CBSE Class 12 Physics Question Paper 2017 with Solution PDF-Set 55/2/3

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 3 hours **Maximum Marks: 70**

General Instructions

(i) **All** questions are **compulsory**. There are **26** questions in all.

(ii) This question paper has **five** sections : Section A, Section B, Section C, Section D and Section E.

(iii) Section A contains **five** questions of **one** mark each, Section B contains **five** questions of **two** marks each, Section C contains **twelve** questions of **three** marks each, Section D contains one value based question of **four** marks and Section E contains **three** questions of **five** marks each.

(iv) There is no overall choice. However, an internal choice has been provided in **one** question of **two** marks, **one** question of **three** marks and all the **three** questions of **five** marks weightage. You have to attempt only **one** of the choices in such questions.

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

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

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

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

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

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

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

Mass of electron $= 9.1 \times 10^{-31}$ kg

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

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

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

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

Section A (5 marks)

1. Does the magnifying power of a microscope depend on the colour of the light used? Justify your answer. [1 mark]

Solution:

Concept:

- The magnifying power of a compound microscope in normal adjustment is approximately $M = LD/(f_o f_e)$, where L is the tube length, D is the least distance of distinct vision, and f_o, f_e are the objective and eyepiece focal lengths.
- For a lens of fixed shape, the lens-maker formula gives $1/f = (n-1)(1/R_1 - 1/R_2)$. The refractive index n depends on the wavelength of light.

Step 1: Relate colour to focal length In ordinary glass, violet light has a larger refractive index than red light. Therefore the same converging lens has a shorter focal length for violet light than for red light.

Step 2: Relate focal length to magnification For the same microscope dimensions and viewing condition, magnifying power varies inversely with the objective and eyepiece focal lengths. A change in colour therefore changes the magnification; the same dependence holds for the near-point expression $M = (L/f_o)(1 + D/f_e)$.

Step 3: Conclusion Yes. Magnifying power depends on colour because lens focal lengths depend on wavelength. It is greater for violet light than for red light in an ordinary glass microscope.

Quick Tip to Solve: Connect colour to refractive index, then focal length, then the inverse focal-length dependence of magnification.

2. A photosensitive surface emits photoelectrons when red light falls on it. Will the surface emit photoelectrons when blue light is incident on it? Give reason. [1 mark]

Solution:

Concept:

- Photoelectric emission occurs when photon energy $h\nu$ is at least the work function ϕ of the surface.
- Frequency and wavelength are related by $\nu = c/\lambda$. Blue light has a shorter wavelength and a higher frequency than red light.

Step 1: Use the observation with red light The given surface emits photoelectrons under red light. Thus the red photons already satisfy $h\nu_{\text{red}} \geq \phi$, or equivalently $\nu_{\text{red}} \geq \nu_0$, where $\nu_0 = \phi/h$ is the threshold frequency.

Step 2: Compare blue photons with the threshold Since $\nu_{\text{blue}} > \nu_{\text{red}}$, we have $h\nu_{\text{blue}} > h\nu_{\text{red}} \geq \phi$. Blue photons can therefore liberate electrons. Their maximum kinetic energy, $K_{\max} = h\nu - \phi$, is also larger for the same surface.

Step 3: Conclusion Yes, blue light will cause photoelectric emission because its photon energy is greater than that of red light, which already exceeds the threshold energy.

Quick Tip to Solve: If a colour causes emission, every higher-frequency colour also clears the same surface threshold.

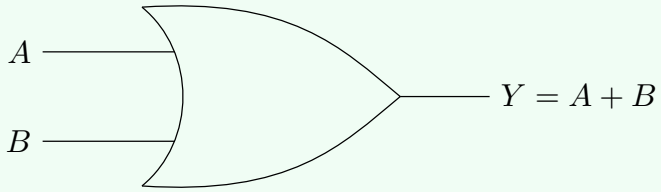
3. Draw logic symbol of an OR gate and write its truth table. [1 mark]

Solution:

Concept:

- An OR gate gives a high output when at least one of its inputs is high.
- For two inputs A and B, the Boolean relation is $Y = A + B$, where $+$ denotes logical OR, not ordinary numerical addition.

Step 1: Draw and identify the gate The two input lines enter the curved input side of the OR symbol. The single line leaving its pointed output side is labelled Y. There is no inversion bubble at the output, so the output is not complemented.



Two-input OR gate with inputs A, B and output Y.

Step 2: Write all input combinations The complete truth table is

A	B	$Y = A + B$
0	0	0
0	1	1
1	0	1
1	1	1

In particular, when both inputs are 1 the output remains the logical value 1; it does not become 2.

Step 3: Conclusion The OR gate symbol is shown above, and its output is 0 only for $(A, B) = (0, 0)$; it is 1 for the other three input combinations.

Quick Tip to Solve: For OR, locate the only low-output row first: both inputs must be 0.

4. A point charge Q is placed at point 'O' as shown in the figure. Is the potential at point A, i.e. V_A, greater, smaller or equal to potential, V_B, at point B, when Q is (i) positive, and (ii) negative charge? [1 mark]



Solution:

Concept:

- Taking potential zero at infinity, the potential due to a point charge is $V = kQ/r$, where $k = 1/(4\pi\varepsilon_0) > 0$ and r is the distance from the charge.
- In the printed figure, O, A, B lie in that order. Thus $r_A = OA < r_B = OB$, so $1/r_A > 1/r_B$.

Step 1: Compare potentials for a positive charge For $Q > 0$, multiplying $1/r_A > 1/r_B$ by the positive factor kQ preserves the inequality: $V_A = kQ/r_A > kQ/r_B = V_B$. Both potentials are positive and the nearer point has the larger value.

Step 2: Compare potentials for a negative charge For $Q < 0$, multiplication by kQ reverses the inequality: $V_A < V_B$. The nearer point has a larger potential magnitude but a more negative potential. Potential magnitude must not be confused with signed potential.

Step 3: Conclusion (i) For a positive charge, $V_A > V_B$. (ii) For a negative charge, $V_A < V_B$.

Quick Tip to Solve: Compare distances first, then reverse the potential inequality when the source charge is negative.

5. Write the expression for speed of electromagnetic waves in a medium of electrical permittivity ε and magnetic permeability μ. [1 mark]

Solution:

Concept:

- In a homogeneous electromagnetic medium, ε is its absolute electrical permittivity and μ is its absolute magnetic permeability.
- The wave equation obtained from Maxwell equations has the coefficient $\mu\varepsilon$ multiplying the second time derivative of the field.

Step 1: Compare with the standard wave equation For a plane electromagnetic wave, $\partial^2 E/\partial x^2 = \mu\varepsilon\,\partial^2 E/\partial t^2$. The standard wave equation has coefficient $1/v^2$, where v is the propagation speed. Hence $1/v^2 = \mu\varepsilon$.

Step 2: Express the positive propagation speed Taking the positive square root gives $v = 1/\sqrt{\mu\varepsilon}$. If relative constants are used, write $\varepsilon = \varepsilon_0\varepsilon_r$ and $\mu = \mu_0\mu_r$, giving $v = c/\sqrt{\mu_r\varepsilon_r}$, with $c = 1/\sqrt{\mu_0\varepsilon_0}$.

Step 3: Conclusion The speed is $\boxed{v = \dfrac{1}{\sqrt{\mu\varepsilon}}}$.

Quick Tip to Solve: Use absolute permittivity and permeability in the reciprocal square-root formula; insert c only with relative constants.

Section B (10 marks)

6. Use the mirror equation to show that an object placed between f and $2f$ of a concave mirror forms an image beyond $2f$. [2 marks]

Solution:

Concept:

- The mirror equation is $1/f = 1/v + 1/u$, with distances measured from the pole using the Cartesian sign convention.
- For a concave mirror facing the incident light, $f = -F$, where $F > 0$ is its focal-length magnitude. A real object in front of the mirror has $u = -x$, with $x > 0$.

Step 1: Express the stated object position An object between the focus and the centre of curvature satisfies $F < x < 2F$. Substitute $u = -x$ and $f = -F$ into the mirror equation:

$$-\frac{1}{F} = \frac{1}{v} - \frac{1}{x}, \qquad \frac{1}{v} = \frac{F - x}{Fx}.$$

Since $x > F$, the right side is negative; the image lies in front of the mirror.

Step 2: Find the image-distance magnitude Rearranging gives

$$v = -\frac{Fx}{x - F}, \qquad |v| = \frac{Fx}{x - F}.$$

The denominator is positive, so the desired inequality can be checked without reversing its sign.

Step 3: Prove that the image is beyond the centre of curvature Subtract the centre-of-curvature distance from the image-distance magnitude:

$$|v| - 2F = \frac{Fx - 2F(x - F)}{x - F} = \frac{F(2F - x)}{x - F} > 0.$$

Both $2F - x$ and $x - F$ are positive because $F < x < 2F$. Thus the image distance exceeds $2F$. Also, $m = -v/u < 0$, consistent with a real inverted image.

Step 4: Conclusion An object between F and $2F$ forms a real, inverted image beyond $2F$, since $\boxed{|v| > 2F}$ (equivalently $v < -2F$).

Quick Tip to Solve: Use positive magnitudes F and x while retaining f=-F and u=-x; this makes the final distance inequality transparent.

OR

6. (a) State the condition under which a large magnification can be achieved in an astronomical telescope.

(b) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope.

[2 marks]

Solution:

Concept:

- For an astronomical telescope in normal adjustment, angular magnification has magnitude $|M| = f_o/f_e$, where f_o and f_e are the focal lengths of the objective and eyepiece.
- Reflection is independent of wavelength, and a large mirror can be supported from behind. These properties are useful in astronomical observations.

Step 1: (a) Condition for large magnification The objective forms a real image of the distant object, and the eyepiece magnifies the angle subtended by this image. Since $|M| = f_o/f_e$ in normal adjustment, the objective should have a large focal length and the eyepiece should have a small focal length, so that $f_o \gg f_e$. The negative sign in $M = -f_o/f_e$ indicates image inversion; the size of magnification is determined by the ratio.

Step 2: (b) Reasons for preferring a reflecting telescope First, a mirror does not disperse light into different colours. Thus a reflecting objective is free from chromatic aberration, whereas a refracting objective requires correction because its refractive index depends on wavelength. Second, a mirror of large aperture can be made and supported from its back. This allows greater light collection and better resolving power, making faint stars and nearby astronomical details easier to observe. A large lens is more difficult to manufacture and support without distortion.

Step 3: Conclusion Large magnification requires f_o/f_e to be large. Reflecting telescopes are preferred because they avoid chromatic aberration and permit large, well-supported objective apertures.

Quick Tip to Solve: For telescope magnification, remember: long-focus objective, short-focus eyepiece; for reflectors, cite colour correction and aperture.

7. Find the intensity at a point on a screen in Young's double slit experiment where the interfering waves have a path difference of (i) $\lambda/6$, and (ii) $\lambda/2$. [2 marks]

Solution:

Concept:

- A path difference Δ gives phase difference $\phi = 2\pi\Delta/\lambda$, where λ is the wavelength.
- For equal slit intensities I_0, the resultant intensity is $I = 4I_0\cos^2(\phi/2)$; the maximum intensity is $I_{\max} = 4I_0$.

Step 1: Relate path difference to intensity In the usual Young double slit arrangement, assume the two coherent waves have equal individual intensities I_0. Superposition gives

$$I = I_0 + I_0 + 2\sqrt{I_0 I_0}\cos\phi = 2I_0(1+\cos\phi).$$

Quick Tip to Solve: Always define whether your reference intensity is that of one slit or the central maximum before substituting the phase difference.

Thus we can express the answer either in terms of the intensity from one slit or the central maximum intensity.

Step 2: (i) Path difference of one-sixth wavelength For $\Delta = \lambda/6$, the phase difference is $\phi = 2\pi/6 = \pi/3$. Therefore

$$I = 2I_0(1 + \cos(\pi/3)) = 2I_0(1 + 1/2) = 3I_0 = \frac{3}{4}I_{\max}.$$

This point is bright but is not an intensity maximum, because the phase difference is not an integral multiple of 2π.

