CBSE Class 12 Physics Question Paper 2007 with Solution PDF-Delhi

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.

(ii) 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 three questions of five marks. You have to attempt only one of the choice in such questions.

(iii) Question numbers **1 to 5** are very short answer type questions, carrying **one** mark each.

(iv) Question numbers **6 to 12** are short answer type questions, carrying **two** marks each.

(v) Question numbers **13 to 24** are also short answer type questions, carrying **three** marks each.

(vi) Questions numbers **25 to 27** are long answer type questions, carrying **five** marks each.

Section A (5 marks)

1. An electron, an alpha-particle and a proton have the same kinetic energy. Which one of these particles has the largest de-Broglie wavelength? [1 mark]

Solution:

Concept:

- The de Broglie relation is $\lambda = h/p$, where h is Planckś constant and p is momentum.
- For nonrelativistic kinetic energy K, $p = \sqrt{2mK}$, where m is the particle mass.

Step 1: Use the equal kinetic energy Substituting the momentum into the wavelength relation gives

$$\lambda = \frac{h}{\sqrt{2mK}}.$$

Since h and K are common to all three particles, wavelength varies inversely as the square root of mass.

Step 2: Compare the particle masses The electron has a much smaller mass than the proton, while an alpha-particle has about four times the proton mass. Thus $m_e < m_p < m_\alpha$, giving $\lambda_e > \lambda_p > \lambda_\alpha$. Equal kinetic energy does not mean equal momentum.

Step 3: Conclusion The electron has the largest de Broglie wavelength.

Quick Tip to Solve: For equal kinetic energies, rank wavelengths by the inverse square root of particle mass.

2. Why should the material used for making permanent magnets have high coercivity? [1 mark]

Solution:

Concept:

- Coercivity is the magnitude of the reverse magnetising field needed to reduce a previously magnetised specimenś magnetisation to zero.
- A permanent magnet must retain its magnetisation against demagnetising influences.

Step 1: Interpret a large coercivity High coercivity means that a strong field opposite to the original magnetisation is required to demagnetise the material. A weak reverse field therefore cannot easily destroy its magnetic state.

Step 2: Apply this to a permanent magnet A permanent magnet may experience stray magnetic fields and its own demagnetising field during use. A material with high coercivity resists these effects and retains its magnetisation for a long time. This stability is the reason for selecting such a material.

Step 3: Conclusion High coercivity prevents a permanent magnet from being easily demagnetised.

Quick Tip to Solve: Connect coercivity to resistance against a reverse magnetic field, rather than field strength alone.

3. The radioactive isotope D decays according to the sequence $D \xrightarrow{\beta^-} D_1 \xrightarrow{\alpha\text{-particle}} D_2$. If the mass number and atomic number of D_2 are 176 and 71 respectively, what is (i) the mass number (ii) atomic number of D? [1 mark]

Solution:

Concept:

- In β^- decay the mass number A stays constant and the atomic number Z increases by one.
- In alpha decay the emitted ${}^4_2\text{He}$ nucleus reduces A by four and Z by two.

Step 1: Follow the printed decay sequence Let the original isotope be ${}^A_Z D$. The printed first step is beta-minus decay, so D_1 has mass number A and atomic number $Z+1$. The following alpha emission makes the final mass number $A-4$ and atomic number $(Z+1)-2 = Z-1$.

Step 2: Recover the parent numbers Using the stated final isotope gives

$$A - 4 = 176, \qquad Z - 1 = 71.$$

Hence $A = 180$ and $Z = 72$. Beta-minus emission changes the neutron-proton balance but does not remove a nucleon, whereas alpha emission removes four nucleons.

Step 3: Conclusion (i) Mass number of D: 180. (ii) Atomic number of D: 72.

Quick Tip to Solve: Work backwards from the daughter: undo alpha decay first, then undo beta-minus decay.

4. What will be the values of input A and B for the Boolean expression $\overline{(A+B)} \cdot \overline{(A \cdot B)} = 1$? [1 mark]

Solution:

Concept:

- In Boolean algebra, $+$ means OR, $\cdot$ means AND, and an overbar means NOT.
- An AND output is one only when both of its input factors are one.

Step 1: Apply the first complemented factor The printed expression contains an overbar on each factor. For $\overline{(A+B)} = 1$, the OR result $A+B$ must be zero. An OR result is zero only if both inputs are zero, so this condition requires $A = 0$ and $B = 0$.

Step 2: Check the second factor With these inputs, $A \cdot B = 0$, and therefore $\overline{(A \cdot B)} = 1$. The complete expression is then $1 \cdot 1 = 1$. Any other input pair has $A + B = 1$, making the first complemented factor zero and the final output zero.

Step 3: Conclusion The required inputs are $A = 0$ and $B = 0$.

Quick Tip to Solve: Check the overbars first: a complemented OR is one only for two zero inputs.

5. Why is frequency modulation preferred over amplitude modulation for transmission of music?

[1 mark]

Solution:

Concept:

- In amplitude modulation (AM), the information is carried by changes in carrier amplitude.
- In frequency modulation (FM), the information is carried by changes in carrier frequency while the carrier amplitude remains constant.

Step 1: Identify the effect of noise Most electrical noise produces unwanted amplitude variations in the received signal. In AM these variations alter the same quantity that carries the music, so they are heard as interference or distortion.

Step 2: Explain the advantage of FM In FM, amplitude fluctuations do not represent the transmitted music. They can be removed by amplitude-limiting circuitry before frequency demodulation. The resulting reproduction has less noise and better fidelity, which is especially desirable for music with a wide range of tones.

Step 3: Conclusion FM is preferred because it is less affected by amplitude noise and gives better fidelity in music reproduction.

Quick Tip to Solve: Remember that noise mainly changes amplitude; FM stores the music in frequency variations.

Section B (14 marks)

6. The output of an OR gate is connected to both the inputs of a NAND gate. Draw the logic circuit of this combination of gates and write its truth table. [2 marks]

Solution:

Concept:

- An OR gate gives the intermediate output $X = A + B$, which is one if either input is one.
- A NAND gate gives the complement of the AND of its two inputs. When both inputs equal X, $Y = \overline{X \cdot X} = \overline{X}$.

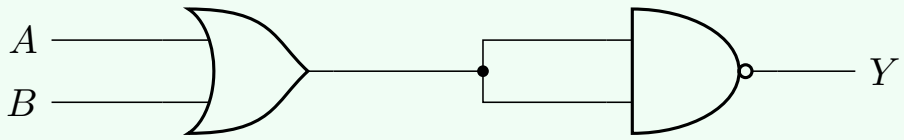
Step 1: Connect the two gates Feed inputs A and B to the OR gate. Split its output wire so that the same intermediate signal X reaches both NAND inputs. The NAND output is

$$Y = \overline{(A + B)(A + B)} = \overline{A + B}.$$

The identity $X \cdot X = X$ shows that the NAND gate acts as an inverter in this connection.

