

CBSE Class 12 Physics Question Paper 2023 with Solution PDF-Set 55/5/2

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 3 hours

Maximum Marks: 70

General Instructions

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

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

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

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

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

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

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

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

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

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

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

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

Section A (18 marks)

1. A charge Q is placed at the centre of a cube. The electric flux through one of its face is [1 mark]

- (A) $\frac{Q}{\epsilon_0}$
- (B) $\frac{Q}{6\epsilon_0}$
- (C) $\frac{Q}{8\epsilon_0}$
- (D) $\frac{Q}{3\epsilon_0}$

Correct Answer: (B) $\frac{Q}{6\epsilon_0}$

Solution:

Concept:

- Gauss's law gives the net flux through a closed surface as $\Phi = Q_{\text{enclosed}}/\epsilon_0$.
- A charge at the centre of a cube has identical geometrical surroundings relative to all six faces, so their fluxes are equal.

Step 1: Find the flux through the cube The closed cube encloses the complete charge Q , irrespective of its side length. Hence the total outward flux through all its faces is Q/ϵ_0 . This is the quantity in option (A), not the flux through just one face.

Step 2: Divide using the symmetry of the faces All six faces are equivalent because the charge is at the centre. If the flux through one face is Φ_f , then

$$6\Phi_f = \frac{Q}{\epsilon_0}, \quad \Phi_f = \frac{Q}{6\epsilon_0}.$$

Dividing by eight as in (C), or by three as in (D), does not count the six equivalent faces correctly.

Step 3: Conclusion The electric flux through one face is $Q/(6\epsilon_0)$. Hence, the correct option is (B).

Quick Tip to Solve: For a central charge in a cube, first find the total Gaussian flux and divide it equally among the six faces.

2. Two long parallel wires kept 2 m apart carry 3A current each, in the same direction. The force per unit length on one wire due to the other is [1 mark]

- (A) $4.5 \times 10^{-5} \text{ N m}^{-1}$, attractive
- (B) $4.5 \times 10^{-7} \text{ N/m}$, repulsive
- (C) $9 \times 10^{-7} \text{ N/m}$, repulsive
- (D) $9 \times 10^{-5} \text{ N/m}$, attractive

Correct Answer: No printed option is correct: the force per unit length is $9 \times 10^{-7} \text{ N m}^{-1}$, attractive.

Solution:

Concept:

- For long parallel wires separated by d , the force per unit length is $F/L = \mu_0 I_1 I_2 / (2\pi d)$.
- Parallel currents flowing in the same direction attract; opposite currents repel.

Step 1: Calculate the force per unit length Substitute $I_1 = I_2 = 3\text{ A}$, $d = 2\text{ m}$ and $\mu_0 = 4\pi \times 10^{-7}\text{ N A}^{-2}$:

$$\frac{F}{L} = \frac{4\pi \times 10^{-7} \times 3 \times 3}{2\pi \times 2} = 9 \times 10^{-7}\text{ N m}^{-1}.$$

The given currents have the same direction, so each wire is pulled towards the other.

Step 2: Check the printed alternatives Options (A) and (D) describe attraction but their printed magnitudes, 4.5×10^{-5} and $9 \times 10^{-5}\text{ N m}^{-1}$, are incorrect. Option (B) has both an incorrect magnitude and the wrong direction. Option (C) has the calculated magnitude but says repulsive, so it is also incorrect. Thus the printed alternatives do not contain the physically correct combination.

Step 3: Conclusion The force per unit length is $9 \times 10^{-7}\text{ N m}^{-1}$, attractive. No printed option is correct.

Quick Tip to Solve: Check magnitude and direction separately: equal-direction currents attract even when a distractor gives the correct numerical force.

3. Which of the following has its permeability less than that of free space?

[1 mark]

- (A) Copper
- (B) Aluminium
- (C) Copper chloride
- (D) Nickel

Correct Answer: (A) Copper

Solution:

Concept:

- The permeability of a linear magnetic material is $\mu = \mu_0\mu_r = \mu_0(1 + \chi_m)$, where χ_m is magnetic susceptibility.
- Diamagnetic substances have a small negative susceptibility, so $\mu_r < 1$ and $\mu < \mu_0$.

Step 1: Translate the permeability condition Permeability less than that of free space means $\mu/\mu_0 < 1$. Therefore the required material must have $\chi_m < 0$: its induced magnetisation weakly opposes the applied magnetic field.

Step 2: Classify the listed substances Copper is diamagnetic and satisfies the required inequality. Aluminium and copper chloride are paramagnetic, with small positive susceptibilities and permeabilities slightly above μ_0 . Nickel is ferromagnetic and has permeability much greater than that of free space under ordinary conditions. Consequently none of these three alternatives meets the stated condition.

Step 3: Conclusion Copper has permeability less than that of free space. Hence, the correct option is (A).

Quick Tip to Solve: Convert $\mu < \mu_0$ into $\chi_m < 0$, then identify the diamagnetic substance among the options.

4. A square shaped coil of side 10 cm, having 100 turns is placed perpendicular to a magnetic field which is increasing at 1 T/s. The induced emf in the coil is [1 mark]

- (A) 0.1 V
- (B) 0.5 V
- (C) 0.75 V
- (D) 1.0 V

Correct Answer: (D) 1.0 V

Solution:

Concept:

- Faraday's law gives the magnitude of induced emf as $|\varepsilon| = N|d\Phi_B/dt|$, where N is the number of turns and Φ_B is flux per turn.
- For a coil whose plane is perpendicular to a uniform field, $\Phi_B = BA$. With fixed area A , the emf magnitude is $NA|dB/dt|$.

Step 1: Convert the side and calculate the area The side of the square is 10 cm = 0.10 m, so the area of each turn is

$$A = (0.10)^2 = 0.010 \text{ m}^2.$$

The plane is perpendicular to the field, making the field parallel to the area vector; the flux factor is therefore unity.

Step 2: Apply Faraday's law to all turns The flux changes through each of the 100 turns at the same rate. Hence

$$|\varepsilon| = 100 \times 0.010 \times 1 = 1.0 \text{ V}.$$

The smaller values in (A), (B) and (C) do not equal the product of the stated number of turns, area and field-change rate. The minus sign in Faraday's law specifies direction, whereas the options ask for magnitude.

Step 3: Conclusion The induced emf has magnitude 1.0 V. Hence, the correct option is (D).

Quick Tip to Solve: Convert the side into metres before squaring it, then multiply the area by both the turns and the field-change rate.

5. Choose the correct option related to wavelengths (λ) of different parts of electromagnetic spectrum. [1 mark]

- (A) $\lambda_{\text{X-rays}} < \lambda_{\text{micro waves}} < \lambda_{\text{radio waves}} < \lambda_{\text{visible}}$
- (B) $\lambda_{\text{visible}} > \lambda_{\text{X-rays}} > \lambda_{\text{radio waves}} > \lambda_{\text{micro waves}}$
- (C) $\lambda_{\text{radio wave}} > \lambda_{\text{micro waves}} > \lambda_{\text{visible}} > \lambda_{\text{X-rays}}$
- (D) $\lambda_{\text{visible}} < \lambda_{\text{micro waves}} < \lambda_{\text{radio waves}} < \lambda_{\text{X-rays}}$

Correct Answer: (C) $\lambda_{\text{radio wave}} > \lambda_{\text{micro waves}} > \lambda_{\text{visible}} > \lambda_{\text{X-rays}}$

Solution:

Concept:

- Electromagnetic waves obey $c = \nu\lambda$ in vacuum, so increasing frequency ν corresponds to decreasing wavelength λ .
- In order of decreasing wavelength, the usual spectral bands are radio waves, microwaves, infrared,

visible light, ultraviolet, X-rays and gamma rays.

Step 1: Select the four relevant bands Radio waves have longer wavelengths than microwaves; microwaves have longer wavelengths than visible light; and X-rays have shorter wavelengths than visible light. Retaining only the bands in the question gives

$$\lambda_{\text{radio}} > \lambda_{\text{micro}} > \lambda_{\text{visible}} > \lambda_{\text{X-rays}}.$$

Step 2: Compare each option with this order Option (C) reproduces the full correct order. Option (A) incorrectly puts radio wavelengths below visible wavelengths. Option (B) incorrectly puts X-ray wavelengths above radio wavelengths. Option (D) incorrectly makes X-ray wavelengths greater than those of radio waves. Each of these contradictions rules out that alternative.

Step 3: Conclusion The order is radio waves, microwaves, visible light, then X-rays in decreasing wavelength. Hence, the correct option is (C).

Quick Tip to Solve: Locate radio waves at the long-wavelength end and X-rays near the short-wavelength end before comparing intermediate bands.

6. In a Young's double-slit experiment, the screen is moved away from the plane of the slits. What will be its effect on the following?

(i) Angular separation of the fringes.

(ii) Fringe-width.

[1 mark]

- (A) Both (i) and (ii) remain constant.
(B) (i) remains constant, but (ii) decreases.
(C) (i) remains constant, but (ii) increases.
(D) Both (i) and (ii) increase.

Correct Answer: (C) (i) remains constant, but (ii) increases.

Solution:

Concept:

- In Young's experiment the fringe width is $\beta = \lambda D/d$, where D is slit-screen distance, d is slit separation and λ is wavelength.
- In the usual small-angle approximation the angular separation of adjacent fringes is $\Delta\theta = \beta/D = \lambda/d$.

Step 1: Examine the angular separation Moving the screen away increases D but changes neither the wavelength nor the slit separation. Since $\Delta\theta = \lambda/d$ does not contain D , the angular separation in part (i) remains constant. This eliminates option (D), which predicts an increase in both quantities.

Step 2: Examine the linear fringe width The distance between adjacent fringes on the screen is $\beta = \lambda D/d$. With λ and d fixed, β is directly proportional to D , so the fringe width in part (ii) increases. Options (A) and (B) are incorrect because they predict a constant or decreasing fringe width.

Step 3: Conclusion Angular separation remains constant while fringe width increases. Hence, the correct option is (C).

Quick Tip to Solve: Distinguish an angle from a screen distance: λ/d is angular spacing, while multiplying by D gives fringe width.

7. The energy of a photon of wavelength λ is:

[1 mark]

(A) $hc\lambda$

(B) hc/λ

(C) λ/hc

(D) $\lambda h/c$

Correct Answer: (B) hc/λ

Solution:

Concept:

- Planck's relation for the energy of one photon is $E = h\nu$, where h is Planck's constant and ν is frequency.
- For light in vacuum, $\nu\lambda = c$, where c is the speed of light and λ is the wavelength.

Step 1: Express the frequency using wavelength Rearrange the wave relation to obtain $\nu = c/\lambda$. Thus a shorter wavelength means a higher frequency and therefore greater photon energy; the energy must vary inversely with wavelength.

Step 2: Substitute into Planck's relation On substitution,

$$E = h \left(\frac{c}{\lambda} \right) = \frac{hc}{\lambda}.$$

Option (A) multiplies by wavelength instead of dividing and has the wrong dimensions. Option (C) is the reciprocal of the energy expression. Option (D) also increases with wavelength and has dimensions of action times time, not energy. Only option (B) obeys both physical relations and has units of joules.

Step 3: Conclusion The photon energy is $E = hc/\lambda$. Hence, the correct option is (B).

Quick Tip to Solve: Start from $E = h\nu$ and replace ν by c/λ ; never multiply photon energy by wavelength.

8. The ratio of the nuclear densities of two nuclei having mass numbers 64 and 125 is

[1 mark]

- (A) $\frac{64}{125}$
- (B) $\frac{4}{5}$
- (C) $\frac{5}{4}$
- (D) 1

Correct Answer: (D) 1

Solution:

Concept:

- A nucleus of mass number A has radius $R = R_0 A^{1/3}$, where R_0 is approximately the same for different nuclei.
- Its mass is approximately Am_N , where m_N is the mean nucleon mass, and its volume is $4\pi R^3/3$.

Step 1: Obtain the dependence of density on mass number Nuclear density is mass divided by volume. Substituting the mass and radius laws gives

$$\rho = \frac{Am_N}{(4\pi/3)(R_0 A^{1/3})^3} = \frac{3m_N}{4\pi R_0^3}.$$

The factor A cancels, so nuclear density is approximately independent of mass number.

Step 2: Compare the two nuclei Both the nucleus with $A = 64$ and that with $A = 125$ have this same density, giving $\rho_{64}/\rho_{125} = 1$. Option (A) is their mass ratio and incorrectly ignores the volume change. Option (B) is their radius ratio, since $64^{1/3}/125^{1/3} = 4/5$; option (C) is its reciprocal. Neither radius ratio is a density ratio.

Step 3: Conclusion The ratio of the nuclear densities is 1 : 1, or 1. Hence, the correct option is (D).

Quick Tip to Solve: Cube the radius law before calculating nuclear density: both nuclear mass and volume are proportional to A .

9. During the formation of a p-n junction:

[1 mark]

- (A) diffusion current keeps increasing.
- (B) drift current remains constant.
- (C) both the diffusion current and drift current remain constant.
- (D) diffusion current remains almost constant but drift current increases till both currents become equal.

Correct Answer: (D) diffusion current remains almost constant but drift current increases till both currents become equal.

Solution:

Concept:

- Diffusion occurs because majority-carrier concentrations differ across a p-n junction.
- The depletion layer sets up an electric field, producing drift current opposite to diffusion current. At equilibrium their magnitudes are equal.

Step 1: Follow junction formation Initially electrons diffuse from the n-side to the p-side and holes diffuse the other way. The uncovered ions create the depletion layer and its electric field. As this field

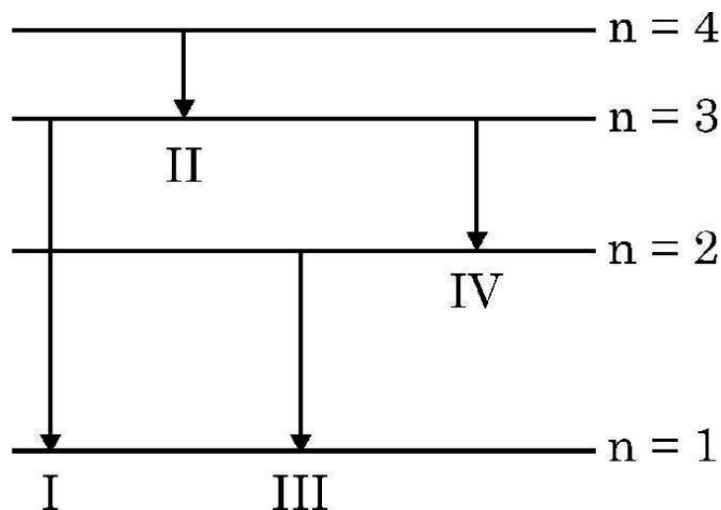
builds up, the opposing drift current increases.

Step 2: Compare the stated trends In the qualitative description used in these options, diffusion current remains almost constant while drift current grows until it balances diffusion current. Thus diffusion does not keep increasing as in (A), and drift cannot remain constant throughout formation as claimed in (B) and (C). Equality of the opposite currents means zero net current in the unbiased junction.

Step 3: Conclusion Drift current increases until it balances the approximately constant diffusion current. Hence, the correct option is (D).

Quick Tip to Solve: During junction formation, track the growing depletion field: it increases the current opposing diffusion until equilibrium is reached.