Step 3: (ii) Path difference of half a wavelength For $\Delta = \lambda/2$, the phase difference is π. Hence

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

The waves arrive in opposite phase and their equal amplitudes cancel completely, giving a dark fringe.

Step 4: Conclusion For equal slit intensities, (i) $I = 3I_0 = 3I_{\max}/4$, and (ii) $I = 0$, where I_0 is the intensity due to either slit alone.

Quick Tip to Solve: Always define whether your reference intensity is that of one slit or the central maximum before substituting the phase difference.

8. Describe, with the help of a circuit diagram, the working of a photodiode. [2 marks]

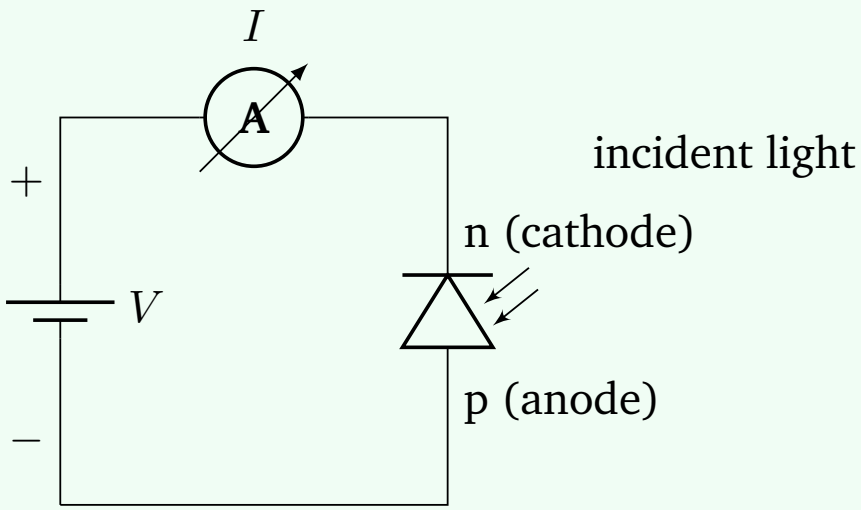
Solution:

Concept:

- A photodiode is a light-sensitive p-n junction operated in reverse bias: the p side is connected to the negative terminal and the n side to the positive terminal.
- Photons with energy $h\nu \geq E_g$, where E_g is the band gap, generate electron-hole pairs in and near the depletion region.

Step 1: Connect the photodiode in reverse bias The circuit connects the cathode (n side) to the positive supply terminal through a current meter and the anode (p side) to the negative terminal. Light is allowed to fall on the junction through its transparent window. In darkness, only a small reverse saturation current, called dark current, flows. Reverse bias produces a depletion-region electric field that efficiently separates photo-generated carriers.

Quick Tip to Solve: In a photodiode circuit, connect n to positive and p to negative, and draw light arrows pointing towards the junction.



Reverse-biased photodiode with light incident on the junction

Step 2: Explain the response to illumination When suitable light falls on the junction, absorbed photons create electron-hole pairs. The electric field sweeps electrons towards the n side and holes towards the p side before they recombine, producing an additional reverse current in the external circuit. For fixed reverse bias, this photocurrent increases approximately in proportion to the incident optical intensity. The meter therefore registers a larger current on illumination, allowing the photodiode to detect light or variations in light intensity.

Step 3: Conclusion A reverse-biased photodiode converts incident light into a measurable reverse photocurrent; brighter illumination produces more carriers and a larger current.

Quick Tip to Solve: In a photodiode circuit, connect n to positive and p to negative, and draw light arrows pointing towards the junction.

9. Distinguish between broadcast mode and point-to-point mode of communication and give one example for each. [2 marks]

Solution:

Concept:

- Communication modes are distinguished by whether information is addressed to one receiver or made available to many receivers.
- Point-to-point communication has a link between a particular transmitter and receiver; broadcast communication distributes a common signal to a large audience.

Step 1: Describe point-to-point communication In point-to-point mode, communication takes place between a single transmitting endpoint and a single receiving endpoint. The information is intended for that particular receiver. For example, a telephone conversation establishes communication between two subscribers. Either endpoint may transmit as well as receive during the conversation, but the link remains between the two selected parties rather than a general audience.

Quick Tip to Solve: Use the receiver count to distinguish the modes: a particular subscriber for a telephone link, many listeners for radio broadcasting.

Step 2: Describe broadcast communication In broadcast mode, one transmitter sends information that many receivers can receive simultaneously. The same programme is made available to the audience throughout the transmitter's coverage area. Radio broadcasting is an example: a radio station transmits a programme that numerous tuned receivers can hear. Unlike a telephone call, the transmission is not directed solely to a single selected listener. Television broadcasting is another familiar example of this mode.

Step 3: Conclusion Point-to-point mode links one transmitter to one particular receiver, as in a telephone call. Broadcast mode links one transmitter to many receivers, as in radio broadcasting.

Quick Tip to Solve: Use the receiver count to distinguish the modes: a particular subscriber for a telephone link, many listeners for radio broadcasting.

10. A light bulb and a solenoid are connected in series across an ac source of voltage. Explain, how the glow of the light bulb will be affected when an iron rod is inserted in the solenoid. [2 marks]

Solution:

Concept:

- A solenoid opposes changes in current through self-induction. Its inductive reactance is $X_L = \omega L = 2\pi f L$, where L is inductance and f is ac frequency.
- For a series resistance R and inductance L, $Z = \sqrt{R^2 + X_L^2}$ and $I_{\text{rms}} = V_{\text{rms}}/Z$.

Step 1: Effect of inserting the iron rod Iron has a much greater magnetic permeability than air. Inserting it increases the flux linkage for a given current and therefore increases the solenoid's self-inductance L. At the unchanged source frequency, $X_L = 2\pi f L$ consequently increases. The induced emf opposing the changing current becomes larger.

Step 2: Relate the current to the bulb's glow The bulb and solenoid carry the same current because they are in series. For the same applied rms voltage, the larger reactance increases the circuit impedance and reduces the rms current. The power dissipated in the bulb is $P_{\text{bulb}} = I_{\text{rms}}^2 R_{\text{bulb}}$. Thus less electrical energy is converted into heat and light in the filament, and the bulb glows less brightly.

Step 3: Conclusion The glow decreases: the iron rod increases the solenoid's inductance and reactance, reducing the series current and the bulb's power.

Quick Tip to Solve: Follow the chain: iron core raises permeability, inductance and reactance; current falls and the bulb dims.

Section C (36 marks)

11. A proton and an α-particle move perpendicular to a magnetic field. Find the ratio of radii of circular paths described by them when both have (i) equal velocities, and (ii) equal kinetic energies.

[3 marks]

Solution:

Concept:

- For perpendicular motion in a uniform magnetic field, the magnetic force supplies centripetal force: $qvB = mv^2/r$. Thus $r = mv/(qB)$.
- A proton has mass m_p and charge e. An alpha particle has approximately mass $4m_p$ and charge $2e$. Ratios below are proton radius to alpha-particle radius.
- With non-relativistic kinetic energy $K = mv^2/2$, momentum is $mv = \sqrt{2mK}$, giving $r = \sqrt{2mK}/(qB)$.

Step 1: Obtain the radius formula Since the velocity is perpendicular to the field, the force has magnitude qvB and always acts perpendicular to the velocity. It changes direction without changing speed, producing a circular orbit. Equating it to the required centripetal force gives

$$qvB = \frac{mv^2}{r} \quad \Rightarrow \quad r = \frac{mv}{qB}.$$

Both particles experience the same field magnitude B, so this common factor cancels from each ratio.

Step 2: Part (i): equal velocities For $v_p = v_\alpha = v$, substitute the respective masses and charges:

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

At the same speed, the alpha particle has four times the momentum but twice the charge. Its radius is therefore twice the proton radius.

Step 3: Part (ii): equal kinetic energies Put $K_p = K_\alpha = K$ in the momentum form of the radius formula:

$$\frac{r_p}{r_\alpha} = \frac{\sqrt{2m_pK}/(eB)}{\sqrt{2(4m_p)K}/(2eB)} = 1.$$

Equivalently, equal kinetic energies imply $v_\alpha = v_p/2$. The alpha particle then has twice the proton's momentum and twice its charge, so the two effects cancel in $r = p/(qB)$.

Step 4: Conclusion The ratios $r_p : r_\alpha$ are (i) $\boxed{1:2}$ for equal velocities, and (ii) $\boxed{1:1}$ for equal kinetic energies.

Quick Tip to Solve: Use mass divided by charge for equal speeds, but square root of mass divided by charge for equal kinetic energies.

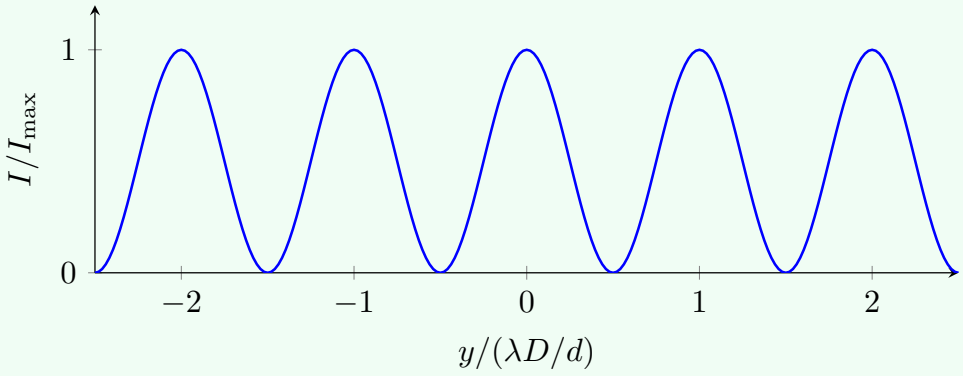
12. Draw the intensity distributions for (i) the fringes produced in interference, and (ii) the diffraction bands produced due to single slit. Write two points of difference between the phenomena of interference and diffraction. [3 marks]

Solution:

Concept:

- Interference is the superposition of light from two coherent sources. For equal source intensities, the distribution is $I = I_{\max}\cos^2(\pi dy/(\lambda D))$, where d is source separation, D is screen distance and y is displacement.
- Single-slit diffraction results from superposition of secondary wavelets from different parts of the same wavefront. Its intensity is $I = I_0(\sin\beta/\beta)^2$, where $\beta = \pi a\sin\theta/\lambda$ and a is slit width.

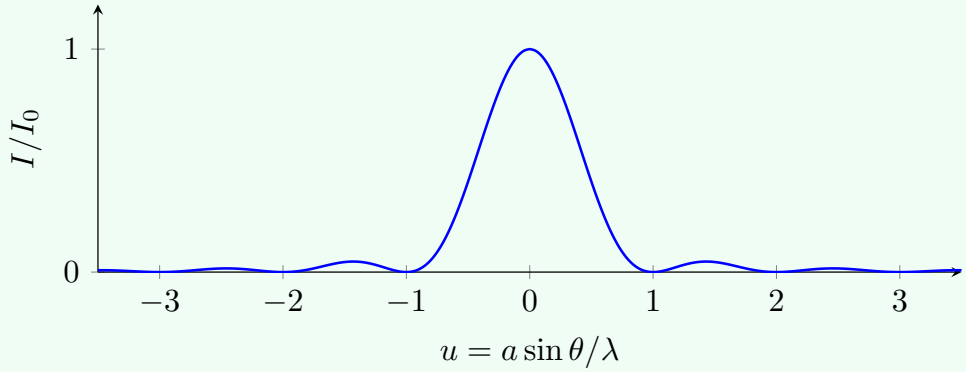
Step 1: Part (i): draw the interference intensity distribution For two equally illuminated narrow coherent sources, the bright fringes have equal maximum intensity and occur at equal intervals. The dark fringes have zero intensity in this ideal case. The fringe width is $\lambda D/d$. The graph shows this ideal distribution with the horizontal coordinate measured in fringe widths; a finite slit width can impose a diffraction envelope, which is omitted in the ideal interference sketch.