Quick Tip to Solve: A NAND gate with its two inputs tied together inverts the common input signal.

$$X = A + B$$



OR output connected to both NAND inputs

Step 2: Construct the truth table For $A = B = 0$, the OR output is zero and the tied NAND inputs are both zero, producing $Y = 1$. For each other pair, $X = 1$, so the NAND output is zero. Thus the complete truth table is

A	B	$X = A + B$	$Y = \overline{X \cdot X}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

These rows exhaust all four binary input combinations.

Step 3: Conclusion The combination behaves as a NOR gate: $Y = \overline{A + B}$, with output one only for $A = B = 0$.

Quick Tip to Solve: A NAND gate with its two inputs tied together inverts the common input signal.

7. Draw a plot of potential energy of a pair of nucleons as a function of their separation. What is the significance of negative potential energy in the graph drawn? [2 marks]

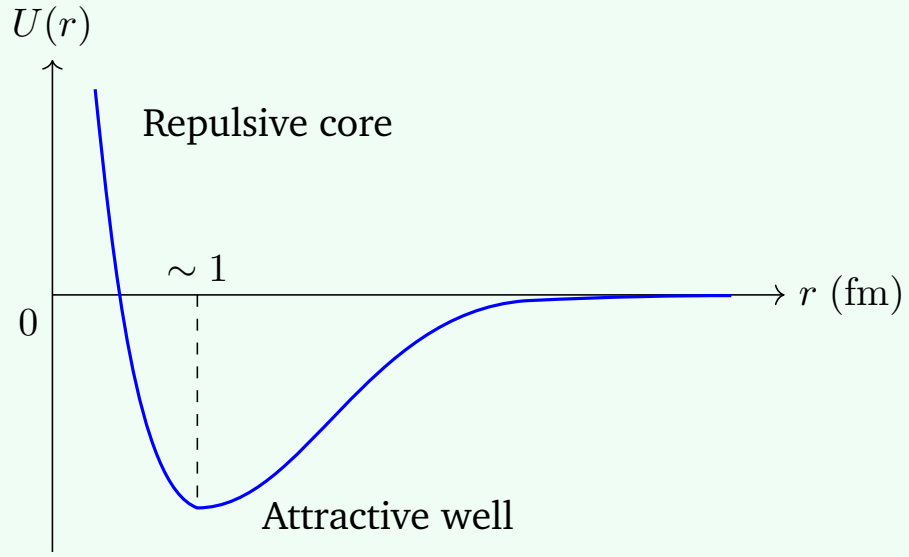
Solution:

Concept:

- The nuclear interaction has a very short range. Its potential energy $U(r)$ is conventionally measured relative to $U(\infty) = 0$, where r is the separation of the nucleons.
- The force is related to the slope by $F_r = -dU/dr$. A steep repulsive core occurs at very small separations, while the well represents the attractive interaction.

Step 1: Draw the potential-energy curve The schematic curve rises sharply to positive values at very small separation, falls into a negative potential well around a separation of order 1 fm, and approaches zero at separations of a few femtometres. The steep inner side represents short-range repulsion. On the outer side of the minimum, the positive slope gives an attractive radial force. The exact depth and position depend on the nuclear state; only the characteristic shape is required here.

Quick Tip to Solve: Choose zero energy at infinite separation before interpreting the negative well.



Schematic nuclear potential; separation is measured in femtometres.

Step 2: Interpret the negative potential energy Within the well, the potential energy is lower than that of two nucleons separated to infinity. Energy must therefore be supplied to separate the pair from this region to infinity. This is the binding tendency of the attractive nuclear interaction. Strictly, a bound state requires the total energy, including kinetic energy, to be negative; negative potential energy alone is not sufficient to establish binding.

Step 3: Conclusion The graph has a steep repulsive core and a negative attractive well, tending to zero at large separation. Negative potential energy means the pair has lower potential energy than separated nucleons and requires energy for separation.

Quick Tip to Solve: Choose zero energy at infinite separation before interpreting the negative well.

8. A convex lens of refractive index 1.5 has a focal length of 18 cm in air. Calculate the change in its focal length when it is immersed in water of refractive index 4/3. [2 marks]

Solution:

Concept:

- For a thin lens in a surrounding medium, the lens-maker formula is $1/f = (n_\ell/n_m - 1)(1/R_1 - 1/R_2)$, where n_ℓ and n_m are the refractive indices of the lens and medium.
- The radii of curvature stay unchanged on immersion. Thus the powers in air and water are compared through their relative refractive-index factors.

Step 1: Compare the powers in the two media Let $K = 1/R_1 - 1/R_2$. In air, $1/f_a = (1.5-1)K = K/2$. In water the relative refractive index is $n_\ell/n_w = (3/2)/(4/3) = 9/8$, so $1/f_w = (9/8 - 1)K = K/8$. Dividing eliminates the unknown curvatures:

$$\frac{f_a}{f_w} = \frac{1/8}{1/2} = \frac{1}{4}.$$

Quick Tip to Solve: Use the relative index in water; distinguish the new focal length from its change.

Step 2: Calculate the focal length and its change Hence $f_w = 4f_a = 4 \times 18 = 72\,\text{cm}$. The requested change is the final value minus the initial value:

$$\Delta f = f_w - f_a = 72 - 18 = 54\,\text{cm}.$$

The lens remains converging because its refractive index exceeds that of water, but its power falls to one quarter of its value in air. This explains why the focal length increases.

Step 3: Conclusion The focal length in water is $72\,\text{cm}$; it increases by $54\,\text{cm}$.

Quick Tip to Solve: Use the relative index in water; distinguish the new focal length from its change.

9. Distinguish between the terms 'average value' and 'rms value' of an alternating current. The instantaneous current from an a.c. source is $I = 5\sin(314\,t)$ ampere. What are the average and rms values of the current? [2 marks]

Solution:

Concept:

- The average value is the arithmetic time average. For sinusoidal a.c., its conventional nonzero average is taken over one half-cycle: $I_{\text{av}} = 2I_0/\pi$. Its signed average over a complete cycle is zero.
- The rms value is the square root of the mean of the squared current over a cycle: $I_{\text{rms}} = I_0/\sqrt{2}$. It equals the steady current producing the same heat in the same resistance over the same time.

Step 1: Distinguish the averages An average current measures the mean of the instantaneous current over a stated interval and retains its sign. For a full sine-wave cycle the positive and negative contributions cancel. In the usual CBSE convention, average a.c. means the average over the positive half-cycle (equivalently the average of its rectified magnitude). In contrast, rms averages the square first, so the negative half-cycle contributes positively and gives a nonzero heating-equivalent value.

Step 2: Use the peak current Comparing $I = 5\sin(314t)\,\text{A}$ with $I = I_0\sin(\omega t)$ gives $I_0 = 5\,\text{A}$. Therefore

$$I_{\text{av}} = \frac{2 \times 5}{\pi} = 3.18\,\text{A}, \qquad I_{\text{rms}} = \frac{5}{\sqrt{2}} = 3.54\,\text{A}.$$

The angular frequency $314\,\text{rad s}^{-1}$ does not alter these ratios. If the average is explicitly taken over a complete cycle, its value is $0\,\text{A}$.