10. The diagram shows four energy level of an electron in Bohr model of hydrogen atom. Identify the transition in which the emitted photon will have the highest energy. [1 mark]



- (A) I
- (B) II
- (C) III
- (D) IV

Correct Answer: (A) I

Solution:

Concept:

- Hydrogen energy levels obey $E_n = -13.6/n^2$ eV, where n is the principal quantum number.
- A downward transition emits a photon with energy $E_\gamma = E_i - E_f > 0$.

Step 1: Read the four arrows The printed diagram gives I: $3 \rightarrow 1$, II: $4 \rightarrow 3$, III: $2 \rightarrow 1$, and IV: $3 \rightarrow 2$. The photon energy depends on the energy difference, not simply on the number of intervening levels.

Step 2: Compare the energy differences Using $E_\gamma = 13.6(1/n_f^2 - 1/n_i^2)$ eV, the energies are

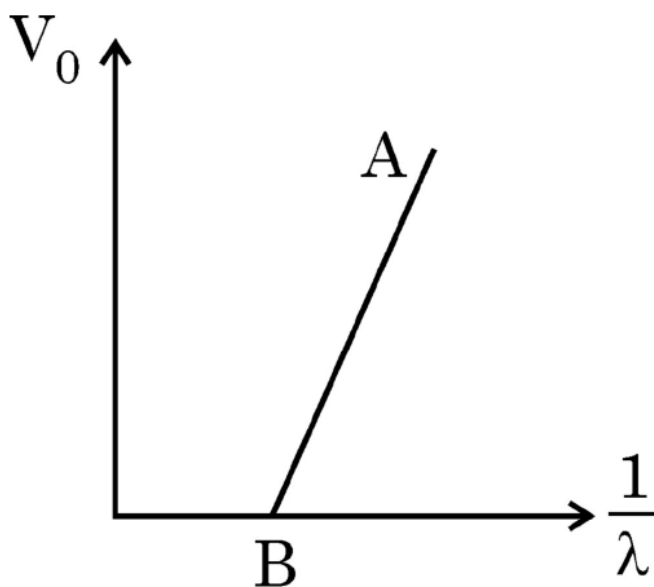
$$\begin{aligned}E_I &= 13.6(1 - 1/9) = 12.09 \text{ eV}, \\E_{II} &= 13.6(1/9 - 1/16) = 0.661 \text{ eV}, \\E_{III} &= 13.6(1 - 1/4) = 10.20 \text{ eV}, \\E_{IV} &= 13.6(1/4 - 1/9) = 1.889 \text{ eV}.\end{aligned}$$

Even III, which also ends at the ground state, releases less energy than I because its initial level is lower.

Step 3: Conclusion Transition I emits the highest-energy photon, approximately 12.09 eV. Hence, the correct option is (A).

Quick Tip to Solve: For transitions ending at the same level, the higher initial level releases more energy; compare actual Bohr energies if final levels differ.

11. Figure shows a plot of stopping potential (V_0) versus $\frac{1}{\lambda}$ where λ is the wavelength of the radiation causing photoelectric emission from a surface. The slope of the line is equal to [1 mark]



- (A) ϕ_0
(B) $\frac{h}{e}$
(C) $\frac{hc}{e}$
(D) $\frac{h^2c}{e^2}$

Correct Answer: (C) $\frac{hc}{e}$

Solution:

Concept:

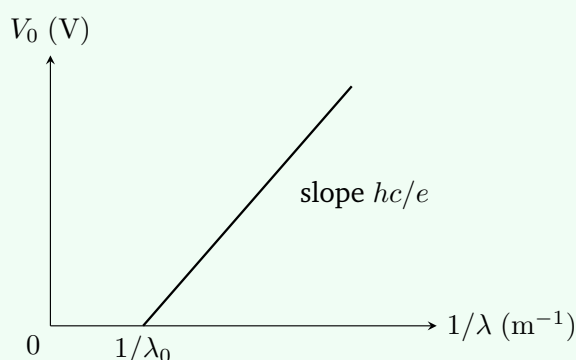
- Einstein's photoelectric equation is $eV_0 = h\nu - \phi_0$, where e is the magnitude of electron charge and ϕ_0 is the work function.

- Since $\nu = c/\lambda$, a graph against reciprocal wavelength has a different slope from a graph against frequency.

Step 1: Express the equation using reciprocal wavelength Substituting $\nu = c/\lambda$ and dividing by e ,

$$V_0 = \frac{hc}{e} \left(\frac{1}{\lambda} \right) - \frac{\phi_0}{e}.$$

The intercept depends on the emitting surface, whereas the coefficient of reciprocal wavelength contains only universal constants.



Stopping potential versus reciprocal wavelength; the positive slope is hc/e .

Step 2: Identify the coefficient of the horizontal variable Comparing with $y = mx + b$, use $y = V_0$ and $x = 1/\lambda$. Thus $m = hc/e$, with units V m. Option (A) is an energy, (B) would be the slope for a frequency axis, and (D) includes an extra factor h/e , so none gives the required coefficient.

Step 3: Conclusion The slope of the V_0 versus $1/\lambda$ graph is hc/e . Hence, the correct option is (C).

Quick Tip to Solve: Read the horizontal axis first: the stopping-potential slope is h/e against frequency but hc/e against reciprocal wavelength.

12. The capacitors, each of $4\ \mu F$ are to be connected in such a way that the effective capacitance of the combination is $6\ \mu F$. This can be achieved by connecting [1 mark]

- (A) All three in parallel
- (B) All three in series
- (C) Two of them connected in series and the combination in parallel to the third.
- (D) Two of them connected in parallel and the combination in series to the third.

Correct Answer: (C) Two of them connected in series and the combination in parallel to the third.

Solution:

Concept:

- For capacitors in parallel, $C_p = C_1 + C_2$, because their potential differences are equal and charges add.

- For capacitors in series, $C_s^{-1} = C_1^{-1} + C_2^{-1}$, because their charge magnitudes are equal and potential differences add.

Step 1: Combine two capacitors in series Each capacitor is $4\ \mu\text{F}$. The equivalent capacitance of two in series is

$$C_s = \frac{4 \times 4}{4 + 4} \mu\text{F} = 2\ \mu\text{F}.$$

Placing this branch in parallel with the third capacitor gives $C_{\text{eq}} = 2 + 4 = 6\ \mu\text{F}$.

Step 2: Check the other arrangements All three in parallel give $12\ \mu\text{F}$, and all three in series give $4/3\ \mu\text{F}$. For option (D), the parallel pair is $8\ \mu\text{F}$; putting it in series with $4\ \mu\text{F}$ gives $8 \times 4 / (8 + 4) = 8/3\ \mu\text{F}$. None of these equals the required value.

Step 3: Conclusion Connect two capacitors in series and place their combination in parallel with the third to obtain $6\ \mu\text{F}$. Hence, the correct option is (C).

Quick Tip to Solve: With three equal capacitors, a series pair in parallel with the third gives $C/2 + C = 3C/2$.

13. An ideal inductor is connected across an AC source of voltage. The current in the circuit [1 mark]

- (A) is ahead of the voltage in phase by π .
- (B) lags voltage in phase by π .
- (C) is ahead of voltage in phase by $\pi/2$.
- (D) lags voltage in phase by $\pi/2$.

Correct Answer: (D) lags voltage in phase by $\pi/2$.

Solution:

Concept:

- For an ideal inductor of inductance L , the applied voltage is $v = L di/dt$.
- For sinusoidal steady-state current, differentiation advances the phase by $\pi/2$.

Step 1: Relate sinusoidal current to voltage Take the current as $i = I_m \sin \omega t$, where I_m is its amplitude and ω is the angular frequency. Then

$$v = L \frac{di}{dt} = \omega L I_m \cos \omega t = V_m \sin(\omega t + \pi/2).$$

Thus the voltage reaches corresponding phases a quarter of a cycle earlier than the current.

Step 2: State the phase relation for current Since voltage leads by $\pi/2$, current lags voltage by $\pi/2$. The shifts π in (A) and (B) mean half a cycle, which does not follow from the derivative. Option (C) reverses the relation and is characteristic of a pure capacitor, not a pure inductor.

Step 3: Conclusion Current lags the applied voltage in phase by $\pi/2$. Hence, the correct option is (D).

Quick Tip to Solve: Use $v = L di/dt$: voltage is largest when current crosses zero while increasing, so voltage reaches its peak first.

14. According to Huygens principle, the amplitude of secondary wavelets is

[1 mark]

- (A) equal in both the forward and the backward directions.
- (B) maximum in the forward direction and zero in the backward direction.
- (C) large in the forward direction and small in the backward direction.
- (D) small in the forward direction and large in the backward direction.

Correct Answer: (B) maximum in the forward direction and zero in the backward direction.

Solution:

Concept:

- In Huygens' construction, each point on a wavefront acts as a source of secondary wavelets; their forward envelope gives the new wavefront.
- In the standard directional description, the secondary-wavelet amplitude is greatest along forward propagation and vanishes in the backward direction.

Step 1: Identify the forward and backward directions The forward direction is along the normal to the advancing wavefront. The backward direction is opposite to that normal. The wavefront construction selects the forward envelope and does not produce a backward-propagating wavefront.

Step 2: Compare the proposed amplitudes The associated obliquity factor is proportional to $1 + \cos \theta$, where θ is measured from the forward normal. It is largest at $\theta = 0$ and zero at $\theta = \pi$. Therefore equal forward and backward amplitudes in (A), a small nonzero backward amplitude in (C), and a larger backward amplitude in (D) are incompatible with this description.

Step 3: Conclusion The amplitude is maximum in the forward direction and zero in the backward direction. Hence, the correct option is (B).

Quick Tip to Solve: Associate the new wavefront with the forward envelope: the directional factor is maximal forward and vanishes directly backward.

15. In Bohr model of hydrogen atom, the radius of the n^{th} orbit is proportional to:

[1 mark]

- (A) n^2
- (B) $1/n^2$
- (C) n
- (D) $1/n$

Correct Answer: (A) n^2

Solution:

Concept:

- Bohr's angular-momentum condition is $m_e v r_n = n\hbar$, where n is the orbit number and $\hbar = h/(2\pi)$.
- In hydrogen, electrostatic attraction supplies the centripetal force: $m_e v^2/r_n = k e^2/r_n^2$, with $k = 1/(4\pi\epsilon_0)$.

Step 1: Eliminate the orbital speed Angular-momentum quantisation gives $v = n\hbar/(m_e r_n)$. Substituting this into the force equation yields

$$\frac{n^2 \hbar^2}{m_e r_n^3} = \frac{k e^2}{r_n^2}, \quad r_n = \frac{\hbar^2}{m_e k e^2} n^2.$$

All factors multiplying n^2 are constants for the hydrogen atom.

Step 2: Compare the proposed dependences The orbit radius therefore grows quadratically with orbit number: doubling n makes the radius four times as large. The inverse-square dependence in (B) describes the magnitude of hydrogen's binding energy, not its radius. Neither the linear dependence in (C) nor the inverse dependence in (D) satisfies both Bohr equations.

Step 3: Conclusion The radius of the n th hydrogen orbit is proportional to n^2 . Hence, the correct option is (A).

Quick Tip to Solve: Keep Bohr scalings separate: radius grows as n^2 , whereas binding-energy magnitude decreases as $1/n^2$.

16. Assertion (A): In insulators, the forbidden gap is very large.

Reason (R): The valence electrons in an atom of an insulator are very tightly bound to the nucleus.

[1 mark]

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

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

Solution:

Concept:

- The forbidden energy gap E_g separates the top of the valence band from the bottom of the conduction band.
- Electrical conduction requires mobile charge carriers; tightly bound valence electrons need substantial energy to enter the conduction band.

Step 1: Judge the assertion An insulator has a large forbidden gap. Ordinary thermal energy is insufficient to promote an appreciable number of electrons from its filled valence band to its empty conduction band. Assertion (A) is true.

Step 2: Judge the reason The valence electrons in an insulator are tightly bound to their atoms. They cannot readily become mobile conduction electrons. Thus Reason (R) is also true.

Step 3: Connect the two statements Strong binding means that a large energy input is needed to free an electron for conduction. In the band picture this corresponds to the large separation between the valence and conduction bands. Therefore R explains A; the option that treats the two true statements as unrelated is inappropriate.

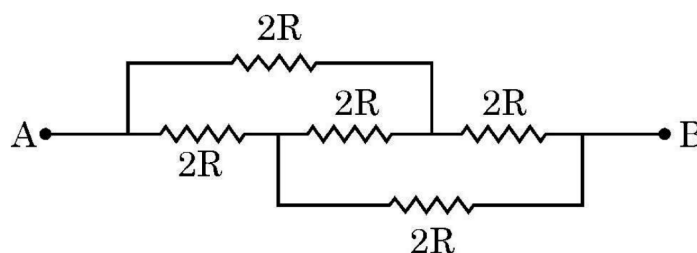
Step 4: Conclusion Both A and R are true, and R is the correct explanation of A. Hence, the correct option is (A).

Quick Tip to Solve: Link tightly bound valence electrons with a large excitation energy and hence a large forbidden gap.

17. Assertion (A): The equivalent resistance between points A and B in the given network is $2R$.

Reason (R): All the resistors are connected in parallel.

[1 mark]



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

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

(C) Assertion (A) is true and Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

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

Solution:

Concept:

- A balanced Wheatstone bridge has equal potentials at its two middle junctions, so no current flows through the bridge resistor.
- Series resistances add; for parallel branches, $1/R_{eq} = 1/R_1 + 1/R_2$.

Step 1: Judge the assertion using bridge balance Call the junction after the left horizontal resistor C and the junction before the right horizontal resistor D. The four arms AC, CB, AD and DB each have resistance $2R$. Their equal ratios make the bridge balanced, so C and D are at the same potential and the central CD resistor carries no current. The two conducting paths ACB and ADB each contain two series resistors:

$$R_{path} = 2R + 2R = 4R, \quad R_{AB} = \frac{4R \times 4R}{4R + 4R} = 2R.$$

Thus Assertion (A) is true.

Step 2: Judge the reason from the connections The five resistors do not share the same two end nodes. The middle resistor connects C to D, while the outer resistors form the bridge arms. Hence they are not all in parallel and Reason (R) is false. Treating five equal resistors as parallel would incorrectly give $2R/5$.

Step 3: Test the explanatory link The assertion follows from bridge balance and the resulting pair of equal series branches in parallel. The false claim in R cannot explain it, so the options requiring R to be true are excluded.

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

Quick Tip to Solve: Label the internal junctions first: equal bridge-arm ratios eliminate the middle resistor before series-parallel reduction.

18. Assertion (A): The deflecting torque acting on a current carrying loop is zero when its plane is perpendicular to the direction of magnetic field.

Reason (R): The deflecting torque acting on a loop of magnetic moment $\vec{m}$ in a magnetic field $\vec{B}$ is given by the dot product of $\vec{m}$ and $\vec{B}$. [1 mark]

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

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

Solution:

Concept:

- A current loop has magnetic moment $\vec{m}$ normal to its plane, with direction given by the right-hand rule.
- Magnetic torque is $\vec{\tau} = \vec{m} \times \vec{B}$, of magnitude $mB \sin \theta$, where θ is the angle between the moment and the field.

Step 1: Judge the assertion When the plane of the loop is perpendicular to the magnetic field, its normal and therefore its magnetic moment are parallel or antiparallel to the field. Then $\theta = 0$ or π , and $\tau = mB \sin \theta = 0$. Assertion (A) is true.

