

CBSE Class 12 Physics Question Paper 2024 with Solution PDF-Set 55/2/3



Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

- (i) This question paper contains **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 :

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

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

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

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

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

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

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

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

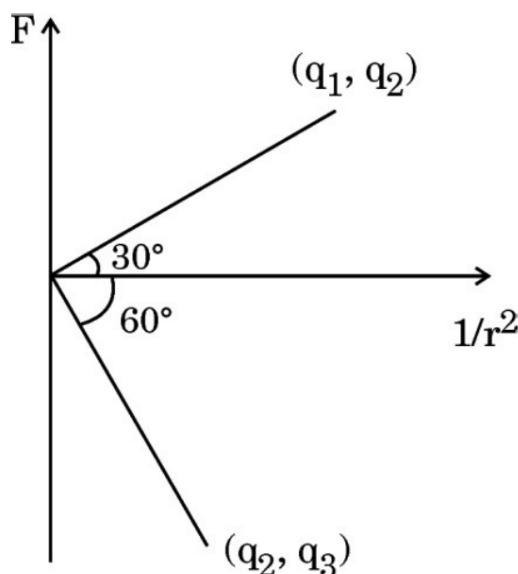
$$\text{Mass of proton} = 1.673 \times 10^{-27} \text{ kg}$$

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

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

Section A (16 marks)

1. Coulomb force F versus $\frac{1}{r^2}$ graphs for two pairs of point charges $(q_1 \text{ and } q_2)$ and $(q_2 \text{ and } q_3)$ are shown in the figure. The ratio of charges $\frac{q_1}{q_3}$ is: [1 mark]



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

Correct Answer: Signed ratio $q_1/q_3 = -1/3$, absent from the options; option (D) gives the magnitude $1/3$.

Solution:

Concept:

- Coulomb's law gives $F = kq_iq_j/r^2$ for signed radial force, where $k = 1/(4\pi\epsilon_0)$.
- The slope of an F versus $1/r^2$ graph is kq_iq_j ; a line below the horizontal axis has negative slope.

Step 1: Read the signed slopes The upper line represents (q_1, q_2) and is inclined at 30° to the positive horizontal axis. The lower line represents (q_2, q_3) and is inclined at -60° . With the common axis scale factor cancelling, their slope ratio is

$$\frac{m_{12}}{m_{23}} = \frac{\tan 30^\circ}{\tan(-60^\circ)} = \frac{1/\sqrt{3}}{-\sqrt{3}} = -\frac{1}{3}.$$

Step 2: Compare the charge ratio with the choices Dividing the slope equations cancels kq_2 , so $q_1/q_3 = m_{12}/m_{23} = -1/3$. Opposite slope signs mean q_1 and q_3 have opposite signs. All printed options are positive. Taking charge magnitudes instead gives $1/3$, option (D); (A) and (B) use incorrect trigonometric ratios, and (C) reverses the required magnitude ratio. The paper does not explicitly ask

for magnitudes.

Step 3: Conclusion The graph gives $q_1/q_3 = -1/3$, for which no printed option is correct. Under a magnitude-only interpretation, $|q_1|/|q_3| = 1/3$, corresponding to (D).

Quick Tip to Solve: Use the ratio of slopes, cancel the common charge, and retain a minus sign for a line below the horizontal axis.

2. Electrons drift with speed v_d in a conductor with potential difference V across its ends. If V is reduced to $\left(\frac{V}{2}\right)$, their drift speed will become: [1 mark]

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

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

Solution:

Concept:

- The electron drift speed is $v_d = eE\tau/m_e$, where e is the charge magnitude, τ the relaxation time and m_e the electron mass.
- In a uniform conductor of length L , the electric field magnitude is $E = V/L$.

Step 1: Relate drift speed to applied voltage Combining the two relations gives $v_d = e\tau V/(m_e L)$. For the same conductor at unchanged temperature, its length and relaxation time are unchanged. Drift speed is therefore directly proportional to the potential difference, not inversely proportional to it.

Step 2: Apply the voltage reduction With $V' = V/2$, compare the new speed with the original:

$$\frac{v'_d}{v_d} = \frac{V'}{V} = \frac{1}{2}.$$

An unchanged speed would require an unchanged field. The choices $2v_d$ and $4v_d$ describe increases, whereas reducing the field reduces the average drift speed. Random thermal motion does not alter this proportionality for the drift component.

Step 3: Conclusion The new drift speed is $v'_d = v_d/2$. Hence, the correct option is (A).

Quick Tip to Solve: For a fixed conductor at constant temperature, multiply the drift speed by exactly the same factor as the voltage.

3. The emf induced in a coil rotating in a magnetic field does not depend upon the following: [1 mark]

- (A) Area of the coil
- (B) Resistance of the coil
- (C) Number of turns in the coil
- (D) Angular speed of rotation of the coil

Correct Answer: (B) Resistance of the coil

Solution:

Concept:

- Faraday's law states that the induced emf is $\varepsilon = -d(N\Phi)/dt$, where $N\Phi$ is magnetic flux linkage.
- For a coil of area A with N turns rotating at angular speed ω in a uniform field B , the peak emf is $\varepsilon_0 = NBA\omega$.

Step 1: Differentiate the rotating flux Choosing the initial orientation so the area normal lies along the field gives $N\Phi = NBA \cos \omega t$. Differentiating gives

$$\varepsilon = NBA\omega \sin \omega t.$$

The area, number of turns and angular speed all occur in this expression. Thus options (A), (C) and (D) each affect the induced emf for the stated rotation.

Step 2: Distinguish emf from current Resistance does not appear in Faraday's law or in the expression just obtained. For a resistive closed coil it affects the induced current through $I = \varepsilon/R$, but it does not set the emf when the magnetic field and prescribed rotational motion are fixed. Confusing induced current with induced emf would incorrectly make resistance seem relevant.

Step 3: Conclusion The induced emf is independent of the resistance of the coil. Hence, the correct option is (B).

Quick Tip to Solve: Write $\varepsilon_0 = NBA\omega$ first: resistance belongs in the current equation, not in the flux-change formula.

4. A circular coil of radius 10 cm is placed in a magnetic field $\vec{B} = (1.0\hat{i} + 0.5\hat{j}) \text{ mT}$ such that the outward unit vector normal to the surface of the coil is $(0.6\hat{i} + 0.8\hat{j})$. The magnetic flux linked with the coil is: [1 mark]

- (A) $0.314 \mu\text{Wb}$
- (B) $3.14 \mu\text{Wb}$
- (C) $31.4 \mu\text{Wb}$
- (D) $1.256 \mu\text{Wb}$

Correct Answer: (C) $31.4 \mu\text{Wb}$

Solution:

Concept:

- Magnetic flux through a plane surface is $\Phi = \vec{B} \cdot \vec{A} = A(\vec{B} \cdot \hat{n})$, where $\hat{n}$ is its unit normal.
- A circular surface of radius r has area $A = \pi r^2$; $1 \text{ mT} = 10^{-3} \text{ T}$ and $1 \mu\text{Wb} = 10^{-6} \text{ Wb}$.

Step 1: Find the normal component of the field Use the dot product with the given outward normal,

whose magnitude is $\sqrt{0.6^2 + 0.8^2} = 1$:

$$B_n = \vec{B} \cdot \hat{n} = [1.0(0.6) + 0.5(0.8)] \text{ mT} = 1.0 \times 10^{-3} \text{ T}.$$

Flux depends on this component, not on the full magnitude $\sqrt{1.0^2 + 0.5^2} \text{ mT}$.

Step 2: Multiply by the area in SI units The radius is $10 \text{ cm} = 0.10 \text{ m}$, so $A = \pi(0.10)^2 = 0.01\pi \text{ m}^2$. Therefore

$$\Phi = (10^{-3})(0.01\pi) = \pi \times 10^{-5} \text{ Wb} = 31.4 \mu\text{Wb}.$$

The dot product is positive for the stated outward normal. Options (A) and (B) have incorrect powers of ten, while (D) does not equal the dot product times the circular area.

Step 3: Conclusion The flux linked with the coil is $31.4 \mu\text{Wb}$. Hence, the correct option is (C).

Quick Tip to Solve: Take the dot product with the unit normal first, then square the radius only after converting it to metres.

5. Which of the following quantity/quantities remains same in primary and secondary coils of an ideal transformer?

Current, Voltage, Power, Magnetic flux

[1 mark]

- (A) Current only
- (B) Voltage only
- (C) Power only
- (D) Magnetic flux and Power both

Correct Answer: (D) Magnetic flux and Power both

Solution:

Concept:

- An ideal transformer has no energy losses, so its input and output powers are equal: $P_p = P_s$.
- With perfect magnetic coupling, the same time-dependent core flux Φ passes through every turn of both coils; the flux linkages are $N_p\Phi$ and $N_s\Phi$.

Step 1: Compare power and magnetic flux No winding resistance, core loss or leakage is present in the ideal model. The secondary receives the power supplied to the primary. The common core also carries the same magnetic flux through the two coils. This statement concerns flux through a turn; total flux linkage can differ because the numbers of turns can differ.

Step 2: Compare voltage and current The voltage ratio is $V_s/V_p = N_s/N_p$, while the current ratio is $I_s/I_p = N_p/N_s$. Thus voltage and current generally change when the turns ratio differs from unity. Options (A) and (B) are not general properties of a transformer. Option (C) includes power but omits the magnetic flux, which is also common to both coils.

Step 3: Conclusion Both magnetic flux and power remain the same in the primary and secondary coils of an ideal transformer. Hence, the correct option is (D).

Quick Tip to Solve: Keep flux separate from flux linkage: the core flux is common, while multiplying it by different turn counts changes the linkage.

6. In an ac circuit, the instantaneous values of current (in A) and voltage (in V) are $I = 5 \sin \omega t$ and $E = 200 \cos \left(\omega t + \frac{\pi}{3} \right)$ respectively. The phase difference between voltage and current at any instant is: [1 mark]

- (A) $\frac{5\pi}{6}$
(B) $\frac{5\pi}{4}$
(C) $\frac{5\pi}{2}$
(D) $\frac{3\pi}{2}$

Correct Answer: (A) $\frac{5\pi}{6}$

Solution:

Concept:

- The phase difference is the difference between constant phase angles when both oscillations are written using the same trigonometric function.
- The identity $\cos \theta = \sin(\theta + \pi/2)$ converts a cosine expression to a sine expression without changing the wave.

Step 1: Express the voltage as a sine The current is already $I = 5 \sin \omega t$, so its phase constant is zero. Convert the voltage:

$$E = 200 \sin \left(\omega t + \frac{\pi}{3} + \frac{\pi}{2} \right) = 200 \sin \left(\omega t + \frac{5\pi}{6} \right).$$

The extra $\pi/2$ comes from the cosine-to-sine conversion; comparing the printed arguments directly would miss it.

Step 2: Subtract the phase constants The common time-dependent term ωt cancels, giving $\Delta\phi = 5\pi/6 - 0$. Thus the phase difference is independent of the chosen instant and of the amplitudes 5 and 200. The other printed angles, $5\pi/4$, $5\pi/2$ and $3\pi/2$, are not equal to this angle even modulo 2π .

Step 3: Conclusion The voltage leads the current by $5\pi/6 \text{ rad} = 150^\circ$. Hence, the correct option is (A).

Quick Tip to Solve: Convert both waves to sine or both to cosine before subtracting their phases; amplitudes play no role in the subtraction.

7. In four regions I, II, III and IV, the magnetic field is given by:

I. $B_y = B_0 \sin kz$

II. $B_y = B_0 \cos kz$

III. $B_y = B_0 \sin(kz - \omega t)$

IV. $B_y = B_0 \sin kz + B_0 \cos kz$

The electromagnetic wave will exist in the region:

[1 mark]

(A) IV

(B) I

(C) III

(D) II

Correct Answer: (C) III

Solution:

Concept:

- A travelling electromagnetic wave has electric and magnetic fields that vary with position and time; a sinusoidal travelling wave has phase $kz - \omega t$ or $kz + \omega t$.
- For propagation along z , a magnetic field along y is transverse; k is the wave number and ω the angular frequency.

Step 1: Identify the time-dependent travelling field Region III has $B_y = B_0 \sin(kz - \omega t)$. At fixed position its field oscillates in time. At constant phase, $kz - \omega t = \text{constant}$, so $z = (\omega/k)t + \text{constant}$: the pattern travels along positive z . The magnetic field direction is perpendicular to this propagation direction.

Step 2: Reject the static spatial patterns Regions I and II contain only kz , so their fields do not change with time at a fixed point. Region IV is also time independent: adding $B_0 \sin kz$ and $B_0 \cos kz$ merely produces another stationary spatial pattern. Spatial variation alone does not establish an electromagnetic wave. Thus options (B), (D) and (A), which refer to I, II and IV respectively, are excluded.

Step 3: Conclusion The electromagnetic wave exists in region III. Hence, the correct option is (C).

Quick Tip to Solve: Look for both position and time in the phase: a sum of sine and cosine terms without time dependence is still static.

8. The momentum (in SI units) associated with a photon of energy 1.5 eV is:

[1 mark]

(A) 4×10^{-27}

(B) 8×10^{-28}

(C) 2×10^{-30}

(D) 6×10^{-29}

Correct Answer: (B) 8×10^{-28}

Solution:

Concept:

- A photon has energy $E = pc$, where p is its momentum and c is the speed of light in vacuum.
- Convert electron volts to joules before using SI values: $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$.

Step 1: Convert the photon energy The given energy is 1.5 eV. Therefore,

$$E = 1.5 \times 1.6 \times 10^{-19} = 2.4 \times 10^{-19} \text{ J.}$$

Step 2: Apply the photon momentum relation Using $c = 3 \times 10^8 \text{ m s}^{-1}$,

$$p = \frac{E}{c} = \frac{2.4 \times 10^{-19}}{3 \times 10^8} = 8 \times 10^{-28} \text{ kg m s}^{-1}.$$

Options (A), (C) and (D) do not equal this value. The massive-particle expression $\sqrt{2mE}$ is inapplicable to a photon, which has zero rest mass.

Step 3: Conclusion The momentum is $8 \times 10^{-28} \text{ kg m s}^{-1}$. Hence, the correct option is (B).

Quick Tip to Solve: Convert eV to joules first, then divide by c ; subtract 8 from the exponent when dividing by 10^8 .