Step 3: Conclusion Using the half-cycle convention, the average current is $3.18\,\text{A}$ and the rms current is $3.54\,\text{A}$. The signed full-cycle average is zero.

Quick Tip to Solve: Identify the peak as 5 A, then specify the averaging interval before using 2/pi.

10. Write the relation for the force $\vec{F}$ acting on a charge carrier q moving with a velocity $\vec{v}$ through a magnetic field $\vec{B}$ in vector notation. Using this relation, deduce the conditions under which this force will be (i) maximum (ii) minimum. [2 marks]

Solution:

Concept:

- The magnetic force on a charge q with velocity $\vec{v}$ in a field $\vec{B}$ is $\vec{F} = q(\vec{v} \times \vec{B})$. It is perpendicular to both vectors.
- If θ is the angle between velocity and field, the magnitude is $F = |q|vB\sin\theta$. For fixed $|q|$, speed v, and field strength B, the angle determines the force magnitude.

Step 1: Write the relation and identify its direction The required vector relation is

$$\boxed{\vec{F} = q(\vec{v} \times \vec{B})}.$$

The cross product gives the direction for a positive charge by the right-hand rule; a negative charge experiences the opposite direction. Taking its magnitude yields $F = |q|vB\sin\theta$, with $0 \le \theta \le \pi$. The magnetic force changes the direction of motion but does no work because $\vec{F} \cdot \vec{v} = 0$.

Step 2: Deduce the maximum and minimum conditions (i) For maximum force, $\sin\theta = 1$, so $\theta = 90^\circ$: the velocity is perpendicular to the magnetic field. Then $F_{\max} = |q|vB$. (ii) For minimum force, $\sin\theta = 0$, so $\theta = 0^\circ$ or 180°: the velocity is parallel or antiparallel to the field. Then $F_{\min} = 0$. A stationary charge also has zero magnetic force, since $v = 0$, although the stated moving-charge comparison assumes fixed nonzero speed.

Step 3: Conclusion $\vec{F} = q(\vec{v} \times \vec{B})$. The force is maximum for $\vec{v} \perp \vec{B}$, and zero for parallel or antiparallel velocity and field.

Quick Tip to Solve: Use the sine in the cross-product magnitude: perpendicular gives maximum; parallel gives zero.

11. A cylindrical metallic wire is stretched to increase its length by 5%. Calculate the percentage change in its resistance. [2 marks]

Solution:

Concept:

- The resistance of a uniform wire is $R = \rho L/A$, where ρ is resistivity, L is length and A is cross-sectional area.
- Assume stretching preserves the volume AL, and the material and temperature remain unchanged, so ρ is constant.

Step 1: Apply conservation of volume Let the original length and area be L and A. A length increase of 5% gives $L\prime = 1.05L$. Since $A\prime L\prime = AL$, the new area is $A\prime = A/1.05$. Thus the wire becomes thinner as well as longer; retaining the original area would omit part of the resistance increase.

Quick Tip to Solve: For constant-volume stretching, use $R\prime/R = (L\prime/L)^2$, because both length and area change.

Step 2: Calculate the resistance ratio Using the new dimensions,

$$\frac{R\prime}{R} = \frac{\rho L\prime/A\prime}{\rho L/A} = \frac{L\prime}{L}\frac{A}{A\prime} = (1.05)^2 = 1.1025.$$

Therefore,

$$\frac{R\prime - R}{R} \times 100 = (1.1025 - 1) \times 100 = 10.25\%.$$

The small-change relation $\Delta R/R \simeq 2\Delta L/L$ would give approximately 10%; the squared ratio keeps the additional 0.25% term.

Step 3: Conclusion The resistance increases by $\boxed{10.25\%}$ (approximately 10% to first order).

Quick Tip to Solve: For constant-volume stretching, use $R\prime/R = (L\prime/L)^2$, because both length and area change.

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12. The electric field E due to a point charge at any point near it is defined as $E = \lim_{q\to 0} \frac{F}{q}$, where q is the test charge and F is the force acting on it. What is the physical significance of $\lim_{q\to 0}$ in this expression? Draw the electric field lines of a point charge Q when (i) $Q > 0$ and (ii) $Q < 0$. [2 marks]

Solution:

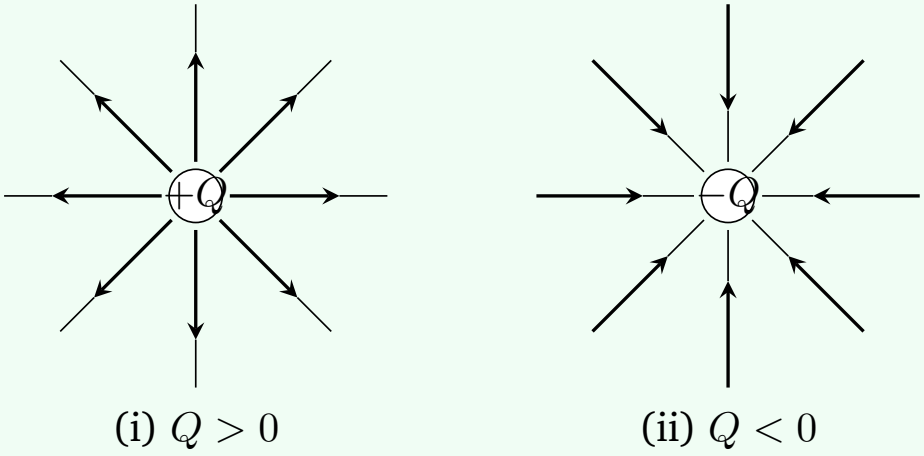
Concept:

- The electric field is the force per unit positive test charge: $\vec{E} = \lim_{q\to 0} \vec{F}/q$.
- A field-line arrow indicates the direction of force on a positive test charge; point-charge fields are radial.

Step 1: Explain the infinitesimal test charge The limit $q \to 0$ means that the test charge must be sufficiently small to produce a negligible disturbance of the source-charge configuration and hence of the field being measured. A finite test charge can exert a force on the source charges and alter their distribution. We determine the ratio F/q for progressively smaller nonzero test charges; we do not set $q = 0$ and divide by zero. For a fixed source charge Q, F decreases in proportion to q, so the ratio tends to the undisturbed field.

Step 2: Draw and interpret the two fields For $Q > 0$, a positive test charge is repelled, so all field lines point radially outwards. For $Q < 0$, it is attracted, so all lines point radially inwards. In the two sketches the arrows show these opposite directions. Field lines never cross, and their decreasing density with distance represents the decrease of field strength $E = |Q|/(4\pi\varepsilon_0 r^2)$.

Quick Tip to Solve: Choose a positive test charge mentally: repulsion gives outward arrows, attraction gives inward arrows.



Radial electric field lines for positive and negative point charges

Step 3: Conclusion The limit ensures measurement of the undisturbed electric field. As shown in the radial sketches, the lines are outward for $Q > 0$ and inward for $Q < 0$.