Step 2: Judge the reason Torque is the vector cross product $\vec{m} \times \vec{B}$, not the scalar dot product. The dot product appears instead in the potential energy $U = -\vec{m} \cdot \vec{B}$. Reason (R) is false.

Step 3: Test the explanatory link Zero torque follows from the sine of the angle between the field and the loop's normal. A dot-product formula would involve a cosine and would not vanish in this orientation. Thus R cannot explain A, and options requiring R to be true are excluded.

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

Quick Tip to Solve: Measure the torque angle from the normal to the loop, and use a cross product for torque and a negative dot product for energy.

Section B (14 marks)

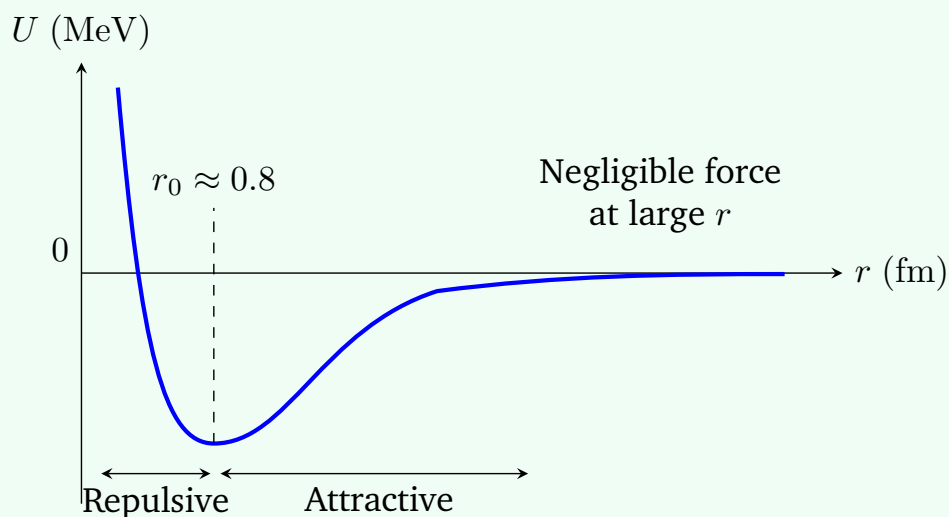
19. Draw a graph showing the variation of potential energy of a pair of nucleons as a function of their separation. Indicate the region in which the nuclear force is (a) attractive and (b) repulsive. [2 marks]

Solution:

Concept:

- For two nucleons separated by distance r , the radial nuclear force is $F_r = -dU/dr$, where U is their interaction potential energy.
- Take $U = 0$ at very large separation. The nuclear interaction has a steep repulsive core and a short-range attractive well.

Step 1: Sketch the potential-energy well At very small separation the potential energy is large and positive. As r increases, U falls steeply, crosses zero and reaches a negative minimum at $r = r_0$, approximately 0.8 fm. It then rises towards zero and is negligible beyond a few femtometres. The curve is schematic: the essential features are the repulsive core, negative minimum and short range.



Schematic nucleon potential: force regions follow the slope of $U(r)$.

Step 2: Identify the force from the slope To the right of the minimum, $dU/dr > 0$, so $F_r < 0$: the force tends to reduce the separation and is attractive. To the left of the minimum, $dU/dr < 0$, so $F_r > 0$: the force tends to increase the separation and is repulsive. At the minimum the slope, and hence the force, is zero. At sufficiently large separation the almost horizontal curve shows that the nuclear force is negligible.

Step 3: Conclusion The nuclear force is (a) attractive for $r > r_0$ within its short range and (b) repulsive for $r < r_0$, with $r_0 \approx 0.8$ fm. These regions are indicated on the graph.

Quick Tip to Solve: Locate the minimum first and use $F_r = -dU/dr$; the sign of potential energy alone does not determine attraction or repulsion.

20(a). How will the De Broglie wavelength associated with an electron be affected when the (i) velocity of the electron decreases? and (ii) accelerating potential is increased? Justify your answer.

[2 marks]

Solution:

Concept:

- A particle of momentum p has de Broglie wavelength $\lambda = h/p$, where h is Planck's constant.
- For a non-relativistic electron, $p = m_e v$. When accelerated from rest through a potential difference V , its kinetic energy is $eV = p^2/(2m_e)$, where e is the magnitude of its charge.

Step 1: Relate the wavelength to electron speed For the same electron, h and its mass m_e remain fixed. Hence

$$\lambda = \frac{h}{m_e v}, \quad \frac{\lambda_2}{\lambda_1} = \frac{v_1}{v_2}.$$

If the speed decreases, its momentum decreases and its de Broglie wavelength increases. For example, halving the speed doubles the wavelength in the non-relativistic regime. A change in direction alone would not change the wavelength; here the stated decrease in velocity refers to a decrease in speed.

Step 2: Relate the wavelength to accelerating potential Equating the work done by the accelerating

electric field to the kinetic energy gives

$$p = \sqrt{2m_e eV}, \quad \lambda = \frac{h}{\sqrt{2m_e eV}}.$$

Thus $\lambda \propto V^{-1/2}$. Increasing the accelerating potential increases the electron's kinetic energy and momentum, and therefore decreases its wavelength. For instance, multiplying the potential by four halves the wavelength.

Step 3: Conclusion (i) A decrease in electron speed increases its de Broglie wavelength. (ii) An increase in accelerating potential decreases it: $\lambda \propto 1/v$ and $\lambda \propto 1/\sqrt{V}$, respectively.

Quick Tip to Solve: Start from $\lambda = h/p$: use $p = m_e v$ for speed and $p = \sqrt{2m_e eV}$ for accelerating potential.

OR

20(b). How would the stopping potential for a given photosensitive surface change if (i) the frequency of the incident radiation were increased? and (ii) the intensity of incident radiation were decreased? Justify your answer. [2 marks]

Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi$, where ν is incident frequency and ϕ is the work function of the given surface.
- The magnitude of stopping potential V_s is defined by $eV_s = K_{\max}$, where e is the magnitude of the electron charge. Intensity controls the photon arrival rate at fixed frequency.

Step 1: Increase the frequency at the same surface The work function remains constant for the given photosensitive surface. Combining the two equations gives

$$V_s = \frac{h\nu - \phi}{e}, \quad \Delta V_s = \frac{h}{e} \Delta \nu.$$

Thus an increase in frequency increases the photon energy and the maximum kinetic energy of the emitted electrons. A larger retarding potential magnitude is required to stop the fastest electrons, so the stopping potential increases. Photoemission requires $h\nu \geq \phi$.

Step 2: Decrease the intensity at fixed frequency Lower intensity means fewer photons arrive per unit time, but the energy $h\nu$ of each photon is unchanged. Since one photon transfers its energy to one electron in the usual photoelectric regime, $K_{\max}$ and hence V_s remain unchanged. The number of emitted photoelectrons per unit time, and therefore the photocurrent, decreases. This comparison assumes nonzero illumination at a frequency above threshold.

Step 3: Conclusion (i) Increasing frequency increases the stopping potential magnitude by $h\Delta\nu/e$. (ii) Decreasing intensity at fixed frequency leaves the stopping potential unchanged, although it reduces the photocurrent.

Quick Tip to Solve: In $eV_s = h\nu - \phi$, frequency appears but intensity does not: intensity changes electron count, not maximum electron energy.

21. Identify the electromagnetic radiation and write its wavelength range, which is used to kill germs in water purifier. Name the two sources of these radiations. [2 marks]

Solution:

Concept:

- Ultraviolet (UV) radiation lies beyond the violet end of visible light and has a shorter wavelength than visible radiation.
- Short-wavelength UV radiation has a germicidal action: absorption by microorganisms damages their genetic material and prevents reproduction.

Step 1: Identify the radiation and its wavelength range The radiation used to kill germs in a water purifier is ultraviolet radiation. Its approximate wavelength range in the electromagnetic spectrum is

$$1 \text{ nm to } 400 \text{ nm} \quad (10^{-9} \text{ m to } 4 \times 10^{-7} \text{ m}).$$

Water purification uses the germicidal part of this band, commonly around 254 nm; this particular wavelength should not be confused with the full ultraviolet range.

Step 2: Name two sources Two sources of ultraviolet radiation are the Sun and a mercury-vapour discharge lamp. The Sun emits ultraviolet radiation along with visible and other radiation. An electrical discharge through mercury vapour produces strong ultraviolet emission and provides a practical artificial source for germicidal lamps.

Step 3: Conclusion The required radiation is ultraviolet, approximately 1–400 nm in wavelength. Two sources are the Sun and mercury-vapour lamps.

Quick Tip to Solve: Give the whole UV wavelength band when asked for its range; mention a germicidal lamp wavelength only as an example within that band.

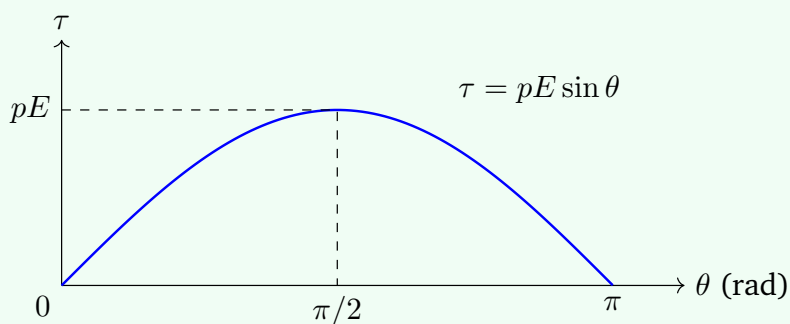
22. An electric dipole of dipole moment ($\vec{p}$) is kept in a uniform electric field $\vec{E}$. Show graphically the variation of torque acting on the dipole (τ) with its orientation (θ) in the field. Find the orientation in which torque is (i) zero and (ii) maximum. [2 marks]

Solution:

Concept:

- In a uniform electric field, equal and opposite forces on the dipole charges form a couple: $\vec{\tau} = \vec{p} \times \vec{E}$.
- The torque magnitude is $\tau = pE \sin \theta$, where p is the dipole-moment magnitude and θ is the angle between $\vec{p}$ and $\vec{E}$, with $0 \leq \theta \leq \pi$.

Step 1: Plot the angular variation Keep p and E constant. The torque then varies as $\sin \theta$: it starts from zero at $\theta = 0$, increases to pE at $\theta = \pi/2$, and decreases to zero at $\theta = \pi$. Thus the graph of torque magnitude against the angle between the two vectors is a positive half-sine curve.



Torque magnitude versus the angle between the dipole moment and the electric field.

Step 2: Find the zero and maximum torque orientations For zero torque, $\sin \theta = 0$, giving $\theta = 0$ or π . The dipole is respectively parallel or antiparallel to the field. For maximum magnitude, $\sin \theta = 1$, giving $\theta = \pi/2$; the dipole is perpendicular to the field and $\tau_{\max} = pE$. The net force remains zero throughout because the external field is uniform, but its couple can still rotate the dipole.

Step 3: Conclusion $\tau = pE \sin \theta$. Torque vanishes at 0° and 180° , and its maximum value pE occurs at 90° .

Quick Tip to Solve: Mark the three anchor points $(0,0)$, $(\pi/2, pE)$, and $(\pi, 0)$, then join them with a smooth half-sine curve.

23(a). Write the expression for the Lorentz force on a particle of charge q moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}$. When is the magnitude of this force maximum? Show that no work is done by this force on the particle during its motion from a point $\vec{r}_1$ to point $\vec{r}_2$. [2 marks]

Solution:

Concept:

- The magnetic Lorentz force on charge q is $\vec{F} = q(\vec{v} \times \vec{B})$; its direction is perpendicular to the instantaneous velocity $\vec{v}$.
- Work is the line integral $W = \int \vec{F} \cdot d\vec{r}$, and the displacement during time dt is $d\vec{r} = \vec{v} dt$.

Step 1: State the force and its maximum magnitude Since only a magnetic field is specified, the force is

$$\vec{F} = q(\vec{v} \times \vec{B}), \quad F = |q|vB \sin \theta,$$

where θ is the angle between velocity and magnetic field. For fixed $|q|$, v , and B , the magnitude is maximum when the particle moves perpendicular to the field: $\theta = 90^\circ$, so $F_{\max} = |q|vB$. The sign of q reverses the force direction, but does not alter its magnitude.

Step 2: Evaluate the work along the actual path Use the instantaneous displacement, which is tangent to the path even when the particle is deflected:

$$\begin{aligned} W &= \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r} \\ &= q \int_{t_1}^{t_2} (\vec{v} \times \vec{B}) \cdot \vec{v} dt = 0. \end{aligned}$$

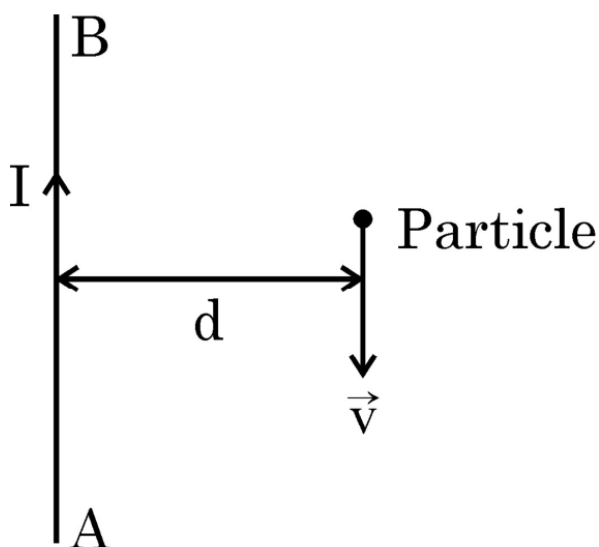
The scalar product vanishes at every point because $\vec{v} \times \vec{B}$ is perpendicular to $\vec{v}$. Thus the magnetic force can change the velocity direction but cannot change the particle's speed or kinetic energy.

Step 3: Conclusion $\vec{F} = q(\vec{v} \times \vec{B})$, with maximum magnitude $|q|vB$ for $\vec{v} \perp \vec{B}$. Its work from $\vec{r}_1$ to $\vec{r}_2$ is zero.

Quick Tip to Solve: To prove zero magnetic work on a curved path, use $d\vec{r} = \vec{v} dt$ and the perpendicularity of the cross product at each instant.

OR

23(b). A long straight wire AB carries a current I . A particle (mass m and charge q) moves with a velocity $\vec{v}$, parallel to the wire, at a distance d from it as shown in the figure. Obtain the expression for the force experienced by the particle and mention its directions. [2 marks]



Solution:

Concept:

- A long straight wire carrying current I produces magnetic field magnitude $B = \mu_0 I / (2\pi d)$ at perpendicular distance d ; its direction follows the right-hand thumb rule.
- The magnetic force is $\vec{F} = q(\vec{v} \times \vec{B})$. Its magnitude is $|q|vB \sin \theta$, where θ is the angle between velocity and magnetic field.

Step 1: Determine the field at the particle In the printed figure the current flows upwards from A to B and the particle is to the right of the wire. Curling the right-hand fingers around the wire with the thumb upwards gives a magnetic field directed into the plane of the page at the particle. Its magnitude there is

$$B = \frac{\mu_0 I}{2\pi d}.$$

Step 2: Calculate the force and its direction The particle velocity is downwards in the plane of the page, and therefore perpendicular to the field. Thus

$$F = |q|vB = \frac{\mu_0 I |q| v}{2\pi d}.$$

For positive q , the cross product of the downward velocity and the inward field points to the right, away from the wire. For negative q , the force reverses and points towards the wire. The mass does

not enter the magnetic-force expression.