9. An n-type semiconducting Si is obtained by doping intrinsic Si with:

[1 mark]

- (A) Al
- (B) B
- (C) P
- (D) In

Correct Answer: (C) P

Solution:

Concept:

- Silicon is tetravalent: each silicon atom normally forms four covalent bonds with neighbouring atoms.
- A pentavalent donor impurity supplies an extra electron, making electrons the majority charge carriers in an n-type semiconductor.

Step 1: Identify the donor impurity Phosphorus (P) has five valence electrons. When it replaces a silicon atom, four electrons form covalent bonds with neighbouring silicon atoms, leaving the fifth weakly bound. This electron can enter the conduction band, increasing the free-electron concentration.

Step 2: Check the remaining choices Aluminium (Al), boron (B) and indium (In) are trivalent. Each lacks one electron needed to complete four bonds, producing a hole and acting as an acceptor impurity. They produce p-type silicon, so options (A), (B) and (D) cannot yield the required n-type material.

Step 3: Conclusion Intrinsic silicon must be doped with phosphorus (P). Hence, the correct option is (C).

Quick Tip to Solve: For silicon doping, count valence electrons: five gives an electron donor, while three gives a hole-producing acceptor.

10. Energy levels A, B and C of an atom correspond to increasing values of energy i.e. $E_A < E_B < E_C$. Let λ_1 , λ_2 and λ_3 be the wavelengths of radiation corresponding to the transitions C to B, B to A and C to A, respectively. The correct relation between λ_1 , λ_2 and λ_3 is: [1 mark]

(A) $\lambda_1^2 + \lambda_2^2 = \lambda_3^2$

(B) $\frac{1}{\lambda_1} + \frac{1}{\lambda_2} = \frac{1}{\lambda_3}$

(C) $\lambda_1 + \lambda_2 + \lambda_3 = 0$

(D) $\lambda_1 + \lambda_2 = \lambda_3$

Correct Answer: (B) $\frac{1}{\lambda_1} + \frac{1}{\lambda_2} = \frac{1}{\lambda_3}$

Solution:

Concept:

- In an atomic transition, the emitted photon energy equals the energy difference between the initial and final levels.
- Photon energy is $E = hc/\lambda$, where h is Planck's constant, c is the speed of light and λ is wavelength.

Step 1: Write the three transition energies For the transitions specified in the question,

$$E_C - E_B = \frac{hc}{\lambda_1}, \quad E_B - E_A = \frac{hc}{\lambda_2}, \quad E_C - E_A = \frac{hc}{\lambda_3}.$$

All three wavelengths are positive because each transition is from a higher to a lower energy level.

Step 2: Add the successive energy differences The intermediate energy E_B cancels when the first two differences are added:

$$(E_C - E_B) + (E_B - E_A) = E_C - E_A.$$

Substitution and cancellation of hc give the reciprocal-wavelength relation. Since the direct transition releases more energy than either individual transition, λ_3 is smaller than both λ_1 and λ_2 . This excludes the sum and sum-of-squares relations in (D) and (A); positive wavelengths cannot sum to zero as in (C).

Step 3: Conclusion

$$\frac{1}{\lambda_1} + \frac{1}{\lambda_2} = \frac{1}{\lambda_3}.$$

Hence, the correct option is (B).

Quick Tip to Solve: Add energy gaps or reciprocal wavelengths for successive transitions; wavelengths themselves do not add.

11. When a p-n junction diode is subjected to reverse biasing:

[1 mark]

- (A) the barrier height decreases and the depletion region widens.
- (B) the barrier height increases and the depletion region widens.
- (C) the barrier height decreases and the depletion region shrinks.
- (D) the barrier height increases and the depletion region shrinks.

Correct Answer: (B) the barrier height increases and the depletion region widens.

Solution:

Concept:

- Reverse bias connects the p-side to the negative terminal and the n-side to the positive terminal of the external source.
- The reverse-bias electric field supports the built-in junction field, increasing the potential barrier and the width of the depletion layer.

Step 1: Follow the majority carriers The negative terminal attracts holes on the p-side away from the junction, while the positive terminal attracts electrons on the n-side away from it. More immobile ionised acceptors and donors are exposed near the junction, so the region depleted of mobile majority carriers widens.

Step 2: Determine the change in the barrier The external reverse voltage adds to the built-in barrier potential. The barrier therefore becomes higher and opposes majority-carrier diffusion more strongly. Option (A) has the wrong barrier change; (C) describes the two changes associated with forward bias; (D) incorrectly states that the depletion region shrinks.

Step 3: Conclusion The barrier height increases and the depletion region widens under reverse bias. Hence, the correct option is (B).

Quick Tip to Solve: For reverse bias, move both majority carriers away from the junction: the depletion layer gets wider and the barrier gets higher.

12. An alpha particle approaches a gold nucleus in Geiger-Marsden experiment with kinetic energy K . It momentarily stops at a distance d from the nucleus and reverses its direction. Then d is proportional to:

[1 mark]

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

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

Solution:

Concept:

- In a head-on approach to a heavy nucleus, an alpha particle slows down because the electrostatic force between the positive charges is repulsive.
- Conservation of mechanical energy relates its initial kinetic energy to the electrostatic potential energy at the distance of closest approach.

Step 1: Write the energy at the turning point Taking the gold nucleus as effectively stationary, the alpha particle has zero kinetic energy at the turning point. If its initial potential energy far away is negligible, its initial kinetic energy K is converted into potential energy. For charges $2e$ and Ze , with $Z = 79$,

$$K = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{d}.$$

Step 2: Isolate the closest distance Rearranging gives

$$d = \frac{2Ze^2}{4\pi\epsilon_0 K}.$$

The nuclear charge and all other factors in the numerator are fixed. Thus doubling the initial kinetic energy halves the stopping distance. The inverse-square-root relation in (A) is incompatible with this energy equation, and the increasing relations in (B) and (D) predict the opposite physical trend.

Step 3: Conclusion The closest-approach distance obeys $d \propto 1/K$. Hence, the correct option is (C).

Quick Tip to Solve: At a head-on turning point set initial kinetic energy equal to Coulomb potential energy, which varies as $1/d$, not $1/d^2$.

13. Assertion (A): An electron and a proton enter with the same momentum $\vec{p}$ in a magnetic field $\vec{B}$ such that $\vec{p} \perp \vec{B}$. Then both describe a circular path of the same radius.

Reason (R): The radius of the circular path described by the charged particle (charge q , mass m) moving in the magnetic field $\vec{B}$ is given by $r = \frac{mv}{qB}$. [1 mark]

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

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

Solution:

Concept:

- When velocity is perpendicular to a uniform magnetic field, magnetic force supplies the centripetal force and the particle follows a circular path.
- The radius is $r = p/(|q|B)$, where $p = mv$ is momentum magnitude, $|q|$ is charge magnitude and B is magnetic field strength.

Step 1: Evaluate the assertion An electron and a proton have equal charge magnitudes e . Their momentum magnitudes and the field strength are also equal, so

$$r_e = \frac{p}{eB} = r_p.$$

Assertion (A) is true. Their opposite charge signs reverse the direction of curvature, but do not change the radii.

Step 2: Evaluate the reason Equating the magnitudes of magnetic and centripetal forces gives

$$|q|vB = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{|q|B}.$$

In the printed scalar-radius formula, q denotes the magnitude of charge. With this standard convention, Reason (R) is true.

Step 3: Check the explanatory link Replacing mv by the momentum p in the reason directly proves that equal momenta and equal charge magnitudes give equal radii in the same field. The different masses do not alter this result; equal momentum does not mean equal speed. Thus the reason explains the assertion, excluding (B), while (C) and (D) give incorrect truth values.

Step 4: Conclusion Both A and R are true, and R is the correct explanation of A. Hence, the correct option is (A).

Quick Tip to Solve: Rewrite the magnetic radius as $p/(|q|B)$ when momentum is given; charge sign determines bending direction only.

14. Assertion (A): The magnifying power of a compound microscope is negative.

Reason (R): The final image formed is erect with respect to the object.

[1 mark]

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

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

Solution:

Concept:

- In a compound microscope, the objective forms a real, enlarged and inverted intermediate image of the object.
- The eyepiece acts as a magnifier for this intermediate image. The final virtual image retains the intermediate image's orientation and is inverted relative to the original object.

Step 1: Evaluate the assertion Under the signed convention used in the assertion, the microscope's magnifying power is negative because the final image is inverted relative to the original object. The objective has negative linear magnification and the eyepiece has positive angular magnification; their product is negative. Thus Assertion (A) is true.

Step 2: Evaluate the reason The eyepiece produces an image erect relative to its own object, which is the already inverted intermediate image. It does not undo the inversion produced by the objective. Therefore the final image is inverted relative to the original object, so the claim that it is erect is false.

Step 3: Check the explanatory link A false reason cannot explain the true assertion. The negative sign indicates inversion, so calling the final image erect would contradict the sign. Options (A) and (B) incorrectly treat the reason as true, while (D) incorrectly treats the assertion as false.

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

Quick Tip to Solve: Track orientation through both lenses: the objective inverts, and the eyepiece magnifies that inverted image without a second inversion.

15. Assertion (A): Lenz's law is a consequence of the law of conservation of energy.

Reason (R): There is no power loss in an ideal inductor.

[1 mark]

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

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

Solution:

Concept:

- Lenz's law gives the direction of induced current: its magnetic effect opposes the change in magnetic flux that produces it.
- An ideal inductor has zero resistance and stores magnetic energy $U = \frac{1}{2}LI^2$, where L is inductance and I is current, without dissipating it as heat.

Step 1: Judge the assertion Assertion (A) is true. If the induced current aided the change producing it, that change would reinforce the current and supply electrical energy without an external energy input. Opposition requires external work, which supplies the electrical energy, consistently with conservation of energy.

Step 2: Judge the reason Reason (R) is true. For an ideal inductor, resistance is zero, so resistive power loss I^2R is zero. Energy can enter its magnetic field and later be returned; storage is not a power loss.

Step 3: Test the explanatory connection The absence of dissipation in an ideal inductor does not explain the direction of induced current in a general circuit. Lenz's law also applies to resistive circuits. Thus option (A) incorrectly claims an explanation, while (C) and (D) incorrectly reject true statements.

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

Quick Tip to Solve: Separate the direction fixed by Lenz's law from energy loss: an ideal inductor stores and returns energy even though its resistive loss is zero.

16. Assertion (A): Photoelectric current increases with an increase in intensity of incident radiation, for a given frequency of incident radiation and the accelerating potential.

Reason (R): Increase in the intensity of incident radiation results in an increase in the number of photoelectrons emitted per second and hence an increase in the photocurrent. [1 mark]

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

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

Solution:

Concept:

- For incident frequency ν above the threshold, a photon of energy $h\nu$ can liberate a photoelectron; h is Planck's constant.
- At fixed frequency, photon flux is proportional to incident intensity. Photocurrent is $I = e\dot{N}$, where e is the electronic charge magnitude and $\dot{N}$ is the number of electrons collected per second.

Step 1: Judge the assertion Assertion (A) is true in the stated photoelectric-emission situation. With frequency and accelerating potential fixed, increasing light intensity increases the photocurrent because more electrons become available for collection each second.

Step 2: Judge the reason Reason (R) is true. Since each photon still has the same energy $h\nu$, a higher intensity means more photons strike the surface per second. The emission rate of photoelectrons consequently increases, increasing the rate of collected charge.

Step 3: Connect the cause to the observation The increased number of emitted electrons per second directly accounts for the increased current at the given accelerating potential. The reason therefore explains the assertion. Option (B) misses this causal link; options (C) and (D) wrongly declare true statements false. Intensity changes electron number, not the maximum kinetic energy at fixed frequency.

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

Quick Tip to Solve: At fixed frequency, use intensity to track photon number and current; use frequency to track the maximum photoelectron kinetic energy.

Section B (10 marks)

17. An electric field E is maintained in a wire of length ' l ' and area of cross-section ' a '. Derive the relation between the current density ' σ ' in the wire and the electric field E . [2 marks]

Solution:

Concept:

- The printed symbol σ denotes current density in this question, so $\sigma = I/a$, where I is current and a is cross-sectional area. Denote conductivity by κ to avoid confusion.
- In a uniform metallic wire, electrons have drift-speed magnitude $v_d = eE\tau/m$, where e is electronic charge magnitude, m electron mass and τ the mean relaxation time.

Step 1: Express current through electron drift Let n be the number of free electrons per unit volume. In time Δt , electrons in a cylinder of length $v_d\Delta t$ pass through a cross-section. The charge magnitude crossing it is $\Delta Q = neav_d\Delta t$. Therefore,

$$I = \frac{\Delta Q}{\Delta t} = neav_d, \quad \sigma = \frac{I}{a} = nev_d.$$

Step 2: Substitute the drift speed Inserting $v_d = eE\tau/m$ gives the required local relation:

$$\sigma = \frac{ne^2\tau}{m}E = \kappa E, \quad \kappa = \frac{ne^2\tau}{m} = \frac{1}{\rho},$$

where ρ is resistivity. Although electrons drift opposite to the field, conventional current density is along the field. Equivalently, using $V = El$, $R = \rho l/a$ and $I = V/R$ gives $I/a = E/\rho$; the wire's length and area cancel.

Step 3: Conclusion With σ used for current density as printed, $\boxed{\sigma = \kappa E = E/\rho}$. In vector form, $\vec{J} = \kappa \vec{E}$, with $\vec{J}$ parallel to $\vec{E}$.

Quick Tip to Solve: Read the symbol definition first: here sigma is current density, so use a different symbol for conductivity and check the result with $I/a = (El)/(\rho l)$.

18. How does the energy gap of an intrinsic semiconductor effectively change when doped with a (a) trivalent impurity, and (b) pentavalent impurity? Justify your answer in each case. [2 marks]

Solution:

Concept:

- In an intrinsic semiconductor, an electron must acquire the band-gap energy $E_g = E_C - E_V$ to move from the valence-band edge E_V to the conduction-band edge E_C .
- Doping introduces impurity energy levels inside the forbidden gap. These reduce the effective energy needed to create mobile charge carriers, while the host's valence-to-conduction band gap remains approximately unchanged for ordinary dilute doping.