Quick Tip to Solve: Choose a positive test charge mentally: repulsion gives outward arrows, attraction gives inward arrows.

OR

12. Define electric flux. Write its S.I. units. A spherical rubber balloon carries a charge that is uniformly distributed over its surface. As the balloon is blown up and increases in size, how does the total electric flux coming out of the surface change? Give reason. [2 marks]

Solution:

Concept:

- Electric flux through a surface is $\Phi_E = \int_S \vec{E} \cdot d\vec{A}$; $d\vec{A}$ is the area element along the chosen normal.
- Gauss's law gives the outward flux through a closed surface: $\oint_S \vec{E} \cdot d\vec{A} = Q_{\text{enclosed}}/\varepsilon_0$.

Step 1: Define electric flux and its unit Electric flux measures the electric field passing through a surface, accounting for the angle between the field and surface normal. For a uniform field through a plane area, $\Phi_E = EA\cos\theta$, with θ measured from the normal. Its SI unit follows from electric field times area: $\boxed{\text{N m}^2\ \text{C}^{-1}}$, equivalently V m. For a closed surface, outward normals define positive outward flux.

Step 2: Apply Gauss law to the expanding balloon Let the total surface charge be Q. Blowing up the balloon spreads the same charge over a larger area; it does not add or remove charge. At radius r, spherical symmetry gives $E = Q/(4\pi\varepsilon_0 r^2)$, directed normally to the surface. Thus

$$\Phi_E = E(4\pi r^2) = \frac{Q}{\varepsilon_0}.$$

The field decreases as the balloon expands, but the surface area increases by the inverse factor. Gauss

Quick Tip to Solve: For a closed surface ask whether the enclosed charge changes; increasing its area alone cannot change total flux.

law therefore gives the same total flux at every radius.

Step 3: Conclusion The total outward electric flux remains unchanged: $\boxed{\Phi_E = Q/\varepsilon_0}$, because the enclosed charge is unchanged.

Quick Tip to Solve: For a closed surface ask whether the enclosed charge changes; increasing its area alone cannot change total flux.

Section C (36 marks)

13. Deduce an expression for the electric potential due to an electric dipole at any point on its axis. Mention one contrasting feature of electric potential of a dipole at a point as compared to that due to a single charge. [3 marks]

Solution:

Concept:

- A dipole consists of charges $-q$ and $+q$ separated by $2a$; its moment $\vec{p}$ points from $-q$ to $+q$, with magnitude $p = 2aq$.
- Potential is a scalar and obeys superposition: $V = (4\pi\varepsilon_0)^{-1}\sum_i q_i/r_i$, with zero potential at infinity.
- The point-dipole approximation requires the observation distance r to be much greater than the charge separation.

Step 1: Specify the axial observation point Place $-q$ at $x = -a$ and $+q$ at $x = +a$, with the midpoint at the origin. First take the point P on the positive axial side, $x = r > a$. Its distances from $+q$ and $-q$ are $r - a$ and $r + a$, respectively. Because potential is a scalar, the contribution of the negative charge enters with a negative sign, rather than being combined as a vector.

Step 2: Add the potentials and simplify Taking potential zero at infinity,

$$\begin{aligned} V(P) &= \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r-a} - \frac{q}{r+a}\right) \\ &= \frac{1}{4\pi\varepsilon_0}\frac{q[(r+a)-(r-a)]}{(r-a)(r+a)} \\ &= \frac{1}{4\pi\varepsilon_0}\frac{2aq}{r^2-a^2} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2-a^2}. \end{aligned}$$

On the negative axial side the sign reverses. More generally, for any axial coordinate $x \neq \pm a$, the exact expression is $V(x) = \frac{q}{4\pi\varepsilon_0}\left(|x-a|^{-1} - |x+a|^{-1}\right)$, which also covers points between the charges.

Step 3: State the distant-point result and contrast For $r \gg a$, neglect a^2 compared with r^2. Then the axial dipole potential is $V_{\text{axial}} \simeq \pm p/(4\pi\varepsilon_0 r^2)$, positive on the side towards $\vec{p}$ and negative on the opposite side. In contrast, a single charge Q has potential $V_Q = Q/(4\pi\varepsilon_0 r)$. Thus the dipole potential falls as $1/r^2$ at large distance, faster than the $1/r$ potential of a single charge.

Step 4: Conclusion On the external axis, $\boxed{V = \pm p/[4\pi\varepsilon_0(r^2 - a^2)]}$; for $r \gg a$, $\boxed{V \simeq \pm p/(4\pi\varepsilon_0 r^2)}$. The dipole potential decreases faster with distance than the potential of a single charge.

Quick Tip to Solve: For dipole potential, subtract the two scalar charge contributions before using the approximation $r \gg a$.

14. A parallel plate capacitor, each with plate area A and separation d, is charged to a potential difference V. The battery used to charge it is then disconnected. A dielectric slab of thickness d and dielectric constant K is now placed between the plates. What change, if any, will take place in

(i) charge on the plates,

(ii) electric field intensity between the plates,

(iii) capacitance of the capacitor.

Justify your answer in each case. [3 marks]

Solution:

Concept:

- For a parallel plate capacitor initially containing air, $C_0 = \varepsilon_0 A/d$, $Q_0 = C_0 V$ and $E_0 = V/d$. Here A is plate area, d the gap and V the initial potential difference.
- A dielectric completely filling the gap changes the permittivity to $K\varepsilon_0$. Disconnecting the battery isolates the plates, so their free charges cannot change.

Step 1: Establish the initial state The original capacitance and magnitude of charge on either plate are

$$C_0 = \frac{\varepsilon_0 A}{d}, \qquad Q_0 = \frac{\varepsilon_0 AV}{d}.$$

The two plates carry opposite charges, $+Q_0$ and $-Q_0$. The battery is removed before the dielectric is inserted; consequently it cannot supply additional charge or keep the voltage fixed.

Step 2: Explain the charge on the plates (i) There is no conducting path through which free charge can enter or leave either isolated plate. Hence Q remains equal to Q_0. Polarisation creates bound charges on the surfaces of the dielectric, but these do not represent a change in the free charge deposited on the metallic plates.

Step 3: Find the electric field (ii) With surface free-charge density $\sigma = Q_0/A$, the field in the completely filled gap is

$$E = \frac{\sigma}{K\varepsilon_0} = \frac{E_0}{K} = \frac{V}{Kd}.$$

The induced polarisation field opposes the original field and reduces its magnitude by a factor K. Since d is unchanged, the new potential difference is V/K.

