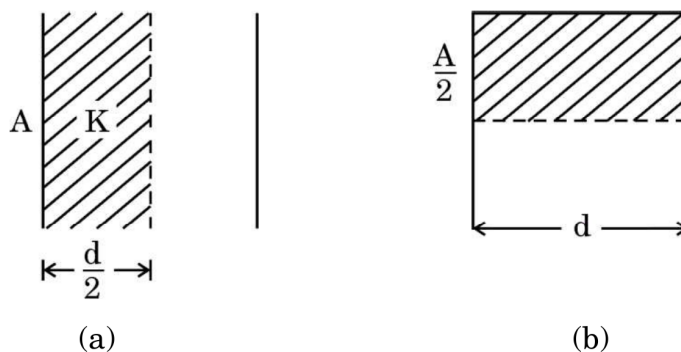
Step 4: Conclusion Conductors have accessible vacant states without a forbidden gap; semiconductors have a small gap and insulators a large gap. Thermal promotion from VB to CB creates an electron-hole pair. Diamond's much larger gap explains why it is insulating while silicon is semiconducting.

Quick Tip to Solve: In a band sketch, show a full VB and empty CB at 0 K, then compare the gap widths; use diamond, rather than graphite, for the stated carbon lattice.

23. A parallel plate capacitor has plate area A and plate separation d . Half of the space between the plates is filled with a material of dielectric constant K in two ways as shown in the figure.

Find the values of the capacitance of the capacitors in the two cases.

[3 marks]



Solution:

Concept:

- A parallel-plate capacitor completely filled with a dielectric has capacitance $C = K\epsilon_0 A/d$, where K is relative permittivity and ϵ_0 is the permittivity of free space. Edge effects are neglected.
- Regions one after another along the electric field act in series: $1/C = 1/C_1 + 1/C_2$. Regions side by side across the plate area have the same potential difference and act in parallel: $C = C_1 + C_2$.

Step 1: Identify the series layers in case (a) The dielectric covers the whole area A , but occupies only thickness $d/2$. The remaining thickness $d/2$ is air. Field lines pass successively through both layers, so their potential drops add for the same charge. The equivalent layer capacitances are

$$C_K = \frac{K\epsilon_0 A}{d/2} = \frac{2K\epsilon_0 A}{d}, \quad C_{\text{air}} = \frac{\epsilon_0 A}{d/2} = \frac{2\epsilon_0 A}{d}.$$

Hence the reciprocal of the total capacitance is

$$\frac{1}{C_a} = \frac{d}{2K\epsilon_0 A} + \frac{d}{2\epsilon_0 A} = \frac{d(K+1)}{2K\epsilon_0 A}.$$

Step 2: Identify the parallel regions in case (b) Here the dielectric spans the entire separation d , but covers only plate area $A/2$. The other area $A/2$ has air between the plates. Both regions connect the same plates and therefore have equal potential difference; their charges add. Thus

$$C'_K = \frac{K\epsilon_0 (A/2)}{d}, \quad C'_{\text{air}} = \frac{\epsilon_0 (A/2)}{d}, \quad C_b = C'_K + C'_{\text{air}}.$$

As a consistency check, setting $K = 1$ makes both arrangements the original air capacitor of capacitance $\epsilon_0 A/d$.

Step 3: Conclusion The capacitances in the two printed arrangements are

$$C_a = \frac{2K\epsilon_0 A}{(K+1)d}, \quad C_b = \frac{(K+1)\epsilon_0 A}{2d}.$$

Quick Tip to Solve: Follow a field line between the plates: crossing both media means series layers; separate areas joining the same plates mean parallel regions.

24. In Young's double slit experiment, the separation between the two slits is 1.0 mm and the screen is 1.0 m away from the slits. A beam of light consisting of two wavelengths 500 nm and 600 nm is used to obtain interference fringes. Calculate:

(a) the distance between the first maxima for the two wavelengths.

(b) the least distance from the central maximum, where the bright fringes due to both the wavelengths coincide. [3 marks]

Solution:

Concept:

- In Young's double-slit experiment, a bright fringe occurs when the path difference is $n\lambda$, where n is an integer. Its position from the central maximum is $y_n = n\lambda D/d$, with screen distance D and slit separation d .
- Bright fringes of two wavelengths coincide when $n_1\lambda_1 = n_2\lambda_2$. The least nonzero common position is obtained from the smallest positive integer orders satisfying this relation.

Step 1: Convert the given quantities to SI units Use $D = 1.0$ m, $d = 1.0 \times 10^{-3}$ m, $\lambda_1 = 500 \times 10^{-9}$ m and $\lambda_2 = 600 \times 10^{-9}$ m. The central maxima of both colours are at zero path difference, so their fringe positions are measured from the same origin.

Step 2: Find the first bright fringe for each wavelength For part (a), take $n = 1$ and compare fringes on the same side of the central maximum:

$$y_1 = \frac{500 \times 10^{-9} \times 1.0}{1.0 \times 10^{-3}} = 5.0 \times 10^{-4} \text{ m} = 0.50 \text{ mm},$$

$$y_2 = \frac{600 \times 10^{-9} \times 1.0}{1.0 \times 10^{-3}} = 6.0 \times 10^{-4} \text{ m} = 0.60 \text{ mm}.$$

Their separation is the difference $y_2 - y_1 = (0.60 - 0.50)$ mm, since the longer wavelength has the more distant first maximum.

Step 3: Determine the first noncentral coincidence For part (b), let the orders of the coincident fringes be n_1 and n_2 . Cancelling the common factor D/d gives

$$500n_1 = 600n_2 \Rightarrow 5n_1 = 6n_2.$$

Since 5 and 6 have no common factor, the smallest positive solution is $n_1 = 6$, $n_2 = 5$. Thus the sixth bright fringe of the 500 nm light coincides with the fifth bright fringe of the 600 nm light:

$$y = \frac{6(500 \times 10^{-9})(1.0)}{1.0 \times 10^{-3}} = 3.0 \times 10^{-3} \text{ m}.$$

The zero-order coincidence is the central maximum itself and is excluded when finding the next common bright fringe.

Step 4: Conclusion (a) The first maxima are separated by 0.10 mm. (b) The least nonzero distance of coincidence is 3.0 mm from the central maximum, on either side.

Quick Tip to Solve: Reduce the wavelength ratio 500 : 600 to 5 : 6; the first coincident fringe orders are the reversed ratio 6 : 5.

25. Differentiate between half-wave and full-wave rectification. With the help of a circuit diagram, explain the working of a full-wave rectifier. [3 marks]

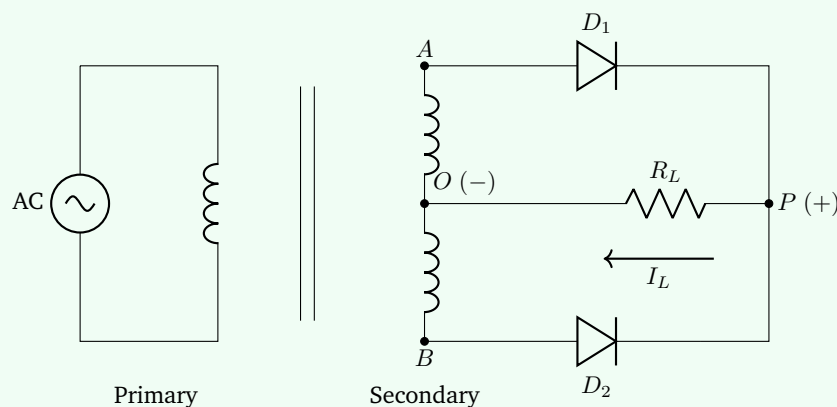
Solution:

Concept:

- A junction diode conducts when forward biased and blocks current when reverse biased. Rectification uses this property to convert alternating current into unidirectional, pulsating current.
- A centre-tapped full-wave rectifier uses two diodes that conduct alternately. If the input frequency is f , the output pulse frequency is $2f$, since each input half-cycle produces a load-current pulse.

Step 1: Compare half-wave and full-wave rectification Half-wave rectification uses one input half-cycle; load current is zero during the other. Its basic circuit has one diode and output pulse frequency f . Full-wave rectification uses both half-cycles with the same load-current direction. Its pulse frequency is $2f$, giving smaller ripple and easier smoothing. The centre-tapped circuit has two diodes.

Step 2: Connect the centre-tapped full-wave circuit Connect the anodes of D_1 and D_2 to the ends A and B of the transformer secondary. Join their cathodes at P . Connect the load R_L between P and the centre tap O . The secondary end voltages relative to O are opposite in phase.



Centre-tapped full-wave rectifier; load current flows from P to O in both half-cycles.

Step 3: Follow the current during each half-cycle When A is positive and B negative relative to O , diode D_1 is forward biased while D_2 is reverse biased. Current flows along

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

and returns through the upper half of the secondary winding. In the next half-cycle, B is positive and A negative relative to O . Now D_2 conducts and D_1 blocks. The path is

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

returning through the lower secondary half. The load-current direction remains the same.

Step 4: Conclusion The full-wave circuit produces two unidirectional pulses per input cycle, with P positive relative to O . Its output is pulsating DC; a filter is needed for smoothing.

Quick Tip to Solve: Trace each conducting loop from the positive secondary end: both must cross the load from the joined cathodes P to the centre tap O .