Step 1: Introduce a trivalent impurity A trivalent dopant creates an acceptor energy level E_A just above the valence band. An electron from the valence band can occupy this level after acquiring the small energy $E_A - E_V$, leaving behind a mobile hole. Thus a p-type semiconductor is formed, and the

effective carrier-excitation gap is reduced:

$$E_{\text{eff},p} = E_A - E_V \ll E_g.$$

Holes are the majority carriers because the dopant accepts a valence electron.

Step 2: Introduce a pentavalent impurity A pentavalent dopant creates a donor level E_D just below the conduction band. Its extra, weakly bound electron can enter the conduction band with the small energy $E_C - E_D$. Thus an n-type semiconductor is formed, and the effective carrier-excitation gap is again reduced:

$$E_{\text{eff},n} = E_C - E_D \ll E_g.$$

Electrons are the majority carriers because donors readily supply conduction electrons.

Step 3: Conclusion Both impurities reduce the effective excitation energy: trivalent doping introduces acceptor levels just above the valence band, and pentavalent doping introduces donor levels just below the conduction band. This does not require a comparable reduction of the host band gap $E_C - E_V$.

Quick Tip to Solve: Place acceptors near the valence band and donors near the conduction band; the small distance to the nearest band gives the effective excitation gap.

19(a). Two waves, each of amplitude 'a' and frequency ' ω ' emanating from two coherent sources of light superpose at a point. If the phase difference between the two waves is ϕ , obtain an expression for the resultant intensity at that point. [2 marks]

Solution:

Concept:

- The superposition principle gives the resultant displacement as the sum of the two wave displacements. Coherent sources maintain a constant phase difference ϕ .
- Intensity is proportional to the square of the wave amplitude: $I = KA^2$. Here K is the common proportionality constant and the intensity of either incident wave is $I_0 = Ka^2$.

Step 1: Add the two coherent waves Taking ω as the common angular frequency, write the displacements at the observation point as

$$y_1 = a \sin \omega t, \quad y_2 = a \sin(\omega t + \phi).$$

Apply $\sin u + \sin v = 2 \sin[(u+v)/2] \cos[(u-v)/2]$:

$$y = y_1 + y_2 = 2a \cos \frac{\phi}{2} \sin \left(\omega t + \frac{\phi}{2} \right).$$

The resultant amplitude magnitude is therefore $A = 2a |\cos(\phi/2)|$. The absolute value expresses a nonnegative amplitude; its square is independent of this sign convention.

Step 2: Convert amplitude into intensity Since the two waves and their resultant propagate in the same medium, use the same constant K :

$$\begin{aligned} I &= KA^2 = 4Ka^2 \cos^2 \frac{\phi}{2} \\ &= 4I_0 \cos^2 \frac{\phi}{2} = 2I_0(1 + \cos \phi). \end{aligned}$$

As checks, in-phase waves give $I_{\max} = 4I_0$, whereas waves with phase difference π cancel and give $I_{\min} = 0$. Simply adding the two individual intensities would omit the interference term.

Step 3: Conclusion The resultant intensity is $I = 4I_0 \cos^2(\phi/2) = 2I_0(1 + \cos \phi)$, where $I_0 = Ka^2$ is the intensity of either wave.

Quick Tip to Solve: For equal coherent amplitudes, add the displacements first and square the resultant amplitude; check zero phase and phase π as quick limits.

OR

19(b). What is the effect on the interference pattern in Young's double-slit experiment when (i) the source slit is moved closer to the plane of the slits, and (ii) the separation between the two slits is increased? Justify your answers. [2 marks]

Solution:

Concept:

- In Young's experiment the fringe width is $\beta = \lambda D/d$, where λ is the wavelength, D is the slit-to-screen distance and d is the slit separation.
- A source slit of finite width illuminates the double slit from a range of angles. Its angular width grows when its distance from the double slit decreases, reducing spatial coherence and fringe contrast.

Step 1: Move the source slit closer Let the source slit have fixed width a and lie a distance L from the double slit. Its angular width is approximately a/L . When L decreases, different points across this source produce interference patterns with a greater relative displacement. On superposition the bright and dark bands become less distinct; for a sufficiently close or wide source the fringes can disappear. The geometrical fringe width $\beta = \lambda D/d$ remains unchanged because λ , D and d have not changed. This loss of visibility assumes the usual source slit of finite width; an ideal point source moved along the perpendicular bisector would retain contrast.

Step 2: Increase the separation of the double slit Keep the wavelength and the screen distance fixed. Comparing two slit separations gives

$$\frac{\beta'}{\beta} = \frac{d}{d'}.$$

Thus increasing d makes the fringe spacing smaller: the bright and dark bands crowd closer together. This follows from the larger rate of change of path difference dx/D with screen position x .

Step 3: Conclusion (i) Moving a finite-width source slit closer reduces fringe visibility without changing the fringe width. (ii) Increasing the double-slit separation decreases fringe width, since $\beta \propto 1/d$.

Quick Tip to Solve: Distinguish fringe spacing from visibility: use $\lambda D/d$ for spacing and the source's angular width a/L to discuss contrast.

20. In Bohr model of hydrogen atom, find the ratio of period of revolution of the electron in the orbit $n = 2$ to that in the orbit $n = 1$. [2 marks]

Solution:

Concept:

- For the hydrogen atom in Bohr's model, the allowed orbit radius is $r_n = r_1 n^2$ and the electron speed is $v_n = v_1/n$, where n is the principal quantum number.
- The period of revolution is the distance covered in one circular orbit divided by speed: $T_n = 2\pi r_n/v_n$.

Step 1: Express the orbital period in terms of the orbit number During one revolution the electron covers the circumference $2\pi r_n$. Substituting the Bohr dependences of radius and speed into the period gives

$$T_n = \frac{2\pi(r_1 n^2)}{v_1/n} = \frac{2\pi r_1}{v_1} n^3 = T_1 n^3.$$

The cubic dependence has two contributions: the circumference increases as n^2 , while the lower speed introduces a further factor of n . Hence using only the radius ratio would not give the time ratio.

Step 2: Compare the second and first orbits For $n = 2$, the orbit radius is four times the ground-state radius, whereas the speed is half the ground-state speed. Therefore,

$$\frac{T_2}{T_1} = \frac{r_2}{r_1} \frac{v_1}{v_2} = 4 \times 2 = 8.$$

The ratio is dimensionless, so the numerical values of the Bohr radius and electron speed are unnecessary.

Step 3: Conclusion The required ratio is $T_2 : T_1 = 8 : 1$; the electron takes eight times as long to complete the second orbit.

Quick Tip to Solve: In a hydrogen Bohr orbit, remember $r_n \propto n^2$, $v_n \propto n^{-1}$, and therefore $T_n \propto n^3$.

21. A convex lens ($n = 1.52$) has a focal length of 15.0 cm in air. Find its focal length when it is immersed in liquid of refractive index 1.65. What will be the nature of the lens? [2 marks]

Solution:

Concept:

- The lens-maker formula for a thin lens in a surrounding medium is $1/f = (n_\ell/n_m - 1)(1/R_1 - 1/R_2)$, where n_ℓ and n_m are the lens and medium refractive indices.
- The radii of curvature do not change on immersion. A positive focal length means convergence, while a negative focal length means divergence.

Step 1: Eliminate the fixed curvature factor Denote the focal lengths in air and liquid by f_a and f_m . Taking the refractive index of air as unity, the ratio of the lens-maker equations gives

$$\frac{f_m}{f_a} = \frac{n_\ell - 1}{n_\ell/n_m - 1}.$$

The same curvature factor cancels because immersion changes the optical surroundings, not the shape of the lens. Here $f_a = +15.0$ cm, $n_\ell = 1.52$ and $n_m = 1.65$.

Step 2: Calculate the focal length and interpret its sign Substituting directly, without rounding the relative refractive index prematurely,

$$\begin{aligned}f_m &= 15.0 \frac{1.52 - 1}{1.52/1.65 - 1} \text{ cm} \\&= 15.0 \frac{0.52 \times 1.65}{-0.13} \text{ cm} \\&= -99.0 \text{ cm}.\end{aligned}$$

The liquid is optically denser than the lens material, so the relative index n_ℓ/n_m is less than unity and the power reverses sign. Although its physical shape remains convex, parallel rays emerging from it diverge and have a virtual principal focus.

Step 3: Conclusion The focal length in the liquid is -99.0 cm . The immersed convex lens behaves as a **diverging lens**.

Quick Tip to Solve: Compare the refractive indices first: if the surrounding liquid has the greater index, a convex lens acquires negative power.

Section C (21 marks)

22(a). Two long, straight, parallel conductors carry steady currents in opposite directions. Explain the nature of the force of interaction between them. Obtain an expression for the magnitude of the force between the two conductors. Hence define one ampere. [3 marks]

Solution:

Concept:

- A long straight wire carrying current I_1 produces a magnetic field $B_1 = \mu_0 I_1 / (2\pi d)$ at a perpendicular distance d in vacuum.
- A straight length ℓ carrying current I_2 in a magnetic field experiences $\vec{F} = I_2 \vec{\ell} \times \vec{B}$. Its magnitude is $I_2 \ell B$ when the wire is perpendicular to the field.

Step 1: Determine the direction of the interaction Place wire 1 to the left of wire 2, with current I_1 upward and current I_2 downward. By the right-hand thumb rule, the magnetic field of wire 1 at wire 2 points into the page. Applying $\vec{F}_2 = I_2 \vec{\ell} \times \vec{B}_1$ gives a force on wire 2 towards the right, away from wire 1. Likewise, wire 1 experiences a force towards the left. Thus opposite parallel currents repel, with equal and opposite forces.

Step 2: Obtain the force on a length of the second conductor Let the perpendicular separation be d and neglect end effects because the wires are long. At wire 2 the field of wire 1 is perpendicular to

the current, so

$$B_1 = \frac{\mu_0 I_1}{2\pi d},$$

$$F_2 = I_2 \ell B_1 = \frac{\mu_0 I_1 I_2 \ell}{2\pi d},$$

$$\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi d}.$$

Interchanging the two wires gives the same magnitude for the force on an equal length of wire 1. For indefinitely long conductors the useful finite quantity is force per unit length.

Step 3: State the force-based definition of one ampere In the traditional force-based definition used with this derivation, one ampere is that constant current which, when maintained in each of two straight, parallel conductors of infinite length and negligible circular cross-section, placed 1 m apart in vacuum, produces a force of 2×10^{-7} N per metre between them. Substitution of $I_1 = I_2 = 1$ A and $d = 1$ m gives

$$\frac{F}{\ell} = \frac{4\pi \times 10^{-7}}{2\pi} = 2 \times 10^{-7} \text{ N m}^{-1}.$$

The defining force magnitude is the same for attraction or repulsion; opposite currents give the repulsive case here.

Step 4: Conclusion The conductors repel. For a common length ℓ , $F = \mu_0 I_1 I_2 \ell / (2\pi d)$. Equal currents of one ampere at one metre separation in vacuum give 2×10^{-7} N of force per metre in the traditional definition.

Quick Tip to Solve: First find the field of one wire at the other, then use $I\ell B$. Parallel currents attract; antiparallel currents repel.

OR

22(b). Obtain an expression for the torque $\vec{\tau}$ acting on a current carrying loop in a uniform magnetic field $\vec{B}$. Draw the necessary diagram. [3 marks]

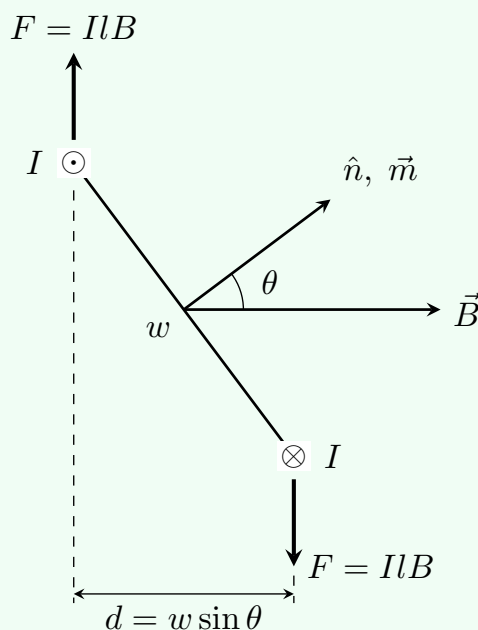
Solution:

Concept:

- A straight conductor carrying current I in a uniform magnetic field experiences $\vec{F} = I\vec{l} \times \vec{B}$, where $\vec{l}$ points along the current.
- The magnetic moment of a plane loop is $\vec{m} = IA\hat{n}$, where A is its area and $\hat{n}$ is fixed by the right-hand rule for the current.

Step 1: Choose a rectangular loop and define the angle Consider a rectangular loop of length l , width w , and area $A = lw$. Let θ be the angle between its normal $\hat{n}$ and $\vec{B}$. Choose the two sides of length l perpendicular to $\vec{B}$. The diagram is an end view along these sides: the loop appears as a line of length w . A dot denotes current towards the viewer and a cross denotes current away from the viewer.

Step 2: Identify the force couple and its arm Each of the two length- l sides experiences a force of magnitude $F = IlB$. Their currents are opposite, so these forces are equal and opposite. Their lines of action are separated by the perpendicular distance $d = w \sin \theta$, as shown. Thus they form a couple. The forces on the other two sides are also equal and opposite; they act along the direction of these length- l sides and produce no net torque about the loop's centre. The total force on the closed loop is zero in a uniform field.



End view along the length- l sides: equal opposite magnetic forces form a couple.

Step 3: Calculate the torque and write its vector form The torque of a couple equals either force multiplied by the perpendicular separation of its lines of action:

$$\tau = Fd = (IlB)(w \sin \theta) = IAB \sin \theta.$$

Its direction, obtained from $\vec{r} \times \vec{F}$, is the direction of $\hat{n} \times \vec{B}$. It tends to align the loop's magnetic moment with the field. Hence the vector expression is $\vec{\tau} = IA\hat{n} \times \vec{B}$. For N identical turns, the torques add and the magnetic moment becomes $\vec{m} = NIA\hat{n}$. The same area-vector result holds for a plane loop of any shape, by adding the torques of infinitesimal area elements.

Step 4: Conclusion $\boxed{\vec{\tau} = \vec{m} \times \vec{B}}$, with $\vec{m} = IA\hat{n}$ for one turn; thus $\tau = IAB \sin \theta$. For N turns, $\tau = N IAB \sin \theta$. Torque is zero when the normal is parallel to the field and maximum when it is perpendicular to the field.