Step 4: Find the capacitance (iii) The dielectric slab has thickness d, so it fills the whole separation rather than only part of it. The geometrical capacitance is therefore

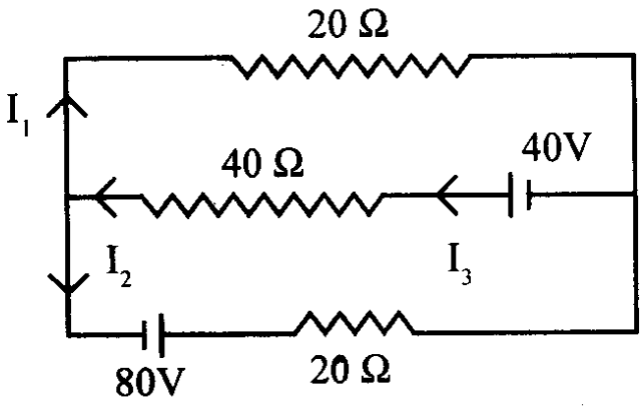
$$C = \frac{K\varepsilon_0 A}{d} = KC_0.$$

Equivalently, the same charge is now supported at the smaller potential difference V/K, so $Q_0/(V/K) = KC_0$.

Step 5: Conclusion The plate charges remain unchanged: $Q = Q_0$. The field decreases to E_0/K, and the capacitance increases to KC_0.

Quick Tip to Solve: First identify what is fixed: a disconnected battery fixes plate charge, so use $E = Q/(K\varepsilon_0 A)$, not a fixed voltage.

15. State Kirchhoff's rules of current distribution in an electrical network. Using these rules determine the value of the current I_1 in the electric circuit given below. [3 marks]



Solution:

Concept:

- Kirchhoff's junction rule expresses conservation of charge: the sum of currents entering a junction equals the sum leaving it.
- Kirchhoff's loop rule expresses conservation of energy: the algebraic sum of potential changes around a closed loop is zero. A cell gives $+\mathcal{E}$ from negative to positive, and a resistor gives $-IR$ along its assumed current.

Step 1: State the rules and read the circuit The junction rule is $\sum I_{\text{in}} = \sum I_{\text{out}}$; the loop rule is $\sum \Delta V = 0$. In the printed circuit, I_1 goes upward at the left and through the top $20\,\Omega$ resistor toward the right. I_2 goes down the left and through the bottom branch toward the right. I_3 enters the left junction from the middle branch. The $40\,\text{V}$ cell is positive on its left, while the $80\,\text{V}$ cell is positive on its right.

Step 2: Apply the junction and upper-loop rules At the left junction,

$$I_3 = I_1 + I_2.$$

Traverse the upper loop from left to right through the top resistor and return from right to left through the middle branch. The cell provides a rise of $40\,\text{V}$, while both resistors provide drops along their assigned currents:

$$-20I_1 + 40 - 40I_3 = 0.$$

Thus $20I_1 + 40I_3 = 40$.

Step 3: Apply the outer-loop rule and solve Traverse the outer loop left to right through the bottom branch, then return right to left through the top branch. The bottom cell gives a rise and the top resistor is traversed opposite to I_1:

$$80 - 20I_2 + 20I_1 = 0, \qquad I_2 = I_1 + 4.$$

Quick Tip to Solve: Keep the printed current arrows while writing equations; a negative current gives the actual direction without changing the circuit midway.

Substitution in the junction rule gives $I_3 = 2I_1 + 4$. Using the upper-loop equation,

$$20I_1 + 40(2I_1 + 4) = 40,$$
$$100I_1 = -120.$$

The negative value means the actual current opposes the arrow in the paper. As a check, $I_2 = 2.8\,\text{A}$ and $I_3 = 1.6\,\text{A}$, and both the junction and loop equations are satisfied.

Step 4: Conclusion $\boxed{I_1 = -1.2\,\text{A}}$ relative to the printed arrow: its magnitude is $1.2\,\text{A}$, downward on the upper left wire and right to left through the upper resistor.

Quick Tip to Solve: Keep the printed current arrows while writing equations; a negative current gives the actual direction without changing the circuit midway.

16. Write the mathematical relation for the resistivity of a material in terms of relaxation time, number density and mass and charge of charge carriers in it. Explain, using this relation, why the resistivity of a metal increases and that of a semi-conductor decreases with rise in temperature. [3 marks]

Solution:

Concept:

- For charge carriers with number density n, mass m, charge magnitude q and mean relaxation time τ, the conductivity is $\sigma = nq^2\tau/m$ and resistivity is $\rho = 1/\sigma$.
- Relaxation time is the mean time between successive collisions of a carrier. Temperature affects both carrier density and scattering, so their combined effect determines resistivity.

Step 1: Obtain the resistivity relation In a field of magnitude E, a carrier has mean drift-speed magnitude $v_d = qE\tau/m$. Thus the current density is

$$J = nqv_d = \frac{nq^2\tau}{m}E.$$

Comparing with $J = \sigma E = E/\rho$,

$$\boxed{\rho = \frac{m}{nq^2\tau}}.$$

For electrons, $q = e$, the magnitude of electronic charge. The square makes the formula independent of the sign of the carriers.

Step 2: Explain the behaviour of a metal A metal already has many free conduction electrons. Over the ordinary temperature range its carrier density n changes very little, and m and e may be treated as fixed. As temperature rises, lattice ions vibrate more strongly. Electrons undergo more frequent scattering, reducing τ. Since $\rho \propto 1/\tau$ for nearly constant n, the resistivity increases.

Step 3: Explain the behaviour of a semiconductor Heating a semiconductor supplies energy that promotes electrons into the conduction band and produces holes in the valence band. The carrier density therefore increases markedly. Scattering also increases, so relaxation time and mobility tend to decrease; however, in the ordinary intrinsic-semiconductor regime the increase in carrier density

Quick Tip to Solve: Compare both n and τ: in a metal scattering dominates; in an intrinsic semiconductor thermal carrier generation dominates.

dominates this effect. The product $n\tau$ increases and the resistivity decreases. More generally, when both carrier types contribute, $\sigma = e(n\mu_e + p\mu_h)$, where n, p are electron and hole densities and μ_e, μ_h their mobilities. The rise in these densities explains the increase in conductivity.

Step 4: Conclusion $\rho = m/(nq^2\tau)$. Heating raises metallic resistivity mainly by reducing τ, while it lowers semiconductor resistivity mainly by greatly increasing the carrier density.

Quick Tip to Solve: Compare both n and τ: in a metal scattering dominates; in an intrinsic semiconductor thermal carrier generation dominates.