Step 3: Conclusion The force magnitude is $\mu_0 I |q| v / (2\pi d)$, directed away from AB for $q > 0$, and towards AB for $q < 0$, for the shown velocity.

Quick Tip to Solve: First find the wire's field with the right-hand thumb rule, then use $\vec{v} \times \vec{B}$; reverse the result only for a negative charge.

24. A potential difference (V) is applied across a conductor of length 'L' and cross-sectional area 'A'. How will the drift velocity of electrons and the current density be affected if another identical conductor of the same material were connected in series with the first conductor? Justify your answers. [2 marks]

Solution:

Concept:

- For a uniform conductor, $R = \rho L / A$, where ρ is resistivity, L is length and A is cross-sectional area. Resistances add in series.
- Current density is $J = I / A = nev_d$, where n is the free-electron number density, e is the electron charge magnitude and v_d is drift-speed magnitude.

Step 1: Compare the current before and after the connection Initially the conductor has resistance $R = \rho L / A$, so the current under the applied potential difference V is $I = V / R$. Connect the identical conductor in series, keeping the same potential difference V across the complete combination. The total resistance becomes $2R$, giving

$$I' = \frac{V}{2R} = \frac{I}{2}.$$

The same reduced current flows through each conductor. Since their resistances are equal, each now has potential difference $V/2$ across its length.

Step 2: Compare current density and electron drift speed The area of each wire remains A , and adding a wire does not change the free-electron density of the material. Hence

$$J' = \frac{I'}{A} = \frac{I}{2A} = \frac{J}{2},$$
$$v'_d = \frac{I'}{neA} = \frac{I}{2neA} = \frac{v_d}{2}.$$

Equivalently, the field in either wire drops from V/L to $V/(2L)$. At unchanged temperature, drift speed is proportional to field, confirming the same factor.

Step 3: Conclusion With the same voltage applied across the series combination, both the electron drift-speed magnitude and current density become half their original values: $v'_d = v_d/2$ and $J' = J/2$.

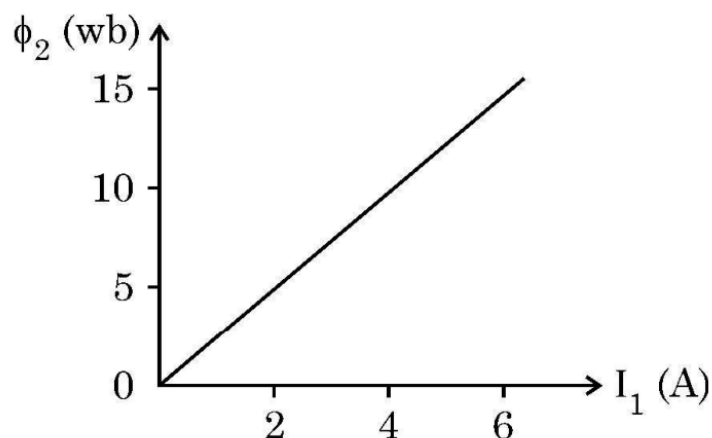
Quick Tip to Solve: For identical wires in series at fixed total voltage, first halve the current; unchanged A and n then make both J and v_d halve.

25. Two coils C_1 and C_2 are placed close to each other. The magnetic flux ϕ_2 linked with the coil C_2 varies with the current I_1 flowing in coil C_1 , as shown in the figure. Find

(i) the mutual inductance of the arrangement, and

(ii) the rate of change of current $\left(\frac{dI_1}{dt}\right)$ that will induce an emf of 100 V in coil C_2 .

[2 marks]



Solution:

Concept:

- Mutual inductance M relates the flux linked with the second coil to the first coil's current: $\phi_2 = MI_1$. Thus M is the slope of the given flux-current graph.
- Faraday's law gives $\varepsilon_2 = -M dI_1/dt$. The minus sign specifies opposition to the change; the emf magnitude is $|\varepsilon_2| = M|dI_1/dt|$.

Step 1: (i) Read the slope of the straight line The line passes through the origin and indicates a flux change of approximately 15 Wb for a current change of 6 A. Using the labelled graph scales,

$$M = \frac{\Delta\phi_2}{\Delta I_1} = \frac{15 - 0}{6 - 0} = 2.5 \text{ Wb A}^{-1} = 2.5 \text{ H}.$$

The flux shown is already the flux linked with coil C_2 , so no extra unspecified number of turns is inserted.

Step 2: (ii) Apply the induced-emf relation For an induced emf of magnitude 100 V, the required magnitude of the rate of change of current is

$$\left|\frac{dI_1}{dt}\right| = \frac{|\varepsilon_2|}{M} = \frac{100}{2.5} = 40 \text{ A s}^{-1}.$$

An increasing and a decreasing current at this rate produce opposite emf polarities. Since the question gives no polarity, only the magnitude of the rate is determined.

Step 3: Conclusion (i) The mutual inductance is 2.5 H. (ii) The required rate of change of current has magnitude 40 A s^{-1} .

Quick Tip to Solve: First take the slope of the flux-current graph to get M , then divide the required emf by this slope.

Section C (15 marks)

26(a). A plane wave-front propagating in a medium of refractive index ' μ_1 ' is incident on a plane surface making an angle of incidence (i). It enters into a medium of refractive index μ_2 ($\mu_2 > \mu_1$). Use Huygen's construction of secondary wavelets to trace the refracted wave-front. Hence verify Snell's law of refraction. [3 marks]

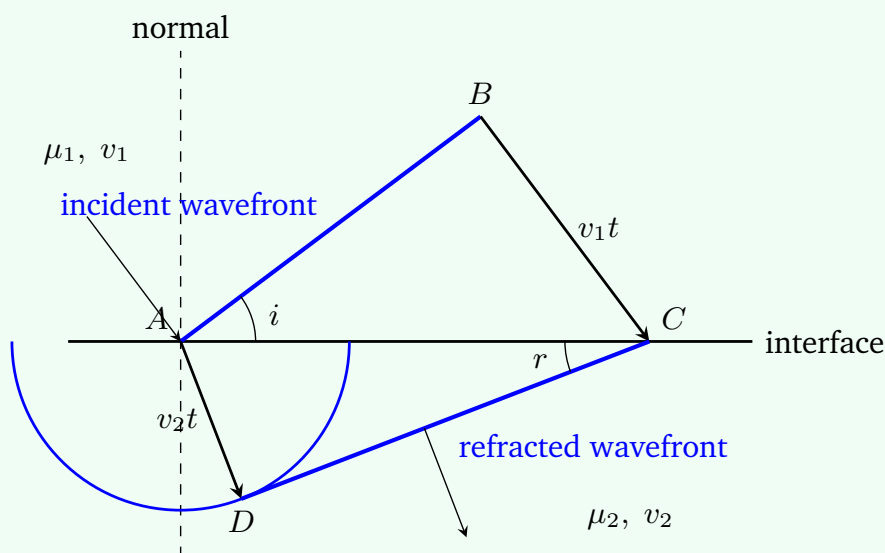
Solution:

Concept:

- By Huygens' principle, every point of a wavefront acts as a source of secondary wavelets. The forward common tangent to these wavelets is the new wavefront.
- Light has speed $v_1 = c/\mu_1$ in medium 1 and $v_2 = c/\mu_2$ in medium 2, where c is its vacuum speed. Since $\mu_2 > \mu_1$, $v_2 < v_1$.
- Rays are normal to their wavefronts. Hence the angle a wavefront makes with the interface equals the corresponding ray's angle with the normal.

Step 1: Construct the incident wavefront and the secondary wavelet Let AB be the incident plane wavefront, with A reaching the interface first. In time t , the disturbance at B reaches C along the incident ray, so $BC = v_1 t$. During the same interval the secondary wavelet from A advances into medium 2 through a radius $AD = v_2 t$. Since light travels more slowly in medium 2, $AD < BC$.

Step 2: Trace the refracted wavefront Draw the tangent CD from C to the secondary wavelet centred at A . The radius AD is perpendicular to CD . This tangent is the refracted plane wavefront, and normals to it give the refracted rays. Points between A and C begin emitting later; their smaller wavelets have the same forward tangent CD .



Huygens construction: $BC = v_1 t$, $AD = v_2 t$, and CD is tangent to the wavelet.

Step 3: Compare the two right triangles The incident wavefront is perpendicular to BC , so triangle ABC is right-angled at B . Triangle ADC is right-angled at D . If i and r are the ray angles to the normal, then $\angle BAC = i$ and $\angle ACD = r$. Therefore,

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

Dividing eliminates the common distance and time:

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{c/\mu_1}{c/\mu_2} = \frac{\mu_2}{\mu_1}.$$

Step 4: Conclusion CD is the refracted wavefront and $\mu_1 \sin i = \mu_2 \sin r$, verifying Snell's law. Since $\mu_2 > \mu_1$, $r < i$: the ray bends towards the normal.

Quick Tip to Solve: Use the common hypotenuse AC : divide BC/AC by AD/AC to obtain the speed ratio immediately.

OR

26(b). Using Huygen's construction, show how a plane wave is reflected from a surface. Hence verify the law of reflection. [3 marks]

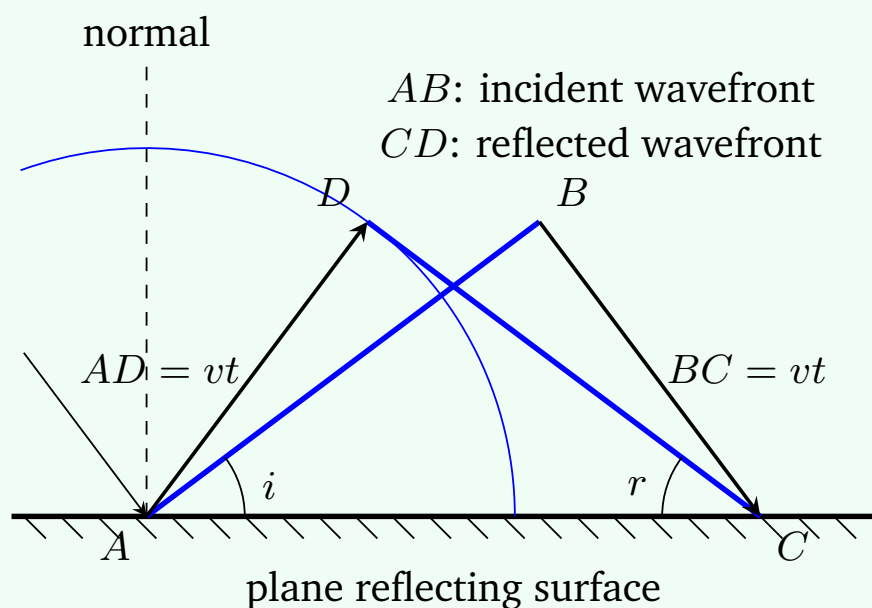
Solution:

Concept:

- Huygens' principle treats each point reached by a wavefront as a source of secondary wavelets. Their forward common tangent forms the new wavefront.
- During reflection the incident and reflected waves travel in the same medium with the same speed v . Their distances travelled in equal times are therefore equal.
- A ray is perpendicular to its wavefront. Angles of incidence and reflection are measured between the rays and the normal to the reflecting surface.

Step 1: Let the incident wavefront reach the mirror Let AB be a plane wavefront incident on the plane reflecting surface. Point A reaches the mirror first. While point B travels along its incident ray to C in a time t , the disturbance from A spreads back into the original medium as a reflected secondary wavelet. Thus $BC = vt$, and the radius of that wavelet is $AD = vt$.

Step 2: Draw the reflected wavefront Draw the tangent CD from C to the reflected wavelet centred at A . This common forward tangent represents the reflected wavefront. The radius AD is perpendicular to CD , so AD is along a reflected ray. Other points of the mirror between A and C emit wavelets after being reached, and their forward envelope is also CD .



Reflection in the same medium: the wavelet radius AD equals BC .

Step 3: Establish the equality of the angles Since $AB \perp BC$ and $AD \perp CD$, triangles ABC and ADC are right triangles. They have the same hypotenuse AC , and $BC = AD = vt$. Denoting the angles between the wavefronts and the surface by i and r , respectively,

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

Hence $\sin i = \sin r$. Both angles lie between 0° and 90° , so $i = r$. As a wavefront and its ray are perpendicular, these are also the incidence and reflection angles measured from the normal. The construction lies in the plane containing the incident ray and the surface normal; the reflected ray lies in this same plane.

Step 4: Conclusion The tangent CD is the reflected plane wavefront. The construction gives $i = r$, with the incident ray, reflected ray and normal in one plane, verifying the laws of reflection.

Quick Tip to Solve: For reflection, write $BC = AD = vt$ first; the common hypotenuse AC then makes the angle equality immediate.

27. A current of 1A flows through a coil when it is connected across a DC battery of 100 V. If DC battery is replaced by an AC source of 100 V and angular frequency 100 rad s^{-1} , the current reduces to 0.5 A. Find

(i) impedance of the circuit.

(ii) self-inductance of coil.

(iii) phase difference between the voltage and the current.

[3 marks]

Solution:

Concept:

- A real coil has resistance R and self-inductance L . At steady DC, $dI/dt = 0$, so its inductive emf vanishes and $R = V_{\text{DC}}/I_{\text{DC}}$.
- For a sinusoidal AC supply, inductive reactance is $X_L = \omega L$ and the impedance magnitude is $Z = \sqrt{R^2 + X_L^2}$. The AC voltage and current values are taken as rms values.
- In a series resistance-inductance circuit, voltage leads current by ϕ , where $\tan \phi = X_L/R$, or equivalently $\cos \phi = R/Z$.

Step 1: Determine the coil resistance from the DC data The stated DC current is the steady current, after the switching transient has ended. The coil's resistance is therefore

$$R = \frac{100}{1} = 100 \Omega.$$

This same resistance acts when the coil is connected to the AC source, along with the additional opposition due to its inductance.

Step 2: (i) Find the impedance under AC Dividing rms voltage by rms current gives the magnitude of the total impedance:

$$Z = \frac{V_{\text{rms}}}{I_{\text{rms}}} = \frac{100}{0.5} = 200 \Omega.$$

The reduced current occurs because Z exceeds the coil resistance. Resistance and inductive reactance combine through a right-triangle relation, rather than by simple scalar addition.

Step 3: (ii) Calculate the self-inductance Isolate the inductive reactance from $Z^2 = R^2 + X_L^2$:

$$X_L = \sqrt{200^2 - 100^2} = 100\sqrt{3} \Omega.$$

The angular frequency is already $\omega = 100 \text{ rad s}^{-1}$; no additional factor of 2π is needed. Thus,

$$L = \frac{X_L}{\omega} = \frac{100\sqrt{3}}{100} = \sqrt{3} \text{ H} \approx 1.73 \text{ H}.$$

Step 4: (iii) Determine the phase difference and its direction The resistance voltage is in phase with current, while the inductive voltage leads current by 90° . Their resultant leads current through the angle

$$\cos \phi = \frac{R}{Z} = \frac{100}{200} = \frac{1}{2}, \quad \phi = 60^\circ = \frac{\pi}{3} \text{ rad}.$$

This is an inductive circuit, so the current lags the applied voltage by this angle.