26. An electron of mass m and charge $-e$ is revolving anticlockwise around the nucleus of an atom.

(a) Obtain the expression for the magnetic dipole moment ($\vec{\mu}$) of the atom.

(b) If $\vec{L}$ is the angular momentum of electron, show that $\vec{\mu} = -\left(\frac{e}{2m}\right)\vec{L}$.

[3 marks]

Solution:

Concept:

- A charge completing a circular orbit of radius r in time T constitutes a current of magnitude $I = e/T$, where e is the positive magnitude of the electron charge.
- The magnetic moment of a planar current loop is $\vec{\mu} = I\vec{A}$, with area magnitude $A = \pi r^2$. Its direction follows the right-hand rule for conventional current.
- The orbital angular momentum of an electron moving at speed v is $\vec{L} = \vec{r} \times m\vec{v}$, of magnitude mvr .

Step 1: (a) Calculate the equivalent orbital current For a circular orbit, the electron travels a distance $2\pi r$ during one revolution. Thus its period and the magnitude of the associated conventional current are

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

The electron moves anticlockwise as viewed in the question. Because its charge is negative, the conventional current circulates clockwise, opposite to its velocity.

Step 2: (a) Obtain the magnitude and direction of the magnetic moment Multiplying the equivalent current by the area enclosed by the orbit gives

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

Let $\hat{n}$ point out of the orbital plane towards the observer viewing the anticlockwise motion. The clockwise conventional current gives a magnetic moment into that plane, so $\vec{\mu} = -(evr/2)\hat{n}$. This is the orbital magnetic dipole moment associated with the revolving electron.

Step 3: (b) Relate the moment to the angular momentum Applying the right-hand rule to the electron's anticlockwise motion gives $\vec{L} = mvr\hat{n}$, directed out of the orbital plane. Eliminating vr between the moment and angular-momentum expressions yields

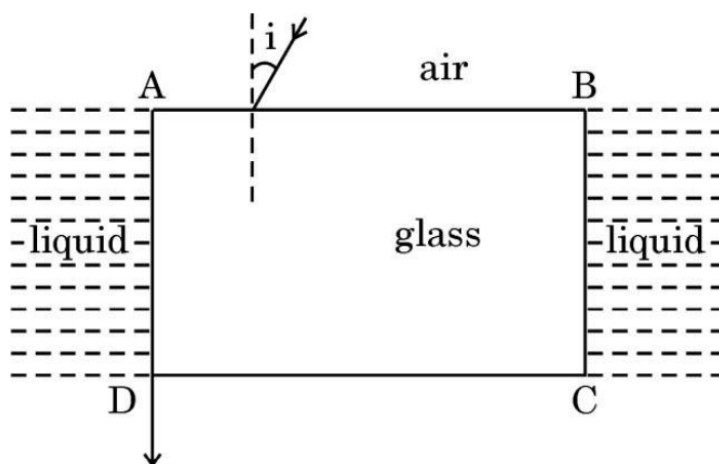
$$\vec{\mu} = -\frac{e}{2m} (mvr\hat{n}) = -\frac{e}{2m} \vec{L}.$$

The minus sign is essential: angular momentum follows the motion of the electron, whereas the magnetic moment follows the opposite conventional-current direction.

Step 4: Conclusion The orbital magnetic moment has magnitude $\mu = evr/2 = eL/(2m)$, in A m^2 , and is directed into the plane for the stated anticlockwise electron motion. Therefore $\boxed{\vec{\mu} = -(e/2m)\vec{L}}$.

Quick Tip to Solve: First reverse the electron's circulation to find conventional current; the magnetic moment is always antiparallel to the electron's orbital angular momentum.

27. A rectangular glass slab $ABCD$ (refractive index 1.5) is surrounded by a transparent liquid (refractive index 1.25) as shown in the figure. A ray of light is incident on face AB at an angle i such that it is refracted out grazing the face AD . Find the value of angle i . [3 marks]



Solution:

Concept:

- Snell's law is $n_1 \sin \theta_1 = n_2 \sin \theta_2$, with angles measured from the surface normal.
- At the critical angle c inside glass, the refracted ray in the less dense liquid grazes the surface: $\sin c = n_\ell / n_g$, where $n_g = 1.5$ and $n_\ell = 1.25$.
- Perpendicular faces have perpendicular normals: the internal angles at AB and AD add to 90° .

Step 1: Identify the media at the two faces The figure labels air above AB and liquid outside AD . Hence the ray enters from air $n_a = 1$ into glass at AB , then exits from glass into liquid at AD . Use the index of the medium adjoining each face.

Step 2: Apply the grazing-emergence condition at face AD Grazing emergence means that the angle of refraction in liquid is 90° . The incidence angle in glass at AD is therefore the critical angle c :

$$1.5 \sin c = 1.25 \sin 90^\circ, \quad \sin c = \frac{5}{6}.$$

The internal ray has angle $r = 90^\circ - c$ to the normal at AB . Since c is acute,

$$\sin r = \cos c = \sqrt{1 - \frac{25}{36}} = \frac{\sqrt{11}}{6}.$$

Step 3: Apply Snell's law at the air-glass face At the upper face AB , Snell's law gives

$$n_a \sin i = n_g \sin r, \quad \sin i = 1.5 \frac{\sqrt{11}}{6} = \frac{\sqrt{11}}{4}.$$

Step 4: Conclusion The required incidence angle is $i = \sin^{-1}(\sqrt{11}/4) \simeq 56.0^\circ$, measured from the normal to AB .

Quick Tip to Solve: Read the medium labels at each face: here entry is from air, while grazing exit is into liquid. Use the perpendicular normals to replace $\sin r$ by $\cos c$.

28(a). Two small solid metal balls A and B of radii R and $2R$ having charge densities 2σ and 3σ respectively are kept far apart. Find the charge densities on A and B after they are connected by a conducting wire.

[3 marks]

Solution:

Concept:

- Excess charge on a solid metal sphere resides on its surface, so the charge density here is surface charge density: $Q = 4\pi r^2 \sigma_s$.
- For a conducting sphere of radius r far from other conductors, its potential is $V = kQ/r$, with $k = 1/(4\pi\epsilon_0)$.
- Connecting the spheres by a conducting wire makes their final potentials equal. Their combined charge is conserved, with charge on the thin connecting wire neglected in the usual idealization.

Step 1: Calculate the initial charges and their sum Sphere A has radius R and surface charge density 2σ , while sphere B has radius $2R$ and surface charge density 3σ . The surface area of B is four times that of A . Hence

$$\begin{aligned} Q_A &= 4\pi R^2(2\sigma) = 8\pi R^2\sigma, \\ Q_B &= 4\pi(2R)^2(3\sigma) = 48\pi R^2\sigma, \\ Q_{\text{total}} &= 56\pi R^2\sigma. \end{aligned}$$

Connecting the spheres redistributes this total charge; it does not create or remove net charge from the pair.

Step 2: Use equality of the final potentials Denote the final charges by q_A and q_B . Since the spheres are far apart, mutual-potential corrections are negligible. Charge flows through the wire until

$$\frac{kq_A}{R} = \frac{kq_B}{2R} \Rightarrow q_B = 2q_A.$$

Combining this ratio with conservation gives

$$3q_A = 56\pi R^2\sigma, \quad q_A = \frac{56}{3}\pi R^2\sigma, \quad q_B = \frac{112}{3}\pi R^2\sigma.$$

The equilibrium condition is equality of potential, not equality of charge or equality of surface charge density.

Step 3: Convert the final charges to surface densities Divide each final charge by the surface area of its own sphere:

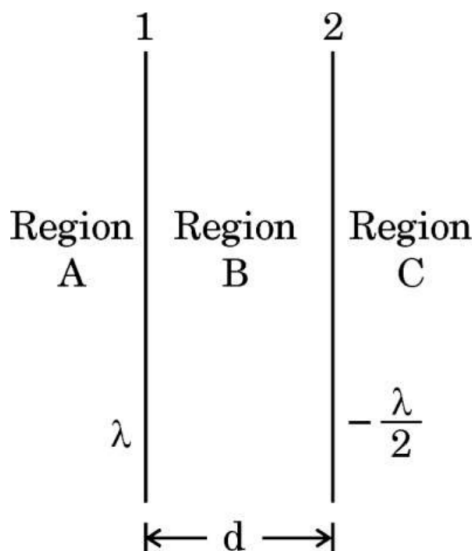
$$\begin{aligned} \sigma'_A &= \frac{q_A}{4\pi R^2} = \frac{14}{3}\sigma, \\ \sigma'_B &= \frac{q_B}{4\pi(2R)^2} = \frac{7}{3}\sigma. \end{aligned}$$

As a check, the final density on the smaller sphere is twice that on the larger sphere. This is consistent with $V = 4\pi k r \sigma_s$: equal potentials require $r\sigma_s$ to be the same for both spheres.

Step 4: Conclusion After connection, the surface charge densities are $\sigma'_A = 14\sigma/3$ and $\sigma'_B = 7\sigma/3$, respectively.

Quick Tip to Solve: Use charge ratio equal to radius ratio at equal potential; then divide by areas. For radii $R : 2R$, final charges are $1 : 2$ but surface densities are $2 : 1$.