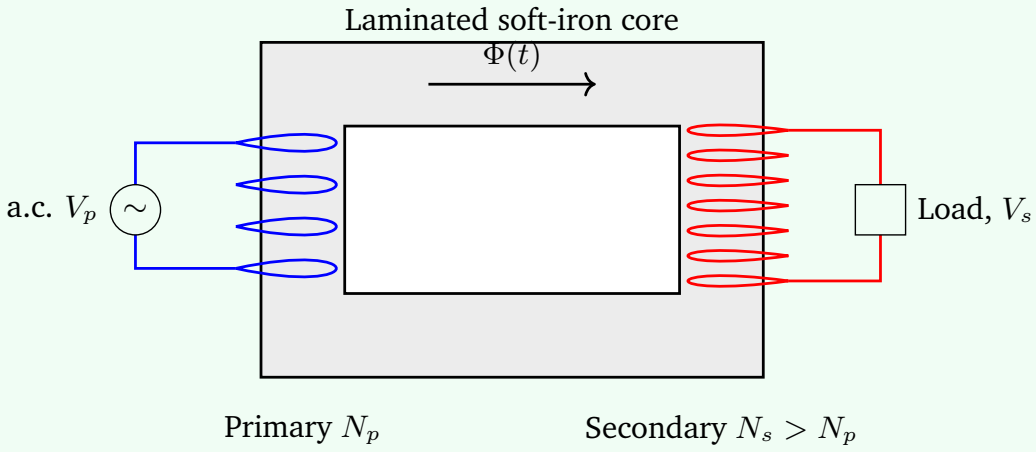
17. Explain with the help of a labelled diagram the underlying principle and working of a step-up transformer. Why cannot such a device be used to step up d.c. voltage? [3 marks]

Solution:

Concept:

- A transformer works on mutual induction: a changing magnetic flux produced by the primary coil induces an emf in a nearby secondary coil.
- 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 the turns and Φ is the common flux through each turn.

Step 1: Construction of a step-up transformer Two insulated coils are wound on a common laminated soft-iron core. The primary, with N_p turns, is connected to an a.c. supply; the secondary, with N_s turns, is connected to the load. For stepping up voltage, $N_s > N_p$. The closed iron core links nearly the same magnetic flux with both coils, while its laminations reduce eddy-current losses.



Step-up transformer: the secondary has more turns than the primary.

Step 2: Working and voltage ratio Alternating current in the primary produces an alternating magnetic flux in the core. This changing flux links the secondary and induces an alternating emf in it. Dividing the two Faraday-law expressions gives the ideal transformer relation

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} > 1.$$

Quick Tip to Solve: Start from the common changing flux: the coil with more turns has the greater induced voltage, but steady flux produces no emf.

Thus the secondary voltage exceeds the primary voltage. Energy is transferred magnetically, without a direct electrical connection between the windings. In an ideal transformer $V_pI_p = V_sI_s$, so the increase in voltage is accompanied by a decrease in current; the transformer does not create energy.

Step 3: Why a steady d.c. voltage cannot be stepped up With a steady d.c. supply, the primary current and core flux become constant after the switching transient. Consequently $d\Phi/dt = 0$, and no sustained secondary emf is induced. A brief emf may occur when the supply is switched on or off, but it is not continuous voltage transformation. Moreover, a d.c.-connected primary can draw a large current limited chiefly by winding resistance, causing overheating.

Step 4: Conclusion A step-up transformer uses mutual induction with $N_s > N_p$ to obtain $V_s > V_p$. It requires changing flux and therefore cannot step up steady d.c. voltage.

Quick Tip to Solve: Start from the common changing flux: the coil with more turns has the greater induced voltage, but steady flux produces no emf.

OR

17. Draw a labelled diagram of an a.c. generator. Explain briefly its principle and working. [3 marks]

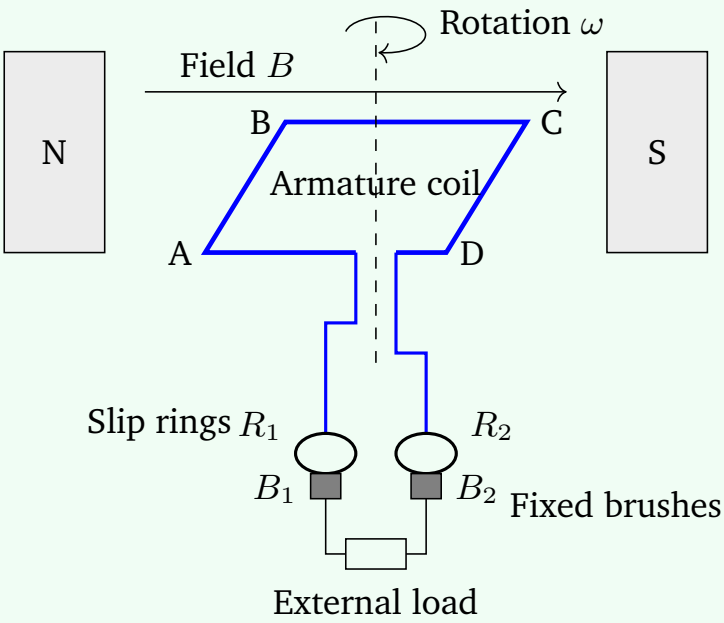
Solution:

Concept:

- An a.c. generator uses electromagnetic induction: an emf is induced when the magnetic flux linked with a coil changes.
- Faraday's law is $e = -d(N\Phi)/dt$, where N is the number of turns and Φ is the flux through one turn. The generator converts mechanical energy into electrical energy.

Step 1: Construction and labelled diagram A rectangular armature coil $ABCD$, with N turns and area A, rotates between the north and south poles of a magnet. Its two ends connect to separate slip rings R_1 and R_2, which rotate with the coil. Fixed carbon brushes B_1 and B_2 press against the rings and connect the armature to the external load. An external mechanical drive rotates the coil in the magnetic field.

Quick Tip to Solve: Distinguish the two complete slip rings of an a.c. generator from the split-ring commutator used to obtain a unidirectional output.



Schematic a.c. generator with rotating armature, two slip rings, fixed brushes and external load.

Step 2: Changing flux produces alternating emf Let the coil rotate with angular speed ω in a uniform field B. Choosing $t = 0$ when its area normal is parallel to the field, the angle between the normal and field is ωt. The flux linkage and induced emf are

$$N\Phi = NBA\cos(\omega t),$$
$$e = -\frac{d(N\Phi)}{dt} = NBA\omega\sin(\omega t) = e_0\sin(\omega t), \qquad e_0 = NBA\omega.$$

The flux changes as the coil rotates, so an emf appears across its ends. For a resistive load this emf drives an alternating current through the brushes and load.

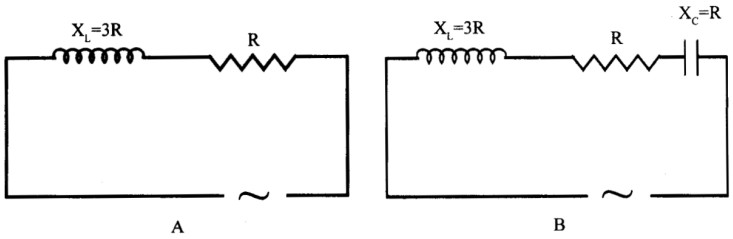
Step 3: Reversal after each half-turn After every half-revolution, the motion of each active side relative to the magnetic field reverses. Hence the induced emf changes polarity, and the current in the external circuit reverses. The slip rings maintain contact with the same respective coil ends throughout rotation, allowing this alternating polarity to reach the load. Unlike a split-ring commutator, they do not rectify the output.

Step 4: Conclusion Rotating a coil in a magnetic field changes its flux linkage and generates $e = e_0\sin(\omega t)$. The slip rings and brushes deliver this alternating emf to the external load.