Ideal equal-source interference intensity versus screen displacement.

Step 2: Part (ii): draw the single-slit diffraction distribution The central maximum is the brightest and is bounded by the first minima at $a\sin\theta = \pm\lambda$. Its angular width is approximately $2\lambda/a$; it is twice as wide as the bands between successive minima on either side. Secondary maxima on both sides have progressively decreasing intensity. The graph uses $u = a\sin\theta/\lambda$, so minima occur at nonzero integer values of u.

Quick Tip to Solve: Sketch interference with equal peak heights; sketch diffraction with a central peak twice as wide and much weaker side peaks.



Single-slit diffraction: central maximum between the first minima at $u = -1$ and $u = 1$.

Step 3: State two differences (1) Interference arises from superposition of waves from two separate coherent sources, whereas diffraction arises from superposition of wavelets from different parts of one wavefront passing through a slit.

(2) In ideal two-source interference with equal amplitudes, the bright fringes are equally intense and equally spaced. In single-slit diffraction, the central bright maximum has twice the width of the secondary bands and is much more intense; successive secondary maxima become weaker.

Step 4: Conclusion Interference gives regularly spaced equal-height bright fringes in the ideal equal-source case. Single-slit diffraction gives a broad, bright central maximum with weaker side maxima. The labelled intensity sketches illustrate these distributions.

Quick Tip to Solve: Sketch interference with equal peak heights; sketch diffraction with a central peak twice as wide and much weaker side peaks.

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13. Using Gauss's law in electrostatics, deduce an expression for electric field intensity due to a uniformly charged infinite plane sheet. If another identical sheet is placed parallel to it, show that there is no electric field in the region between the two sheets. [3 marks]

Solution:

Concept:

- Gauss's law is $\oint \mathbf{E} \cdot d\mathbf{A} = Q_{\text{enclosed}}/\varepsilon_0$, where ε_0 is the permittivity of free space.
- By symmetry, an infinite uniformly charged sheet produces a field normal to its surface, equal in magnitude on both sides. Fields from separate sheets add vectorially.

Step 1: Choose a Gaussian pillbox Let the surface charge density be σ. Consider a cylindrical Gaussian surface crossing the sheet, with each flat face of area A parallel to it. For positive charge the field points away from the sheet on both sides. The curved wall contributes no flux, because the field lies parallel to that wall. Each flat face contributes EA, since the field is along its outward normal. Total outward flux is therefore $2EA$, and enclosed charge is σA.

Step 2: Apply Gauss's law Consequently,

$$2EA = \frac{\sigma A}{\varepsilon_0}, \qquad E = \frac{\sigma}{2\varepsilon_0}.$$

Quick Tip to Solve: Count both flat faces of the pillbox and compare field directions before adding fields.

The magnitude is $|\sigma|/(2\varepsilon_0)$, independent of distance from the sheet. The field is away from a positive sheet and towards a negative sheet. The cancellation of A shows that the arbitrary size of our Gaussian surface does not affect the result.

Step 3: Superpose the two sheet fields Identical sheets have equal charge density, including the sign. Between two positive sheets, the left sheet produces a field towards the right and the right sheet produces a field towards the left. Their magnitudes are equal. With $\hat{\mathbf{n}}$ directed from left to right,

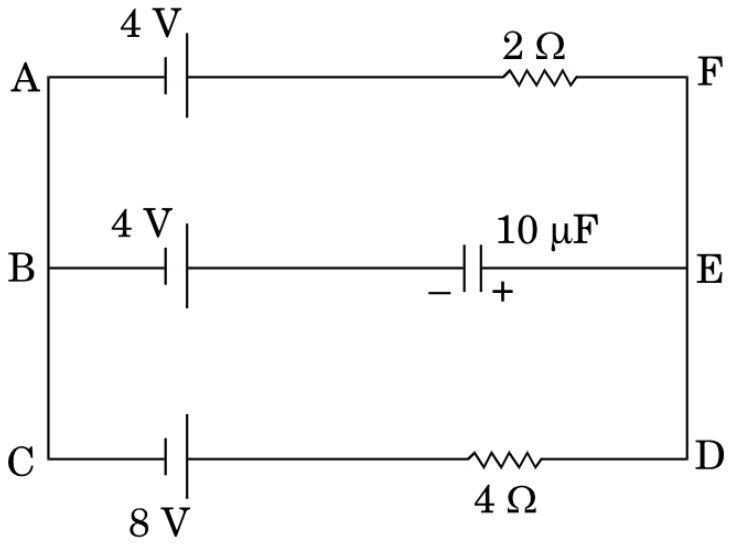
$$\mathbf{E}_{\text{between}} = \frac{\sigma}{2\varepsilon_0}\hat{\mathbf{n}} - \frac{\sigma}{2\varepsilon_0}\hat{\mathbf{n}} = \mathbf{0}.$$

For two negatively charged identical sheets, both directions reverse and cancellation still occurs.

Step 4: Conclusion The single-sheet field has magnitude $\boxed{|\sigma|/(2\varepsilon_0)}$. The electric field between two identical parallel sheets is $\boxed{\mathbf{E} = \mathbf{0}}$.

Quick Tip to Solve: Count both flat faces of the pillbox and compare field directions before adding fields.

14. In the given circuit, with steady current, calculate the potential drop across the capacitor and the charge stored in it. [3 marks]



Solution:

Concept:

- In steady direct current, an ideal capacitor passes no current. Its branch is open, but its terminal potential difference can be nonzero.
- Kirchhoff's voltage law fixes the current in the outer loop. Stored charge is $Q = CV$, where C is capacitance and V the capacitor voltage.

Step 1: Identify the conducting loop The middle branch carries zero steady current. Thus current circulates only through the upper $4\,\text{V}$ cell and $2\,\Omega$ resistor, and the lower $8\,\text{V}$ cell and $4\,\Omega$ resistor. The printed cells all have their positive terminals on the right. The two cells in the outer loop oppose one another; the $8\,\text{V}$ cell drives current from C towards D in the lower branch and from F towards A in the

Quick Tip to Solve: Open the capacitor branch first, find the rail voltage, then subtract its series cell voltage.

upper branch.

Step 2: Find the common rail voltage The outer-loop current is

$$I = \frac{8-4}{4+2} = \frac{2}{3}\,\text{A}.$$

Points A, B and C have the same potential, as do D, E and F. Taking the left rail as zero, crossing the lower cell and resistor from C to D gives

$$V_E - V_B = 8 - I(4) = 8 - \frac{8}{3} = \frac{16}{3}\,\text{V}.$$

Checking along the upper branch gives $4 + I(2) = 16/3\,\text{V}$, because this traversal is against the upper resistor current.

Step 3: Obtain the capacitor voltage and charge Let X be the point immediately to the right of the middle $4\,\text{V}$ cell, which is the capacitor left plate. That cell makes $V_X = V_B + 4\,\text{V}$. Therefore

$$V_E - V_X = \frac{16}{3} - 4 = \frac{4}{3}\,\text{V}.$$

The right plate is positive, agreeing with the indicated polarity. With $C = 10\,\mu\text{F}$,

$$Q = CV = 10 \times 10^{-6} \times \frac{4}{3} = \frac{40}{3} \times 10^{-6}\,\text{C}.$$

The two plates carry equal and opposite charges.

Step 4: Conclusion The potential drop from the positive right plate to the left plate is $\boxed{4/3\,\text{V} \simeq 1.33\,\text{V}}$; stored charge magnitude is $\boxed{40/3\,\mu\text{C} \simeq 13.3\,\mu\text{C}}$.

Quick Tip to Solve: Open the capacitor branch first, find the rail voltage, then subtract its series cell voltage.

15. (a) How are electromagnetic waves produced? Explain.

(b) A plane electromagnetic wave is travelling through a medium along the +ve z-direction. Depict the electromagnetic wave showing the directions of the oscillating electric and magnetic fields. [3 marks]

Solution:

Concept:

- Accelerating charges emit electromagnetic radiation. Time-varying electric and magnetic fields are coupled through Maxwellś laws.
- A plane electromagnetic wave is transverse: $\mathbf{E} \perp \mathbf{B}$, and both are perpendicular to propagation. Energy flows along $\mathbf{E} \times \mathbf{B}$.

Step 1: Explain production of electromagnetic waves (a) An oscillating charge is accelerated and creates a changing electric field. This changing electric field produces a changing magnetic field, and the changing magnetic field produces an electric field. These coupled disturbances propagate away from the charge as an electromagnetic wave. For example, alternating current in a transmitting antenna causes its charges to oscillate and radiate. A stationary charge produces only a static electric

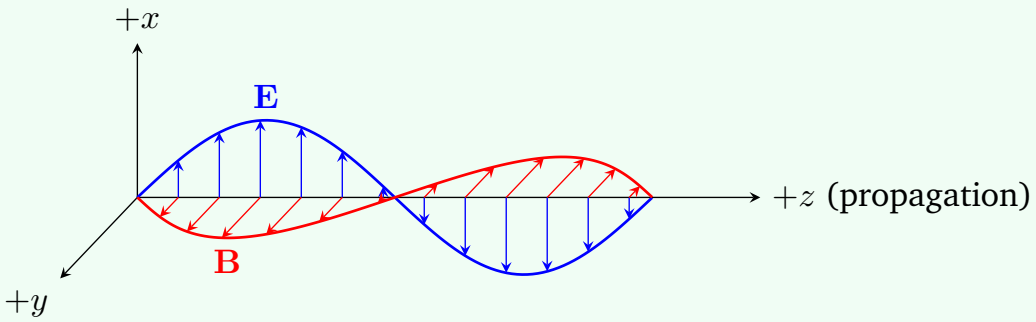
Quick Tip to Solve: Use the right-hand rule on E cross B to check the indicated direction of propagation.

field; acceleration of the source charge is essential for radiation. Once emitted, the fields propagate through space and do not require a material medium.

Step 2: Choose consistent transverse directions (b) For propagation along $+z$, take the electric field along the x-axis and magnetic field along the y-axis. One consistent wave is

$$\mathbf{E} = E_0 \sin(kz - \omega t)\,\hat{\mathbf{x}}, \qquad \mathbf{B} = B_0 \sin(kz - \omega t)\,\hat{\mathbf{y}}.$$

Here k is the wave number, ω the angular frequency, and E_0, B_0 the amplitudes. In the usual lossless-medium plane-wave treatment the two fields oscillate in phase and $E_0/B_0 = v$, the wave speed in the medium. Since $\hat{\mathbf{x}} \times \hat{\mathbf{y}} = \hat{\mathbf{z}}$, their cross product points along $+z$. During the opposite half-cycle both field directions reverse, keeping the propagation direction unchanged. The diagram depicts their mutually perpendicular oscillation planes at one instant.



Electric and magnetic oscillations in perpendicular planes; propagation is along +z.

Step 3: Conclusion Accelerating or oscillating charges produce electromagnetic waves. For the wave along $\boxed{+z}$, a valid choice is $\boxed{\mathbf{E} \parallel x,\ \mathbf{B} \parallel y}$, with $\mathbf{E} \times \mathbf{B} \parallel +z$.

Quick Tip to Solve: Use the right-hand rule on E cross B to check the indicated direction of propagation.

16. (a) Derive the relation between the decay constant and half life of a radioactive substance.
(b) A radioactive element reduces to 25% of its initial mass in 1000 years. Find its half life. [3 marks]

Solution:

Concept:

- The radioactive decay law is $-dN/dt = \lambda N$, where N is the number of undecayed nuclei and λ is the positive decay constant.
- Half life $T_{1/2}$ is the time required for the number of original radioactive nuclei to decrease to half its initial value. Their remaining mass is proportional to this number.