28(b). Two infinitely long straight wires '1' and '2' are placed d distance apart, parallel to each other, as shown in the figure. They are uniformly charged having charge densities λ and $-\frac{\lambda}{2}$ respectively. Locate the position of the point from wire '1' at which the net electric field is zero and identify the region in which it lies. [3 marks]



Solution:

Concept:

- The electric field of an infinite line charge at perpendicular distance r has magnitude $E = |\lambda|/(2\pi\epsilon_0 r)$, where λ is its linear charge density.
- Fields point away from a positive wire and towards a negative wire. Cancellation requires equal magnitudes and opposite directions, so the region must be checked before solving.

Step 1: Exclude the region between the wires Take wire 1 at $x = 0$ and wire 2 at $x = d$, with the positive direction towards wire 2. In region B, both fields point from the positive wire towards the negative wire. They therefore add, and no finite point between the wires can have zero net field.

Step 2: Check the outside region near the stronger wire In region A let the point be a distance r to the left of wire 1. Its distance from wire 2 is $r + d$. Although the fields oppose, their ratio is

$$\frac{E_1}{E_2} = \frac{\lambda/r}{(\lambda/2)/(r+d)} = \frac{2(r+d)}{r} > 2.$$

The field of wire 1 is always stronger here; cancellation is impossible.

Step 3: Equate field magnitudes beyond wire 2 In region C, let $x > d$ be the distance from wire 1. The distances from the wires are x and $x - d$. The first field points right and the second points left. Equating their magnitudes gives

$$\begin{aligned} \frac{\lambda}{2\pi\epsilon_0 x} &= \frac{\lambda/2}{2\pi\epsilon_0(x-d)}, \\ 2(x-d) &= x, \\ x &= 2d. \end{aligned}$$

This satisfies $x > d$. At this position the weaker wire is only distance d away, whereas the stronger wire is distance $2d$ away, compensating exactly for the charge-density ratio.

Step 4: Conclusion The net electric field vanishes in region C, at perpendicular distance $2d$ from wire 1, or distance d beyond wire 2.

Quick Tip to Solve: For unequal opposite line charges, look outside on the side of the smaller charge density and use the inverse-distance field law, not an inverse-square law.

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. A galvanometer is an instrument used to show the direction and strength of the current passing through it. In a galvanometer, a coil placed in a magnetic field experiences a torque and hence gets deflected when a current passes through it. The name is derived from the surname of Italian scientist L. Galvani, who in 1791 discovered that electric current makes a dead frog's leg jerk. A spring attached with the coil provides a counter torque. In equilibrium, the deflecting torque is balanced by the restoring torque of the spring and we have: $NBAI = k\phi$, where N is the total number of turns in the coil, A is the area of cross-section of each turn, B is the radial magnetic field, k is the torsional constant of the spring, ϕ is the angular deflection of the coil. As the current (I_g) which produces full scale deflection in the galvanometer is very small, the galvanometer cannot as such be used to measure current in electric circuits. A small resistance, called shunt, of a suitable value is connected with the galvanometer to convert it into an ammeter of desired range. By using a higher resistance, a galvanometer can also be converted into a voltmeter. [4 marks]

29(i). (i) The value of the current sensitivity of a galvanometer is given by: [1 mark]

- (A) $\frac{k}{NBA}$
(B) $\frac{NBA}{k}$
(C) $\frac{kBA}{N}$
(D) $\frac{kNB}{A}$

Correct Answer: (B) $\frac{NBA}{k}$

Solution:

Concept:

- Current sensitivity S_I is the angular deflection per unit current: $S_I = \phi/I$.
- In the radial magnetic field, equilibrium requires $NBAI = k\phi$, where N is the number of turns, B the field, A the coil area and k the torsional constant.

Step 1: Isolate deflection per unit current Divide the torque-balance equation by kI :

$$\frac{\phi}{I} = \frac{NBA}{k}.$$

A larger magnetic torque per ampere therefore increases the sensitivity, while a stiffer spring decreases it.

Step 2: Compare the printed expressions Option (B) has the required factors and dependencies. Option (A) gives the reciprocal, current per unit deflection. Options (C) and (D) put k in the numerator

and thus incorrectly suggest that a stiffer spring makes the instrument more sensitive.

Step 3: Conclusion The current sensitivity is $S_I = NBA/k$, in rad A^{-1} . Hence, the correct option is (B).

Quick Tip to Solve: Write sensitivity as deflection divided by the quantity measured before rearranging the torque equation.

29(ii). (ii) A galvanometer of resistance $6\ \Omega$ shows full scale deflection for a current of $0.2\ \text{A}$. The value of shunt to be used with this galvanometer to convert it into an ammeter of range $(0 - 5\ \text{A})$ is: [1 mark]

- (A) $0.25\ \Omega$
- (B) $0.30\ \Omega$
- (C) $0.50\ \Omega$
- (D) $6.0\ \Omega$

Correct Answer: (A) $0.25\ \Omega$

Solution:

Concept:

- A low resistance shunt S is connected in parallel with a galvanometer of resistance G , so both branches have the same potential difference.
- At full scale the galvanometer carries I_g , while the shunt carries $I - I_g$. Thus $I_g G = (I - I_g)S$.

Step 1: Find the current through the shunt The desired ammeter range is $I = 5\ \text{A}$, while $I_g = 0.2\ \text{A}$. The current bypassing the galvanometer is

$$I_s = 5 - 0.2 = 4.8\ \text{A}.$$

Step 2: Use equal branch voltages With $G = 6\ \Omega$, the full-scale voltage is $I_g G = 1.2\ \text{V}$. Therefore

$$S = \frac{I_g G}{I - I_g} = \frac{0.2 \times 6}{4.8} = 0.25\ \Omega.$$

None of $0.30\ \Omega$, $0.50\ \Omega$ or $6.0\ \Omega$ carries the required $4.8\ \text{A}$ at this voltage. The shunt must be much smaller than G to divert most of the current.

Step 3: Conclusion The required parallel shunt is $0.25\ \Omega$. Hence, the correct option is (A).

Quick Tip to Solve: Subtract the galvanometer current from the desired range before calculating the shunt resistance.

29(iii). (iii) The value of resistance of the ammeter in case (ii) will be:

[1 mark]

- (A) $0.20\ \Omega$
- (B) $0.24\ \Omega$
- (C) $6.0\ \Omega$
- (D) $6.25\ \Omega$

Correct Answer: (B) $0.24\ \Omega$

Solution:

Concept:

- The ammeter consists of galvanometer resistance G and shunt S in parallel, with equivalent resistance $R_A = GS/(G + S)$.
- Equivalently, $R_A = V/I$, where $V = I_g G$ is the common branch voltage and I is the total ammeter current.

Step 1: Substitute the galvanometer and shunt resistances From part (ii), $G = 6\ \Omega$ and $S = 0.25\ \Omega$. Hence

$$R_A = \frac{6 \times 0.25}{6 + 0.25} = \frac{1.5}{6.25} = 0.24\ \Omega.$$

Step 2: Check the result using full-scale voltage The branch voltage is $0.2 \times 6 = 1.2\text{ V}$, and the total current is 5 A , giving $R_A = 1.2/5 = 0.24\ \Omega$. This is slightly below the smaller parallel resistance. Option (C) ignores the shunt, option (D) adds the resistances as if in series, and option (A) does not satisfy the voltage-current ratio.

Step 3: Conclusion The ammeter resistance is $0.24\ \Omega$. Hence, the correct option is (B).

Quick Tip to Solve: For a converted ammeter, use the galvanometer's full-scale voltage divided by the new total current range.

29(iv)(a). A galvanometer is converted into a voltmeter of range $(0 - V)$ by connecting with it, a resistance R_1 . If R_1 is replaced by R_2 , the range becomes $(0 - 2V)$. The resistance of the galvanometer is:

[1 mark]

- (A) $(R_2 - 2R_1)$
- (B) $(R_2 - R_1)$
- (C) $(R_1 + R_2)$
- (D) $(R_1 - 2R_2)$

Correct Answer: (A) $(R_2 - 2R_1)$

Solution:

Concept:

- A galvanometer of resistance G and full-scale current I_g becomes a voltmeter by connecting a resistance R in series. The voltage range is $I_g(G + R)$.
- The full-scale current of the same galvanometer remains unchanged when the external series resistance is replaced.

Step 1: Write the two full-scale voltage equations At full-scale deflection the current through the coil

and the series resistance is I_g . Applying Ohm's law to the complete instrument gives

$$V = I_g(G + R_1), \quad 2V = I_g(G + R_2).$$

The internal resistance G must be included in both expressions; the given range is the voltage across the complete voltmeter.

Step 2: Eliminate the unchanged full-scale current Divide the second equation by the first and rearrange:

$$\begin{aligned} 2 &= \frac{G + R_2}{G + R_1}, \\ 2G + 2R_1 &= G + R_2, \\ G &= R_2 - 2R_1. \end{aligned}$$

Option (B) merely subtracts the series resistances and misses the factor of two. Options (C) and (D) also fail the relation $G + R_2 = 2(G + R_1)$. For a physical coil with positive resistance, the required new series resistance obeys $R_2 > 2R_1$.

Step 3: Conclusion The galvanometer resistance is $G = R_2 - 2R_1$. Hence, the correct option is (A).

Quick Tip to Solve: When the voltage range doubles, double the total resistance, including the unchanged galvanometer resistance.