Quick Tip to Solve: Measure θ from the loop's normal, not its plane; then the couple arm is $w \sin \theta$ and the torque follows immediately.

23. (a) On what factors does the speed of an electromagnetic wave in a medium depend?
 (b) How is an electromagnetic wave produced?
 (c) Sketch a schematic diagram depicting the electric and magnetic fields for an electromagnetic wave propagating along z-axis. [3 marks]

Solution:

Concept:

- In a homogeneous, isotropic medium, electromagnetic waves travel at $v = 1/\sqrt{\mu\epsilon}$, where μ and ϵ are the medium's permeability and permittivity.
- An electromagnetic wave is transverse: $\vec{E}$, $\vec{B}$ and the direction of propagation are mutually perpendicular, with propagation along $\vec{E} \times \vec{B}$.

Step 1: (a) State the factors determining the speed The speed depends on the electric permittivity ϵ and magnetic permeability μ of the medium. In terms of their relative values,

$$v = \frac{1}{\sqrt{\mu\epsilon}} = \frac{c}{\sqrt{\mu_r\epsilon_r}}, \quad c = \frac{1}{\sqrt{\mu_0\epsilon_0}}.$$

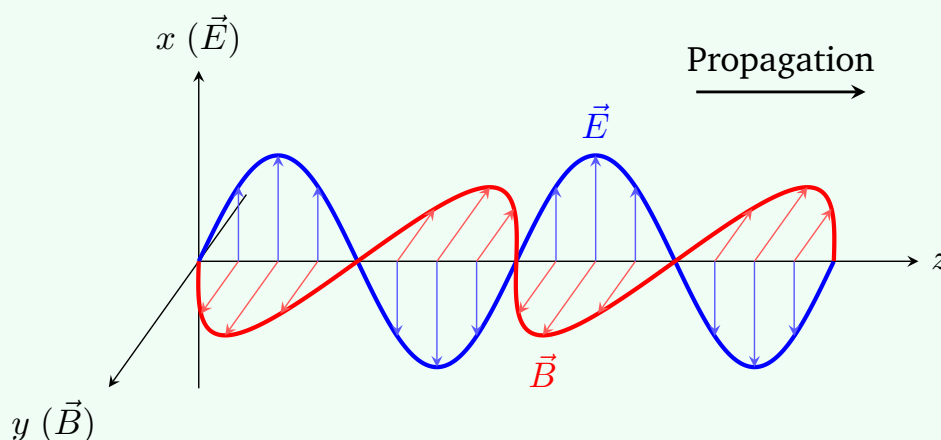
Thus the material's electric and magnetic response determines the speed. In vacuum it is c ; in a non-magnetic medium, $\mu_r \simeq 1$, giving $v \simeq c/\sqrt{\epsilon_r}$.

Step 2: (b) Explain how the wave is produced An accelerated electric charge produces electromagnetic radiation. For example, an oscillating charge in an antenna sets up a time-varying electric field. A changing electric field is associated with a magnetic field, and a changing magnetic field induces an electric field. The coupled disturbances propagate away from the source as an electromagnetic wave, carrying energy. Charges at rest or moving uniformly do not radiate in this way, and no material medium is required for propagation.

Step 3: (c) Represent a wave travelling along the positive z-axis Choose the electric field along the x -axis and the magnetic field along the y -axis, so that $\hat{x} \times \hat{y} = \hat{z}$. One possible plane wave is

$$\begin{aligned} \vec{E}(z, t) &= E_0 \sin(kz - \omega t) \hat{x}, \\ \vec{B}(z, t) &= B_0 \sin(kz - \omega t) \hat{y}, \quad \frac{E_0}{B_0} = v. \end{aligned}$$

Here k is the wave number and ω is the angular frequency. The fields reach maxima and zeros at the same positions and times: they are in phase. The sketch is a spatial snapshot; the two field amplitudes use separate schematic scales.



In-phase transverse fields for propagation along $+z$; amplitudes are schematic.

Step 4: Conclusion The wave speed is $v = 1/\sqrt{\mu\epsilon}$. Accelerated charges produce electromagnetic waves. For propagation along $+z$, the electric and magnetic fields may oscillate along x and y , respectively, in phase and perpendicular to each other.

Quick Tip to Solve: For a wave along $+z$, choose $\vec{E} \parallel \hat{x}$ and $\vec{B} \parallel \hat{y}$; check $\hat{x} \times \hat{y} = \hat{z}$ and align their peaks and zeros.

24. An ac voltage $v_i = 140 \sin(100\pi t)$ V is applied to the primary coil having 200 turns, of an ideal transformer and it supplies a power of 5 kW. If the secondary coil has 1000 turns, find:

- (a) the output voltage,
(b) the instantaneous voltage across the secondary coil, and
(c) the current in the secondary coil. (Take $\sqrt{2} = 1.4$)

[3 marks]

Solution:

Concept:

- For an ideal transformer, the secondary-to-primary voltage ratio equals the turns ratio: $V_s/V_p = N_s/N_p$. This holds for both rms values and peak values.
- A sinusoidal voltage of peak value V_0 has rms value $V = V_0/\sqrt{2}$. An ideal transformer conserves power, so $P_s = P_p$; using the usual resistive-load convention, $P_s = V_s I_s$.

Step 1: (a) Calculate the rms output voltage The coefficient of the sine in $v_i = 140 \sin(100\pi t)$ V is the peak primary voltage, not its rms value. With the given approximation $\sqrt{2} = 1.4$,

$$V_p = \frac{140}{1.4} = 100 \text{ V}, \quad \frac{N_s}{N_p} = \frac{1000}{200} = 5.$$

The secondary has more turns, so this is a step-up transformer. Its rms output is

$$V_s = 5V_p = 5(100) = 500 \text{ V}.$$

Step 2: (b) Write the instantaneous secondary voltage The frequency is unchanged by the transformer. The secondary peak voltage is $V_{s0} = 5(140) = 700$ V, while the angular frequency remains $100\pi \text{ rad s}^{-1}$. Taking the secondary terminal polarity corresponding to the given primary voltage,

$$v_s(t) = 700 \sin(100\pi t) \text{ V}.$$

Thus the output has the same sinusoidal time dependence, with its amplitude multiplied by the turns ratio.

Step 3: (c) Use power conservation to find the current With no transformer losses, the secondary receives the supplied power $5 \text{ kW} = 5000 \text{ W}$. On the unity-power-factor load assumption implicit in this numerical question, use rms voltage with rms current:

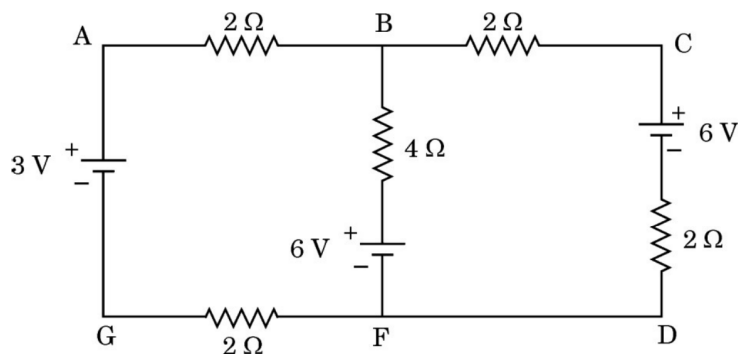
$$I_s = \frac{P_s}{V_s} = \frac{5000}{500} = 10 \text{ A}.$$

A consistency check gives $I_p = 5000/100 = 50$ A, so the fivefold voltage rise accompanies a fivefold current reduction. If a non-unity load power factor were intended, it would need to be specified to determine the current.

Step 4: Conclusion (a) The rms output voltage is 500 V. (b) The instantaneous secondary voltage is $700 \sin(100\pi t)$ V. (c) The rms secondary current is 10 A, assuming unity load power factor.

Quick Tip to Solve: First divide the sine coefficient by the given $\sqrt{2}$ to get rms voltage; use rms values, not peak values, in the power calculation.

25. The figure shows a circuit with three ideal batteries. Find the magnitude and direction of currents in the branches AG, BF and CD. [3 marks]



Solution:

Concept:

- Kirchhoff's junction rule: the algebraic sum of currents leaving a junction is zero.
- Kirchhoff's loop rule: the net potential change around a loop is zero. A battery gives a drop from positive to negative, and a resistor gives a drop IR along the current.

Step 1: Choose common nodes and reference directions F and D are equipotential. Set $V_F = V_D = 0$, and write $V_B = V$. Along B-A-G-F, B-F, and B-C-D-F choose currents i_1, i_2, i_3 from B towards F along these paths. Their reference directions in the requested branches are A to G, B to F, and C to D, respectively.

Step 2: Express the branch currents using the loop rule Each path has total resistance 4Ω : the left and right paths each contain two series 2Ω resistors. Traversing from B to F crosses every battery from positive to negative; the drops are respectively $3V$, $6V$, and $6V$. Hence, in SI units,

$$i_1 = \frac{V - 3}{4}, \quad i_2 = \frac{V - 6}{4}, \quad i_3 = \frac{V - 6}{4}.$$

Step 3: Apply the junction rule and interpret signs Since the three chosen reference currents all leave B, the junction rule is $i_1 + i_2 + i_3 = 0$. Substitution gives

$$\frac{V - 3}{4} + \frac{V - 6}{4} + \frac{V - 6}{4} = 0 \Rightarrow 3V = 15 \Rightarrow V = 5V.$$

Hence

$$i_1 = \frac{5 - 3}{4} = 0.50 \text{ A}, \quad i_2 = i_3 = \frac{5 - 6}{4} = -0.25 \text{ A}.$$

The negative signs reverse the assumed directions in the middle and right branches. The check at B is $0.25 + 0.25 = 0.50 \text{ A}$.

Step 4: Conclusion In AG, the current is 0.50 A from A to G. In BF, it is 0.25 A from F to B. In CD, it is 0.25 A from D to C.

Quick Tip to Solve: View the network as three paths between B and F; each path has 4Ω , and the identical $6V$ paths carry equal currents.

26. (a) Briefly discuss three characteristics of the forces between nucleons.

(b) Which out of 8_4X and 5_3Y nuclei is more stable and why?

[3 marks]

Solution:

Concept:

- The nuclear force acts between nucleons, namely protons and neutrons, and binds them within a nucleus despite the electrostatic repulsion between protons.
- For a nucleus A_ZX , the proton number is Z and the neutron number is $N = A - Z$. Light nuclei generally favour N/Z close to unity; pairing also favours even proton and neutron numbers.

Step 1: (a) State three characteristics of the nuclear force **Short range:** The nuclear force is appreciable only over separations of a few femtometres, with $1 \text{ fm} = 10^{-15} \text{ m}$. It falls rapidly and is negligible at ordinary atomic distances, so each nucleon interacts strongly mainly with nearby nucleons.

Attractive with a repulsive core: At typical nucleon separations the attraction is very strong and can overcome the Coulomb repulsion between protons. At extremely small separations, however, the force becomes strongly repulsive; this prevents nucleons from collapsing onto one another.

Approximately charge independent: After separating out the electromagnetic interaction, the nuclear interaction between proton-proton, neutron-neutron and proton-neutron pairs is approximately the same for comparable nuclear states. It is not an electrostatic force and therefore acts on neutral neutrons as well.

Step 2: (b) Compare neutron and proton numbers For the first printed nucleus, 8_4X ,

$$Z_X = 4, \quad N_X = 8 - 4 = 4, \quad \frac{N_X}{Z_X} = 1.$$

For the second nucleus, 5_3Y ,

$$Z_Y = 3, \quad N_Y = 5 - 3 = 2, \quad \frac{N_Y}{Z_Y} = \frac{2}{3}.$$

For these light nuclei, equal neutron and proton numbers give the more favourable neutron-proton balance. X has this balance, whereas Y is proton rich. X also has both even neutron and even proton numbers, so pairing provides an additional favourable feature. These criteria establish the expected relative comparison; they do not assert that X is absolutely stable against every possible decay.

Step 3: Conclusion Nuclear forces are short ranged, strongly attractive at ordinary nuclear separations with a repulsive core, and approximately charge independent. Of the two printed nuclei, 8_4X is more stable because $N/Z = 1$, with even neutron and proton numbers, whereas 5_3Y has $N/Z = 2/3$.

Quick Tip to Solve: Read the superscript as A and the subscript as Z ; calculate $N = A - Z$ before comparing the neutron-to-proton ratios of light nuclei.

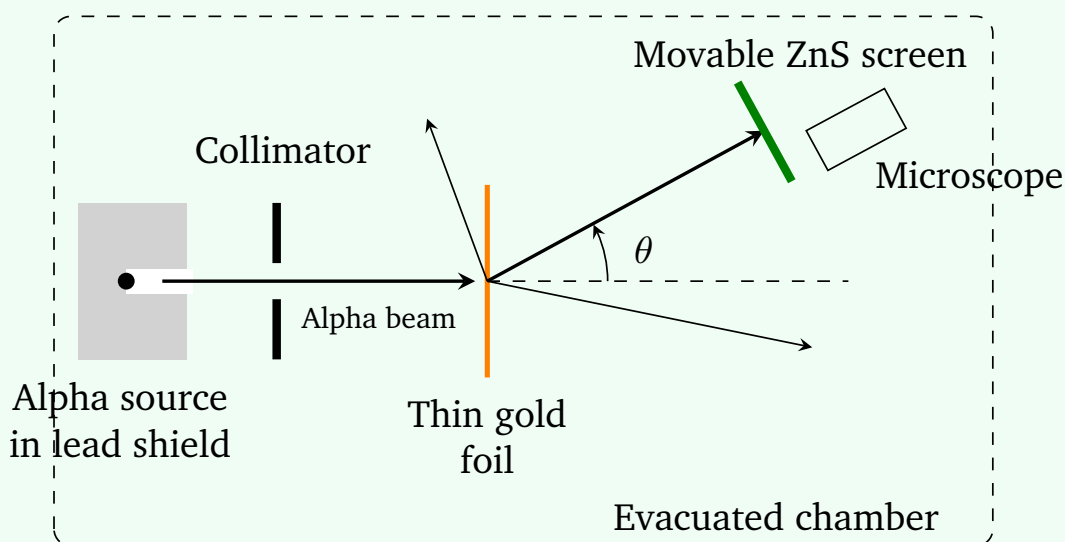
27. Draw a schematic arrangement of Geiger-Marsden experiment. Briefly explain the conclusions drawn from the observations about the structure of an atom. Define ‘distance of closest approach’ in this case. [3 marks]

Solution:

Concept:

- A positively charged alpha particle is repelled by the positive nuclear charge. Its scattering therefore probes the distribution of charge and mass within an atom.
- For a head-on approach, conservation of energy gives $K = (4\pi\epsilon_0)^{-1}(2Ze^2/r_0)$, where K is the initial kinetic energy, Ze is the nuclear charge and r_0 is the closest separation, neglecting nuclear recoil.