Quick Tip to Solve: Distinguish the two complete slip rings of an a.c. generator from the split-ring commutator used to obtain a unidirectional output.

18. Given below are two electric circuits A and B.

Calculate the ratio of power factor of the circuit B to the power factor of circuit A. [3 marks]



Solution:

Concept:

- The power factor is $\cos\phi = R/Z$, where ϕ is the phase difference between applied voltage and current, R is the series resistance and Z is impedance.
- For a series circuit, $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Inductive and capacitive reactances oppose each other in the net reactive voltage.

Step 1: Read the reactances in the two printed circuits Circuit A has a resistor R and an inductor with $X_L = 3R$, with no capacitor. Circuit B has the same resistance and inductive reactance, together with a capacitor whose reactance is $X_C = R$. Both are series circuits. Thus the net reactance is $3R$ in A and $3R - R = 2R$ in B; the capacitor reduces the inductive phase difference.

Step 2: Calculate each impedance and power factor For circuit A,

$$Z_A = \sqrt{R^2 + (3R)^2} = \sqrt{10}R, \qquad \cos\phi_A = \frac{R}{\sqrt{10}R} = \frac{1}{\sqrt{10}}.$$

For circuit B,

$$Z_B = \sqrt{R^2 + (3R - R)^2} = \sqrt{5}R, \qquad \cos\phi_B = \frac{R}{\sqrt{5}R} = \frac{1}{\sqrt{5}}.$$

Resistance is positive, so it cancels in both expressions. The power factors are dimensionless and each is less than unity, as required for these reactive circuits.

Step 3: Form the requested ratio in the printed order The question asks for B relative to A. Therefore

$$\frac{\cos\phi_B}{\cos\phi_A} = \frac{1/\sqrt{5}}{1/\sqrt{10}} = \sqrt{\frac{10}{5}} = \sqrt{2}.$$

This ratio can exceed unity even though neither individual power factor exceeds unity: B has the larger power factor because its net reactance is smaller.

Step 4: Conclusion The ratio of the power factor of circuit B to that of circuit A is $\boxed{\sqrt{2} : 1}$.

Quick Tip to Solve: Subtract capacitive reactance from inductive reactance before calculating impedance; then keep the requested B-to-A order.

19. Define the term 'resolving power' of an astronomical telescope. How does it get affected on
(i) increasing the aperture of the objective lens?
(ii) increasing the wavelength of the light used?
Justify your answer in each case. [3 marks]

Solution:

Concept:

- Resolving power measures the ability to distinguish two closely spaced distant point sources as separate images. It is the reciprocal of their minimum resolvable angular separation.
- Rayleigh's criterion for a circular objective of diameter D gives $\theta_{\min} = 1.22\lambda/D$, where λ is the wavelength and the angle is measured in radians.

Step 1: Define the resolving power quantitatively An astronomical telescope resolves two distant stars if their diffraction images can just be distinguished. At the limiting separation, the central maximum of one diffraction pattern coincides with the first minimum of the other. Thus its resolving power is

$$\mathcal{R} = \frac{1}{\theta_{\min}} = \frac{D}{1.22\lambda}.$$

A larger resolving power means that the telescope can distinguish sources with a smaller angular separation. This concerns image detail, rather than merely the enlargement produced by the eyepiece.

Step 2: Increasing the objective aperture At fixed wavelength, $\mathcal{R} \propto D$ and $\theta_{\min} \propto 1/D$. Increasing the aperture, meaning the diameter of the objective, therefore increases the resolving power. A larger objective produces a narrower diffraction pattern, so images of closer stars overlap less and can be distinguished. For example, doubling D halves the limiting angular separation and doubles the resolving power. If aperture is expressed as area, increasing the area also increases D, with $D \propto \sqrt{\text{area}}$.

Step 3: Increasing the wavelength At fixed objective diameter, $\mathcal{R} \propto 1/\lambda$ and $\theta_{\min} \propto \lambda$. Increasing the wavelength therefore decreases the resolving power. Longer wavelengths spread more by diffraction, broadening the central image and requiring a larger angular separation for resolution. Doubling the wavelength doubles $\theta_{\min}$ and halves $\mathcal{R}$.

Step 4: Conclusion Resolving power is $\boxed{\mathcal{R} = 1/\theta_{\min} = D/(1.22\lambda)}$. It increases with objective aperture and decreases with wavelength, because these changes respectively narrow and broaden the diffraction pattern.

Quick Tip to Solve: Write the limiting angle first: a smaller $1.22\lambda/D$ always means better resolution and a larger resolving power.

20. Write any four characteristics of electromagnetic waves. Give two uses each of (i) Radio-waves (ii) Micro-waves. [3 marks]

Solution:

Concept:

- Electromagnetic waves consist of coupled, time-varying electric and magnetic fields that propagate through space.
- All electromagnetic waves obey $c = \nu\lambda$ in vacuum, where ν is frequency, λ is wavelength and c is the speed of light.

Step 1: State four characteristics (1) Electromagnetic waves are transverse: the electric field **E** and magnetic field **B** are perpendicular to one another and both are perpendicular to the direction of propagation.

(2) They do not need a material medium and can travel through vacuum, unlike mechanical waves such as sound.

(3) In vacuum, all electromagnetic waves travel at the same speed,

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \simeq 3.0 \times 10^8 \text{ m s}^{-1},$$

where μ_0 and ε_0 are the permeability and permittivity of free space.

(4) They transport energy and momentum. Consequently, an electromagnetic wave incident on a surface can exert radiation pressure by transferring momentum to it.

Step 2: Give two uses of radio waves (i) Radio waves carry signals in radio broadcasting, such as amplitude-modulated and frequency-modulated transmissions, from a transmitting antenna to receiving sets.

(ii) They carry television broadcast signals from transmitting stations to receiving antennas. The information is encoded by modulation of the wave; the carrier supplies the means of sending that information over a distance.

Step 3: Give two uses of microwaves (i) Microwaves are used in radar to locate objects and determine their distance by measuring the time between transmission and reception of a reflected pulse. Their short wavelength helps form directional beams.

(ii) They are used in microwave ovens to heat food. The alternating electric field transfers energy to polar molecules, particularly water molecules, and the absorbed energy produces heating.

Step 4: Conclusion Four characteristics are transverse fields, propagation without a material medium, the common vacuum speed c, and transport of energy and momentum. Radio waves serve radio and television broadcasting; microwaves serve radar and microwave cooking.

Quick Tip to Solve: Give four separate physical characteristics, then list exactly two concrete applications for each requested wave band.

21. In a plot of photoelectric current versus anode potential, how does

(i) the saturation current vary with anode potential for incident radiations of different frequencies but same intensity?

(ii) the stopping potential vary for incident radiations of different intensities but same frequency?

(iii) photoelectric current vary for different intensities but same frequency of incident radiations?