Step 1: (a) Integrate the decay law Let N_0 denote the number at $t = 0$. Separating variables and integrating gives

$$\int_{N_0}^{N} \frac{dN'}{N'} = -\lambda \int_0^t dt', \qquad \ln(N/N_0) = -\lambda t.$$

Thus $N = N_0 e^{-\lambda t}$. The negative sign shows that the original radioactive species decreases with time.

Quick Tip to Solve: Express the remaining fraction as a power of one half: 25 percent represents two elapsed half lives.

The decay constant has units of inverse time, ensuring that the exponent is dimensionless.

Step 2: Substitute the half-life condition At $t = T_{1/2}$, the definition requires $N = N_0/2$. Consequently,

$$\frac{1}{2} = e^{-\lambda T_{1/2}}, \qquad -\ln 2 = -\lambda T_{1/2}.$$

This gives $\lambda T_{1/2} = \ln 2$. The cancellation of N_0 shows why the half life does not depend on the initial amount of the radioactive element.

Step 3: (b) Count the elapsed half lives The remaining mass fraction is $25/100 = 1/4 = (1/2)^2$. After one half life the mass is $M_0/2$; after another it becomes $M_0/4$. Thus the given time of $1000\,\text{years}$ corresponds to two half lives. Equivalently, $1/4 = e^{-\lambda(1000\,\text{years})}$ implies $\lambda = \ln 4/(1000\,\text{years})$. Using $\ln 4 = 2\ln 2$ yields the same result.

Step 4: Conclusion

$$\boxed{T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}}, \qquad \boxed{T_{1/2} = 500\,\text{years}}.$$

Quick Tip to Solve: Express the remaining fraction as a power of one half: 25 percent represents two elapsed half lives.

17. A charge Q is distributed uniformly over a metallic sphere of radius R. Obtain the expressions for the electric field (E) and electric potential (V) at a point $0 < x < R$.
Show on a plot the variation of E and V with x for $0 < x < 2R$. [3 marks]

Solution:

Concept:

- In electrostatic equilibrium the electric field inside a conductor is zero, and excess charge resides on its surface.
- Gauss's law is $\oint \mathbf{E} \cdot d\mathbf{A} = Q_{\text{enc}}/\varepsilon_0$; potential satisfies $E_x = -dV/dx$, taking $V(\infty) = 0$.

Step 1: Determine the field inside and outside Here x is radial distance from the centre, and $k = 1/(4\pi\varepsilon_0)$. A spherical Gaussian surface with $0 < x < R$ encloses no net charge, since all the excess charge lies at $x = R$. Spherical symmetry and Gauss's law give $E(4\pi x^2) = 0$, so the interior field vanishes. Outside, the Gaussian surface encloses Q, giving

$$E_x(x) = \begin{cases} 0, & 0 < x < R, \\ kQ/x^2, & x > R. \end{cases}$$

For positive Q, the outside field points radially outward. The limiting values at the surface are $E(R^-) = 0$ and $E(R^+) = kQ/R^2$; the ideal surface charge causes this jump.

Step 2: Obtain the potential in the interior The exterior field is that of a point charge at the centre. Integration from infinity gives $V(x) = kQ/x$ for $x \geq R$, hence $V(R) = kQ/R$. Inside the conductor,

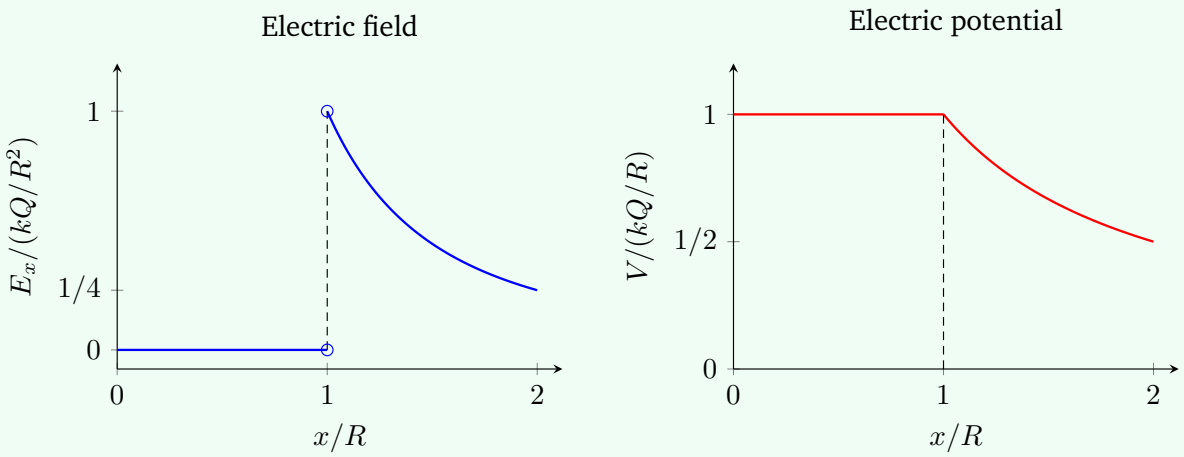
Quick Tip to Solve: First identify the sphere as metallic: its interior field is zero and its interior potential equals the surface value.

$E_x = 0$, so

$$V(x) - V(R) = -\int_R^x E_x\, dx' = 0.$$

Therefore every interior point has the same potential as the surface: $V(x) = kQ/R$ for $0 < x < R$. Zero electric field means constant potential, not necessarily zero potential.

Step 3: Plot the variations up to twice the radius The plots below use $u = x/R$, with field scaled by kQ/R^2 and potential by kQ/R, for $Q > 0$. The field is zero until the surface, jumps there to its exterior value, and then falls as $1/x^2$, reaching one quarter of that value at $2R$. Potential is constant inside and continuous at the surface; outside it decreases as $1/x$, reaching half its surface value at $2R$. For negative charge the signed curves reflect below the horizontal axis.



Radial field and potential of a positively charged metallic sphere (normalised axes).

Step 4: Conclusion For $0 < x < R$, $\boxed{E = 0}$ and $\boxed{V = Q/(4\pi\varepsilon_0 R)}$. Outside, $E_x = kQ/x^2$ and $V = kQ/x$; the field jumps at the surface while the potential remains continuous.

Quick Tip to Solve: First identify the sphere as metallic: its interior field is zero and its interior potential equals the surface value.

18. Using Bohr's postulates, derive the expression for the orbital period of the electron moving in the n^{th} orbit of hydrogen atom. [3 marks]

Solution:

Concept:

- Bohr's stationary-orbit postulate permits an electron to revolve without radiation in selected orbits, with angular momentum $m_e v_n r_n = n\hbar = nh/(2\pi)$.
- The Coulomb attraction supplies the centripetal force: $m_e v_n^2/r_n = e^2/(4\pi\varepsilon_0 r_n^2)$. The period of circular motion is $T_n = 2\pi r_n/v_n$.

Step 1: Apply force balance and angular-momentum quantisation Let m_e and $-e$ be the electron mass and charge, and r_n, v_n its radius and speed in orbit n, where $n = 1, 2, \ldots$. In the usual hydrogen

Quick Tip to Solve: Derive radius and speed separately: the scaling check is radius proportional to n squared and speed inversely proportional to n, giving period proportional to n cubed.

model the proton is treated as fixed. From Bohr's quantisation rule,

$$v_n = \frac{n\hbar}{m_e r_n}.$$

Substitution in the radial force equation gives

$$\frac{n^2\hbar^2}{m_e r_n^3} = \frac{e^2}{4\pi\varepsilon_0 r_n^2}.$$

Quantisation selects the permitted classical orbits.

Step 2: Obtain the radius and speed of the permitted orbit Multiplying the last equation by r_n^3 and rearranging gives

$$r_n = \frac{4\pi\varepsilon_0\hbar^2}{m_e e^2}\, n^2 = \frac{\varepsilon_0 h^2}{\pi m_e e^2}\, n^2.$$

Using this radius in the quantised angular momentum yields

$$v_n = \frac{e^2}{4\pi\varepsilon_0\hbar}\frac{1}{n} = \frac{e^2}{2\varepsilon_0 h}\frac{1}{n}.$$

Thus the orbital circumference grows as n^2, while the electron speed decreases as $1/n$.

Step 3: Divide circumference by orbital speed One revolution covers distance $2\pi r_n$. Therefore

$$\begin{aligned} T_n &= \frac{2\pi r_n}{v_n} \\ &= 2\pi\left(\frac{\varepsilon_0 h^2 n^2}{\pi m_e e^2}\right)\left(\frac{2\varepsilon_0 h n}{e^2}\right) \\ &= \frac{4\varepsilon_0^2 h^3}{m_e e^4}\, n^3. \end{aligned}$$

The radius factor n^2 and inverse-speed factor n give the cubic dependence; the SI period is in seconds.

Step 4: Conclusion

$$\boxed{T_n = \frac{4\varepsilon_0^2 h^3}{m_e e^4}\, n^3 = \frac{32\pi^3\varepsilon_0^2\hbar^3}{m_e e^4}\, n^3}.$$

Quick Tip to Solve: Derive radius and speed separately: the scaling check is radius proportional to n squared and speed inversely proportional to n, giving period proportional to n cubed.

19. (a) Draw a plot showing the variation of photoelectric current with collector potential for different frequencies but same intensity of incident radiation.

(b) Use Einstein's photoelectric equation to explain the observations from this graph.

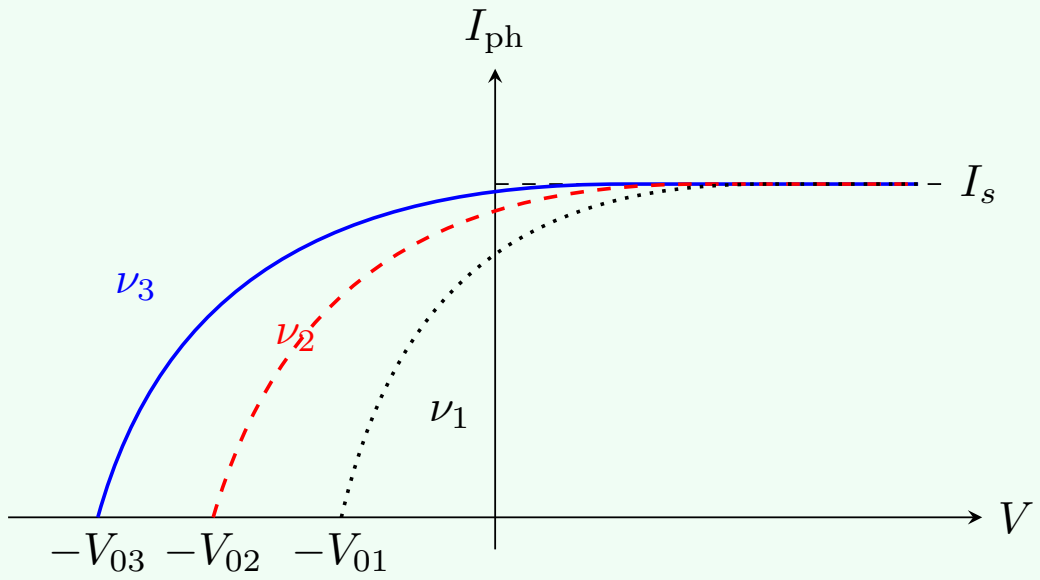
(c) What change will you observe if intensity of incident radiation is changed but the frequency remains the same? [3 marks]

Solution:

Concept:

- Einstein's equation is $h\nu = \phi + K_{\max}$, where ϕ is the work function of the emitter and ν is the incident frequency.
- The stopping potential satisfies $eV_0 = K_{\max}$, where e is the magnitude of electronic charge. Saturation current is reached when all emitted photoelectrons are collected.