OR

29(iv)(b). A current of 5 mA flows through a galvanometer. Its coil has 100 turns, each of area of cross-section 18 cm^2 and is suspended in a magnetic field 0.20 T. The deflecting torque acting on the coil will be: [1 mark]

- (A) $3.6 \times 10^{-3} \text{ N m}$
- (B) $1.8 \times 10^{-4} \text{ N m}$
- (C) $2.4 \times 10^{-3} \text{ N m}$
- (D) $1.2 \times 10^{-4} \text{ N m}$

Correct Answer: (B) $1.8 \times 10^{-4} \text{ N m}$

Solution:

Concept:

- A current-carrying coil in a radial magnetic field experiences deflecting torque $\tau = NBAI$, where N is the number of turns, B the field, A the area per turn and I the current.
- Substitution requires SI units: $1 \text{ mA} = 10^{-3} \text{ A}$ and $1 \text{ cm}^2 = 10^{-4} \text{ m}^2$.

Step 1: Convert the current and area to SI units The given current and area of each turn become

$$I = 5 \times 10^{-3} \text{ A}, \quad A = 18 \times 10^{-4} \text{ m}^2.$$

The coil has $N = 100$ turns and the field is $B = 0.20 \text{ T}$. The area conversion uses the square of the centimetre-to-metre factor. The passage specifies a radial field, for which the coil's magnetic moment remains perpendicular to the field.

Step 2: Calculate the deflecting torque The torque contributions from all the turns add. Substituting

the data gives

$$\begin{aligned}\tau &= 100(0.20)(18 \times 10^{-4})(5 \times 10^{-3}) \\ &= 1.8 \times 10^{-4} \text{ N m.}\end{aligned}$$

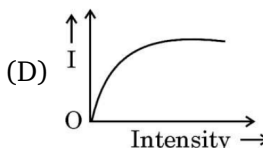
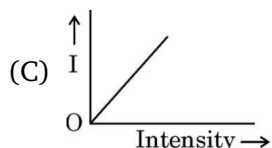
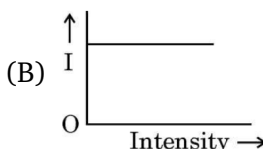
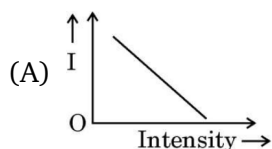
Option (A), $3.6 \times 10^{-3} \text{ N m}$, and option (C), $2.4 \times 10^{-3} \text{ N m}$, are both larger than this product. Option (D), $1.2 \times 10^{-4} \text{ N m}$, has the wrong numerical coefficient. None satisfies $\tau = NBAI$ with the stated values.

Step 3: Conclusion The deflecting torque is $1.8 \times 10^{-4} \text{ N m}$. Hence, the correct option is (B).

Quick Tip to Solve: Before multiplying $NBAI$, convert both milliamperes and square centimetres; square centimetres contribute a factor of 10 to the power minus four.

30. Einstein explained photoelectric effect on the basis of Planck's quantum theory, where light travels in the form of small bundles of energy called photons. The energy of each photon is $h\nu$, where ν is the frequency of incident light and h is Planck's constant. The number of photons in a beam of light determines the intensity of the incident light. A photon incident on a metal surface transfers its total energy $h\nu$ to a free electron in the metal. A part of this energy is used in ejecting the electron from the metal and is called its work function. The rest of the energy is carried by the ejected electron as its kinetic energy. [4 marks]

30(i). (i) Which of the following graphs shows the variation of photoelectric current I with the intensity of light? [1 mark]



Correct Answer: (C)

Solution:

Concept:

- At fixed frequency above threshold, increasing light intensity increases the number of photons reaching the metal per second, and hence the rate of photoelectron emission.
- With collecting conditions unchanged, photoelectric current is proportional to the emission rate: $I = e\dot{N}_e$, where $\dot{N}_e$ is the number of collected electrons per second.

Step 1: Relate current to incident intensity Each photon has the fixed energy $h\nu$. Doubling the intensity therefore doubles the photon arrival rate and the emitted-electron rate. The photocurrent obeys $I \propto \text{intensity}$, so the graph must be a straight line through the origin with positive slope.

Step 2: Inspect the four graphs Graph (C) shows precisely this proportional increase. Graph (A) incorrectly decreases, graph (B) incorrectly remains constant, and graph (D) curves towards a plateau. Saturation with increasing collecting voltage should not be confused with the dependence on light

intensity at fixed frequency.

Step 3: Conclusion Photocurrent increases linearly with the intensity of incident light. Hence, the correct option is (C).

Quick Tip to Solve: Read the horizontal axis first: current is proportional to intensity, whereas a current-versus-collecting-voltage graph can saturate.

30(ii). (ii) When the frequency of the incident light is increased without changing its intensity, the saturation current: [1 mark]

- (A) increases linearly
- (B) decreases
- (C) increases non-linearly
- (D) remains the same

Correct Answer: (D) remains the same

Solution:

Concept:

- In the standard school-level photoelectric-effect treatment used in this question, saturation current is controlled by the incident intensity, while frequency controls the maximum kinetic energy of the photoelectrons.
- At saturation the collector receives all emitted photoelectrons. Einstein's equation $K_{\max} = h\nu - \phi_0$, with work function ϕ_0 , determines their maximum energy.

Step 1: Identify the unchanged control of saturation current The question keeps the intensity unchanged and asks for the saturation current, rather than the stopping potential. Applying the textbook dependence of saturation current on intensity, the current remains unchanged, assuming photoemission already occurs.

Step 2: Distinguish increased energy from increased current Increasing frequency raises $K_{\max}$ and the magnitude of the stopping potential. It does not raise the saturation current in the school-level model intended here. Thus neither a linear nor a nonlinear current increase follows; a decrease is also not the intended textbook dependence.

Step 3: Conclusion In the standard CBSE treatment, the saturation current remains the same. Hence, the correct option is (D).

Quick Tip to Solve: For textbook photoelectric graphs, associate intensity with saturation current and frequency with stopping potential and maximum kinetic energy.

30(iii). (iii) Which of the following graphs can be used to obtain the value of Planck's constant?

[1 mark]

- (A) Photocurrent versus Intensity of incident light
- (B) Photocurrent versus Frequency of incident light
- (C) Cut-off potential versus Frequency of incident light
- (D) Cut-off potential versus Intensity of incident light

Correct Answer: (C) Cut-off potential versus Frequency of incident light

Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi$, where h is Planck's constant, ν the incident frequency and ϕ the work function.
- The stopping or cut-off potential V_0 satisfies $eV_0 = K_{\max}$, where e is the magnitude of electronic charge.

Step 1: Express cut-off potential in terms of frequency Combining the two equations gives

$$V_0 = \frac{h}{e}\nu - \frac{\phi}{e}.$$

This has the straight-line form $y = mx + c$. Therefore a plot of cut-off potential on the vertical axis against frequency on the horizontal axis has slope h/e .

Step 2: Identify the measurable slope If the measured slope is $m = \Delta V_0 / \Delta \nu$, then $h = em$. Photocurrent versus intensity primarily measures the rate of electron emission, while photocurrent versus frequency does not give the required linear slope h/e . At fixed frequency the cut-off potential is independent of intensity, so its graph against intensity cannot supply h .

Step 3: Conclusion Plot cut-off potential versus frequency of incident light and multiply its slope by e to obtain Planck's constant. Hence, the correct option is (C).

Quick Tip to Solve: Rewrite Einstein's equation as $V_0 = (h/e)\nu - \phi/e$: the coefficient of frequency immediately identifies the useful graph.

30(iv)(a). Red light, yellow light and blue light of the same intensity are incident on a metal surface successively. K_R , K_Y and K_B represent the maximum kinetic energy of photoelectrons respectively, then:

[1 mark]

- (A) $K_R > K_Y > K_B$
- (B) $K_Y > K_B > K_R$
- (C) $K_B > K_Y > K_R$
- (D) $K_R > K_B > K_Y$

Correct Answer: (C) $K_B > K_Y > K_R$

Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi$, where h is Planck's constant, ν is the incident frequency and ϕ is the metal's work function.
- The work function stays fixed for the same metal. Maximum kinetic energy depends on photon

frequency, not on the intensity of the incident light.

Step 1: Compare the incident frequencies Blue light has a shorter wavelength than yellow light, and yellow has a shorter wavelength than red light. Since $\nu = c/\lambda$, the corresponding frequencies obey $\nu_B > \nu_Y > \nu_R$. Equal intensities therefore do not imply equal photon energies.

Step 2: Apply the same work function For the photoelectrons described in the question, subtract the same ϕ from each photon energy. Thus $K_B - K_Y = h(\nu_B - \nu_Y) > 0$ and $K_Y - K_R = h(\nu_Y - \nu_R) > 0$. Option (A) reverses the frequency ordering, option (B) incorrectly puts yellow above blue, and option (D) incorrectly puts red above blue.

Step 3: Conclusion The maximum kinetic energies satisfy $K_B > K_Y > K_R$. Hence, the correct option is (C).

Quick Tip to Solve: For one metal, rank maximum kinetic energies by frequency: blue exceeds yellow, which exceeds red; equal intensity does not change this ranking.

OR

30(iv)(b). Which of the following metals exhibits photoelectric effect with visible light?

[1 mark]

- (A) Caesium
- (B) Zinc
- (C) Cadmium
- (D) Magnesium

Correct Answer: (A) Caesium

Solution:

Concept:

- Photoelectric emission is possible when the energy of an incident photon equals or exceeds the metal's work function: $h\nu \geq \phi$.
- The threshold frequency is $\nu_0 = \phi/h$. A metal with a smaller work function can emit electrons when illuminated with lower-frequency light.