Step 1: Arrange the source, foil and detector Place a radioactive alpha source inside a lead shield with a narrow aperture. A collimator produces a narrow beam incident on a very thin gold foil in an evacuated chamber. A movable zinc sulphide (ZnS) screen, observed with a microscope, detects the scattered alpha particles through scintillations. Moving the detector around the foil measures scattering at different angles.



Schematic Geiger–Marsden arrangement; the detector moves around the gold foil.

Step 2: Connect each observation to atomic structure Most alpha particles pass through the foil without appreciable deflection: most of an atom is empty space. A small fraction undergo small deflections because of electrostatic repulsion. Very few are deflected through large angles, and an extremely small fraction rebound: nearly all the atomic mass and all the positive charge are concentrated in a tiny, dense nucleus. Electrons occupy the surrounding region; the nucleus is much smaller than the atomic radius.

Step 3: Define the distance of closest approach The distance of closest approach is the minimum distance between the centre of an alpha particle and the centre of the nucleus during a head-on encounter. At that point the alpha particle is momentarily at rest before reversing direction, so its initial kinetic energy has become electrostatic potential energy:

$$K = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{r_0}, \quad r_0 = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{K}.$$

The initial potential energy is taken as zero far from the nucleus. This turning-point distance is not, in general, the nuclear radius.

Step 4: Conclusion The experiment establishes an atom with a tiny, massive, positively charged nucleus and a largely empty surrounding region. For head-on alpha scattering, $r_0 = (4\pi\epsilon_0)^{-1}2Ze^2/K$.

Quick Tip to Solve: Link straight-through particles to empty space and rare backward scattering to a tiny massive nucleus; define closest approach using a head-on trajectory.

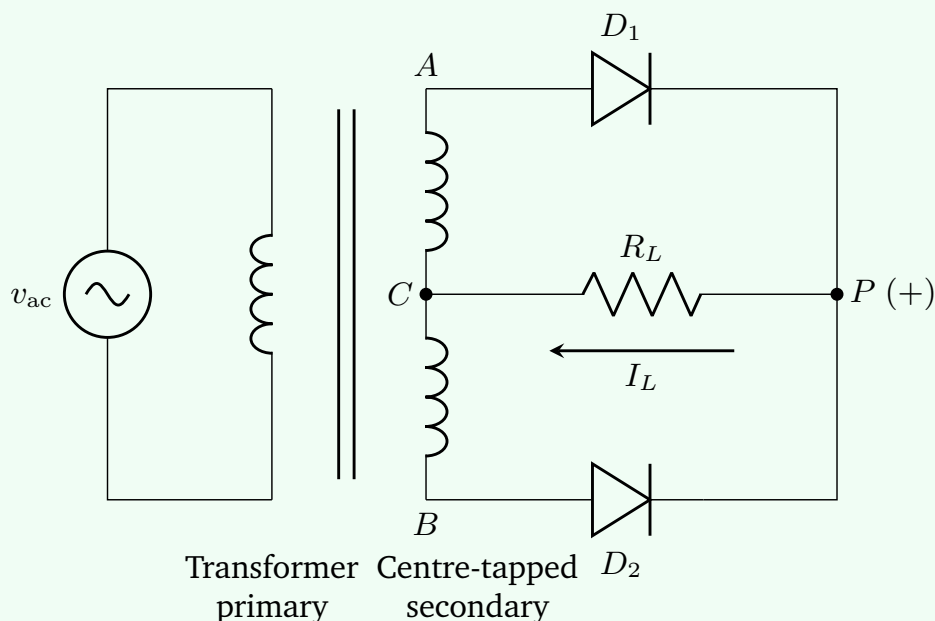
28. With the help of a circuit diagram, explain the working of a p-n junction diode as a full wave rectifier. Draw its input and output waveforms. [3 marks]

Solution:

Concept:

- A p-n junction diode conducts when forward biased and blocks when reverse biased. Rectification converts alternating voltage into a unidirectional output.
- A centre-tapped transformer provides equal secondary voltages of opposite phase relative to its centre tap C . Two diodes use alternate half-cycles to send current through a load R_L in the same direction.

Step 1: Connect the full-wave rectifier Connect the anodes of diodes D_1 and D_2 to the secondary ends A and B , respectively. Join their cathodes at output terminal P . Connect the load resistance R_L between P and the centre tap C . The AC supply is applied to the transformer primary. The output is the voltage of P relative to C .



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

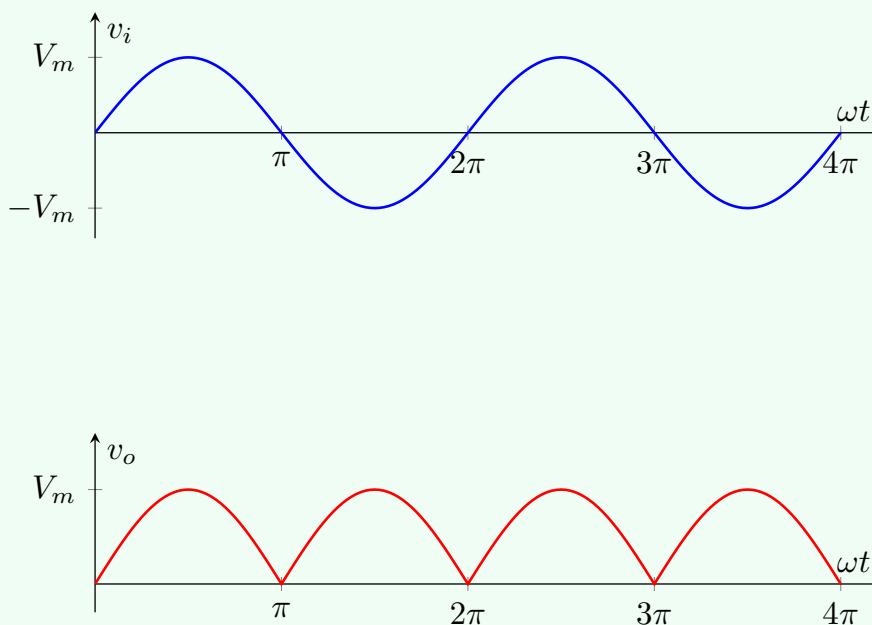
Step 2: Follow the positive half-cycle When A is positive relative to C , B is negative. Diode D_1 is forward biased and conducts, whereas D_2 is reverse biased. Current flows through A , D_1 , P , the load and C , returning through the upper half of the secondary. The load current therefore flows from P towards C .

Step 3: Follow the negative half-cycle and draw the waveforms In the next half-cycle, B is positive and A is negative relative to C . Diode D_2 conducts and D_1 blocks. The path is now B , D_2 , P , the

load and C , returning through the lower half of the secondary. Again the load current flows from P towards C . Thus both half-cycles contribute to a positive output. For ideal diodes, if the voltage of A relative to C is $v_i = V_m \sin \omega t$, then

$$v_o = V_m |\sin \omega t|.$$

The output is pulsating DC; its ripple frequency is twice the input frequency. A real diode reduces the output peak by its forward voltage drop, but does not change the direction of load current.



Input voltage across one half-secondary and ideal rectified output across the load.

Step 4: Conclusion The two diodes conduct alternately, maintaining the same current direction through R_L . Both input half-cycles produce positive output pulses, giving full-wave rectification with output pulse frequency $2f$.

Quick Tip to Solve: Trace each conducting path through the load: it must run from the joined cathodes to the centre tap during both half-cycles.

Section D (8 marks)

Case Study Based Questions

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

29. When a ray of light propagates from a denser medium to a rarer medium, it bends away from the normal. When the incident angle is increased, the refracted ray deviates more from the normal. For a particular angle of incidence in the denser medium, the refracted ray just grazes the interface of the two surfaces. This angle of incidence is called the critical angle for the pair of media involved.

[4 marks]

29(i). For a ray incident at the critical angle, the angle of reflection is:

[1 mark]

- (A) 0°
- (B) $< 90^\circ$
- (C) $> 90^\circ$
- (D) 90°

Correct Answer: (B) $< 90^\circ$

Solution:

Concept:

- The law of reflection gives $r = i$, with both angles measured from the normal to the interface.
- The critical angle C for propagation from a denser to a rarer medium satisfies $\sin C = n_r/n_d$, where $n_d > n_r > 0$; hence $0 < C < 90^\circ$.

Step 1: Distinguish reflection from refraction At critical incidence, the refracted ray grazes the interface, so its angle of refraction is 90° . This does not make the reflected angle 90° : the reflected ray still obeys the law of reflection.

Step 2: Apply the reflection law at critical incidence Since $i = C$, the reflected angle is $r = C$. The index ratio is strictly between zero and one, so r is less than 90° . Option (A) would require normal incidence; (C) cannot be the reflected angle measured from the normal; (D) confuses the refracted and reflected angles.

Step 3: Conclusion The angle of reflection equals the critical angle and is $< 90^\circ$. Hence, the correct option is (B).

Quick Tip to Solve: At critical incidence, attach 90° to the refracted ray only; the reflected angle remains equal to the incident angle.

29(ii). A ray of light of wavelength 600 nm is incident in water $\left(n = \frac{4}{3}\right)$ on the water-air interface at an angle less than the critical angle. The wavelength associated with the refracted ray is: [1 mark]

- (A) 400 nm
- (B) 450 nm
- (C) 600 nm
- (D) 800 nm

Correct Answer: (D) 800 nm

Solution:

Concept:

- Frequency f remains unchanged across a stationary refracting interface, while speed and wavelength obey $v = f\lambda$.
- Refractive index is $n = c/v$, so for fixed frequency $n\lambda$ is constant. Take the refractive index of air as unity.

Step 1: Identify the wavelength in the incident medium The incident ray is in water, so the given wavelength is $\lambda_w = 600$ nm. On entering air the light travels faster, while its frequency stays the same; its wavelength must therefore increase. Incidence below the critical angle permits a refracted ray in air.

Step 2: Apply the wavelength ratio From $n_w\lambda_w = n_a\lambda_a$,

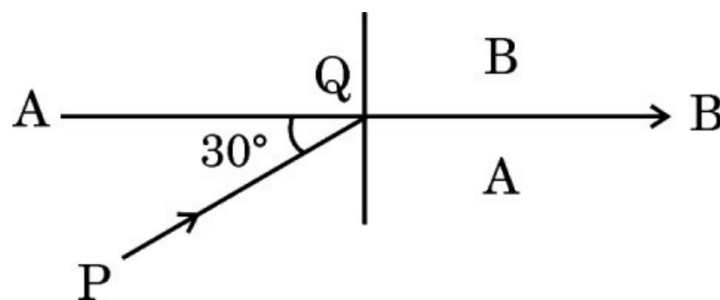
$$\lambda_a = \frac{n_w}{n_a}\lambda_w = \frac{4}{3} \times 600 \text{ nm} = 800 \text{ nm}.$$

The values in (A) and (B) decrease the wavelength, contrary to the increase in speed. Option (C) incorrectly keeps wavelength fixed; frequency, rather than wavelength, is conserved on refraction.

Step 3: Conclusion The wavelength of the refracted ray in air is 800 nm. Hence, the correct option is (D).

Quick Tip to Solve: When light passes from water to air, multiply its wavelength in water by the refractive index of water, since frequency stays fixed.

29(iii)(a). The interface AB between the two media A and B is shown in the figure. In the denser medium A, the incident ray PQ makes an angle of 30° with the horizontal. The refracted ray is parallel to the interface. The refractive index of medium B w.r.t. medium A is: [1 mark]



- (A) $\frac{\sqrt{3}}{2}$
- (B) $\frac{\sqrt{5}}{2}$
- (C) $\frac{4}{\sqrt{3}}$
- (D) $\frac{2}{\sqrt{3}}$

Correct Answer: (A) $\frac{\sqrt{3}}{2}$

Solution:

Concept:

- Snell's law gives $n_A \sin i = n_B \sin r$, where the angles are measured from the normal.
- The refractive index of B relative to A is $n_{BA} = n_B/n_A$. At the critical angle, $r = 90^\circ$.

Step 1: Read the incidence angle from the figure The marked angle of 30° is between the incident ray and the horizontal interface. The normal is perpendicular to that interface, so the angle of incidence is

$$i = 90^\circ - 30^\circ = 60^\circ.$$

The refracted ray travels along the interface, making 90° with the normal.

Step 2: Apply Snell's law and check the ratios Putting $r = 90^\circ$ in Snell's law gives

$$\frac{n_B}{n_A} = \frac{\sin 60^\circ}{\sin 90^\circ} = \frac{\sqrt{3}}{2}.$$

Since B is optically rarer than A, this ratio must be less than one. Each of options (B), (C) and (D) is greater than one and therefore cannot represent B relative to A.

Step 3: Conclusion The refractive index of B with respect to A is $\sqrt{3}/2$. Hence, the correct option is (A).

Quick Tip to Solve: Convert an angle measured from the interface to its complement before applying Snell's law.

29(iii)(b). Two media A and B are separated by a plane boundary. The speed of light in medium A and B is $2 \times 10^8 \text{ ms}^{-1}$ and $2.5 \times 10^8 \text{ ms}^{-1}$ respectively. The critical angle for a ray of light going from medium A to medium B is: [1 mark]

- (A) $\sin^{-1} \frac{1}{2}$
 (B) $\sin^{-1} \frac{4}{5}$
 (C) $\sin^{-1} \frac{3}{5}$
 (D) $\sin^{-1} \frac{2}{5}$

Correct Answer: (B) $\sin^{-1} \frac{4}{5}$

Solution:

Concept:

- The absolute refractive index is $n = c/v$, where v is the speed in the medium and c is the vacuum speed.
- For propagation from denser A to rarer B, the critical angle C satisfies $\sin C = n_B/n_A = v_A/v_B$.