Step 1: Draw the frequency comparison For the same emitter take $\nu_3 > \nu_2 > \nu_1 > \nu_0$, where $\nu_0 = \phi/h$. The standard CBSE comparison for equal incident intensity shows a common saturation current. The higher-frequency curve reaches zero current at a more negative collector potential. The curves below show the stopping-potential order $V_{03} > V_{02} > V_{01}$; positive collector potential attracts the emitted electrons.



Photoelectric current for $\nu_3 > \nu_2 > \nu_1$, at the same incident intensity.

Step 2: Explain the observations using Einstein's equation Writing Einstein's equation in terms of stopping potential gives

$$eV_0 = h\nu - \phi.$$

For a fixed emitter, ϕ is constant, so an increase in frequency increases the maximum kinetic energy and hence the magnitude of the stopping potential. Therefore a stronger retarding potential is needed to stop the fastest electrons. Once the collector attracts all emitted electrons, further increasing its positive potential cannot increase the current; the curves flatten at saturation.

Step 3: Change intensity while holding frequency fixed At fixed frequency above threshold, increasing

Quick Tip to Solve: Use the negative-axis intercept to compare frequency and the plateau height to compare intensity.

intensity increases the number of photoelectrons emitted per second and therefore increases the saturation current; decreasing intensity decreases it. However, $K_{\max} = h\nu - \phi$ remains unchanged, so the stopping potential remains unchanged. Thus the curves have different saturation levels but the same intercept on the negative potential axis.

Step 4: Conclusion Higher frequency gives a larger stopping-potential magnitude. At fixed frequency, higher intensity gives a larger saturation current without changing the stopping potential.

Quick Tip to Solve: Use the negative-axis intercept to compare frequency and the plateau height to compare intensity.

20. Using Biot-Savart law, deduce the expression for the magnetic field at a point (x) on the axis of a circular current carrying loop of radius R. How is the direction of the magnetic field determined at this point? [3 marks]

Solution:

Concept:

- Biot-Savart law: $d\mathbf{B} = \dfrac{\mu_0 I}{4\pi}\dfrac{d\boldsymbol{\ell} \times \mathbf{s}}{s^3}$, where $\mathbf{s}$ runs from a current element to the observation point.
- For a circular loop, symmetry cancels magnetic-field components perpendicular to the axis; the components along the axis add.

Step 1: Set up the geometry Let the loop of radius R lie in a plane perpendicular to its axis, with centre O. Let P be a point on the axis a distance x from O. Every current element is at the same distance $s = \sqrt{R^2 + x^2}$ from P. The tangent element $d\boldsymbol{\ell}$ is perpendicular to the plane containing its radius and the axis, and therefore perpendicular to $\mathbf{s}$. Thus the sine factor in Biot-Savart law is unity.

Step 2: Resolve and integrate the axial component The magnitude of the elemental field is $dB = \mu_0 I\, d\ell/(4\pi s^2)$. Its axial projection has factor R/s. Diametrically opposite elements have equal and opposite transverse components but axial components in the same direction. Consequently,

$$\begin{aligned} B(x) &= \oint dB\frac{R}{s} \\ &= \frac{\mu_0 I R}{4\pi(R^2 + x^2)^{3/2}} \oint d\ell \\ &= \frac{\mu_0 I R}{4\pi(R^2 + x^2)^{3/2}}(2\pi R). \end{aligned}$$

All constants can be taken outside the integral because R, I and s are fixed.

Step 3: Determine the direction Curl the fingers of the right hand in the direction of current around the loop. The extended thumb gives the direction of the axial magnetic field at P. Viewed from the observation point, an anticlockwise current produces a field towards the observer, while a clockwise current produces a field away from the observer. As a check, putting $x = 0$ recovers the familiar centre field $\mu_0 I/(2R)$.

Quick Tip to Solve: In the axial derivation, include the projection factor R/s before integrating around the loop.

Step 4: Conclusion

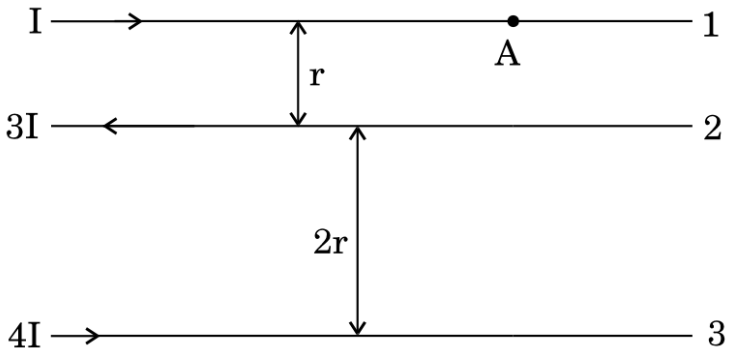
$$\boxed{B(x) = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}}.$$

The field is along the loop axis in the direction given by the right-hand grip rule.

Quick Tip to Solve: In the axial derivation, include the projection factor R/s before integrating around the loop.

OR

20. The figure shows three infinitely long straight parallel current carrying conductors. Find the (i) magnitude and direction of the net magnetic field at point A lying on conductor 1, (ii) magnetic force on conductor 2. [3 marks]



Solution:

Concept:

- An infinite straight wire produces $B = \mu_0 I/(2\pi d)$ at perpendicular distance d. Its direction follows the right-hand thumb rule.
- The force per unit length between parallel wires is $F/L = \mu_0 I_a I_b/(2\pi d)$. Parallel currents attract; antiparallel currents repel.

Step 1: Identify source currents and field directions at A Wire 1 carries I to the right, wire 2 carries $3I$ to the left, and wire 3 carries $4I$ to the right. Their separations are $d_{12} = r$, $d_{23} = 2r$, and hence $d_{13} = 3r$. The field at A on wire 1 means the external field due to wires 2 and 3; the ideal wire's own singular self-field is excluded. At a point above wire 2 its leftward current gives a field into the page. Above wire 3 its rightward current gives a field out of the page.

Step 2: Calculate the net field at A The two contributions oppose one another. Their magnitudes are

$$B_2 = \frac{3\mu_0 I}{2\pi r}, \qquad B_3 = \frac{4\mu_0 I}{2\pi(3r)}.$$

Since $B_2 > B_3$, the net field is into the plane of the page. Subtracting the smaller contribution gives

$$B_A = \frac{\mu_0 I}{2\pi r}\left(3 - \frac{4}{3}\right) = \frac{5\mu_0 I}{6\pi r}.$$

Quick Tip to Solve: Write each pairwise direction first; use the full separation 3r for the field from wire 3 at A.

The distance of wire 3 from A is the sum of the two marked gaps, rather than just $2r$.

Step 3: Find the resultant force on conductor 2 Wire 2 has current opposite to each of the other two wires, so both pairwise forces are repulsive. Wire 1 pushes wire 2 downwards, while wire 3 pushes it upwards. Their force magnitudes per unit length are

$$\frac{F_{21}}{L} = \frac{3\mu_0 I^2}{2\pi r}, \qquad \frac{F_{23}}{L} = \frac{\mu_0 (3I)(4I)}{2\pi (2r)} = \frac{6\mu_0 I^2}{2\pi r}.$$

The upward force is larger. Thus the resultant is $F_2/L = 3\mu_0 I^2/(2\pi r)$ upwards, towards wire 1. Since the conductors are infinitely long and no finite length is specified, force must be reported per unit length; for a segment of length L, multiply this value by L.

Step 4: Conclusion (i) $\boxed{B_A = 5\mu_0 I/(6\pi r)}$, into the page. (ii) $\boxed{F_2/L = 3\mu_0 I^2/(2\pi r)}$, upwards towards conductor 1.

Quick Tip to Solve: Write each pairwise direction first; use the full separation 3r for the field from wire 3 at A.

21. What is space wave propagation? Which systems of communication use space waves? What is 'radio horizon' of a transmitting antenna of height h? Why is space wave propagation suitable for frequencies above 40 MHz? [3 marks]

Solution:

Concept:

- Space waves travel through the lower atmosphere between antennas, mainly along a line of sight. The direct wave and the wave reflected from the ground together form the space wave.
- The curvature of Earth limits line-of-sight coverage. For Earth radius R and antenna height $h \ll R$, the distance to the radio horizon is $d \simeq \sqrt{2Rh}$.

Step 1: Define space waves and identify their uses In space wave propagation, electromagnetic waves travel from the transmitting antenna to the receiving antenna through the troposphere. The received signal may contain a direct component and a component reflected from Earth's surface. Since these waves travel approximately in straight lines, the transmitting and receiving antennas must have an unobstructed line of sight. Television broadcasting, frequency-modulated (FM) radio broadcasting, radar and microwave communication links use space waves. Satellite communication also uses such high-frequency line-of-sight propagation between the ground station and the satellite.

Step 2: Obtain the radio horizon The radio horizon is the farthest point on Earth's surface that can be reached directly by waves from an antenna of height h. The limiting ray is tangent to Earth at that point. With R as Earth's radius, the right triangle formed by the centre, the antenna top and the tangent point gives

$$d^2 + R^2 = (R+h)^2, \qquad d = \sqrt{2Rh + h^2} \simeq \sqrt{2Rh}.$$

The approximation uses $h \ll R$. When both antennas are elevated, the approximate maximum direct communication range is $\sqrt{2Rh_t} + \sqrt{2Rh_r}$, where h_t and h_r are their heights.

Step 3: Explain the high-frequency suitability Above about 40 MHz, waves are generally not returned

Quick Tip to Solve: Draw an imaginary tangent from the antenna top to Earth: Pythagoras immediately gives the horizon distance, which grows as the square root of antenna height.

to Earth by the ionosphere; they pass through it, so sky-wave communication is unsuitable. Ground-wave propagation also suffers strong attenuation at high frequencies. Such waves can instead travel along a direct line of sight with useful reception, using suitably elevated antennas or relay stations. Their relatively short wavelengths also allow practical directional antennas for microwave links.

Step 4: Conclusion Space waves are direct and ground-reflected waves used for line-of-sight communication, including TV, FM, radar and microwave systems. The transmitting antenna's radio horizon is approximately $d = \sqrt{2Rh}$; space-wave propagation is suitable above 40 MHz because ionospheric return and ground-wave transmission are ineffective there.

Quick Tip to Solve: Draw an imaginary tangent from the antenna top to Earth: Pythagoras immediately gives the horizon distance, which grows as the square root of antenna height.

22. A source of ac voltage $v = v_0 \sin \omega t$ is connected across a pure inductor of inductance L. Derive the expressions for the instantaneous current in the circuit. Show that average power dissipated in the circuit is zero. [3 marks]

Solution:

Concept:

- An ideal inductor has no resistance. Its induced emf opposes the change in current, so the applied voltage satisfies $v = L\, di/dt$.
- The inductive reactance is $X_L = \omega L$, and the sinusoidal current amplitude is $i_0 = v_0/X_L$. In an ideal inductive circuit the current lags the voltage by $\pi/2$.

Step 1: Derive the instantaneous current Applying the circuit equation to the pure inductor gives

$$L\frac{di}{dt} = v_0 \sin \omega t.$$

Integrating with respect to time,

$$i = -\frac{v_0}{\omega L}\cos \omega t + C.$$

For the usual sinusoidal ac steady state there is no dc current component, so $C = 0$. Hence the instantaneous current is

$$i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right), \qquad i_0 = \frac{v_0}{\omega L}.$$

Comparing this expression with $v = v_0 \sin \omega t$ shows that the current reaches the same phase a quarter-cycle later than the voltage: it lags by $\pi/2$. The integration constant represents a possible constant current determined by initial conditions; the standard pure ac solution uses its zero value.

Step 2: Calculate the average power over a complete cycle The instantaneous power delivered to the inductor is

$$\begin{aligned} p(t) &= v(t)i(t) \\ &= -v_0 i_0 \sin \omega t \cos \omega t \\ &= -\frac{v_0 i_0}{2}\sin 2\omega t. \end{aligned}$$

Quick Tip to Solve: Integrate the sine voltage to obtain a negative cosine current; this immediately reveals the quarter-cycle lag and the zero average power factor.