Step 1: Identify the low-work-function metal Caesium is an alkali metal with a low work function. Photons in the visible region can supply enough energy to overcome its surface binding energy, so suitable visible light can eject photoelectrons from caesium.

Step 2: Eliminate the other metals Zinc, cadmium and magnesium have larger work functions and require ultraviolet radiation in the usual photoelectric-effect experiment. Visible photons cannot supply their required threshold energy. Raising visible-light intensity only supplies more photons; it does not increase the energy of each photon or overcome this threshold.

Step 3: Conclusion Caesium exhibits the photoelectric effect with visible light. Hence, the correct option is (A).

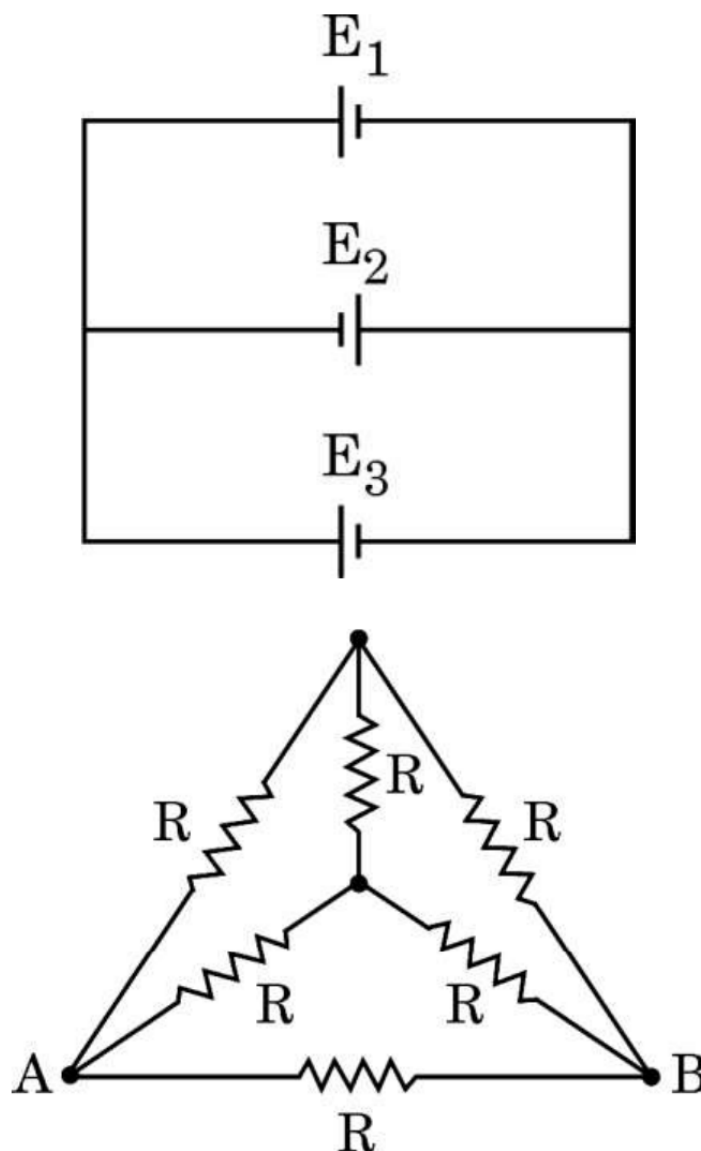
Quick Tip to Solve: For visible-light photoemission, look for a low-work-function alkali metal such as caesium; compare photon energy with the threshold, not light intensity.

Section E (15 marks)

31(a). (i) Three batteries E_1 , E_2 and E_3 of emfs and internal resistances $(4\text{ V}, 2\ \Omega)$, $(2\text{ V}, 4\ \Omega)$ and $(6\text{ V}, 2\ \Omega)$ respectively are connected as shown in the figure. Find the values of the currents passing through batteries E_1 , E_2 and E_3 .

(ii) The ends of six wires, each of resistance $R (= 10\ \Omega)$ are joined as shown in the figure. The points A and B of the arrangement are connected in a circuit. Find the value of the effective resistance offered by it to the circuit.

[5 marks]



Solution:

Concept:

- Kirchhoff's junction law states that the algebraic sum of currents at a junction is zero. The potential difference between two common nodes is the same for all branches joining them.

- For a battery with its positive terminal on the left, the left-to-right potential drop is $E + Ir$, with I defined positive from left to right; reversing the battery changes E to $-E$.
- Symmetrically placed nodes have equal potentials. No current flows through a resistance joining equipotential nodes; the remaining series and parallel resistances can then be combined.

Step 1: (i) Read the battery polarities and choose current directions Call the common left and right junctions L and M , and put $V = V_L - V_M$. The longer cell plate is positive. Thus E_1 and E_3 have positive terminals on the left, whereas E_2 has its positive terminal on the right. Define all three branch currents I_1, I_2, I_3 as positive from left to right. Including the given internal resistances, the branch equations are

$$\begin{aligned} V &= 4 + 2I_1, & I_1 &= \frac{V - 4}{2}, \\ V &= -2 + 4I_2, & I_2 &= \frac{V + 2}{4}, \\ V &= 6 + 2I_3, & I_3 &= \frac{V - 6}{2}. \end{aligned}$$

Here emf and potential are in volts, resistance in ohms and current in amperes.

Step 2: Apply the junction law and evaluate each branch current There is no external connection drawing current from these junctions. Therefore the signed currents satisfy

$$\begin{aligned} I_1 + I_2 + I_3 &= 0, \\ \frac{V - 4}{2} + \frac{V + 2}{4} + \frac{V - 6}{2} &= 0, \\ 2(V - 4) + (V + 2) + 2(V - 6) &= 0, \\ 5V - 18 &= 0, & V &= 3.6 \text{ V}. \end{aligned}$$

Substitution gives

$$\begin{aligned} I_1 &= \frac{3.6 - 4}{2} = -0.2 \text{ A}, \\ I_2 &= \frac{3.6 + 2}{4} = 1.4 \text{ A}, \\ I_3 &= \frac{3.6 - 6}{2} = -1.2 \text{ A}. \end{aligned}$$

The negative signs reverse the initially chosen directions for the first and third branches. The magnitude check $0.2 + 1.2 = 1.4$ confirms current conservation at each junction.

Step 3: (ii) Identify the equipotential internal nodes Name the top vertex C and the central junction D . The paths $A - C - B$ and $A - D - B$ each contain two equal resistances R . Interchanging C and D leaves the circuit and its terminal connections unchanged, so $V_C = V_D$. Equivalently, the bridge is balanced because $R_{AC}/R_{CB} = R_{AD}/R_{DB} = 1$. Hence no current flows through CD , and this connecting resistance may be omitted when calculating the resistance between A and B .

Step 4: Combine the three remaining parallel paths After omitting the zero-current bridge branch, the direct path AB has resistance R , while $A - C - B$ and $A - D - B$ each have resistance $2R$. All

three are connected across the same terminals, so

$$\frac{1}{R_{AB}} = \frac{1}{R} + \frac{1}{2R} + \frac{1}{2R} = \frac{2}{R},$$

$$R_{AB} = \frac{R}{2} = \frac{10}{2} \Omega = 5 \Omega.$$

Step 5: Conclusion (i) The currents through E_1, E_2, E_3 are respectively 0.2 A right to left, 1.4 A left to right, and 1.2 A right to left in the printed circuit. (ii) The effective resistance between A and B is 5Ω .

Quick Tip to Solve: Read the longer battery plate before assigning emf signs. In the six-wire network, spot the equal-potential top and central nodes before combining resistances.

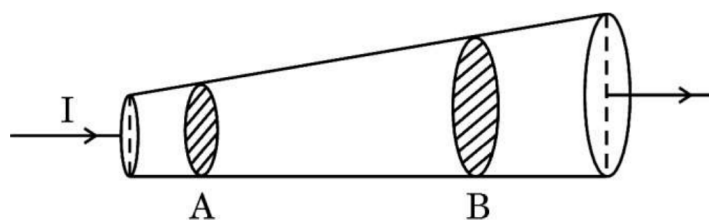
OR

31(b). (i) Current I ($= 1 \text{ A}$) is passing through a copper rod ($n = 8.5 \times 10^{28} \text{ m}^{-3}$) of varying cross-sections as shown in the figure. The areas of cross-section at points A and B along its length are $1.0 \times 10^{-7} \text{ m}^2$ and $2.0 \times 10^{-7} \text{ m}^2$ respectively. Calculate:

(I) the ratio of electric fields at points A and B .

(II) the drift velocity of free electrons at point B .

(ii) Two point charges q_1 ($= 16 \mu\text{C}$) and q_2 ($= 1 \mu\text{C}$) are placed at points $\vec{r}_1 = (3 \text{ m})\hat{i}$ and $\vec{r}_2 = (4 \text{ m})\hat{j}$. Find the net electric field $\vec{E}$ at point $\vec{r} = (3 \text{ m})\hat{i} + (4 \text{ m})\hat{j}$. [5 marks]



Solution:

Concept:

- In a steady current, the same current I flows through every cross-section of the rod. The current density is $J = I/A$, where A is the local cross-sectional area.
- Microscopic Ohm's law is $E = \rho J$, where ρ is the resistivity. For a copper rod at uniform temperature, ρ is the same at both points, so E varies inversely with area.
- The electron drift speed satisfies $I = neAv_d$, where n is the number of free electrons per unit volume and $e = 1.6 \times 10^{-19} \text{ C}$. Electron drift is opposite to conventional current.
- The electric field of a point charge follows Coulomb's law, $\vec{E} = kq\vec{R}/R^3$, where $\vec{R}$ points from the charge to the observation point and $k = 9 \times 10^9 \text{ N m}^2\text{C}^{-2}$. Fields add vectorially.