Step 5: Conclusion (i) $Z = 200 \Omega$; (ii) $L = \sqrt{3} \text{ H} \approx 1.73 \text{ H}$; (iii) the phase difference is 60° , with current lagging voltage.

Quick Tip to Solve: Obtain R from DC first and Z from AC; then $R/Z = 1/2$ immediately gives the 60° phase lag.

28. The primary coil having N_p turns of an ideal transformer is supplied with an alternating voltage V_p . Obtain an expression for the voltage V_s induced in its secondary coil having N_s turns. Mention two main sources of power loss in real transformers. [3 marks]

Solution:

Concept:

- A transformer works by mutual induction: alternating current in the primary produces a changing magnetic flux linked with both coils.
- Faraday's law gives the induced emf $e = -N d\Phi/dt$, where N is the number of turns and Φ is the magnetic flux through each turn.
- In an ideal transformer, both coils link the same flux, their resistances vanish, and there are no core losses or flux leakage. Terminal-voltage magnitudes then equal the induced-emf magnitudes.

Step 1: Apply Faraday's law to both windings Let $\Phi(t)$ be the common instantaneous magnetic flux through one turn of each winding. With corresponding winding reference directions, the induced emfs are

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

The minus signs express Lenz's law. Since the same flux varies at the same rate in both coils, dividing the two expressions eliminates the common flux factor:

$$\frac{e_s}{e_p} = \frac{N_s}{N_p}.$$

Step 2: Relate the induced emfs to terminal voltages With no winding resistance, the applied primary voltage balances the primary back emf, and the secondary terminal voltage equals its induced emf. Therefore the ratio of voltage magnitudes, and also of their rms values, is

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

Thus more secondary turns produce a step-up transformer, while fewer secondary turns produce a step-down transformer. The voltage frequency remains that of the alternating supply.

Step 3: Identify two losses in a real transformer **Copper loss:** the primary and secondary winding resistances produce Joule heating, with total loss $I_p^2 R_p + I_s^2 R_s$.

Eddy-current loss: the changing core flux induces circulating currents in the conducting iron core; these currents dissipate energy as heat. Insulated laminations restrict the current loops and reduce this loss.

Step 4: Conclusion The secondary voltage is $V_s = (N_s/N_p)V_p$, where voltages denote rms values or corresponding amplitudes. Two main losses in real transformers are copper loss in the windings and eddy-current loss in the core.

Quick Tip to Solve: Write the same flux derivative for both coils and divide: secondary-to-primary voltage follows secondary-to-primary turns.

29. (a) Briefly describe how the current sensitivity of a moving coil galvanometer can be increased.
(b) A galvanometer shows full scale deflection for current I_g . A resistance R_1 is required to convert it into a voltmeter of range $(0 - V)$ and a resistance R_2 to convert it into a voltmeter of range $(0 - 2V)$. Find the resistance of the galvanometer. [3 marks]

Solution:

Concept:

- In the radial magnetic field of a moving coil galvanometer, magnetic torque $NIAB$ balances restoring torque $k\theta$. Here N is the turn count, A is the coil area, B is the field and k is the torsional constant.
- Current sensitivity is deflection per unit current: $S_I = \theta/I = NAB/k$.
- A galvanometer of resistance G becomes a voltmeter by adding a high resistance R in series. Its full-scale voltage is $V_{fs} = I_g(G + R)$.

Step 1: Relate current sensitivity to construction For a steady deflection, torque balance gives

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

Therefore the current sensitivity can be increased by increasing the number of coil turns, increasing the coil area, increasing the radial magnetic field, or reducing the torsional constant of the suspension. A stronger permanent magnet with a soft iron core increases B ; a suspension with a smaller restoring torque per unit twist reduces k . These changes increase deflection for the same small current. Simply increasing the current produces more deflection but does not change the sensitivity itself.

Step 2: Write the full-scale relation for each range Let G be the resistance of the galvanometer. The same full-scale current I_g flows through it and its series resistance in either conversion. Thus

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

The resistances R_1 and R_2 are the additional series resistances, not the total resistances of the converted instruments.

Step 3: Eliminate the full-scale current and voltage Divide the second relation by the first, then

rearrange:

$$2 = \frac{G + R_2}{G + R_1},$$
$$2G + 2R_1 = G + R_2,$$
$$G = R_2 - 2R_1.$$

For a physical galvanometer of positive resistance this implies $R_2 > 2R_1$. Doubling the range doubles the total voltmeter resistance, which includes G , rather than merely doubling the added resistance.

Step 4: Conclusion (a) Increase N , A , or B , or reduce k , to increase $S_I = NAB/k$. (b) The galvanometer resistance is $G = R_2 - 2R_1$.

Quick Tip to Solve: For two voltmeter ranges, write the total series resistance as $G + R$ each time before taking the ratio of the ranges.

30(a). (i) Write the limitations of Rutherford's model of atom.

(ii) The wavelength of the second line of the Balmer series in the hydrogen spectrum is $4861 \text{ \AA}$. Calculate the wavelength of the first line of the same series. [3 marks]

Solution:

Concept:

- According to classical electrodynamics, an accelerated charged particle radiates energy. An electron moving in a circular orbit is accelerated even when its speed is constant.
- Hydrogen has discrete spectral lines. For the Balmer series, transitions terminate at $n = 2$, and $1/\lambda = R_H(1/2^2 - 1/n^2)$, where R_H is the Rydberg constant.

Step 1: Explain the limitations of Rutherford's model **Atomic stability:** an orbiting electron experiences centripetal acceleration and should continuously radiate electromagnetic energy according to classical physics. Losing mechanical energy, it should spiral into the nucleus. Rutherford's model therefore predicts an unstable atom, contrary to observation.

Line spectra: as the electron loses energy and its orbit changes continuously, its orbital frequency changes continuously. The classical model provides no permitted discrete energies or selection of fixed frequencies, and cannot explain the observed discrete spectral lines of atoms.

Step 2: Identify the first two Balmer transitions Both lines end at the second energy level. The first line is the $n = 3 \rightarrow 2$ transition, whereas the second is $n = 4 \rightarrow 2$. Denote their wavelengths by λ_1 and λ_2 , respectively. Applying the Rydberg formula gives

$$\frac{1}{\lambda_1} = R_H \left(\frac{1}{4} - \frac{1}{9} \right) = \frac{5R_H}{36},$$

$$\frac{1}{\lambda_2} = R_H \left(\frac{1}{4} - \frac{1}{16} \right) = \frac{3R_H}{16}.$$

Step 3: Take the wavelength ratio and substitute Taking the ratio removes R_H . Since wavelength is

inversely proportional to wavenumber, the order of the factors reverses:

$$\begin{aligned}\frac{\lambda_1}{\lambda_2} &= \frac{3/16}{5/36} = \frac{27}{20}, \\ \lambda_1 &= \frac{27}{20} \times 4861 \text{ \AA} \\ &= 6562.35 \text{ \AA}.\end{aligned}$$

The first line has the smaller photon energy and thus the longer wavelength, consistent with this result.

Step 4: Conclusion Rutherford's model cannot explain atomic stability or discrete line spectra. The first Balmer wavelength is $\lambda_1 \approx 6562 \text{ \AA} = 656.2 \text{ nm}$, to the precision of the given wavelength.

Quick Tip to Solve: Balmer lines end at $n = 2$: use upper levels 3 and 4 for the first two lines, and remember to invert the wavenumber ratio.

OR

30(b). (i) Increase in the intensity of the radiation causing photo-electric emission from a surface, does not affect the maximum K.E. of the photo electrons. Explain.

(ii) The photon emitted during the de-excitation from the first excited level to the ground state of hydrogen atom is used to irradiate a photo cathode in which stopping potential is 5 V. Calculate the work function of the cathode used. [3 marks]

Solution:

Concept:

- Photon energy is $h\nu$, with Planck's constant h and frequency ν . At fixed frequency, higher intensity means a higher photon rate.
- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi$, where ϕ is the work function. The stopping potential V_0 satisfies $K_{\max} = eV_0$, with e the magnitude of electron charge.
- Hydrogen energy levels are $E_n = -13.6/n^2 \text{ eV}$. The energy of an emitted photon equals the initial atomic energy minus the final atomic energy.

Step 1: Explain why intensity does not change maximum kinetic energy One electron absorbs one photon in the usual photoelectric effect. At fixed frequency, each photon supplies the same energy $h\nu$, independent of intensity. After spending energy ϕ to escape, the maximum remaining kinetic energy is

$$K_{\max} = h\nu - \phi.$$

Increasing intensity changes neither ν nor ϕ , so $K_{\max}$ is unchanged. More photons can emit more electrons per second and increase the saturation photocurrent, without raising the photon energy.

Step 2: Calculate the hydrogen photon energy The first excited level is $n = 2$, and the ground state is $n = 1$. Their energies are

$$E_2 = -\frac{13.6}{4} = -3.4 \text{ eV}, \quad E_1 = -13.6 \text{ eV}.$$

The atom loses energy in this transition, so the positive emitted photon energy is

$$h\nu = E_2 - E_1 = (-3.4) - (-13.6) = 10.2 \text{ eV}.$$

Step 3: Use stopping potential to obtain the work function The stopping potential gives $K_{\max} = eV_0 = 5 \text{ eV}$. Rearranging Einstein's equation,

$$\begin{aligned}\phi &= h\nu - K_{\max} \\ &= 10.2 - 5 = 5.2 \text{ eV} \\ &= 5.2 \times 1.6 \times 10^{-19} \text{ J} = 8.32 \times 10^{-19} \text{ J}.\end{aligned}$$

The photon energy exceeds this work function, as required for photoemission.

Step 4: Conclusion At fixed frequency, intensity changes the photon rate but leaves $K_{\max} = h\nu - \phi$ unchanged. The photocathode work function is $5.2 \text{ eV} = 8.32 \times 10^{-19} \text{ J}$.

Quick Tip to Solve: Keep energies in electronvolts: a stopping potential of 5 V immediately gives $K_{\max} = 5 \text{ eV}$, to subtract from the hydrogen photon energy.

Section D (15 marks)

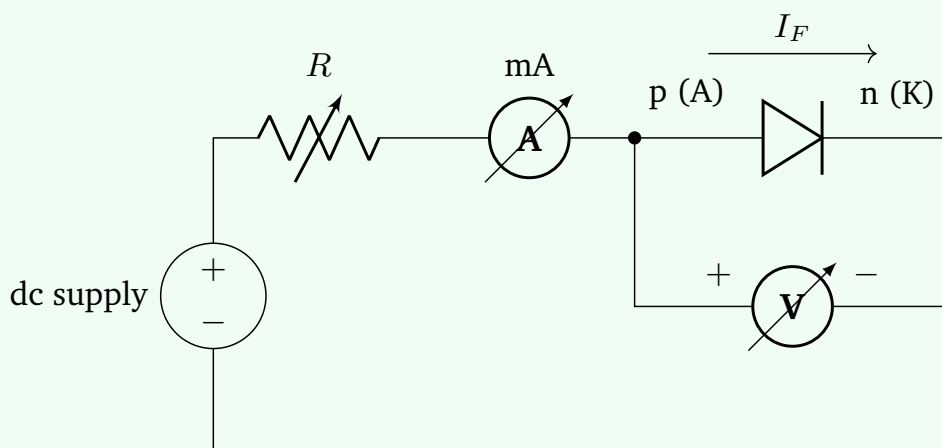
31(a). Draw the circuit arrangement for studying V-I characteristics of a p-n junction diode in (i) forward biasing and (ii) reverse biasing. Draw the typical V-I characteristics of a silicon diode. Describe briefly the following terms: (i) minority carrier injection in forward biasing and (ii) breakdown voltage in reverse biasing. [5 marks]

Solution:

Concept:

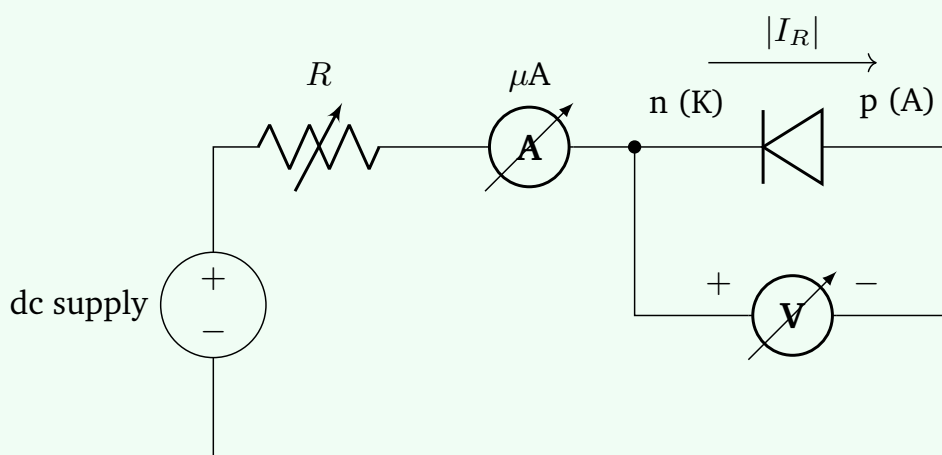
- Forward bias connects the p side to the positive terminal and the n side to the negative terminal. It reduces the junction barrier and depletion-layer width, allowing majority carriers to cross the junction.
- Reverse bias connects the n side to the positive terminal and the p side to the negative terminal. The barrier and depletion width increase; a small minority-carrier current flows before breakdown.
- The diode voltage is measured by a voltmeter in parallel, while diode current is measured by an ammeter in series. A series variable resistor limits and adjusts current.

Step 1: Arrange the forward-bias circuit Connect the positive terminal of the dc supply through a variable resistor and a milliammeter to the p side (anode) of the silicon diode. Connect its n side (cathode) to the negative terminal. Place a voltmeter across the diode with its positive terminal on the p side. Vary the applied voltage slowly and record corresponding diode voltage V_F and forward current I_F . The series resistor protects the diode when its current rises rapidly.



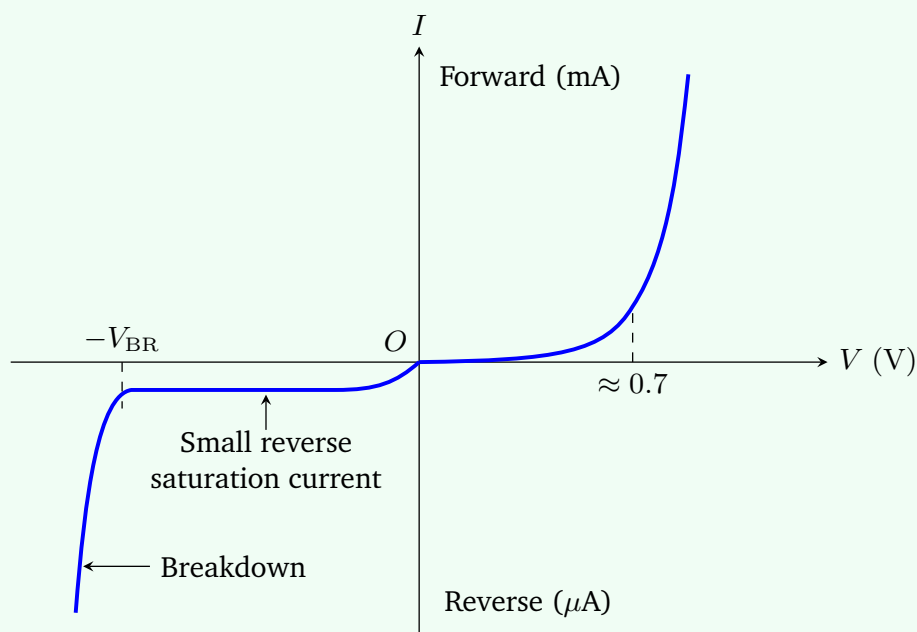
Forward bias: p side to positive, n side to negative; voltmeter across the diode.