With $T = 2\pi/\omega$, its cycle average is

$$P_{\text{av}} = \frac{1}{T}\int_0^T p(t)\,dt$$
$$= -\frac{v_0 i_0}{2T}\int_0^T \sin 2\omega t\,dt = 0.$$

The positive and negative portions cancel over a complete cycle. Equivalently, $P_{\text{av}} = V_{\text{rms}} I_{\text{rms}} \cos(\pi/2) = 0$. Energy is stored in the magnetic field as $U = \frac{1}{2}Li^2$ while the current magnitude increases, and is returned to the source while it decreases. With no resistance, there is no conversion into heat.

Step 3: Conclusion The sinusoidal current is $i = \frac{v_0}{\omega L}\sin(\omega t - \pi/2)$, so it lags the voltage by $90°$. The average power dissipated by a pure inductor over a complete cycle is zero.

Quick Tip to Solve: Integrate the sine voltage to obtain a negative cosine current; this immediately reveals the quarter-cycle lag and the zero average power factor.

Section D (4 marks)

23. Sunil and his parents were travelling to their village in their car. On the way his mother noticed some grey coloured panels installed on the roof of a low building. She enquired from Sunil what those panels were and Sunil told his mother that those were solar panels.

(a) What were the values displayed by Sunil and his mother? State one value for each.

(b) In what way would the use of solar panels prove to be very useful?

(c) Name the semiconductor device used in solar panels. Briefly explain with the help of a diagram, how this device works. [4 marks]

Solution:

Concept:

- A solar cell is a semiconductor p-n junction device that converts incident light energy directly into electrical energy by the photovoltaic effect.
- Photons of energy $h\nu \geq E_g$, where E_g is the semiconductor band gap, produce electron-hole pairs. The built-in electric field in the depletion layer separates these carriers.
- A solar cell supplies a current through an external load without an externally applied bias. Connecting many cells produces a solar panel with a useful output.

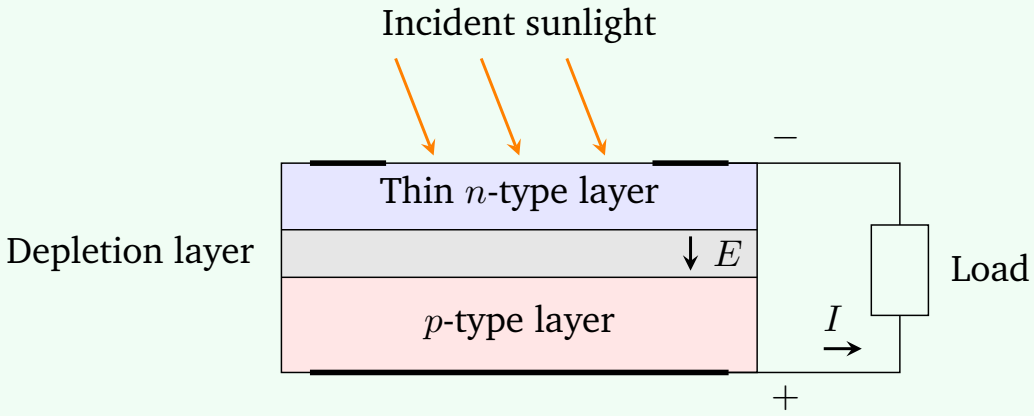
Step 1: (a) Identify the values displayed Sunil displays scientific awareness: he recognises the panels and explains their purpose to his mother. His mother displays curiosity and a willingness to learn: she notices an unfamiliar installation and asks what it is. These are values supported directly by the incident.

Step 2: (b) Explain the usefulness of solar panels Solar panels use freely available sunlight to generate electricity. Solar energy is renewable, and electricity generation by the panels does not require burning fossil fuels; this reduces fuel consumption and air pollution during operation. Panels can also provide electricity in villages or remote places where a grid connection is unavailable or unreliable. Thus they

Quick Tip to Solve: In a solar-cell diagram, show incoming light, both semiconductor layers, the junction and an external load; label the p-contact positive and the n-contact negative.

help meet energy needs while conserving conventional energy resources.

Step 3: (c) Name the device and explain carrier generation The device is a **solar cell**, made using a semiconductor p-n junction with a light-accessible surface. Incident photons with sufficient energy are absorbed and create electron-hole pairs in and near the depletion region. The diagram shows a thin upper n-type layer, a lower p-type layer and the junction's depletion region. The front contact allows light to reach the semiconductor; the contacts connect the cell to an external load.



Solar cell: light generates carriers, and the junction field separates them to power the load.

Step 4: (c) Explain charge separation and electrical output The junction's built-in field is directed from the n-side to the p-side. It drives photo-generated electrons towards the n-side and holes towards the p-side, reducing their immediate recombination. Consequently, the n-contact becomes negative and the p-contact positive. With an external load connected, electrons flow through the load from the n-contact to the p-contact; conventional current through the load flows in the opposite direction. Continued illumination maintains carrier generation and hence a supply of electrical energy. No external battery is needed to operate the cell in this mode.

Step 5: Conclusion Sunil shows scientific awareness and his mother shows curiosity. Solar panels supply renewable electricity and conserve fossil fuels. Their active device is the solar cell, whose illuminated p-n junction separates photo-generated charge carriers to supply current to a load.

Quick Tip to Solve: In a solar-cell diagram, show incoming light, both semiconductor layers, the junction and an external load; label the p-contact positive and the n-contact negative.

Section E (15 marks)

24. (a) A point object is placed on the principal axis of a convex spherical surface of radius of curvature R, which separates the two media of refractive indices n_1 and n_2 $(n_2 > n_1)$. Draw the ray diagram and deduce the relation between the object distance (u), image distance (v) and the radius of curvature (R) for refraction to take place at the convex spherical surface from rarer to denser medium.

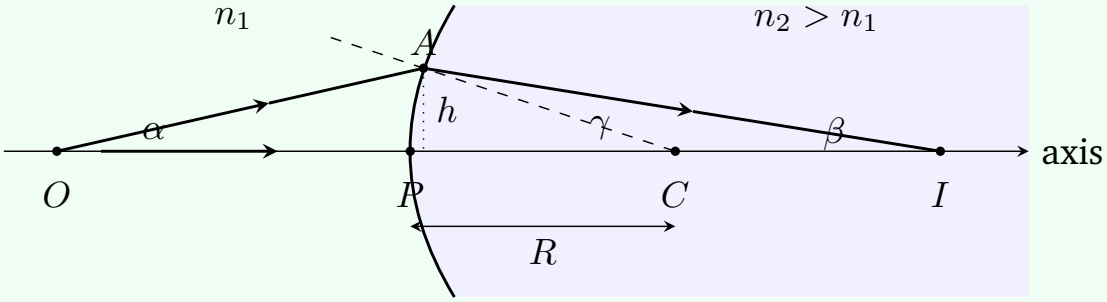
(b) A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index $1 \cdot 6$. If it is immersed in a liquid of refractive index $1 \cdot 3$, find its new focal length. [5 marks]

Solution:

Concept:

- For paraxial rays, Snell's law becomes $n_1 i = n_2 r$, since $\sin\theta \simeq \theta$ for small angles measured in radians. The normal to a spherical surface passes through its centre of curvature.
- Use the Cartesian sign convention: distances are measured from the pole in the direction of incident light as positive. For the configuration shown, $u < 0$, $v > 0$ and $R > 0$.
- The lens-maker formula in a surrounding medium is $1/f = (n_{\text{lens}}/n_{\text{medium}} - 1)(1/R_1 - 1/R_2)$. The radii remain unchanged when the lens is immersed.

Step 1: (a) Draw the paraxial ray geometry Let O be the point object, P the pole, C the centre of curvature and I the real image in the denser medium. A ray along the principal axis is undeviated. A second ray strikes the surface at A, a small height h above the axis, and bends towards the normal AC, meeting the axis at I. Define α, β and γ as the positive small angles made with the axis by OA, AI and AC, respectively. The diagram illustrates a real-image configuration for the derivation.



Paraxial refraction at a convex surface; the dashed line through A and C is the normal.

Step 2: (a) Apply Snell's law and the small-angle geometry The incident ray slopes upward, whereas the normal and the refracted ray slope downward. Hence the incidence and refraction angles are

$$i = \alpha + \gamma, \qquad r = \gamma - \beta.$$

Snell's law therefore gives

$$n_1(\alpha + \gamma) = n_2(\gamma - \beta),$$

or

$$n_1\alpha + n_2\beta = (n_2 - n_1)\gamma.$$

Quick Tip to Solve: For the same lens in two media, divide the lens-maker equations to cancel both radii; use the relative refractive index in the liquid.

For a paraxial ray, the axial displacement of A from P is negligible to first order, so

$$\alpha \simeq \frac{h}{OP}, \qquad \beta \simeq \frac{h}{PI}, \qquad \gamma \simeq \frac{h}{PC}.$$

Substituting and cancelling the nonzero height h,

$$\frac{n_1}{OP} + \frac{n_2}{PI} = \frac{n_2 - n_1}{PC}.$$

Step 3: (a) Express the result using signed distances In the Cartesian convention, $OP = -u$, $PI = v$ and $PC = R$. Thus the spherical-refraction equation is

$$\boxed{\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}}.$$

It is the paraxial relation; signed distances allow the same expression to describe other object and image configurations. For example, the negative object distance makes the object term positive in the real-object configuration drawn.

Step 4: (b) Compare the lens powers in air and liquid Write $K = 1/R_1 - 1/R_2$. In air, whose refractive index is taken as unity,

$$\frac{1}{f_{\text{air}}} = (1.6 - 1)K = 0.6K.$$

In the liquid the relative refractive index is $1.6/1.3 = 16/13$, so

$$\frac{1}{f_{\text{liquid}}} = \left(\frac{16}{13} - 1\right) K = \frac{3}{13}K.$$

Divide the two equations to eliminate the unknown curvatures:

$$\frac{f_{\text{liquid}}}{f_{\text{air}}} = \frac{0.6}{3/13} = 2.6.$$

Therefore $f_{\text{liquid}} = 2.6 \times 20\,\text{cm} = 52\,\text{cm}$. The focal length stays positive because the lens material is still optically denser than the liquid; the smaller relative index reduces its converging power.

Step 5: Conclusion (a) $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$, using Cartesian signs. (b) The new focal length is $\boxed{+52\,\text{cm}}$.

Quick Tip to Solve: For the same lens in two media, divide the lens-maker equations to cancel both radii; use the relative refractive index in the liquid.

OR

24. (a) Draw the ray diagram showing refraction of light through a glass prism and hence obtain the relation between the refractive index μ of the prism, angle of prism and angle of minimum deviation.
(b) Determine the value of the angle of incidence for a ray of light travelling from a medium of refractive index $\mu_1 = \sqrt{2}$ into the medium of refractive index $\mu_2 = 1$, so that it just grazes along the surface of separation. [5 marks]

Solution:

Concept:

- Snell's law for refraction from air into glass is $\mu = \sin i / \sin r_1$, where i is the angle of incidence and r_1 is the first refracted angle, both measured from the normal.
- For a prism of apex angle A, the internal angles satisfy $r_1 + r_2 = A$. The deviation is $\delta = i + e - A$, where e is the angle of emergence.
- At minimum deviation δ_m, the path through the prism is symmetric: $i = e$ and $r_1 = r_2$. For grazing refraction at a denser-to-rarer boundary, the refracted angle is 90°.