Step 1: Identify the denser medium The speed in A is $2.0 \times 10^8 \text{ m s}^{-1}$, lower than the speed $2.5 \times 10^8 \text{ m s}^{-1}$ in B. Thus $n_A > n_B$, so a critical angle exists for light travelling from A to B.

Step 2: Evaluate the speed ratio At critical incidence, the refracted ray makes 90° with the normal. Hence

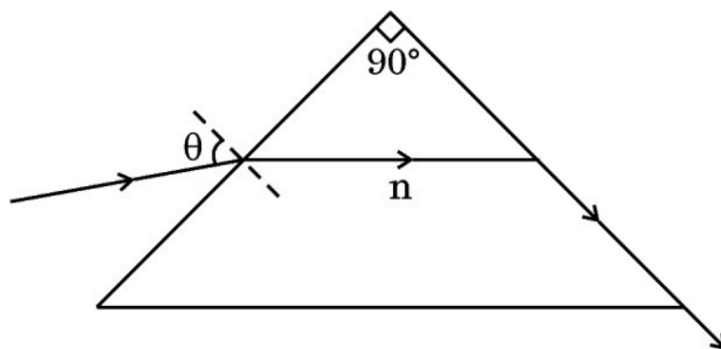
$$\sin C = \frac{n_B}{n_A} = \frac{2.0 \times 10^8}{2.5 \times 10^8} = \frac{4}{5}.$$

The common power of ten cancels. Options (A), (C) and (D) use ratios $1/2$, $3/5$ and $2/5$, respectively, none of which equals the required speed ratio.

Step 3: Conclusion The critical angle is $C = \sin^{-1}(4/5)$. Hence, the correct option is (B).

Quick Tip to Solve: For a critical angle, divide the smaller speed in the denser medium by the larger speed in the rarer medium.

29(iv). The figure shows the path of a light ray through a triangular prism. In this phenomenon, the angle θ is given by: [1 mark]



(A) $\sin^{-1} \sqrt{n^2 - 1}$

(B) $\sin^{-1}(n^2 - 1)$

(C) $\sin^{-1} \left[\frac{1}{\sqrt{n^2 - 1}} \right]$

(D) $\sin^{-1} \left[\frac{1}{(n^2 - 1)} \right]$

Correct Answer: (A) $\sin^{-1} \sqrt{n^2 - 1}$

Solution:

Concept:

- Inside a prism, the refracted angle at the first face and incidence angle at the second satisfy $r_1 + r_2 = A$, where A is the prism angle.
- For a prism of refractive index n in air, grazing emergence means $n \sin r_2 = 1$; entry refraction gives $\sin \theta = n \sin r_1$.

Step 1: Use the grazing ray at the second face The outgoing ray lies along the second face, so its angle to the normal is 90° . Thus the internal angle r_2 is critical:

$$\sin r_2 = \frac{1}{n}.$$

The marked prism angle is 90° , giving $r_1 = 90^\circ - r_2$. The external angle θ in the figure is measured from the normal at the first face.

Step 2: Apply refraction at the first face Using $\sin r_1 = \cos r_2$, we obtain

$$\begin{aligned} \sin \theta &= n \cos r_2 \\ &= n \sqrt{1 - \sin^2 r_2} \\ &= n \sqrt{1 - \frac{1}{n^2}} = \sqrt{n^2 - 1}. \end{aligned}$$

Option (B) omits the square root, while (C) and (D) introduce reciprocals that do not follow from Snell's law. The depicted path requires $\sqrt{n^2 - 1} \leq 1$, as expected for a real incident angle.

Step 3: Conclusion The incident angle is $\theta = \sin^{-1} \sqrt{n^2 - 1}$. Hence, the correct option is (A).

Quick Tip to Solve: Work backwards from the grazing emergent ray: find the critical angle, use the prism angle, then apply refraction at entry.

30. When the terminals of a cell are connected to a conductor of resistance R , an electric current flows through the circuit. The electrolyte of the cell also offers some resistance in the path of the current, like the conductor. This resistance offered by the electrolyte is called internal resistance of the cell (r). It depends upon the nature of the electrolyte, the area of the electrodes immersed in the electrolyte and the temperature. Due to internal resistance, a part of the energy supplied by the cell is wasted in the form of heat.

When no current is drawn from the cell, the potential difference between the two electrodes is known as emf of the cell (ε). With a current drawn from the cell, the potential difference between the two electrodes is termed as terminal potential difference (V). [4 marks]

30(i). Choose the incorrect statement: [1 mark]

- (A) The potential difference (V) between the two terminals of a cell in a closed circuit is always less than its emf (ε), during discharge of the cell.
- (B) The internal resistance of a cell decreases with the decrease in temperature of the electrolyte.
- (C) When current is drawn from the cell then $V = \varepsilon - Ir$.
- (D) The graph between potential difference between the two terminals of the cell (V) and the current (I) through it is a straight line with a negative slope.

Correct Answer: (B) The internal resistance of a cell decreases with the decrease in temperature of the electrolyte.

Solution:

Concept:

- For a discharging cell, $V = \varepsilon - Ir$, where ε is its emf, I is the current and r is its internal resistance.
- In the usual electrolyte model, increasing temperature increases ionic mobility and reduces the internal resistance.

Step 1: Check the electrical statements For a cell delivering a nonzero current with finite internal resistance, the internal drop Ir is positive. Therefore $V < \varepsilon$, so statement (A) is correct. Statement (C) is exactly the discharge relation. With r constant, a plot of V against I is a straight line with intercept ε and negative slope $-r$, so statement (D) is also correct.

Step 2: Check the temperature statement Cooling the electrolyte reduces ionic mobility, making it harder for current to pass through the cell. Its internal resistance therefore increases as temperature decreases, rather than decreasing as claimed in statement (B). Since the question asks for the incorrect statement, the temperature claim is the one to select.

Step 3: Conclusion Statement (B) reverses the temperature dependence of the electrolyte resistance. Hence, the correct option is (B).

Quick Tip to Solve: For an electrolyte, remember that warming usually aids ion motion and lowers resistance; check the word "incorrect" before choosing.

30(ii). Two cells of emfs 2.0 V and 6.0 V and internal resistances 0.1 Ω and 0.4 Ω respectively, are connected in parallel. The equivalent emf of the combination will be: [1 mark]

- (A) 2.0 V
- (B) 2.8 V
- (C) 6.0 V
- (D) 8.0 V

Correct Answer: (B) 2.8 V

Solution:

Concept:

- For cells joined in parallel with like terminals together, their equivalent emf is $\varepsilon_{\text{eq}} = (\varepsilon_1/r_1 + \varepsilon_2/r_2)/(1/r_1 + 1/r_2)$.
- This emf is the open-circuit terminal voltage; each emf is weighted by its internal conductance $1/r$.

Step 1: Set up the parallel-cell expression The given emfs are $\varepsilon_1 = 2.0 \text{ V}$ and $\varepsilon_2 = 6.0 \text{ V}$, with $r_1 = 0.1 \Omega$ and $r_2 = 0.4 \Omega$. For the usual parallel connection of like poles, multiply the numerator and denominator by $r_1 r_2$:

$$\varepsilon_{\text{eq}} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}.$$

Step 2: Substitute and compare the options On substitution,

$$\varepsilon_{\text{eq}} = \frac{2.0(0.4) + 6.0(0.1)}{0.1 + 0.4} = \frac{1.4}{0.5} = 2.8 \text{ V}.$$

The result lies between the two emfs and is nearer 2.0 V, whose internal resistance is smaller. Options (A) and (C) ignore the other cell. Option (D), 8.0 V, adds the emfs as for a series aiding connection.

Step 3: Conclusion The equivalent emf is 2.8 V. Hence, the correct option is (B).

Quick Tip to Solve: For unequal cells in parallel, cross-multiply each emf by the other cell resistance; do not add the emfs.

30(iii). Dipped in the solution, the electrode exchanges charges with the electrolyte. The positive electrode develops a potential V_+ ($V_+ > 0$), and the negative electrode develops a potential $-V_-$ ($V_- \geq 0$), relative to the electrolyte adjacent to it. When no current is drawn from the cell then: [1 mark]

- (A) $\varepsilon = V_+ + V_- > 0$
- (B) $\varepsilon = V_+ - V_- > 0$
- (C) $\varepsilon = V_+ + V_- < 0$
- (D) $\varepsilon = V_+ + V_- = 0$

Correct Answer: (A) $\varepsilon = V_+ + V_- > 0$

Solution:

Concept:

- The emf of a cell is its open-circuit potential difference: $\varepsilon = \phi_+ - \phi_-$.
- The negative electrode has potential $-V_-$, while V_- itself denotes a nonnegative magnitude.

Step 1: Write the signed electrode potentials Choose the electrolyte as the reference potential. With

no current drawn, there is no ohmic potential drop through the electrolyte. The positive electrode is at $\phi_+ = V_+$ and the negative electrode is at $\phi_- = -V_-$, where $V_+ > 0$ and $V_- \geq 0$.

Step 2: Subtract the potentials in the correct order The emf is the positive-terminal potential minus the negative-terminal potential:

$$\varepsilon = V_+ - (-V_-) = V_+ + V_- > 0.$$

Option (B) treats the negative-electrode magnitude as its signed potential and therefore makes a sign error. Options (C) and (D) contradict the strictly positive sum, since $V_+ > 0$ and $V_- \geq 0$.

Step 3: Conclusion The emf is $\varepsilon = V_+ + V_- > 0$. Hence, the correct option is (A).

Quick Tip to Solve: Write the negative electrode potential with its minus sign before taking the terminal-potential difference.

30(iv)(a). Five identical cells, each of emf 2 V and internal resistance 0.1Ω are connected in parallel. This combination in turn is connected to an external resistor of 9.98Ω . The current flowing through the resistor is: [1 mark]

- (A) 0.05 A
- (B) 0.1 A
- (C) 0.15 A
- (D) 0.2 A

Correct Answer: (D) 0.2 A

Solution:

Concept:

- For N identical cells connected in parallel with like poles together, $\varepsilon_{\text{eq}} = \varepsilon$ and $r_{\text{eq}} = r/N$.
- The current through an external resistance R is $I = \varepsilon_{\text{eq}}/(R + r_{\text{eq}})$.

Step 1: Replace the parallel bank by its equivalent cell All five cells have the same emf, so the bank emf remains 2 V. The five identical internal resistances act in parallel:

$$r_{\text{eq}} = \frac{0.1}{5} = 0.02 \Omega.$$

Adding emfs would apply to a series connection and is inappropriate here.

Step 2: Calculate the load current The external resistor is in series with the equivalent internal resistance. Thus

$$R_{\text{total}} = 9.98 + 0.02 = 10.00 \Omega,$$
$$I = \frac{2}{10.00} = 0.2 \text{ A}.$$

Options (A), (B) and (C) give smaller values that do not satisfy this circuit equation. This is the current through the external resistor; it is shared equally among the five cell branches, rather than

being the current of just one branch.

Step 3: Conclusion The current through the external resistor is 0.2 A. Hence, the correct option is (D).

Quick Tip to Solve: With identical parallel cells, keep the emf unchanged and divide only the internal resistance by the number of cells.

OR

30(iv)(b). Potential difference across a cell in the open circuit is 6 V. It becomes 4 V when a current of 2 A is drawn from it. The internal resistance of the cell is: [1 mark]

- (A) 1.0 Ω
- (B) 1.5 Ω
- (C) 2.0 Ω
- (D) 2.5 Ω

Correct Answer: (A) 1.0 Ω

Solution:

Concept:

- With the circuit open, no current flows and the terminal voltage equals the emf ε .
- For a discharging cell, $V = \varepsilon - Ir$; hence $r = (\varepsilon - V)/I$, with I the load current.

Step 1: Identify the internal voltage drop The open-circuit reading gives $\varepsilon = 6$ V. When $I = 2$ A is drawn, the terminal reading falls to $V = 4$ V. The lost voltage appears across the internal resistance:

$$Ir = \varepsilon - V = 6 - 4 = 2 \text{ V.}$$

Step 2: Divide the lost voltage by the current The internal resistance is therefore

$$r = \frac{2 \text{ V}}{2 \text{ A}} = 1.0 \Omega.$$

Using $V/I = 4/2 = 2 \Omega$, as in option (C), would give the external load resistance instead. Options (B) and (D) would imply internal drops of 3 V and 5 V, respectively, inconsistent with the observed drop of 2 V.

Step 3: Conclusion The internal resistance of the cell is 1.0 Ω . Hence, the correct option is (A).

Quick Tip to Solve: Use the fall from open-circuit to loaded voltage in the numerator; the loaded voltage alone gives the external resistance.

Section E (15 marks)

- 31(a).** (i) Give any two differences between the interference pattern obtained in Young's double-slit experiment and a diffraction pattern due to a single slit.
- (ii) Draw an intensity distribution graph in case of a double-slit interference pattern.
- (iii) In Young's double-slit experiment using monochromatic light of wavelength λ , the intensity of light at a point on the screen, where path difference is λ , is K units. Find the intensity of light at a point on the screen where the path difference is $\frac{\lambda}{6}$. [5 marks]

Solution:

Concept:

- Interference is the superposition of coherent waves from two slits. For equal individual intensities I_0 , the resultant intensity at path difference Δ is $I = 4I_0 \cos^2(\pi\Delta/\lambda)$, where λ is the wavelength.
- The phase difference is $\phi = 2\pi\Delta/\lambda$. Constructive interference occurs at $\Delta = n\lambda$, and destructive interference at $\Delta = (n + \frac{1}{2})\lambda$, with integer n .
- Single-slit diffraction results from superposition of secondary wavelets across one slit. Its central maximum has twice the width of a secondary maximum, and the secondary maxima become progressively weaker.