Step 1: (i)(I) Compare the electric fields in the rod The rod carries a steady current of 1 A, so charge conservation makes the current at A equal to that at B . The narrower section therefore has the larger current density. Applying microscopic Ohm's law separately at the two cross-sections gives

$$E_A = \frac{\rho I}{A_A}, \quad E_B = \frac{\rho I}{A_B}.$$

The common resistivity and current cancel in the ratio:

$$\frac{E_A}{E_B} = \frac{A_B}{A_A} = \frac{2.0 \times 10^{-7}}{1.0 \times 10^{-7}} = 2.$$

Thus the field is stronger at the narrower section A ; no numerical value of the copper resistivity is needed.

Step 2: (i)(II) Calculate the electron drift speed at B Use the area at B , not that at A , in the current–drift relation. Substituting the number density and the magnitude of electron charge,

$$\begin{aligned} v_{dB} &= \frac{I}{neA_B} \\ &= \frac{1}{(8.5 \times 10^{28})(1.6 \times 10^{-19})(2.0 \times 10^{-7})} \\ &= \frac{1}{2.72 \times 10^3} \text{ m s}^{-1} \\ &= 3.68 \times 10^{-4} \text{ m s}^{-1}. \end{aligned}$$

This is the speed of the mean directed motion of the electrons. Its direction is opposite to the arrow of conventional current in the figure, hence from right to left along the rod.

Step 3: (ii) Find each charge-to-point displacement Let the observation point be P , whose position vector is $\vec{r} = 3\hat{i} + 4\hat{j}$ in metres. Subtract each charge's position from the observation point:

$$\begin{aligned} \vec{R}_1 &= \vec{r} - \vec{r}_1 = 4\hat{j} \text{ m}, & R_1 &= 4 \text{ m}, \\ \vec{R}_2 &= \vec{r} - \vec{r}_2 = 3\hat{i} \text{ m}, & R_2 &= 3 \text{ m}. \end{aligned}$$

Both charges are positive, so their fields at P point away from them: the field due to q_1 is along $+\hat{j}$, and that due to q_2 is along $+\hat{i}$. The relevant distances are from each charge to P , not the distance of P from the origin.

Step 4: (ii) Apply Coulomb's law and superpose the fields Convert the charges from microcoulombs to coulombs and calculate their perpendicular field components:

$$\begin{aligned} \vec{E}_1 &= \frac{kq_1}{R_1^2} \hat{j} = \frac{(9 \times 10^9)(16 \times 10^{-6})}{4^2} \hat{j} = 9.0 \times 10^3 \hat{j} \text{ N C}^{-1}, \\ \vec{E}_2 &= \frac{kq_2}{R_2^2} \hat{i} = \frac{(9 \times 10^9)(1 \times 10^{-6})}{3^2} \hat{i} = 1.0 \times 10^3 \hat{i} \text{ N C}^{-1}. \end{aligned}$$

By the superposition principle, $\vec{E} = \vec{E}_1 + \vec{E}_2$. Since the individual fields are perpendicular, their magnitudes must not be added as scalars; their x - and y -components give the required vector directly.

Step 5: Conclusion (i)(I) $E_A : E_B = 2 : 1$. (i)(II) The electron drift velocity at B has magnitude $3.68 \times 10^{-4} \text{ m s}^{-1}$, directed opposite to the current (right to left). (ii) The net electric field is

$$\vec{E} = (1.0 \times 10^3 \hat{i} + 9.0 \times 10^3 \hat{j}) \text{ N C}^{-1}.$$

Quick Tip to Solve: For the same material and steady current, both electric field and drift speed vary as $1/A$. For point charges, first subtract position vectors to obtain each source-to-observation displacement; this fixes both the distance and field direction.

32(a). (i) Define self-inductance of a coil. Derive the expression for the energy required to build up a current I in a coil of self-inductance L .

(ii) The currents passing through two inductors of self-inductances 10 mH and 20 mH increase with time at the same rate. Draw graphs showing the variation of:

(I) the magnitude of emf induced with the rate of change of current in each inductor.

(II) the energy stored in each inductor with the current flowing through it.

[5 marks]

Solution:

Concept:

- Self-induction is the production of an emf in a coil when its own current changes. The induced emf opposes that change: $\varepsilon = -L di/dt$, where L is the self-inductance.
- For a coil of N turns with flux Φ through each turn, the flux linkage is $N\Phi = Li$, assuming a constant inductance and no external flux.
- The work done against the opposing induced emf is stored as magnetic energy in an ideal inductor. Its instantaneous input power is $P = Li di/dt$.

Step 1: (i) Define the self-inductance The self-inductance of a coil is the magnetic flux linkage per unit current in it:

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

Equivalently, its numerical value equals the magnitude of the induced emf when the current changes at unit rate, since $|\varepsilon| = L|di/dt|$. Its SI unit is the henry (H). A coil has an inductance of 1 H if a current changing at 1 A s^{-1} produces an emf of magnitude 1 V. The minus sign in the induced-emf law expresses Lenz's law, not a negative inductance.

Step 2: (i) Calculate the work required to establish the current Let the current at an intermediate instant be i . The source must provide a voltage $V_L = L di/dt$ across the ideal inductive part of the coil to overcome the back emf. During a small interval dt , the charge supplied is $dq = i dt$. Hence the work done is

$$\begin{aligned} dW &= V_L dq \\ &= \left(L \frac{di}{dt} \right) i dt \\ &= Li di. \end{aligned}$$

For constant L , increasing the current from zero to I therefore requires

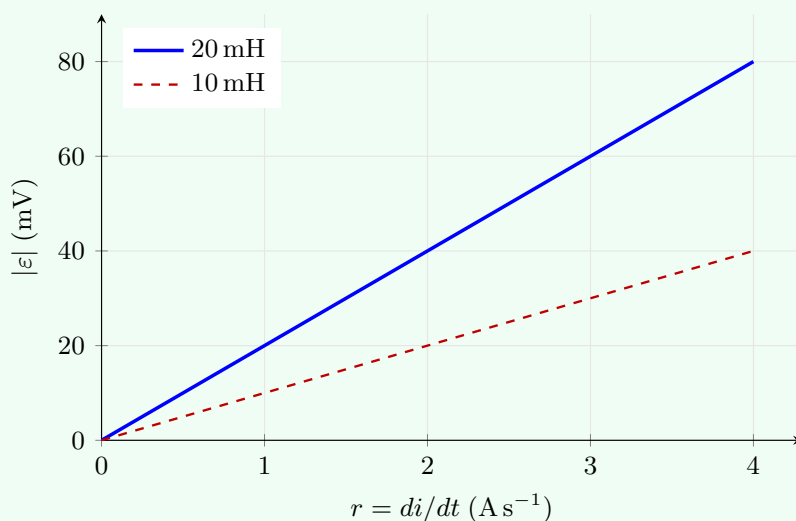
$$W = \int_0^I Li di = L \left[\frac{i^2}{2} \right]_0^I = \frac{1}{2} LI^2.$$

This work is stored in the magnetic field, so $U = \frac{1}{2} LI^2$. If the coil also has resistance, the source must additionally supply Joule heat; the expression above gives the magnetic energy alone.

Step 3: (ii)(I) Plot induced-emf magnitude against current-change rate Write $r = di/dt > 0$, because both currents increase. The two inductances are $L_1 = 10 \text{ mH} = 0.010 \text{ H}$ and $L_2 = 20 \text{ mH} = 0.020 \text{ H}$. Thus

$$|\varepsilon_1| = 0.010r, \quad |\varepsilon_2| = 0.020r \quad (\text{emf in V, } r \text{ in A s}^{-1}).$$

Each graph is a straight line through the origin, with slope equal to the inductance when SI units are used. The line for 20 mH has twice the slope of that for 10 mH. At the same current-change rate, it therefore gives twice the emf magnitude. The graph uses millivolts for convenient vertical-axis values.

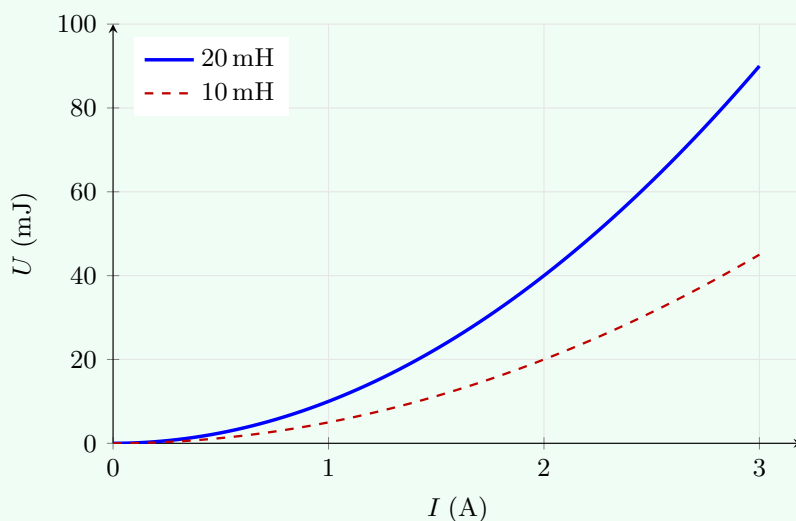


Induced-emf magnitude versus rate of increase of current.