Step 2: Arrange the reverse-bias circuit Reverse the diode so that the positive supply terminal is connected to the n side and the negative terminal to the p side. Use a microammeter in series, since the reverse current is very small, and connect the voltmeter across the diode with its positive terminal on the n side. Record reverse voltage and current while varying the supply. A suitable high-voltage supply is needed to investigate breakdown, and current must always be limited by the series resistor.



Reverse bias: n side to positive, p side to negative; microammeter measures the small reverse current.

Step 3: Plot the silicon-diode characteristic Take diode voltage $V = V_p - V_n$ along the horizontal axis and current I , positive from p to n, along the vertical axis. In forward bias the current is initially small and then rises steeply near the silicon knee voltage, approximately 0.7 V at room temperature. This knee is an approximate operating feature, not an abrupt universal threshold. Under reverse bias a small, nearly constant reverse saturation current flows. At $V = -V_{BR}$, its magnitude rises sharply. The reverse-current scale is expanded in the schematic because reverse currents before breakdown are usually in microamperes whereas forward currents are in milliamperes.



Typical silicon V-I curve (schematic; forward and reverse scales differ).

Step 4: Explain minority-carrier injection Forward bias lowers the potential barrier. Electrons, which are majority carriers on the n side, diffuse across the junction into the p side, where they become minority carriers. Similarly, holes diffuse from the p side into the n side and become minority carriers there. The resulting increase in minority-carrier concentration near each side of the junction is called minority-carrier injection. These injected carriers diffuse into the neutral regions and recombine; the external supply maintains the forward current.

Step 5: Define the breakdown voltage Breakdown voltage V_{BR} is the magnitude of reverse bias at which the reverse current increases very sharply for a small further increase in applied voltage. The strong junction electric field causes Zener tunnelling or avalanche carrier multiplication, depending on the junction. The voltage is negative on the signed characteristic, but its quoted breakdown magnitude is positive. Without current limiting, excessive heating can damage an ordinary diode.

Step 6: Conclusion The forward circuit uses a milliammeter with p connected to positive; the reverse circuit uses a microammeter with n connected to positive. Silicon conducts strongly beyond its approximate 0.7 V knee. Forward bias injects carriers into regions where they are minority carriers; reverse breakdown begins at the characteristic voltage magnitude V_{BR} .

Quick Tip to Solve: Label both diode sides before wiring: p-to-positive means forward bias. Use mA for forward current and microamperes for reverse current, and put the voltmeter across the diode in both circuits.

31(b). Name two important processes involved in the formation of a p-n junction diode. With the help of a circuit diagram, explain the working of junction diode as a full wave rectifier. Draw its input and output waveforms. State the characteristic property of a junction diode that makes it suitable for rectification. [5 marks]

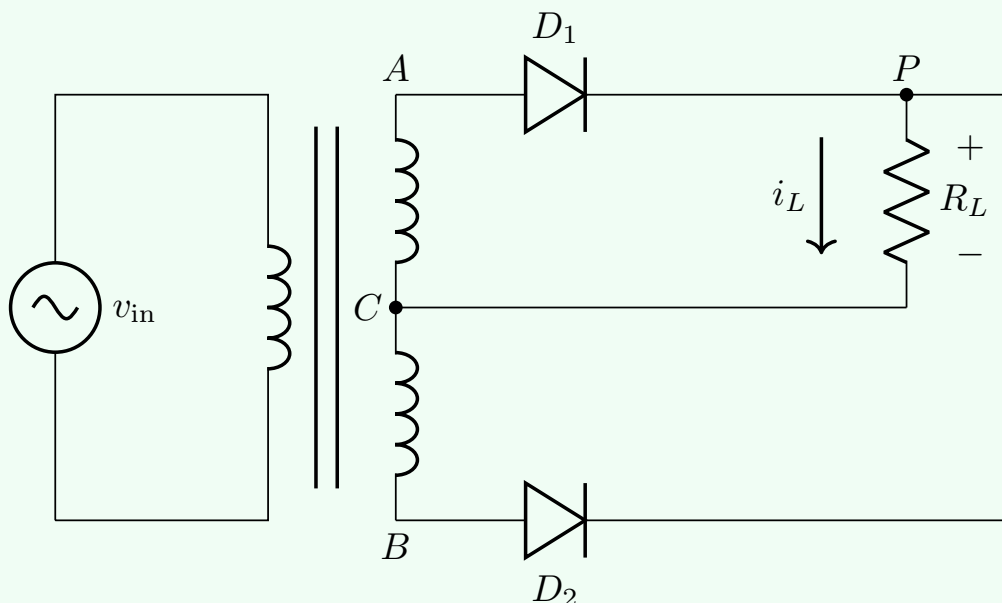
Solution:

Concept:

- Diffusion is carrier motion from higher to lower concentration. Drift is carrier motion under an electric field; both processes participate in the formation and equilibrium of a p-n junction.
- A junction diode has low resistance in forward bias and very high resistance in reverse bias (below breakdown), allowing essentially unidirectional conduction.
- A centre-tapped full-wave rectifier uses two diodes alternately. If each half-secondary has peak voltage V_m , an ideal rectifier gives $v_o = V_m |\sin \omega t|$, where $\omega = 2\pi f$ and f is the input frequency.

Step 1: Identify the junction-formation processes The two important processes are **diffusion and drift**. On joining p-type and n-type material, electrons diffuse from the n side to the p side, while holes diffuse from the p side to the n side. Recombination near the junction leaves behind immobile positive donor ions on the n side and negative acceptor ions on the p side. The region depleted of mobile charge carriers is the depletion layer. Its electric field points from the n side to the p side and produces a potential barrier that opposes further majority-carrier diffusion. The field also drives minority carriers, producing a drift current opposite to the diffusion current. At equilibrium these currents are equal in magnitude, so the net current is zero.

Step 2: Connect the full-wave rectifier Apply the alternating input to the primary of a transformer having a centre-tapped secondary. Let A and B be its ends and C its centre tap. Connect A to the anode of diode D_1 , B to the anode of D_2 , and join their cathodes at P . Connect load resistor R_L between P and C . Measure the output with P positive relative to C . The two secondary-end voltages relative to C are equal in amplitude and opposite in phase.



Full-wave rectifier with centre tap C . Both cathodes join at P ; load current flows from P to C .

Step 3: Follow current in the positive half-cycle When A is positive relative to C , B is negative

relative to C . Diode D_1 is forward biased and conducts; D_2 is reverse biased and blocks. Conventional current follows

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

returning through the upper half of the secondary winding. Thus current in the load flows from P to C .

Step 4: Follow current in the negative half-cycle On reversal of the input polarity, B is positive and A is negative relative to C . Now D_2 conducts and D_1 blocks. The current path is

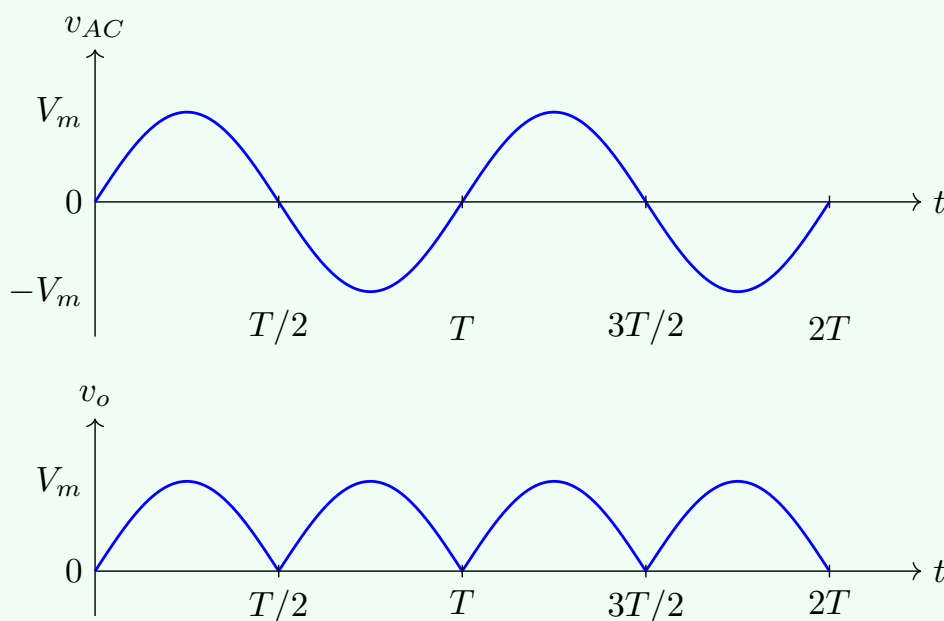
$$B \longrightarrow D_2 \longrightarrow P \longrightarrow R_L \longrightarrow C,$$

returning through the lower half of the secondary. Load current again flows from P to C , so both half-cycles produce the same output polarity.

Step 5: Sketch and interpret the waveforms The input is sinusoidal and changes sign every half-cycle. Neglecting diode drops, the output across R_L consists of successive positive half-sine pulses. For $v_{AC} = V_m \sin \omega t$,

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

The output is pulsating direct voltage, not a constant voltage. There are two output pulses in each input cycle, giving a ripple frequency of $2f$. In the waveform sketch, the input voltage is referred to one half-secondary; the primary input has the same sinusoidal time dependence, with its amplitude set by the turns ratio.



Sinusoidal input and full-wave rectified output for ideal diodes; $T = 1/f$.

Step 6: Conclusion Junction formation involves **diffusion and drift**. A two-diode, centre-tapped full-wave rectifier uses alternate diode conduction to maintain the same load-current direction during both input half-cycles. Rectification is possible because a junction diode conducts readily in forward bias and offers very high resistance in reverse bias below breakdown.

Quick Tip to Solve: Trace both conducting paths from a secondary end through its diode and the load to the centre tap: the load arrow must point the same way for both half-cycles.

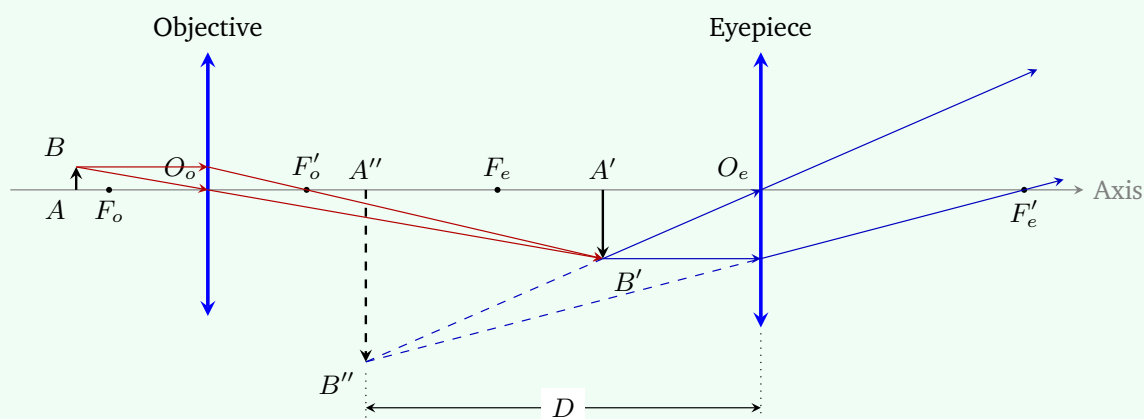
32(a)(i). Draw a ray diagram to show the working of a compound microscope. Obtain the expression for the total magnification for the final image to be formed at the near point. [3 marks]

Solution:

Concept:

- A compound microscope uses a short-focal-length objective to form a real, inverted, enlarged intermediate image; the eyepiece acts as a magnifying glass for that image.
- For a thin lens, $1/f = 1/v - 1/u$, using the Cartesian sign convention. The objective's signed linear magnification is $m_o = v_o/u_o$.
- Total angular magnification is $M = m_o m_e$. Here m_e is the eyepiece's angular magnification and $D = 25 \text{ cm}$ is the least distance of distinct vision for a normal eye.

Step 1: Construct the two successive images Place the small object AB just beyond the first focal point F_o of the objective. Its rays converge to form the real, inverted and enlarged image $A'B'$. Adjust the eyepiece so that $A'B'$ lies between its first focal point F_e and its optical centre O_e . The rays leaving the eyepiece then diverge; their backward extensions meet at B'' . The final image $A''B''$ is virtual, enlarged and inverted relative to the original object. For near-point viewing, its distance from the eyepiece (with the eye close to it) is D . In the schematic, solid arrows show forward light propagation and dashed lines show backward extensions.



Compound microscope adjusted for a final virtual image at the near point (schematic, not to scale).

Step 2: Derive the eyepiece magnification at the near point Let the magnitude of the eyepiece object distance be s , so that $u_e = -s$ and $v_e = -D$. The eyepiece lens formula gives

$$\frac{1}{f_e} = -\frac{1}{D} + \frac{1}{s},$$

$$\frac{D}{s} = 1 + \frac{D}{f_e}.$$

If the intermediate image has height magnitude h' , the small angle at the eye is $\beta \simeq h'/s$. The same image viewed directly at the near point would subtend $\alpha' \simeq h'/D$. Thus

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

Step 3: Combine the objective and eyepiece magnifications An original object of height h , viewed directly at the near point, subtends $\alpha \simeq h/D$. Since the objective produces $|h'/h| = |v_o/u_o|$, the

magnitude of the microscope's total angular magnification is

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

The signed expression is $M = (v_o/u_o)(1 + D/f_e)$; its negative sign denotes inversion. In the usual microscope approximation, $|u_o| \simeq f_o$ and $v_o \simeq L$, where L is the effective tube length. Hence $|M| \simeq (L/f_o)(1 + D/f_e)$.

Step 4: Conclusion For the final virtual image at the near point, $|M| = \frac{v_o}{|u_o|} \left(1 + \frac{D}{f_e} \right) \simeq \frac{L}{f_o} \left(1 + \frac{D}{f_e} \right)$. The signed magnification is negative because the final image is inverted relative to the original object.

Quick Tip to Solve: Multiply the objective linear magnification by the eyepiece angular factor. Near-point viewing requires $1 + D/f_e$; keep the extra 1.

32(a)(ii). In a compound microscope an object is placed at a distance of 1.5 cm from the objective of focal length 1.25 cm. If the eye-piece has a focal length of 5 cm and the final image is formed at the near point, find the magnifying power of the microscope. [2 marks]

Solution:

Concept:

- A compound microscope uses a short-focal-length objective to form a real, inverted, enlarged intermediate image; the eyepiece acts as a magnifying glass for that image.
- For a thin lens, $1/f = 1/v - 1/u$, using the Cartesian sign convention. The objective's signed linear magnification is $m_o = v_o/u_o$.
- Total angular magnification is $M = m_o m_e$. Here m_e is the eyepiece's angular magnification and $D = 25$ cm is the least distance of distinct vision for a normal eye.

Step 1: Calculate the objective image distance With light travelling from the object towards the objective, $u_o = -1.5$ cm and $f_o = +1.25$ cm. Therefore,

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

The positive image distance confirms a real intermediate image, and the negative linear magnification confirms its inversion.