Step 1: (a) Draw the prism path and obtain the geometrical relations The ray enters the first face at P, refracts towards its normal, travels along PQ, and emerges at Q, bending away from the second normal. The figure shows the symmetric path at minimum deviation. Let the two internal refraction angles be r_1 and r_2. The angle between the inward-facing segments of the normals is $180^\circ - A$; the triangle formed with PQ therefore gives

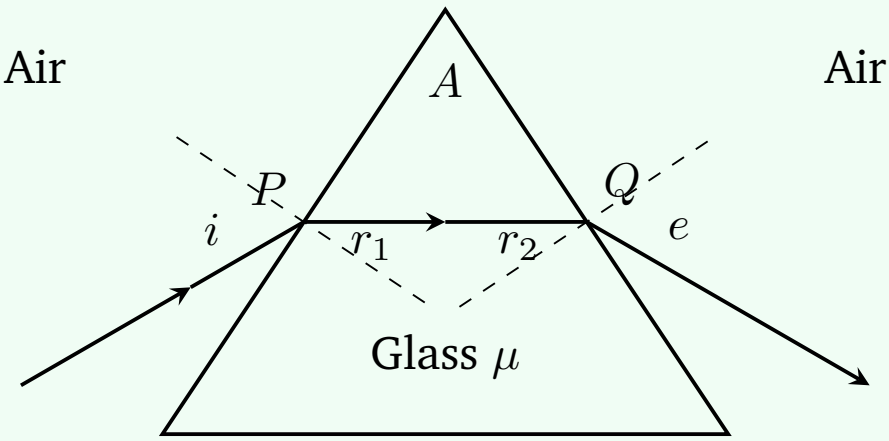
$$r_1 + r_2 + (180^\circ - A) = 180^\circ, \qquad r_1 + r_2 = A.$$

The changes in direction at the two faces are $i - r_1$ and $e - r_2$. Adding them gives

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

All incidence, refraction and emergence angles are measured with respect to the appropriate face normal, not the prism face.

Quick Tip to Solve: At minimum deviation use equal angles at the two prism faces; for a grazing refracted ray set its angle to the normal equal to 90°.



$$i = e, \quad r_1 = r_2 = A/2$$

Symmetric ray path through a prism at minimum deviation; dashed lines are the face normals. Angles are measured from these normals.

Step 2: (a) Use the condition of minimum deviation As incidence varies, the deviation first decreases and then increases. At the minimum, the reversible ray path is symmetric, so $i = e$. Snell's law at the two faces then gives equal internal refraction angles. Combining this with the prism geometry,

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

Applying Snell's law at the first face, with air taken to have refractive index unity,

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

Thus the required expression relates the glass refractive index relative to air to the measured apex angle and minimum deviation. Equal incidence and emergence is the minimum-deviation condition; it should not be imposed on a general prism path.

Step 3: (b) Find the incidence angle for grazing emergence The ray travels from the denser medium $\mu_1 = \sqrt{2}$ to the rarer medium $\mu_2 = 1$. Just grazing the separating surface means that its refracted angle to the normal is $r = 90^\circ$. This is the critical-angle condition. Snell's law gives

$$\mu_1 \sin i_c = \mu_2 \sin 90^\circ, \qquad \sin i_c = \frac{1}{\sqrt{2}}, \qquad i_c = 45^\circ.$$

The acute value is appropriate to an incident ray meeting the interface. At this limiting angle the transmitted ray lies along the surface; an incidence angle greater than this gives total internal reflection. The requested incidence angle is measured from the normal to the interface.

Step 4: Conclusion (a) For a prism in air at minimum deviation, $\mu = \dfrac{\sin[(A + \delta_m)/2]}{\sin(A/2)}$. (b) The incidence angle for grazing refraction is $\boxed{45^\circ}$.

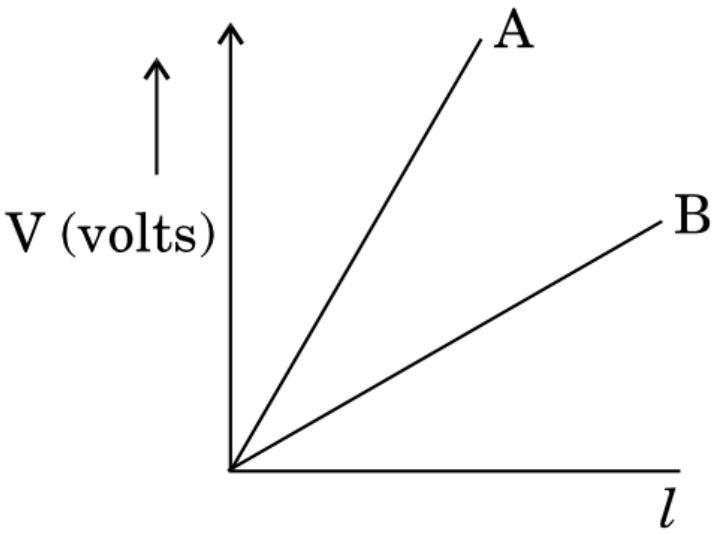
Quick Tip to Solve: At minimum deviation use equal angles at the two prism faces; for a grazing refracted ray set its angle to the normal equal to 90°.

25. (a) (i) State the principle on which a potentiometer works. How can a given potentiometer be made more sensitive?

(ii) In the graph shown below for two potentiometers, state with reason which of the two potentiometers, A or B, is more sensitive.

(b) Two metallic wires, P_1 and P_2 of the same material and same length but different cross-sectional areas, A_1 and A_2 are joined together and connected to a source of emf. Find the ratio of the drift velocities of free electrons in the two wires when they are connected (i) in series, and (ii) in parallel.

[5 marks]



Solution:

Concept:

- A potentiometer compares emf with the potential drop along a uniform wire carrying a steady current. The potential gradient is $k = V/L$, where V is the drop along total length L.
- Current and drift-speed magnitude are related by $I = neAv_d$, where n is the free-electron number density, e is the elementary charge and A is the wire's cross-sectional area.
- For a wire of resistivity ρ, length L and area A, $R = \rho L/A$. Series wires carry the same current; parallel wires have the same potential difference.

Step 1: (a)(i) State the principle and improve sensitivity For a uniform wire at constant temperature carrying a steady current, the potential difference across any portion is directly proportional to its length:

$$V_l = I\frac{\rho l}{A} = kl.$$

Thus an unknown emf $\mathcal{E}$ is balanced by a length l satisfying $\mathcal{E} = kl$. At balance no current is drawn from the test cell, so its emf is measured. Sensitivity increases when a small change of emf produces a larger change of balance length. Since $\Delta l = \Delta\mathcal{E}/k$, reduce the potential gradient. For the given wire, reduce its current using a larger series resistance in the primary circuit. Keep the total wire drop greater than the largest emf to be measured so that a balance remains possible.

Step 2: (a)(ii) Compare the graph slopes The graph has potential difference V vertically and wire length l horizontally. Its slope equals $k = V/l$. Line B is less steep than line A, hence $k_B < k_A$. The

Quick Tip to Solve: Read the potentiometer graph's slope as potential gradient; for drift speed, first identify whether current or voltage is common.

same small potential difference therefore corresponds to a longer balancing length on B. Its null point can be located with smaller relative length error; potentiometer B is more sensitive.

Step 3: (b)(i) Connect the wires in series Both wires carry the same current I. Since their material is the same, their free-electron densities are equal. Their drift-speed magnitudes are

$$v_{d1} = \frac{I}{neA_1}, \qquad v_{d2} = \frac{I}{neA_2}.$$

Dividing these expressions gives $v_{d1}/v_{d2} = A_2/A_1$. The thinner wire has the larger drift speed, because the same charge per second passes through a smaller cross-sectional area.

Step 4: (b)(ii) Connect the wires in parallel Let their common potential difference be V. Using the same resistivity and length,

$$I_1 = \frac{VA_1}{\rho L}, \qquad I_2 = \frac{VA_2}{\rho L}.$$

Substitution in $v_d = I/(neA)$ gives $v_{d1} = v_{d2} = V/(ne\rho L)$. Equivalently, both wires experience the same electric field V/L and have the same electron mobility. Although their currents differ, their drift-speed magnitudes are equal.

Step 5: Conclusion The potentiometer works on $V_l \propto l$ for a uniform wire carrying steady current. Reduce the potential gradient to increase sensitivity; B is more sensitive. The drift-speed ratios are $v_{d1} : v_{d2} = A_2 : A_1$ in series and $1 : 1$ in parallel.

Quick Tip to Solve: Read the potentiometer graph's slope as potential gradient; for drift speed, first identify whether current or voltage is common.

OR

25. (a) Define the capacitance of a capacitor. Obtain the expression for the capacitance of a parallel plate capacitor in vacuum in terms of plate area A and separation d between the plates.

(b) A slab of material of dielectric constant K has the same area as the plates of a parallel plate capacitor but has a thickness $\frac{3d}{4}$. Find the ratio of the capacitance with dielectric inside it to its capacitance without the dielectric. [5 marks]

Solution:

Concept:

- Capacitance is $C = Q/V$, where Q is the magnitude of charge on either plate and V is the potential difference between the plates; its SI unit is the farad.
- In vacuum, two large oppositely charged parallel plates produce field $E = \sigma/\varepsilon_0$ between them, where $\sigma = Q/A$ and ε_0 is vacuum permittivity.
- A dielectric of relative permittivity K reduces the field at fixed free charge to $E = \sigma/(K\varepsilon_0)$. Potential drops across successive layers add.

Step 1: (a) Define capacitance and find the plate field Capacitance is the ratio of charge stored on either conductor to the potential difference between the conductors. It represents charge stored per

Quick Tip to Solve: For a slab filling the plate area, replace the gap by effective thickness $(d - t) + t/K$, then use $C = \varepsilon_0 A/d_{\text{eff}}$.

unit potential difference. Consider parallel conducting plates of area A, separated by d, carrying equal and opposite charges $+Q$ and $-Q$. Assume their dimensions are much larger than d, so edge effects can be neglected. Each plate produces field magnitude $\sigma/(2\varepsilon_0)$. Between the plates the two fields reinforce, giving

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}.$$

Outside ideal large plates the two contributions cancel. The field in the vacuum gap is therefore uniform.

Step 2: (a) Relate potential difference to charge The potential difference magnitude across the gap is the field multiplied by separation:

$$V = Ed = \frac{Qd}{\varepsilon_0 A}.$$

Consequently,

$$C_0 = \frac{Q}{V} = \frac{\varepsilon_0 A}{d}.$$

Although this derivation uses a charge Q, it cancels from the result. For the specified geometry and vacuum medium, capacitance depends only on A, d and ε_0, increasing with area and decreasing with separation.

Step 3: (b) Add the drops across dielectric and vacuum The printed slab thickness is $t = 3d/4$. It fills the entire plate area, leaving a total vacuum thickness $d - t = d/4$. For free charge Q, the normal electric displacement is the same through both layers. Thus the vacuum field is $Q/(\varepsilon_0 A)$, and the dielectric field is $Q/(K\varepsilon_0 A)$. The total drop is

$$\begin{aligned} V' &= \frac{Q}{\varepsilon_0 A}(d - t) + \frac{Q}{K\varepsilon_0 A}t \\ &= \frac{Qd}{4\varepsilon_0 A}\left(1 + \frac{3}{K}\right). \end{aligned}$$

This also treats the two layers as capacitors in series; any vacuum on the two sides contributes through its total thickness.

Step 4: (b) Calculate the requested ratio The new capacitance follows by dividing the free charge by the total potential difference:

$$C' = \frac{Q}{V'} = \frac{4K\varepsilon_0 A}{d(K + 3)}.$$

Divide by $C_0 = \varepsilon_0 A/d$ to obtain $C'/C_0 = 4K/(K + 3)$. As a check, for $K = 1$ the slab behaves like vacuum and the ratio is unity. As K becomes very large, the remaining vacuum quarter-gap controls the capacitance and the ratio tends to four.