Step 4: (ii)(II) Plot stored energy against current Substituting each inductance into the energy expression gives

$$U_1 = 0.005I^2, \quad U_2 = 0.010I^2 \quad (\text{energy in J, current in A}).$$

Both curves are upward-opening parabolas passing through the origin with zero initial slope. At every common nonzero current, the 20 mH coil stores twice as much energy, so its curve lies above that of the 10 mH coil. Only the nonnegative-current portions are needed for the indicated build-up; the complete mathematical curves are symmetric about $I = 0$. The vertical axis below is in millijoules.



Magnetic energy versus current; the higher-inductance coil stores more energy at the same current.

Step 5: Conclusion The self-inductance is $L = N\Phi/I$, and the energy required to establish current I against the back emf is $U = \frac{1}{2}LI^2$. The emf-rate graphs are straight lines with slopes in the ratio 1 : 2; the energy-current graphs are parabolas with energies in the ratio 1 : 2 at the same current, for the 10 mH and 20 mH coils respectively.

Quick Tip to Solve: First write $|\varepsilon| = Lr$ and $U = \frac{1}{2}LI^2$: the power of the horizontal-axis variable tells you whether to draw a straight line or a parabola, and doubling L doubles each vertical ordinate.

- 32(b).** (i) Define the term mutual inductance. Deduce the expression for the mutual inductance of two long coaxial solenoids of the same length having different radii and different number of turns.
- (ii) The current through an inductor is uniformly increased from zero to 2 A in 40 s. An emf of 5 mV is induced during this period. Find the flux linked with the inductor at $t = 10$ s. [5 marks]

Solution:**Concept:**

- Mutual inductance relates the flux linkage in one coil to current in another: $N_2\Phi_{21} = M_{21}I_1$. Here Φ_{21} is the flux through one turn of coil 2 due to current I_1 in coil 1.
- A long air-cored solenoid of length ℓ , N turns and current I produces an approximately uniform internal field $B = \mu_0 NI/\ell$; its external field is negligible when end effects are ignored.
- For a linear inductor, total flux linkage is $\lambda = N\Phi = LI$, and the magnitude of induced emf is $|\varepsilon| = L|dI/dt|$. Here L is its self-inductance.

Step 1: (i) Define mutual inductance The mutual inductance of two coils is the magnetic flux linkage with either coil per unit current in the other coil, with their geometry and magnetic medium fixed:

$$M_{21} = \frac{N_2\Phi_{21}}{I_1}, \quad \varepsilon_2 = -M_{21} \frac{dI_1}{dt}.$$

Equivalently, it is the magnitude of emf induced in one coil when current in the other changes at a unit rate. Its SI unit is henry (H): a rate of 1 A s^{-1} induces 1 V when $M = 1 \text{ H}$. The minus sign in the emf equation expresses Lenz's law.

Step 2: (i) Calculate the flux linkage due to the inner solenoid Let the inner solenoid have radius r_1 and N_1 turns, and the outer solenoid have radius $r_2 > r_1$ and N_2 turns. Both have length ℓ , are long, coaxial and air-cored. For current I_1 through the inner solenoid,

$$B_1 = \mu_0 \frac{N_1}{\ell} I_1.$$

This field is appreciable only inside the inner solenoid. Therefore, although an outer turn encloses a larger area, the flux passing through it is the field multiplied by the smaller common area $A_1 = \pi r_1^2$:

$$\begin{aligned} \Phi_{21} &= B_1 A_1 = \frac{\mu_0 N_1 I_1 A_1}{\ell}, \\ N_2 \Phi_{21} &= \frac{\mu_0 N_1 N_2 A_1}{\ell} I_1. \end{aligned}$$

Comparing this with $N_2\Phi_{21} = M_{21}I_1$ identifies the required geometrical factor.

Step 3: (i) Reverse the current source to verify reciprocity Now pass current I_2 through the outer solenoid. Its field $B_2 = \mu_0 N_2 I_2 / \ell$ fills the inner solenoid, but each inner turn still encloses only area A_1 . Thus

$$\begin{aligned} N_1 \Phi_{12} &= N_1 B_2 A_1 = \frac{\mu_0 N_1 N_2 A_1}{\ell} I_2, \\ M_{12} &= M_{21} = M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{\ell}. \end{aligned}$$

In terms of turns per unit length $n_1 = N_1/\ell$ and $n_2 = N_2/\ell$, this is $M = \mu_0 n_1 n_2 A_1 \ell$. The smaller radius enters because it determines the shared flux area. For a uniform linear medium of permeability μ , replace μ_0 by μ .

Step 4: (ii) Find the self-inductance from the induced emf The current rises uniformly, so its rate of change is constant. Convert the emf to volts before substitution:

$$\begin{aligned}\frac{dI}{dt} &= \frac{2 - 0}{40} = 0.05 \text{ A s}^{-1}, \\ |\varepsilon| &= 5 \times 10^{-3} \text{ V}, \\ L &= \frac{|\varepsilon|}{dI/dt} = \frac{5 \times 10^{-3}}{0.05} = 0.10 \text{ H}.\end{aligned}$$

The induced emf opposes the current increase; its supplied magnitude is sufficient to determine the positive self-inductance.

Step 5: (ii) Evaluate the flux linkage at the specified time Since the current starts at zero and increases linearly, at $t = 10 \text{ s}$ its value is

$$I(10) = 0.05 \times 10 = 0.50 \text{ A}.$$

Hence the total flux linked with the inductor is

$$\lambda(10) = LI(10) = 0.10 \times 0.50 = 5.0 \times 10^{-2} \text{ Wb}.$$

Here “flux linked” means $N\Phi$, often expressed as Wb-turn; the flux through a single turn cannot be found without the number of turns. As a check, with zero initial self-flux linkage, $\lambda = |\varepsilon|t = (5 \times 10^{-3})(10)$ gives the same value.

Step 6: Conclusion (i) The mutual inductance is $M = \frac{\mu_0 N_1 N_2 A_{\text{smaller}}}{\ell}$ for two long air-cored coaxial solenoids. (ii) The flux linkage at 10 s is $N\Phi = 5.0 \times 10^{-2} \text{ Wb}$ (Wb-turn).

Quick Tip to Solve: Use the smaller solenoid’s area for mutual flux. For constant induced emf and zero initial flux linkage, obtain the linkage directly from $N\Phi = |\varepsilon|t$.

- 33(a).** (i) Draw a ray diagram of a reflecting telescope (Cassegrain) and explain the formation of image. State two important advantages that a reflecting telescope has over a refracting telescope.
 (ii) In a refracting telescope, the focal length of the objective is 50 times the focal length of the eyepiece. When the final image is formed at infinity, the length of the tube is 102 cm. Find the focal lengths of the two lenses. [5 marks]

Solution:

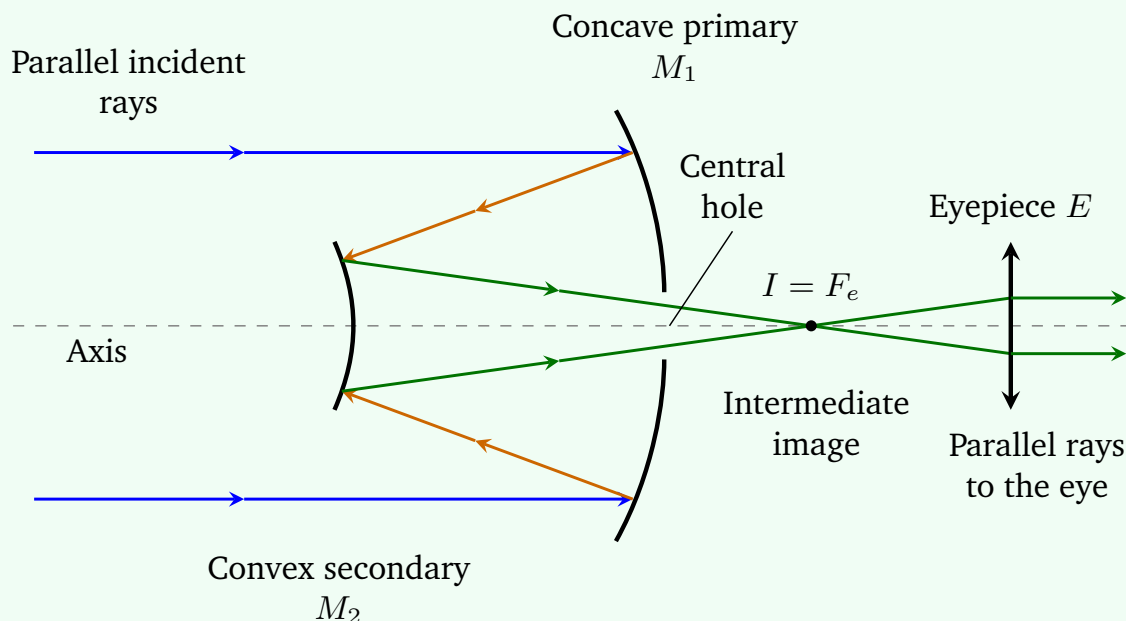
Concept:

- A Cassegrain reflecting telescope uses a large concave primary mirror and a small convex secondary mirror. Reflection brings rays from a distant object to a real focus behind the primary mirror through its central aperture.
- The eyepiece magnifies the real intermediate image. For relaxed viewing, this image lies in the focal plane of the eyepiece, so the final image is virtual and at infinity.
- For a refracting astronomical telescope in normal adjustment, the separation of the objective and eyepiece is $L = f_o + f_e$, where f_o and f_e are their positive focal lengths.