Step 2: Evaluate the near-point eyepiece factor For $f_e = 5$ cm and $D = 25$ cm, the eyepiece factor is

$$m_e = 1 + \frac{25}{5} = 6.$$

Multiplying this angular factor by the objective's linear factor gives $M = (-5)(6)$. Magnifying power is conventionally quoted as the magnitude of this dimensionless product; the sign separately indicates image orientation.

Step 3: Conclusion The magnifying power is $\boxed{30}$, or 30 times. Its signed angular magnification is

$M = -30$, indicating that the final image is inverted.

Quick Tip to Solve: When the objective object distance is given, calculate v_o first instead of guessing a tube length. For a final image at the near point, use $1 + D/f_e$, retaining the extra 1.

OR

32(b). (i) Draw a ray diagram for the formation of image of an object by an astronomical telescope, in normal adjustment. Obtain the expression for its magnifying power.

(ii) The magnifying power of an astronomical telescope in normal adjustment is 2.9 and the objective and the eyepiece are separated by a distance of 150 cm. Find the focal lengths of the two lenses.

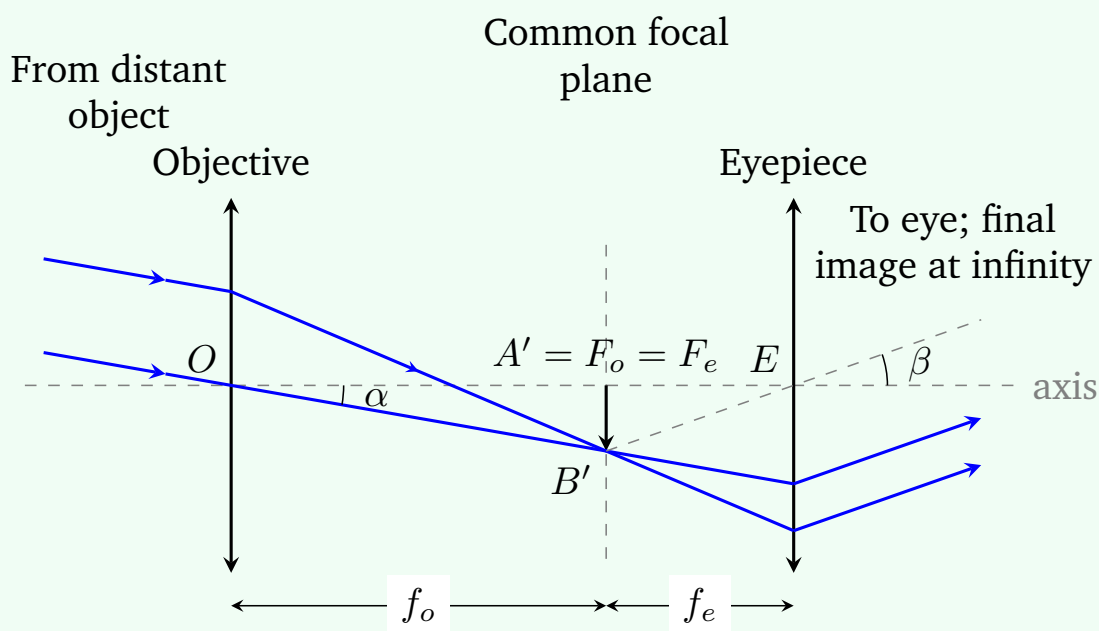
[5 marks]

Solution:

Concept:

- An astronomical telescope uses a convex objective of long focal length f_o and a convex eyepiece of shorter focal length f_e . The objective forms a real inverted image of a distant object.
- In normal adjustment, the objective's image lies in the eyepiece's first focal plane. The final image is at infinity, so the lens separation is $L = f_o + f_e$.
- Angular magnification is $M = \beta/\alpha$, where α is the small angle subtended by the distant object at the unaided eye and β is the angle subtended by the final image through the telescope.

Step 1: (i) Construct the image in normal adjustment Parallel rays from a distant off-axis object are collected by the objective O . They converge at B' , forming the real inverted intermediate image $A'B'$ in the objective's focal plane. Place the eyepiece E so that this same plane is its first focal plane. The rays then emerge parallel from the eyepiece, and the relaxed eye sees the final inverted image at infinity. In the diagram, the dashed oblique line through the eyepiece centre shows the viewing direction; the solid arrows show two rays of the same bundle.



Astronomical telescope in normal adjustment: the common focal plane contains the inverted intermediate image; emerging rays are parallel.

Step 2: Derive the angular magnification Let the magnitude of the intermediate image height be $h = A'B'$. Using the small-angle approximation, the angular size of the distant object and that of the final image have magnitudes

$$|\alpha| \simeq \frac{h}{f_o}, \quad |\beta| \simeq \frac{h}{f_e}.$$

Consequently,

$$|M| = \frac{|\beta|}{|\alpha|} = \frac{h/f_e}{h/f_o} = \frac{f_o}{f_e}.$$

Since the final image is inverted relative to the distant object, the signed angular magnification is $M = -f_o/f_e$. The lens separation is the sum of the positive focal lengths because the intermediate image is simultaneously f_o to the right of the objective and f_e to the left of the eyepiece.

Step 3: (ii) Solve for the two focal lengths The given magnifying power is its magnitude, so $f_o/f_e = 2.9$. Normal adjustment also gives $f_o + f_e = 150$ cm. Substitute $f_o = 2.9f_e$:

$$\begin{aligned} 2.9f_e + f_e &= 150 \text{ cm}, \\ f_e &= \frac{150}{3.9} \text{ cm} \simeq 38.46 \text{ cm}, \\ f_o &= 2.9 \left(\frac{150}{3.9} \right) \text{ cm} \simeq 111.54 \text{ cm}. \end{aligned}$$

The values add to 150 cm, and their ratio is 2.9. The objective has the larger focal length, as required for angular magnification greater than unity.

Step 4: Conclusion In normal adjustment, $M = -f_o/f_e$ (magnitude f_o/f_e) and the final image is inverted at infinity. The focal lengths are $f_o \simeq 111.54$ cm and $f_e \simeq 38.46$ cm.

Quick Tip to Solve: For telescope length L and magnifying-power magnitude m , use $f_e = L/(m + 1)$, then $f_o = mf_e$; normal adjustment uses the sum of the focal lengths.

33(a)(i). Explain how free electrons in a metal at constant temperature attain an average velocity under the action of an electric field. Hence obtain an expression for it. [3 marks]

Solution:

Concept:

- Free electrons have random thermal motion. Without an electric field their mean velocity is zero, although their individual speeds are not zero.
- An electron of charge $-e$ and mass m in a uniform electric field $\vec{E}$ experiences $\vec{F} = -e\vec{E}$, giving acceleration $\vec{a} = -e\vec{E}/m$. Here e is the positive magnitude of the electron charge.
- Relaxation time τ is the mean time between successive collisions. Drift velocity is the ensemble-average velocity acquired under the field: $\vec{v}_d = -e\tau\vec{E}/m$.

Step 1: Explain the origin of a steady drift At constant temperature, free electrons in a metal move rapidly in random directions and collide with the vibrating lattice and imperfections. These random velocities cancel in the average, so thermal motion alone produces no net current. When a field is applied, an electron accelerates opposite to the field during each free flight. Collisions interrupt this acceleration and randomise its motion. Repeated acceleration and collisions establish a small steady average velocity superposed on the random thermal motion, rather than an indefinitely increasing average speed.

Step 2: Average the field-induced velocity Suppose the velocity of an electron just after its last collision is $\vec{u}_i$, and the time since that collision is t_i . Its velocity before the next collision is described by

$$\vec{v}_i = \vec{u}_i - \frac{e\vec{E}}{m}t_i.$$

In the relaxation-time model, the random post-collision velocities satisfy $\langle \vec{u}_i \rangle = 0$, while the relevant mean free-flight time is $\langle t_i \rangle = \tau$. Taking the average over the electrons gives

$$\vec{v}_d = \langle \vec{v}_i \rangle = -\frac{e\tau}{m}\vec{E}, \quad v_d = \frac{eE\tau}{m}.$$

The negative sign specifies that electron drift is opposite to the electric field; conventional current flows along the field. At a fixed temperature, τ is taken as fixed in this model, so the drift speed is proportional to the applied field.

Step 3: Conclusion The average electron velocity is $\vec{v}_d = -\frac{e\tau}{m}\vec{E}$, opposite to the applied electric field. Its magnitude is $v_d = eE\tau/m$, where τ is the relaxation time.

Quick Tip to Solve: Begin with the electron force $-e\vec{E}$, multiply its acceleration by the relaxation time, and retain the minus sign to show the drift direction.

33(a)(ii). Consider two conducting wires A and B of the same diameter but made of different materials joined in series across a battery. The number density of electrons in A is 1.5 times that in B. Find the ratio of drift velocity of electrons in wire A to that in wire B. [2 marks]

Solution:

Concept:

- Current magnitude is $I = neAv_d$, where n is free-electron number density, A is the wire's cross-sectional area and v_d is drift-speed magnitude.
- Series conductors carry the same steady current. Equal diameters give equal cross-sectional areas, so $n_A v_{dA} = n_B v_{dB}$, even when the materials differ.

Step 1: Relate drift speed to the common current In time Δt , electrons within a length $v_d \Delta t$ cross a wire section. The charge transported has magnitude $neAv_d \Delta t$, hence $I = neAv_d$. Both wires carry the same current because they are in series; otherwise charge would continually accumulate at their junction. Their equal diameters imply the same cross-sectional area A . Therefore,

$$n_A e A v_{dA} = n_B e A v_{dB}.$$

Step 2: Substitute the carrier-density ratio Cancel the common charge magnitude and cross-sectional area and use $n_A = 1.5n_B$:

$$\frac{v_{dA}}{v_{dB}} = \frac{n_B}{n_A} = \frac{1}{1.5} = \frac{2}{3}.$$

Thus more carriers per unit volume in A require a smaller drift speed for the same current. The electric fields and relaxation times of the two wires need not be equal, since the materials are different. Here drift velocities are compared along the common electron-flow direction.

Step 3: Conclusion The ratio of electron drift speeds in wires A and B is $v_{dA} : v_{dB} = 2 : 3$.

Quick Tip to Solve: For wires in series use equal current first. With equal areas, nv_d is constant, so the drift-speed ratio is the inverse of the carrier-density ratio.

OR

33(b)(i). A cell emf of (E) and internal resistance (r) is connected across a variable load resistance (R). Draw plots showing the variation of terminal voltage V with (i) R and (ii) the current (I) in the load. [2 marks]

Solution:

Concept:

- For a cell of emf E , internal resistance r and external resistance R , Kirchhoff's loop rule gives $E = I(R + r)$. Its terminal voltage is $V = IR = E - Ir$.
- The terminal voltage is the potential difference across the load. A graph of V against R follows $V = ER/(R + r)$, whereas V against I follows the linear relation $V = E - rI$.

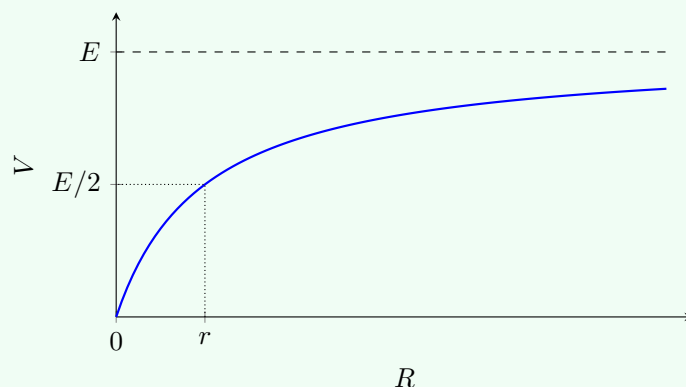
Step 1: Plot terminal voltage against load resistance The current supplied by the cell is $I = E/(R + r)$. Hence the potential difference across the external load is

$$V(R) = IR = \frac{ER}{R + r}.$$

At $R = 0$, the cell is short-circuited and $V = 0$. Increasing R reduces the internal voltage drop, so the terminal voltage increases. In fact,

$$\frac{dV}{dR} = \frac{Er}{(R + r)^2} > 0, \quad \frac{d^2V}{dR^2} = -\frac{2Er}{(R + r)^3} < 0.$$

Thus the graph rises with decreasing slope and approaches the horizontal asymptote $V = E$ as $R \rightarrow \infty$. At $R = r$, its voltage is $E/2$.



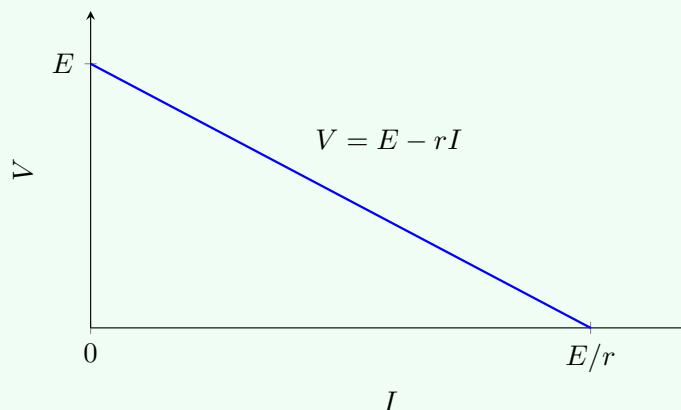
Terminal voltage versus load resistance; the dashed line is the asymptote $V = E$.

Step 2: Plot terminal voltage against load current The emf balances the terminal voltage and the

internal voltage drop:

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

Therefore the V -versus- I plot is a straight line of slope $-r$, with voltage intercept E at open circuit and current intercept E/r at short circuit. For a passive load $R \geq 0$, the relevant current range is $0 \leq I \leq E/r$.



Terminal voltage versus load current; slope $-r$.

Step 3: Conclusion The V -versus- R curve rises from the origin with decreasing slope and approaches $V = E$. The V -versus- I graph is a straight line of slope $-r$, joining $(0, E)$ and $(E/r, 0)$.

Quick Tip to Solve: For both voltage plots, first mark the open-circuit limit $V = E$ and the short-circuit limit $V = 0$; only the current plot is linear.

33(b)(ii). Three cells, each of emf E but internal resistances $2r$, $3r$ and $6r$ are connected in parallel across a resistor R . Obtain expressions for (i) current flowing in the circuit, and (ii) the terminal potential difference across the equivalent cell. [3 marks]

Solution:

Concept:

- Cells of equal emf connected in parallel with like terminals joined have equivalent emf E . Their internal conductances add, so $1/r_{\text{eq}} = \sum 1/r_j$.
- Kirchhoff's junction rule adds the currents supplied by the parallel cells. For load resistance R , Ohm's law gives the common terminal voltage $V = IR$, where I is the total load current.

Step 1: Determine the equivalent cell With all three positive terminals together and all negative terminals together, the cells have the same terminal voltage V . Their branch currents are

$$I_1 = \frac{E - V}{2r}, \quad I_2 = \frac{E - V}{3r}, \quad I_3 = \frac{E - V}{6r}.$$

The total load current is their sum. Therefore

$$I = (E - V) \left(\frac{1}{2r} + \frac{1}{3r} + \frac{1}{6r} \right) = \frac{E - V}{r}.$$

Comparing with $V = E_{\text{eq}} - Ir_{\text{eq}}$ gives $E_{\text{eq}} = E$ and $r_{\text{eq}} = r$. The equal emfs are not added in a parallel connection.