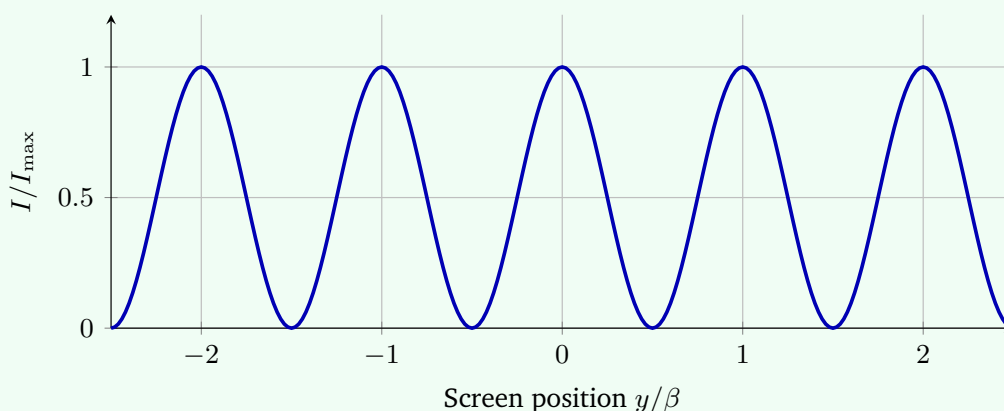
Step 1: (i) Compare the fringe widths In the ideal Young's double-slit pattern, bright and dark fringes have equal widths, and successive bright fringes are equally spaced. With slit separation d and screen distance D , their common fringe width is $\beta = \lambda D/d$. In the single-slit diffraction pattern, for slit width a , the first minima lie at $y = \pm\lambda D/a$. Thus its central bright maximum has width $2\lambda D/a$, twice the width $\lambda D/a$ between successive minima on either side. The central maximum is consequently broader than the other bright regions.

Step 2: (i) Compare the maximum intensities For equally illuminated narrow slits in ideal double-slit interference, all bright fringes have the same maximum intensity $4I_0$, and the minima have zero intensity. In single-slit diffraction, the central maximum is brightest; successive secondary maxima decrease in intensity as one moves away from the centre. These comparisons use the usual ideal interference pattern, neglecting the diffraction envelope due to a finite slit width.

Step 3: (ii) Plot the interference intensity Using the small-angle relation $\Delta \simeq dy/D$, the intensity at transverse screen coordinate y is

$$I(y) = I_{\max} \cos^2\left(\frac{\pi y}{\beta}\right), \quad \beta = \frac{\lambda D}{d}.$$

The graph below has equal-height maxima at $y = 0, \pm\beta, \pm2\beta, \dots$, zero minima halfway between them, and symmetry about the central bright fringe. The horizontal axis shows position in units of fringe width; the vertical axis shows intensity relative to its maximum.



Ideal double-slit interference: equal maxima and equally spaced fringes.

Step 4: (iii) Identify the given intensity as the maximum At the stated path difference $\Delta = \lambda$, the waves differ in phase by 2π , so they interfere constructively. Substituting this path difference gives

$$K = 4I_0 \cos^2 \pi = 4I_0 = I_{\max}.$$

Therefore the given K is the combined maximum intensity, rather than the intensity from either slit alone.

Step 5: (iii) Substitute the printed path difference For the required path difference $\Delta = \lambda/6$, the phase difference is $\phi = \pi/3$. The intensity formula uses half this phase difference:

$$\begin{aligned} I &= I_{\max} \cos^2 \left(\frac{\pi \Delta}{\lambda} \right) \\ &= K \cos^2 \left(\frac{\pi}{6} \right) \\ &= K \left(\frac{\sqrt{3}}{2} \right)^2. \end{aligned}$$

Step 6: Conclusion Ideal interference fringes have equal widths and equal maximum intensities; single-slit diffraction has a central maximum twice as wide as the others and progressively weaker secondary maxima. The required interference graph is shown above. At path difference $\lambda/6$, the intensity is $\boxed{3K/4 \text{ units}}$.

Quick Tip to Solve: First identify K as the maximum intensity at an integer-wavelength path difference. Then use $I/K = \cos^2(\pi\Delta/\lambda)$; the cosine contains half the phase difference.

31(b). (i) Draw a labelled ray diagram of a compound microscope showing image formation at least distance of distinct vision. Derive an expression for its magnifying power.

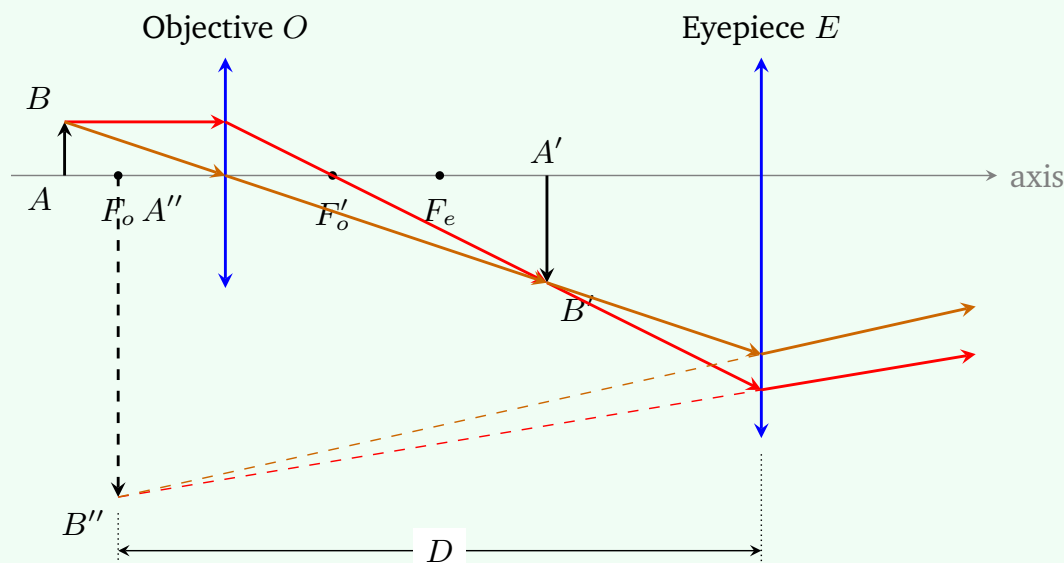
(ii) A telescope consists of two lenses of focal length 100 cm and 5 cm. Find the magnifying power when the final image is formed at infinity. [5 marks]

Solution:

Concept:

- A compound microscope combines the objective's linear magnification with the eyepiece's angular magnification: $M = m_o m_e$. The objective forms a real, inverted, enlarged intermediate image, which the eyepiece views as a magnifier.
- For a convex lens, $1/f = 1/v - 1/u$ in the Cartesian sign convention. The least distance of distinct vision is D , conventionally 25 cm; the eye is assumed close to the eyepiece.
- An astronomical telescope in normal adjustment has angular magnifying power of magnitude f_o/f_e , where the objective has the longer focal length and the eyepiece the shorter one.

Step 1: (i) Form the two microscope images Place the small object AB just beyond the first focus F_o of the objective O . Its real, enlarged and inverted image $A'B'$ lies between the eyepiece E and the eyepiece's first focus F_e . The rays diverging from B' are refracted by the eyepiece; their backward extensions meet at B'' . Thus $A''B''$ is the final virtual image at distance D to the left of the eyepiece and is inverted relative to AB . Solid arrows show light travelling to the right; dashed lines show only backward extensions. The diagram is schematic.



Dashed rays: backward extensions to the virtual image

Compound microscope adjusted for a final virtual image at D ; schematic, not to scale.

Step 2: Derive the objective magnification Let $u_o < 0$ and $v_o > 0$ be the objective's object and image distances. Similar triangles at its optical centre give

$$m_o = \frac{A'B'}{AB} = \frac{v_o}{u_o}, \quad |m_o| = \frac{v_o}{|u_o|}.$$

The negative sign of m_o records inversion. Since the object is just beyond the objective focus, $|u_o| \simeq f_o$. With a long microscope tube, $v_o \simeq L$, where L is the effective tube length in the usual approximation;

hence $|m_o| \simeq L/f_o$.

Step 3: Derive the eyepiece magnification at the near point Write the positive magnitude of the eyepiece's object distance as x . For the virtual final image, $u_e = -x$ and $v_e = -D$. Applying the lens formula,

$$\frac{1}{f_e} = -\frac{1}{D} + \frac{1}{x}, \quad \frac{D}{x} = 1 + \frac{D}{f_e}.$$

If $h' = |A'B'|$, the angle subtended at an eye close to the eyepiece is approximately $\beta = h'/x$. The same intermediate image viewed unaided at the near point subtends $\alpha' = h'/D$. Therefore

$$m_e = \frac{\beta}{\alpha'} = \frac{D}{x} = 1 + \frac{D}{f_e}.$$

Step 4: Combine the magnifications For the original object height h , the unaided near-point angle is $\alpha = h/D$. Thus the microscope's angular magnifying power is

$$|M| = \frac{\beta}{\alpha} = \frac{h'}{h} \frac{D}{x} = \frac{v_o}{|u_o|} \left(1 + \frac{D}{f_e}\right) \simeq \frac{L}{f_o} \left(1 + \frac{D}{f_e}\right).$$

If image orientation is included, the signed magnification is $M \simeq -(L/f_o)(1 + D/f_e)$; its negative sign indicates the inverted final image.

Step 5: (ii) Apply normal adjustment to the telescope The longer-focus lens is the objective, so $f_o = 100$ cm and $f_e = 5$ cm. When the final image is at infinity, the objective's focal plane coincides with the eyepiece's first focal plane. If the intermediate image has height h , the small incident and emergent angles have magnitudes h/f_o and h/f_e , respectively. Hence

$$|M_{\text{tel}}| = \frac{h/f_e}{h/f_o} = \frac{f_o}{f_e} = \frac{100}{5} = 20.$$

No near-point correction is used because this final image is at infinity.

Step 6: Conclusion (i) The compound microscope at the near point has magnifying power $|M| \simeq \frac{L}{f_o} \left(1 + \frac{D}{f_e}\right)$, with an inverted virtual final image. (ii) The telescope's magnifying power is 20 (signed value -20 , indicating inversion).

Quick Tip to Solve: For a microscope image at the near point, multiply the objective factor by $1 + D/f_e$. For a telescope image at infinity, use only the ratio of the longer to the shorter focal length.

32(a). (i) Obtain an expression for the electric potential due to a small dipole of dipole moment $\vec{p}$, at a point $\vec{r}$ from its centre, for much larger distances compared to the size of the dipole.

(ii) Three point charges q , $2q$ and nq are placed at the vertices of an equilateral triangle. If the potential energy of the system is zero, find the value of n . [5 marks]

Solution:

Concept:

- Electric potential is a scalar and obeys superposition. With potential zero at infinity, a point charge Q contributes $V = Q/(4\pi\epsilon_0 R)$ at distance R , where ϵ_0 is the permittivity of free space.
- A dipole comprises charges $-Q$ and $+Q$ separated by $2a$. Its dipole moment is $\vec{p} = 2Qa \hat{p}$, directed from the negative charge to the positive charge. The small-dipole approximation requires $r \gg a$.

- The potential energy of a collection of point charges is the sum of the interaction energies of its distinct pairs: $U = \sum_{i < j} q_i q_j / (4\pi\epsilon_0 r_{ij})$. Each pair must be counted only once.

Step 1: (i) Write the exact potential of the two dipole charges Place the dipole centre at the origin, with $+Q$ at $a\hat{p}$ and $-Q$ at $-a\hat{p}$. Let the observation point have position vector $\vec{r}$, magnitude r , and angle θ with $\vec{p}$. Its distances from the positive and negative charges are respectively

$$r_+ = \sqrt{r^2 + a^2 - 2ar \cos \theta}, \quad r_- = \sqrt{r^2 + a^2 + 2ar \cos \theta}.$$

Since potentials add algebraically, the exact potential is

$$V = \frac{Q}{4\pi\epsilon_0} \left(\frac{1}{r_+} - \frac{1}{r_-} \right).$$

The minus sign comes from the negative dipole charge, rather than from a direction assigned to potential.

Step 2: (i) Expand for a point far from the dipole Factor r out of each distance and use $(1+x)^{-1/2} \simeq 1 - x/2$ for small x . Retaining the leading terms in a/r ,

$$\begin{aligned} \frac{1}{r_+} &= \frac{1}{r} \left(1 + \frac{a^2}{r^2} - \frac{2a \cos \theta}{r} \right)^{-1/2} \simeq \frac{1}{r} \left(1 + \frac{a \cos \theta}{r} \right), \\ \frac{1}{r_-} &= \frac{1}{r} \left(1 + \frac{a^2}{r^2} + \frac{2a \cos \theta}{r} \right)^{-1/2} \simeq \frac{1}{r} \left(1 - \frac{a \cos \theta}{r} \right). \end{aligned}$$

Subtracting cancels the equal $1/r$ terms. Consequently,

$$V \simeq \frac{2Qa \cos \theta}{4\pi\epsilon_0 r^2} = \frac{p \cos \theta}{4\pi\epsilon_0 r^2} = \frac{\vec{p} \cdot \vec{r}}{4\pi\epsilon_0 r^3}.$$

The potential varies as $1/r^2$ for a fixed direction. It vanishes on the equatorial plane, where $\cos \theta = 0$; this also follows because the point is equally distant from the opposite charges.

Step 3: (ii) Add the three pair energies Let the common side of the equilateral triangle be ℓ . Its three distinct charge pairs are $(q, 2q)$, $(2q, nq)$, and (nq, q) . All pair separations equal ℓ , so

$$\begin{aligned} U &= \frac{1}{4\pi\epsilon_0} \left[\frac{q(2q)}{\ell} + \frac{(2q)(nq)}{\ell} + \frac{(nq)q}{\ell} \right] \\ &= \frac{q^2}{4\pi\epsilon_0 \ell} (2 + 2n + n). \end{aligned}$$

For nonzero q and a finite triangle, the prefactor is nonzero. Imposing the given condition $U = 0$ therefore gives $2 + 3n = 0$. The negative sign of the required third charge permits its attractive pair energies to balance the repulsive energy of the first pair.

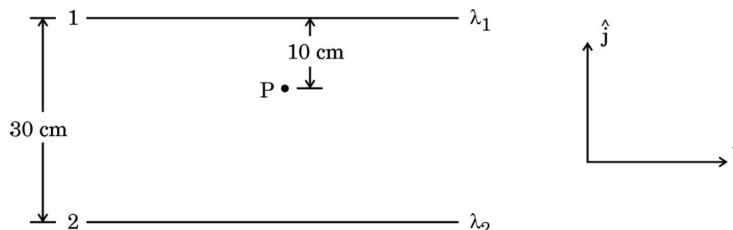
Step 4: Conclusion (i) For $r \gg a$, $V(\vec{r}) \simeq \frac{1}{4\pi\epsilon_0} \frac{\vec{p} \cdot \vec{r}}{r^3} = \frac{p \cos \theta}{4\pi\epsilon_0 r^2}$, with zero potential at infinity. (ii)

$$n = -\frac{2}{3}, \text{ so the third charge is } -2q/3.$$

Quick Tip to Solve: For an equilateral triangle, factor out the common Coulomb factor and separation first; zero total energy then means the sum of the three charge products is zero.