Step 1: (i) Trace the rays through the Cassegrain telescope Parallel rays from a distant object fall on the large concave primary mirror M_1 . After reflection they travel back towards its focus. Before reaching that focus, they strike the small convex secondary mirror M_2 , which is placed on the same

axis in front of the primary mirror. The secondary reflects the converging beam back towards the primary, reducing its convergence. The rays now pass through the central hole in M_1 and meet at I , behind it. Thus the two mirrors together form a real, inverted intermediate image of an extended distant object.

The eyepiece E , placed behind the primary mirror, acts as a magnifier for this image. In normal adjustment, I is in its front focal plane and the emerging rays are parallel, giving a magnified virtual image at infinity. The diagram shows the path of rays from an axial point of the distant object; arrows show the successive directions of propagation.



Cassegrain telescope: the beam returns through the central hole to I , then reaches eyepiece E . Schematic, not to scale.

Step 2: (i) State two advantages over a refracting telescope **Freedom from chromatic aberration:** the mirror objective focuses light by reflection, whose law does not depend on wavelength. Thus it does not produce the colour-dependent focal lengths of a lens objective.

A large aperture is practical: a mirror can be supported from its back, whereas a large lens is supported principally at its rim. Large reflecting objectives are therefore easier to construct and support. Their larger aperture collects more light, allowing fainter objects to be seen, and improves angular resolving power.

Step 3: (ii) Use the normal-adjustment condition The final image is at infinity, so the real image made by the objective must coincide with the front focal plane of the eyepiece. Consequently the tube length equals the sum of the two focal lengths, not their difference. The two supplied conditions are

$$f_o = 50f_e, \quad f_o + f_e = 102 \text{ cm.}$$

Substituting the first relation into the second gives

$$50f_e + f_e = 102 \text{ cm,} \quad 51f_e = 102 \text{ cm.}$$

Step 4: (ii) Calculate and check both focal lengths Dividing by 51, then using the given ratio,

$$f_e = \frac{102}{51} \text{ cm} = 2 \text{ cm,} \quad f_o = 50(2 \text{ cm}) = 100 \text{ cm.}$$

These values satisfy both checks: their sum is 102 cm, the tube length, and their ratio is $100/2 = 50$. Both focal lengths are positive because the objective and eyepiece of this refracting telescope are converging lenses.

Step 5: Conclusion The Cassegrain telescope forms its intermediate image behind the primary mirror after two reflections; the eyepiece magnifies it. Its mirror objective avoids chromatic aberration and permits a large supported aperture. For the refracting telescope, $f_o = 100 \text{ cm}$, $f_e = 2 \text{ cm}$.

Quick Tip to Solve: For normal adjustment with $f_o = kf_e$, use $f_e = L/(k+1)$ and $f_o = kL/(k+1)$; here divide the tube length by 51.

OR

33(b). (i) Write any two advantages of a compound microscope over a simple microscope. Draw a ray diagram for the image formation at the near point by a compound microscope and explain it.

(ii) A thin planoconcave lens with its curved face of radius of curvature R is made of glass of refractive index n_1 . It is placed coaxially in contact with a thin equiconvex lens of same radius of curvature of refractive index n_2 . Obtain the power of the combination lens. [5 marks]

Solution:

Concept:

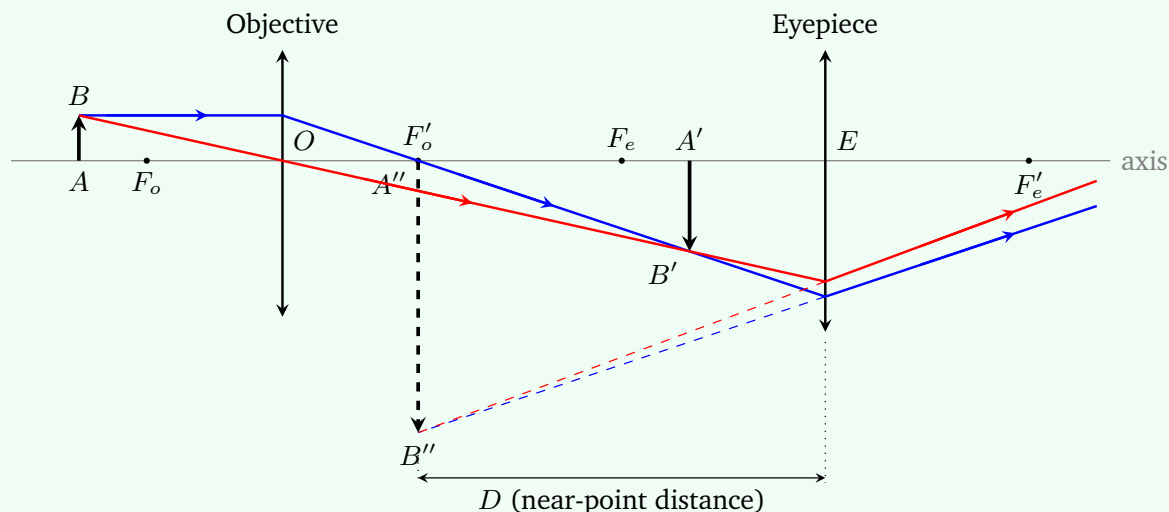
- A compound microscope uses a short-focal-length objective to form a real enlarged intermediate image, and an eyepiece to magnify it further. Its angular magnification is the product of objective linear magnification and eyepiece angular magnification.
- For a final image at the near point, the intermediate image lies between the eyepiece and its first focus. The least distance of distinct vision is $D \simeq 25 \text{ cm}$.
- For a thin lens in air, the lens-maker formula is $P = 1/f = (n-1)(1/R_1 - 1/R_2)$, where the radii have Cartesian signs. Powers of thin lenses in contact add.

Step 1: (i) State two advantages First, a compound microscope provides much greater magnification: the objective enlarges the object and the eyepiece magnifies that intermediate image again. A simple microscope has only one stage of angular magnification. Second, a suitably designed compound microscope has greater resolving power, so it can distinguish finer details and more closely spaced points. This is provided by its high-numerical-aperture objective; increasing eyepiece magnification alone would not improve resolution.

Step 2: Trace the image formation at the near point Place the small object AB just beyond the first focal point F_o of the objective O . A ray from B parallel to the principal axis refracts through F'_o ; a ray through the optical centre O is undeviated. Their intersection gives B' , so $A'B'$ is a real, inverted and enlarged intermediate image. Adjust the separation so that $A'B'$ lies between the eyepiece E and its first focus F_e . Rays reaching the eyepiece from B' emerge diverging. Their backward extensions meet at B'' , forming the final virtual, further enlarged image $A''B''$ at the near point, a distance D to the left of the eyepiece. It remains inverted relative to the original object. Solid lines in the diagram are actual light rays; dashed lines are backward extensions. With the eye close to the eyepiece, the magnitude of the angular magnification is

$$|M| = \left| \frac{v_o}{u_o} \right| \left(1 + \frac{D}{f_e} \right),$$

where u_o, v_o are the objective object and image distances, and f_e is the eyepiece focal length.



Compound microscope adjusted for the final virtual image at the near point (schematic).

Step 3: (ii) Find the power of the planoconcave lens Take light from left to right and let $R > 0$ be the magnitude of each curved surface's radius. For the planoconcave lens with its plane surface first, $R_1 = \infty$ and $R_2 = +R$. The lens-maker formula gives

$$P_1 = (n_1 - 1) \left(\frac{1}{\infty} - \frac{1}{R} \right) = -\frac{n_1 - 1}{R}.$$

The negative sign is required because a glass planoconcave lens in air is diverging. Reversing its orientation gives the same power.

Step 4: Find the equiconvex power and combine the lenses For the equiconvex lens, its first surface has $R_1 = +R$ and its second has $R_2 = -R$. Therefore,

$$P_2 = (n_2 - 1) \left(\frac{1}{R} - \frac{1}{-R} \right) = \frac{2(n_2 - 1)}{R}.$$

Since the lenses are thin and in contact, their separation contributes no additional term:

$$\begin{aligned} P &= P_1 + P_2 \\ &= -\frac{n_1 - 1}{R} + \frac{2(n_2 - 1)}{R} = \frac{2n_2 - n_1 - 1}{R}. \end{aligned}$$

Here R must be in metres to obtain power in dioptres. The combination is converging, diverging or of zero power according as $2n_2 - n_1 - 1$ is positive, negative or zero.

Step 5: Conclusion The compound microscope gives greater magnification and, with a suitable objective, better resolution. Its near-point image is virtual, enlarged and inverted. The contact combination has power $P = (2n_2 - n_1 - 1)/R$, in dioptres when R is in metres.

Quick Tip to Solve: Put the intermediate image inside the eyepiece focal length for a near-point image. For the lens pair, assign the concave lens negative power before adding the two powers.