Step 2: Calculate load current and terminal potential difference Since the external resistor has voltage $V = IR$, substitute this into $I = (E - V)/r$:

$$Ir = E - IR, \quad I(R + r) = E.$$

Thus the load current and terminal voltage are obtained directly as

$$I = \frac{E}{R + r}, \quad V = IR = \frac{ER}{R + r} = E - Ir.$$

These expressions have the correct limits: an open circuit has zero current and terminal voltage E , while a short circuit has current E/r and zero terminal voltage.

Step 3: Conclusion The equivalent cell has emf E and internal resistance r . Hence (i) the circuit current is $I = E/(R + r)$, and (ii) the terminal potential difference is $V = ER/(R + r)$.

Quick Tip to Solve: For equal-emf parallel cells, retain the common emf and add internal conductances: here $1/2 + 1/3 + 1/6 = 1$, so the equivalent internal resistance is r .

Section E (8 marks)

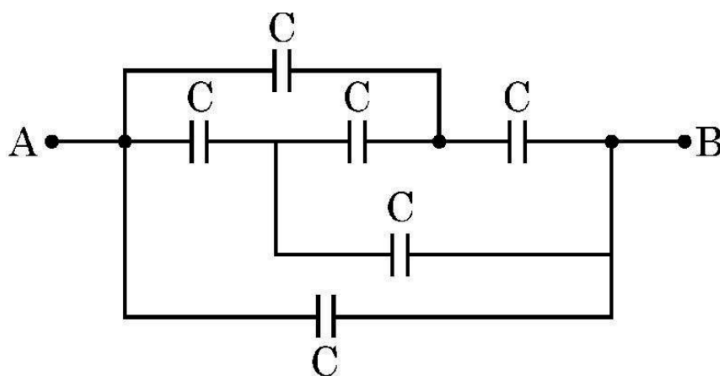
Note : Questions number 34 and 35 are Case Study based questions. Read the following paragraph and answer the questions.

34. A capacitor is a system of two conductors separated by an insulator. The two conductors have equal and opposite charges with a potential difference between them. The capacitance of a capacitor depends on the geometrical configuration (shape, size and separation) of the system and also on the nature of the insulator separating the two conductors. They are used to store charges. Like resistors, capacitors can be arranged in series or parallel or a combination of both to obtain desired value of capacitance.

[4 marks]

34(i). Find the equivalent capacitance between points A and B in the given diagram.

[1 mark]



Solution:

Concept:

- Equal capacitors in series have capacitance $C/2$, while capacitances of branches in parallel add.
- In a balanced capacitor bridge, the two midpoint potentials are equal; the capacitor joining these midpoints has zero potential difference and carries no charge.

Step 1: Recognise the balanced bridge Call the two internal junctions on the central horizontal line X and Y . Apart from the capacitor joining X to Y , each junction connects to A through one capacitor

C and to B through another capacitor C . The two branches are identical, so $V_X = V_Y$. Hence the middle capacitor between them can be ignored in finding the equivalent capacitance.

Step 2: Combine the remaining branches The paths A–X–B and A–Y–B each contain two equal capacitors in series. Each has capacitance $C/2$. The bottom branch is a single capacitor C , directly between A and B. These three branches are in parallel, so

$$C_{\text{eq}} = \frac{C}{2} + \frac{C}{2} + C.$$

Step 3: Conclusion The equivalent capacitance between A and B is $2C$.

Quick Tip to Solve: Identify the two identical A-to-B branches first; equal midpoint potentials let you remove their bridging capacitor before combining series and parallel elements.

34(ii). A dielectric slab is inserted between the plates of a parallel plate capacitor. The electric field between the plates decreases. Explain. [1 mark]

Solution:

Concept:

- A dielectric polarises in an applied electric field: its positive and negative bound charges are displaced slightly, or its permanent molecular dipoles become partly aligned.
- The electric field of these induced bound charges opposes the original field between the charged capacitor plates.

Step 1: Describe the induced surface charges On inserting the slab, its surface facing the positive plate acquires negative bound charge, while its surface facing the negative plate acquires positive bound charge. The resulting polarisation field E_p points opposite to the field E_0 produced by the free charges on the plates.

Step 2: Superpose the opposing fields Hence the net field inside the dielectric is $E = E_0 - E_p$, smaller than the original field. If the dielectric fills the gap and the plate charge is held fixed, then $E = E_0/K$, where $K > 1$ is its relative permittivity. This decrease describes fixed free charge; if a battery instead maintains fixed voltage across a completely filled gap, it supplies extra charge and $E = V/d$ remains fixed.

Step 3: Conclusion Polarisation of the dielectric produces an opposing electric field, reducing the net field for a given free charge on the capacitor plates.

Quick Tip to Solve: Draw the induced bound-charge signs facing each plate; their field opposes the original field. State whether charge or voltage is fixed before using E_0/K .

34(iii). A capacitor A of capacitance C , having charge Q is connected across another uncharged capacitor B of capacitance $2C$. Find an expression for (a) the potential difference across the combination and (b) the charge lost by capacitor A.

[2 marks]

Solution:

Concept:

- When two capacitors are connected in parallel, charge redistributes until they have the same potential difference V_f .
- With no external source connected, the total charge on each connected set of plates is conserved. The charge on a capacitor is $q = CV$.

Step 1: (a) Apply conservation of charge Initially capacitor A has capacitance C and charge Q , while capacitor B, of capacitance $2C$, is uncharged. The total charge available on the connected positive-side plates is therefore Q . After connection across one another, their equivalent capacitance is $C + 2C = 3C$. If their common potential difference is V_f , charge conservation gives

$$Q = CV_f + 2CV_f = 3CV_f, \quad V_f = \frac{Q}{3C}.$$

This is one third of A's initial potential difference Q/C .

Step 2: (b) Calculate the charge transferred from A The charge retained by A at the common voltage is

$$Q_{A,f} = CV_f = C \frac{Q}{3C} = \frac{Q}{3}.$$

Hence the charge lost by A is its initial charge minus its final charge:

$$\Delta Q_A = Q - Q_{A,f} = Q - \frac{Q}{3} = \frac{2Q}{3}.$$

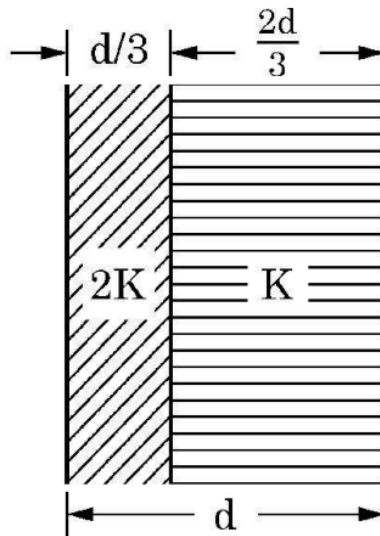
This equals the charge gained by B, since $Q_{B,f} = 2CV_f = 2Q/3$. Thus the individual charges change, but their sum remains Q .

Step 3: Conclusion (a) The common potential difference is $\boxed{Q/(3C)}$. (b) Capacitor A loses charge $\boxed{2Q/3}$, retaining $Q/3$.

Quick Tip to Solve: Find the common voltage from total charge divided by total parallel capacitance, then subtract A's final charge from its initial charge to find the charge lost.

OR

34(iii). Two slabs of dielectric constants $2K$ and K fill the space between the plates of a parallel plate capacitor of plate area A and plate separation d as shown in figure. Find an expression for capacitance of the system. [2 marks]



Solution:

Concept:

- A parallel plate capacitor containing a uniform dielectric of relative permittivity k , thickness t and plate area A has capacitance $C = \epsilon_0 k A / t$, neglecting fringing.
- Layers placed successively along the plate separation behave as capacitors in series: their voltage drops add while the magnitude of charge is the same.

Step 1: Identify the thickness of each dielectric layer The printed figure divides the separation d , not the plate area. The layer of dielectric constant $2K$ has thickness $d/3$; the layer of dielectric constant K has thickness $2d/3$. Each layer spans the full area A . Hence their individual capacitances are

$$C_1 = \frac{\epsilon_0 (2K) A}{d/3} = \frac{6\epsilon_0 K A}{d}, \quad C_2 = \frac{\epsilon_0 K A}{2d/3} = \frac{3\epsilon_0 K A}{2d}.$$

Step 2: Add the potential drops across the layers For free charge magnitude Q on the plates, the total voltage is $V = Q/C_1 + Q/C_2$. Therefore the equivalent capacitance satisfies

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d}{6\epsilon_0 K A} + \frac{2d}{3\epsilon_0 K A} = \frac{5d}{6\epsilon_0 K A}.$$

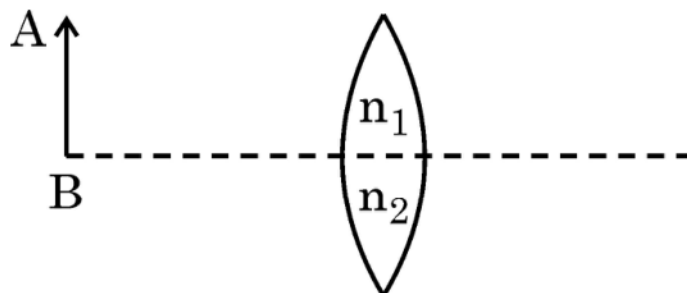
Adding the capacitances directly would describe parallel regions sharing the area; that is not the geometry shown here.

Step 3: Conclusion The capacitance of the system is $C = \frac{6\epsilon_0 K A}{5d}$.

Quick Tip to Solve: Read the dimension arrows first: dividing the separation into dielectric thicknesses means adding inverse capacitances, with the full area for each layer.

35. A lens is a transparent optical medium bounded by two surfaces; at least one of which should be spherical. Considering image formation by a single spherical surface successively at the two surfaces of a lens, lens maker's formula is obtained. It is useful to design lenses of desired focal length using surfaces of suitable radii of curvature. This formula helps us obtain a relation between u , v and f for a lens. Lenses form images of objects and they are used in a number of optical devices, for example microscopes and telescopes. [4 marks]

35(i). An object AB is kept in front of a composite convex lens, as shown in figure. Will the lens produce one image? If not, explain. [1 mark]



Solution:

Concept:

- Lens power depends on refractive index: $1/f = (n - 1)(1/R_1 - 1/R_2)$ for a thin lens in air.
- Each part of a lens can form a complete image; reducing the aperture chiefly reduces its brightness.

Step 1: Compare the powers of the two portions The upper and lower portions have the same surface curvatures but different refractive indices n_1 and n_2 . They therefore have different focal lengths f_1 and f_2 .

Step 2: Apply the lens formula to each portion The object distance u is common to both portions. Since $1/v = 1/f + 1/u$, the different focal lengths give different image distances. Each portion receives rays from the entire object and forms its own complete image, rather than only one half of the image.

Step 3: Conclusion No. For $n_1 \neq n_2$, the composite lens produces two complete images at different positions because its two portions have different focal lengths.

Quick Tip to Solve: For a lens divided into different materials, compare refractive indices first: equal curvatures do not imply equal focal lengths.

35(ii). A real image of an object formed by a convex lens is observed on a screen. If the screen is removed, will the image still be formed? Explain. [1 mark]

Solution:

Concept:

- A real image forms where the refracted rays from each object point actually converge.
- A screen intercepts and scatters the arriving light so the image can be viewed conveniently; it does not bring the rays to focus.

Step 1: Locate what determines the image position The convex lens refracts the rays, and the object distance and focal length determine where they meet. The screen simply occupies that image plane

and makes the focused pattern visible by scattering light toward the observer.

Step 2: Remove the screen without changing the rays Removing the screen leaves the object and lens unchanged, so the rays still converge at the same positions and then diverge beyond the image plane. An eye suitably placed beyond that plane can receive the rays and see the real image. A screen is useful for projection, but is not required for image formation.

Step 3: Conclusion Yes. The real image is still formed at the same position even when the screen is removed, because the refracted rays continue to converge there.

Quick Tip to Solve: Separate the role of the lens, which focuses the rays, from the role of the screen, which scatters those rays for viewing.

35(iii). A double convex lens is made of glass of refractive index 1.55 with both faces of the same radius of curvature. Find the radius of curvature required if focal length is 20 cm. [2 marks]

Solution:

Concept:

- For a thin lens in air, the lens maker's formula is $1/f = (n - 1)(1/R_1 - 1/R_2)$, where n is the glass refractive index and the radii are signed.
- With light travelling from left to right, an equiconvex lens has $R_1 = +R$ and $R_2 = -R$, where R is the common positive radius magnitude.

Step 1: Insert the correct signs of the radii The first surface has its centre of curvature to the right and the second to the left. Thus equal radius magnitudes do not mean equal signed radii. Substituting their signs gives

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R} - \frac{1}{-R} \right) = \frac{2(n - 1)}{R}.$$

This positive power agrees with the converging nature of the double convex lens in air.

Step 2: Substitute the refractive index and focal length Rearrange the formula to obtain $R = 2(n - 1)f$. With $n = 1.55$ and $f = +20$ cm,

$$R = 2(1.55 - 1)(20 \text{ cm}) = 1.10(20 \text{ cm}) = 22 \text{ cm}.$$

As a check, inserting this radius gives $1/f = 1.10/22 = 0.050 \text{ cm}^{-1}$, recovering the given focal length.

Step 3: Conclusion Each face must have radius of curvature 22 cm in magnitude; the signed radii are $R_1 = +22$ cm and $R_2 = -22$ cm.

Quick Tip to Solve: For an equiconvex lens in air, use $R = 2(n - 1)f$; the factor 2 comes from the opposite signs of its two surface radii.

35(iii). Two convex lenses A and B of focal lengths 15 cm and 10 cm respectively are placed coaxially 'd' distance apart. A point object is kept at a distance of 30 cm in front of lens A. Find the value of 'd' so that the rays emerging from lens B are parallel to its principal axis. [2 marks]

Solution:

Concept:

- For each thin lens, the Cartesian lens formula is $1/v - 1/u = 1/f$, where distances are measured from that lens.
- A convex lens sends out parallel rays when the incident rays diverge from a point at its first principal focus, a distance f in front of it.

Step 1: Find the image formed by lens A Take the direction of incident light as positive. For lens A, $f_A = +15$ cm and $u_A = -30$ cm. The lens formula gives

$$\frac{1}{v_A} = \frac{1}{f_A} + \frac{1}{u_A} = \frac{1}{15} - \frac{1}{30} = \frac{1}{30} \text{ cm}^{-1}.$$

Thus A alone brings the rays to an intermediate image 30 cm to its right, as expected for an object at twice its focal length.

Step 2: Place that image at the front focus of lens B The intermediate image must lie 10 cm to the left of B, so that rays reaching B diverge from its front focus. Relative to B the object coordinate is $u_B = 30 - d$, in centimetres. For parallel emergent rays $1/v_B = 0$, so

$$-\frac{1}{u_B} = \frac{1}{10}, \quad u_B = -10 \text{ cm}, \quad 30 - d = -10.$$

This places B beyond the intermediate image; the rays cross before reaching B. Placing B before that image would supply converging incident rays and would not produce the required parallel output.

Step 3: Conclusion The required separation between the lenses is $d = 40$ cm.

Quick Tip to Solve: First locate the image made by A alone; then place B one focal length beyond it so that its incoming rays diverge from its front focus.