32(b). (i) State Gauss's Law in electrostatics. Apply this to obtain the electric field $\vec{E}$ at a point near a uniformly charged infinite plane sheet.

(ii) Two long straight wires 1 and 2 are kept as shown in the figure. The linear charge density of the two wires are $\lambda_1 = 10 \mu\text{C}/\text{m}$ and $\lambda_2 = -20 \mu\text{C}/\text{m}$. Find the net force $\vec{F}$ experienced by an electron held at point P. [5 marks]



Solution:

Concept:

- Gauss's law relates the electric flux through a closed surface to its enclosed charge: $\oint_S \vec{E} \cdot d\vec{A} = Q_{\text{enc}}/\epsilon_0$, with $d\vec{A}$ directed outwards.
- For a uniform infinite sheet, symmetry makes the electric field perpendicular to the sheet and equal in magnitude on its two sides. The surface charge density is $\sigma = Q/A$.
- A long uniformly charged wire produces a field of magnitude $E = |\lambda|/(2\pi\epsilon_0 r)$ at perpendicular distance r . Electric fields add vectorially, and an electron experiences $\vec{F} = -e\vec{E}$.

Step 1: (i) State Gauss's law The total electric flux through any closed surface equals the net charge enclosed by that surface divided by the permittivity of free space:

$$\oint_S \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\epsilon_0}.$$

Here the flux uses the total electric field on the surface, while the right-hand side includes only the enclosed charge. The area vector is always along the outward normal.

Step 2: Choose a pillbox across the infinite sheet Let the sheet have uniform surface charge density σ . Take a short cylindrical Gaussian surface with its axis perpendicular to the sheet, one flat face on either side, and face area A . Translation symmetry along the sheet excludes any preferred tangential direction; hence the field is normal to it. Reflection symmetry gives equal field magnitudes at the two faces. For a positively charged sheet, both fields point away from the sheet. The curved surface contributes no flux because its outward normal is parallel to the sheet and perpendicular to $\vec{E}$. Each flat face contributes EA , so the total flux is $2EA$. The enclosed charge is σA .

Step 3: Obtain the field of the sheet Applying Gauss's law to this pillbox gives

$$2EA = \frac{\sigma A}{\epsilon_0}, \quad E = \frac{\sigma}{2\epsilon_0} \quad (\sigma > 0).$$

More generally the magnitude is $|\sigma|/(2\epsilon_0)$. If $\hat{n}$ points normally away from the sheet on the side containing the observation point, then $\vec{E} = \sigma\hat{n}/(2\epsilon_0)$. Thus the field points away from a positive sheet and towards a negative sheet. It is independent of the distance from an ideal infinite sheet.

Step 4: (ii) Find the two wire fields at P The upper wire is positive and the lower wire is negative. Since P lies between them, the upper wire's field points downwards, away from wire 1; the lower wire's field also points downwards, towards wire 2. Both therefore have direction $-\hat{j}$, according to

the printed axes. The distances are

$$r_1 = 0.10 \text{ m}, \quad r_2 = 0.30 - 0.10 = 0.20 \text{ m}.$$

Using $1/(2\pi\epsilon_0) = 2(9 \times 10^9) \text{ N m}^2\text{C}^{-2}$,

$$E_1 = \frac{(18 \times 10^9)(10 \times 10^{-6})}{0.10} = 1.8 \times 10^6 \text{ N C}^{-1},$$

$$E_2 = \frac{(18 \times 10^9)(20 \times 10^{-6})}{0.20} = 1.8 \times 10^6 \text{ N C}^{-1}.$$

Equal magnitudes do not imply cancellation: the fields have the same direction at this point.

Step 5: Apply the electron's negative charge Superposing the wire fields and multiplying by the electron charge gives

$$\vec{E}_{\text{net}} = -(E_1 + E_2)\hat{j} = -3.6 \times 10^6 \hat{j} \text{ N C}^{-1},$$

$$\vec{F} = (-1.6 \times 10^{-19})(-3.6 \times 10^6)\hat{j} \text{ N}.$$

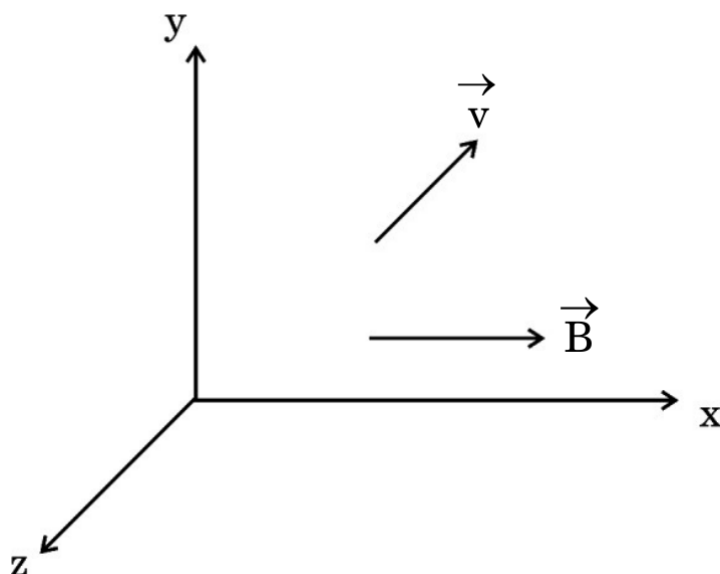
The force has no horizontal component. Its upward direction also follows directly: the positive upper wire attracts the electron and the negative lower wire repels it upwards.

Step 6: Conclusion For the infinite plane sheet, $\vec{E} = \sigma\hat{n}/(2\epsilon_0)$, where $\hat{n}$ is the normal pointing away from the sheet on the chosen side. The net force on the electron is $\vec{F} = +5.76 \times 10^{-13}\hat{j} \text{ N}$, upwards towards wire 1.

Quick Tip to Solve: At P, first subtract the given distances to get $r_2 = 20 \text{ cm}$. Draw both field directions before adding magnitudes, then reverse the net field direction for the negative electron.

33(a). (i) A particle of mass m and charge q is moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}$ as shown in the figure. Show that it follows a helical path. Hence, obtain its frequency of revolution.

(ii) In a hydrogen atom, the electron moves in an orbit of radius $2 \text{ \AA}$ making 8×10^{14} revolutions per second. Find the magnetic moment associated with the orbital motion of the electron. [5 marks]



Solution:

Concept:

- The magnetic force on a moving charge is $\vec{F} = q\vec{v} \times \vec{B}$. It is perpendicular to the velocity, so a uniform magnetic field changes the direction of motion without doing work.
- Resolve the velocity into components $v_{\parallel}$ along the field and $v_{\perp}$ perpendicular to it. The parallel component remains constant, while the perpendicular component produces circular motion.
- An electron completing f_e revolutions per second constitutes a current of magnitude $I = ef_e$, where e is the magnitude of the electron charge. Its orbital magnetic moment has magnitude $\mu = IA$, with A the orbit area.

Step 1: (i) Resolve the incident velocity Let θ be the angle between $\vec{v}$ and $\vec{B}$. In the figure, $\vec{B}$ is along the positive x -axis, and the velocity has both parallel and perpendicular components:

$$v_{\parallel} = v \cos \theta, \quad v_{\perp} = v \sin \theta.$$

The component along the field experiences no magnetic force because its cross product with $\vec{B}$ is zero. Hence the particle advances uniformly along the x -direction with speed $v_{\parallel}$.

Step 2: Establish circular motion in the perpendicular plane The transverse magnetic force has magnitude $|q|v_{\perp}B$ and remains perpendicular to the transverse velocity. It provides the centripetal force for circular motion in the plane perpendicular to $\vec{B}$:

$$|q|v_{\perp}B = \frac{mv_{\perp}^2}{r} \Rightarrow r = \frac{mv_{\perp}}{|q|B}.$$

The simultaneous uniform advance along the field and circular motion around its direction produce a helix whose axis is parallel to $\vec{B}$. The sign of the charge determines the sense of revolution, while its magnitude determines the radius and period.

Step 3: Derive the revolution frequency In one revolution, the transverse motion covers a circumference $2\pi r$ at speed $v_{\perp}$. Therefore

$$T = \frac{2\pi r}{v_{\perp}} = \frac{2\pi m}{|q|B}, \quad f = \frac{1}{T} = \frac{|q|B}{2\pi m}.$$

The distance advanced along the field during this time is the pitch:

$$p = v_{\parallel}T = \frac{2\pi mv \cos \theta}{|q|B}.$$

Thus the pitch and radius depend on the incident velocity, whereas the frequency is independent of speed and angle in this nonrelativistic treatment. If q denotes the positive magnitude of charge, the frequency is written $qB/(2\pi m)$.

Step 4: (ii) Calculate the equivalent orbital current Use the given radius and revolution frequency directly:

$$r_e = 2 \times 10^{-10} \text{ m}, \quad f_e = 8 \times 10^{14} \text{ s}^{-1}.$$

A charge of magnitude $e = 1.6 \times 10^{-19} \text{ C}$ passes a fixed point of the orbit once per revolution. Hence

$$I = ef_e = (1.6 \times 10^{-19})(8 \times 10^{14}) = 1.28 \times 10^{-4} \text{ A}.$$

The conventional current flows opposite to the electron's motion because the electron is negatively

charged.

Step 5: Obtain the orbital magnetic moment The orbit encloses an area $A = \pi r_e^2$. Multiplying this area by the equivalent current gives

$$\begin{aligned}\mu &= I\pi r_e^2 \\ &= (1.28 \times 10^{-4})\pi(2 \times 10^{-10})^2 \\ &= 5.12\pi \times 10^{-24} \text{ A m}^2 \\ &\simeq 1.61 \times 10^{-23} \text{ A m}^2.\end{aligned}$$

The magnetic moment is perpendicular to the orbital plane in the right-hand-rule direction for conventional current; it is opposite to the electron's orbital angular momentum.

Step 6: Conclusion (i) The particle follows a helix along $\vec{B}$, with revolution frequency $f = |q|B/(2\pi m)$. (ii) The orbital magnetic moment has magnitude $\mu \simeq 1.61 \times 10^{-23} \text{ A m}^2$, directed opposite to the electron's orbital angular momentum.

Quick Tip to Solve: Use only the velocity perpendicular to the field when finding the circular radius. For the electron orbit, convert angstroms to metres before squaring the radius in $\mu = e f_e \pi r_e^2$.

OR

33(b). (i) What is current sensitivity of a galvanometer? Show how the current sensitivity of a galvanometer may be increased. "Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity." Explain.

(ii) A moving coil galvanometer has a resistance 15Ω and takes 20 mA to produce full scale deflection. How can this galvanometer be converted into a voltmeter of range 0 to 100 V ? [5 marks]

Solution:

Concept:

- In a radial magnetic field, the magnetic torque on a moving coil is $\tau_m = NIAB$, where N is the number of turns, I the coil current, A the area of each turn and B the magnetic field strength.
- The suspension provides restoring torque $\tau_r = k\theta$, where k is the torsional constant and θ the angular deflection. At equilibrium, $NIAB = k\theta$.
- Current sensitivity is $S_I = \theta/I$; voltage sensitivity is $S_V = \theta/V$. For coil resistance G , Ohm's law gives $V = IG$.
- A galvanometer becomes a voltmeter by connecting a high resistance R in series. At full-scale current I_g , the selected maximum voltage is $V_{\max} = I_g(G + R)$.

Step 1: (i) Define and obtain current sensitivity Current sensitivity is the angular deflection produced per unit current through the galvanometer. For a radial field, the coil's plane remains parallel to the magnetic field, so its magnetic torque has magnitude $NIAB$ throughout its motion. At the steady deflection, magnetic and restoring torques balance:

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

Its SI unit is rad A^{-1} . Thus the instrument gives greater deflection for the same current when N , A or B is increased, or when k is decreased, with the other factors held fixed. A stronger magnetic field

and a suspension with a smaller torsional constant are practical ways to improve sensitivity.

Step 2: (i) Compare current and voltage sensitivities Voltage sensitivity measures deflection for a given potential difference across the coil. Since $I = V/G$, the torque relation gives

$$S_V = \frac{\theta}{V} = \frac{\theta/I}{V/I} = \frac{S_I}{G} = \frac{NAB}{kG}.$$

Therefore a larger current sensitivity does not by itself guarantee a larger voltage sensitivity: the coil resistance must also be considered. For example, increasing the number of turns increases S_I , but it also increases the length of wire and hence G . If the turn area, wire material and cross-section are unchanged, G is approximately proportional to N . Doubling N then approximately doubles both S_I and G , leaving $S_V = S_I/G$ unchanged. This explains the stated qualification. By contrast, increasing B with G fixed increases both sensitivities.

Step 3: (ii) Calculate the series resistance The coil resistance is $G = 15 \Omega$, and its full-scale current is

$$I_g = 20 \text{ mA} = 0.020 \text{ A}.$$

To obtain full-scale deflection at 100 V, the total series resistance must limit the current to this value:

$$G + R = \frac{V_{\max}}{I_g} = \frac{100}{0.020} = 5000 \Omega,$$
$$R = 5000 - 15 = 4985 \Omega.$$

Connect this resistance in series with the galvanometer and use the two outer terminals of the combination across the potential difference to be measured. At full scale, the coil drops $I_g G = 0.30 \text{ V}$, and the series resistor drops 99.70 V; their sum is 100 V. The resulting linear deflection scale is calibrated from 0 to 100 V.

Step 4: Conclusion $S_I = NAB/k$ increases with N , A , B , or a decrease in k . Since $S_V = S_I/G$, an accompanying increase in coil resistance can offset the gain in current sensitivity. For the specified voltmeter, connect 4985 Ω in series with the galvanometer.

Quick Tip to Solve: For sensitivity comparisons, check both NAB/k and the coil resistance. For voltmeter conversion, calculate $V_{\max}/I_g$ first, then subtract the galvanometer resistance to find the added series resistance.