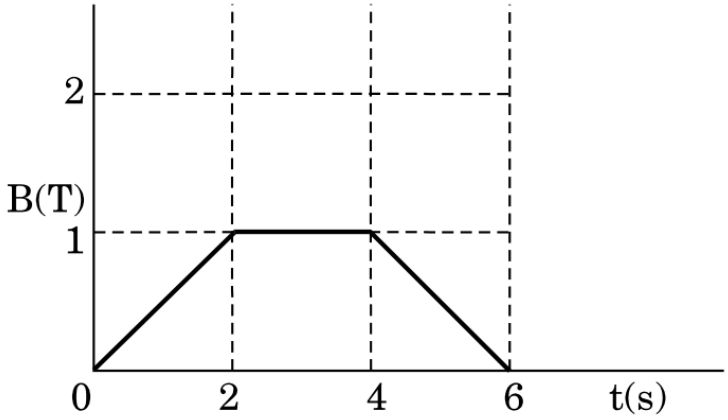
Step 5: Conclusion Capacitance is $C = Q/V$; for the vacuum parallel plate capacitor, $C_0 = \varepsilon_0 A/d$. With the printed dielectric thickness $3d/4$, the required ratio is $C'/C_0 = 4K/(K + 3)$.

Quick Tip to Solve: For a slab filling the plate area, replace the gap by effective thickness $(d - t) + t/K$, then use $C = \varepsilon_0 A/d_{\text{eff}}$.

26. (a) State Faraday's law of electromagnetic induction.

(b) The magnetic field through a circular loop of wire 12 cm in radius and $8 \cdot 5\ \Omega$ resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the induced current in the loop and plot it as a function of time.

(c) Show that Lenz's law is a consequence of conservation of energy. [5 marks]



Solution:

Concept:

- Magnetic flux through a plane loop is $\Phi_B = BA\cos\theta$, where A is its area and θ is the angle between the magnetic field and the chosen positive normal.
- Faraday's law gives $\varepsilon = -d\Phi_B/dt$ for a single turn. With resistance R, the induced current is $I = \varepsilon/R$, neglecting self-inductance as in this problem.
- Lenz's law states that the induced current has a direction which opposes the change in magnetic flux responsible for producing it; the minus sign expresses this opposition.

Step 1: (a) State Faraday's law Whenever the magnetic flux linked with a circuit changes, an emf is induced in it. The magnitude of the induced emf equals the rate of change of flux linkage. For a coil of N turns,

$$\varepsilon = -N\frac{d\Phi_B}{dt}.$$

Here Φ_B is the flux through one turn. The negative sign specifies the direction according to Lenz's law. An induced current flows when the circuit is closed.

Step 2: (b) Calculate the area and read the slopes The radius is $r = 12\,\text{cm} = 0.12\,\text{m}$, so

$$A = \pi r^2 = \pi(0.12)^2 = 0.04524\,\text{m}^2.$$

Since the field is perpendicular to the loop, choose the positive normal along the field shown, so $\Phi_B = BA$. The graph rises from 0 to $1\,\text{T}$ in $2\,\text{s}$, stays at $1\,\text{T}$ until $4\,\text{s}$, then falls to zero at $6\,\text{s}$. Thus the slopes dB/dt are respectively $+0.5$, 0 and $-0.5\,\text{T s}^{-1}$.

Step 3: (b) Obtain the current in each interval and plot it Take positive circulation around the loop to be the direction given by the right-hand rule about the chosen positive normal. Using $R = 8.5\,\Omega$,

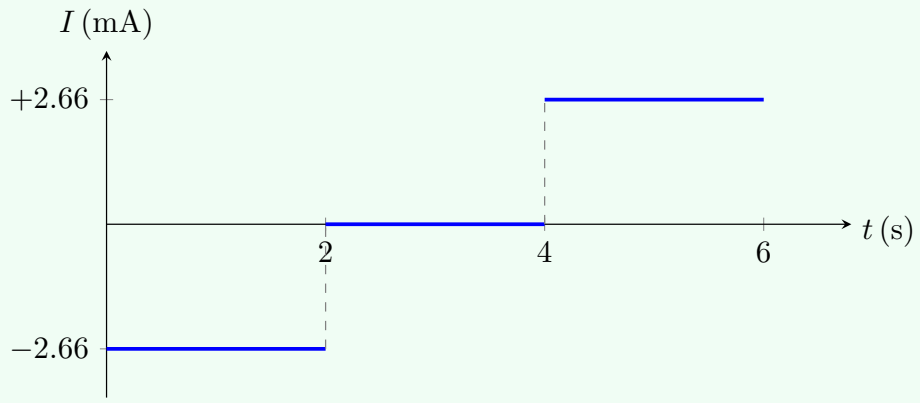
$$I = -\frac{A}{R}\frac{dB}{dt}, \qquad \frac{0.04524 \times 0.5}{8.5} = 0.00266\,\text{A}.$$

Quick Tip to Solve: Read the slope of the magnetic-field graph, not its height: a horizontal section gives zero induced current even when the field is nonzero.

Therefore the signed current is

$$I(t) = \begin{cases} -2.66\,\text{mA}, & 0 < t < 2\,\text{s}, \\ 0, & 2 < t < 4\,\text{s}, \\ +2.66\,\text{mA}, & 4 < t < 6\,\text{s}. \end{cases}$$

During the rise, the induced field opposes the applied field; during the fall it is along the applied field, opposing its decrease. No current is induced during the constant-field interval. The current graph consists of three horizontal segments. At the sharp corners of the idealized field graph the derivative changes abruptly; the intervals specify the values on either side. If the field stays zero after $6\,\text{s}$, the current is also zero then.



Signed induced current versus time; positive circulation follows the right-hand rule about the applied-field direction.

Step 4: (c) Explain conservation of energy Consider pushing the north pole of a magnet towards a conducting loop. The magnetic flux through the loop increases. Lenz's law makes the near face of the loop a north pole, so the magnet experiences a force opposing its motion. An external agent must do work to keep moving the magnet. This mechanical work supplies the electrical energy, which is dissipated as Joule heat in the resistive loop. For steady motion with negligible energy storage, the supplied mechanical power equals I^2R. If the induced current instead reinforced the flux increase, the loop would attract the approaching north pole and accelerate the magnet. Its faster motion would induce a still larger current, giving both increasing kinetic energy and Joule heat without any external energy supply. This would violate conservation of energy. On withdrawing the magnet, the induced current reverses and the loop attracts it, again opposing the motion and requiring external work. Thus the opposing direction required by Lenz's law is a consequence of conservation of energy.

Step 5: Conclusion Faraday's law is $\varepsilon = -N\,d\Phi_B/dt$. The induced-current magnitude is $2.66\,\text{mA}$ during both changing-field intervals, with opposite directions, and is zero from 2 to $4\,\text{s}$. Lenz's law ensures that induced electrical energy comes from the work done against the opposing force.

Quick Tip to Solve: Read the slope of the magnetic-field graph, not its height: a horizontal section gives zero induced current even when the field is nonzero.

OR

26. (a) Describe, with the help of a suitable diagram, the working principle of a step-up transformer. Obtain the relation between input and output voltages in terms of the number of turns of primary and secondary windings and the currents in the input and output circuits.

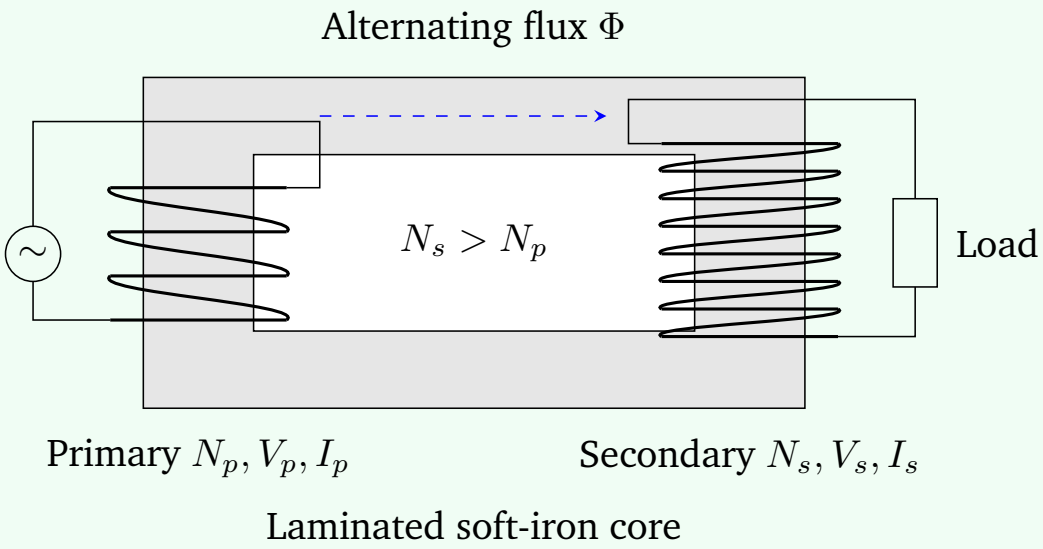
(b) Given the input current 15 A and the input voltage of 100 V for a step-up transformer having 90% efficiency, find the output power and the voltage in the secondary if the output current is 3 A. [5 marks]

Solution:

Concept:

- A transformer works on mutual induction: an alternating current in the primary produces a changing magnetic flux in a common iron core, inducing an emf in the secondary.
- Faraday's law gives $e_p = -N_p\, d\Phi/dt$ and $e_s = -N_s\, d\Phi/dt$, where N_p, N_s are winding turns and Φ is the flux linking each turn.
- In an ideal transformer, input and output powers are equal: $V_p I_p = V_s I_s$. For a real transformer, efficiency is $\eta = P_{\text{out}}/P_{\text{in}}$.

Step 1: (a) Construction and working of a step-up transformer Two insulated coils, called the primary and secondary, are wound on a common laminated soft-iron core. The primary is connected to an alternating-voltage source; the secondary is connected to the load. In a step-up transformer the secondary has more turns than the primary, $N_s > N_p$. The alternating primary current creates alternating magnetic flux in the core. This flux links the secondary and induces an alternating emf by mutual induction. The iron core provides a path for magnetic flux, while laminations reduce eddy-current losses. A steady direct-current supply cannot provide continuous transformer action because its steady flux has no time variation.



Step-up transformer: more secondary turns link the alternating flux in the laminated iron core.

Step 2: (a) Derive the voltage and current relations Neglect flux leakage so that the same flux $\Phi(t)$

Quick Tip to Solve: Apply the efficiency to input power first, then divide output power by the secondary current; using ideal power equality here would give the wrong voltage.

links each turn of both coils. Applying Faraday's law separately gives

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

Thus the ratio of emf magnitudes, and hence the ratio of rms terminal voltages when winding drops are negligible, is

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

For an ideal transformer, energy conservation requires $V_p I_p = V_s I_s$, so

$$\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}, \qquad \frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}.$$

Increasing the voltage therefore reduces the available current in the ideal case. For a real transformer, the exact power relation is $V_s I_s = \eta V_p I_p$; the ideal reciprocal current ratio should not be applied without accounting for losses.

Step 3: (b) Calculate input and output power With the given input voltage and current,

$$P_{\text{in}} = V_p I_p = (100)(15) = 1500\,\text{W}.$$

The efficiency is $90\% = 0.90$, hence

$$P_{\text{out}} = \eta P_{\text{in}} = 0.90(1500) = 1350\,\text{W}.$$

The remaining $150\,\text{W}$ is lost in the transformer. We use the given efficiency rather than assuming input and output powers are equal.

Step 4: (b) Obtain the secondary voltage Using the given output current $I_s = 3\,\text{A}$, the output-power relation gives

$$V_s = \frac{P_{\text{out}}}{I_s} = \frac{1350}{3} = 450\,\text{V}.$$

This is greater than the input voltage, as required for step-up operation. It also checks the efficiency directly: $(450 \times 3)/(100 \times 15) = 0.90$.

Step 5: Conclusion A step-up transformer uses mutual induction with $N_s > N_p$. Ideally, $V_s/V_p = N_s/N_p = I_p/I_s$. For the given transformer, the output power is $\boxed{1350\,\text{W}}$ and the secondary voltage is $\boxed{450\,\text{V}}$.

Quick Tip to Solve: Apply the efficiency to input power first, then divide output power by the secondary current; using ideal power equality here would give the wrong voltage.