Justify your answer in each case. [3 marks]

Solution:

Concept:

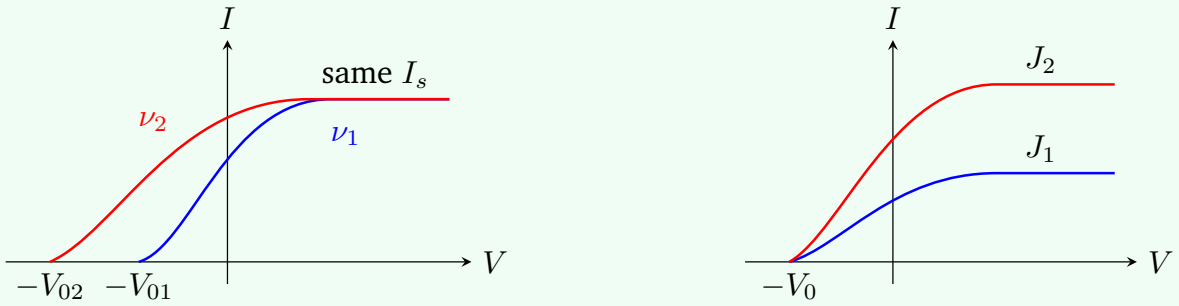
- Saturation occurs when all emitted photoelectrons are collected; increasing positive anode potential further cannot increase their collection rate.
- Einstein's equation is $eV_0 = h\nu - \phi$, where V_0 is the magnitude of stopping potential, e is electronic charge, ν is frequency and ϕ is the metal's work function.
- In the usual CBSE photoelectric-current model, intensity controls the rate of photoelectron emission, whereas frequency controls their maximum kinetic energy. Frequencies are assumed to exceed the threshold frequency.

Step 1: (i) Same intensity and different frequencies The saturation current is the same for the different incident frequencies at the same intensity. As the anode becomes positive, the current approaches this common maximum; after saturation it remains constant despite a further increase in anode potential. The emission rate is fixed by intensity in this model. A greater frequency increases maximum photoelectron energy and makes the stopping potential more negative, but does not raise the common saturation level.

Step 2: (ii) Same frequency and different intensities The stopping potential is unchanged because $V_0 = (h\nu - \phi)/e$. Neither incident intensity nor positive anode potential appears in this energy relation. Increasing intensity emits more electrons per second, but each electron still receives the energy of one photon of the same frequency. The largest kinetic energy, and hence the retarding potential required to stop even the fastest electrons, remain the same.

Step 3: (iii) Current at different intensities At a given collecting anode potential, greater incident intensity gives a larger photoelectric current because more photoelectrons are emitted and collected per second. In particular, the saturation current increases with intensity. For two intensities $J_2 > J_1$, the second curve lies above the first in the collecting region, but both meet the potential axis at the same stopping potential. At potentials at or below the stopping value, both currents are zero.

Quick Tip to Solve: Separate the two controls: intensity sets the current level, while frequency sets the stopping-potential intercept.



Left: equal saturation current for equal intensity, with $\nu_2 > \nu_1$. Right: higher intensity raises saturation current at the same stopping potential.

Step 4: Conclusion (i) The saturation current is the same and becomes independent of further anode-potential increase. (ii) The stopping potential is the same. (iii) Increasing intensity increases the photoelectric current and saturation current, without changing the stopping potential.

Quick Tip to Solve: Separate the two controls: intensity sets the current level, while frequency sets the stopping-potential intercept.

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22. Calculate the energy released during the α-decay of $^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$.

Given:

1. atomic mass of $^{238}_{92}\mathrm{U}$ = 238.05079 u

2. atomic mass of $^{234}_{90}\mathrm{Th}$ = 234.04363 u

3. atomic mass of $^{4}_{2}\mathrm{He}$ = 4.00260 u

$1\,\mathrm{u} = 931.5\,\mathrm{MeV}/c^2$.

Is this decay spontaneous? Give reason. [3 marks]

Solution:

Concept:

- The decay energy is the decrease in rest energy: $Q = (M_U - M_{Th} - M_{He})c^2$. The masses must be consistently atomic or nuclear.
- Atomic masses can be used here because the parent has 92 electrons and the product atoms together have $90 + 2 = 92$ electrons; their electron rest masses cancel.
- A positive Q-value means that the products have lower total rest energy and energy is released, making spontaneous decay energetically possible.

Step 1: Calculate the mass decrease The total mass of the product atoms is

$$M_{Th} + M_{He} = 234.04363 + 4.00260 = 238.04623\,\mathrm{u}.$$

Hence the decrease in mass is

$$\Delta M = 238.05079 - 238.04623 = 0.00456\,\mathrm{u}.$$

Quick Tip to Solve: Add the two product masses before subtracting from uranium; a positive difference gives a positive decay energy.

The mass number is conserved, since $238 = 234 + 4$, and the nuclear charge is conserved, since $92 = 90 + 2$. The small mass decrease does not violate conservation of energy: it is converted into the kinetic energy of the alpha particle and the recoiling thorium nucleus.

Step 2: Convert the mass decrease into released energy Using $1\,\text{u}\,c^2 = 931.5\,\text{MeV}$,

$$\begin{aligned} Q &= \Delta M c^2 \\ &= 0.00456 \times 931.5\,\text{MeV} \\ &= 4.24764\,\text{MeV} \simeq 4.25\,\text{MeV}. \end{aligned}$$

This is the total energy available to both decay products, not just the alpha particle's kinetic energy. No external energy input is required to supply a negative mass-energy balance.

Step 3: Decide whether the decay is spontaneous The parent atomic mass exceeds the sum of the product atomic masses, so $Q > 0$. Thus the decay is energetically allowed and is spontaneous. Its finite lifetime arises from alpha-particle tunnelling through the nuclear potential barrier; a positive released energy does not mean the nucleus must decay immediately.

Step 4: Conclusion The energy released is $\boxed{Q \simeq 4.25\,\text{MeV}}$. The decay is spontaneous because the products have smaller total rest mass and the Q-value is positive.

Quick Tip to Solve: Add the two product masses before subtracting from uranium; a positive difference gives a positive decay energy.

23. What is a digital signal? Explain the function of modem in data communication. Write two advantages of digital communication. [3 marks]

Solution:

Concept:

- Digital information is represented by discrete levels, usually binary states 0 and 1, rather than a continuously varying range of amplitudes.
- A modem is a modulator-demodulator. It adapts digital data to a transmission channel by modulation and recovers data by demodulation.

Step 1: Define a digital signal A digital signal is a signal that takes discrete values or levels. In a binary digital system, a low level represents 0 and a high level represents 1; sequences of these two states encode the information. For example, a sequence of voltage pulses can represent successive data bits. Unlike an analogue signal whose amplitude varies continuously with the message, a binary receiver identifies which of two permitted states each received pulse represents.

Step 2: Explain the modem's function At the transmitting end, the modem modulates a carrier according to the outgoing digital data, producing a signal suitable for transmission over a channel such as a conventional telephone line. The bits may control the carrier's amplitude, frequency or phase, depending on the modulation method. At the receiving end, a modem demodulates the received signal and recovers the original digital bit sequence for the computer or other data device. Thus its two complementary functions are modulation for transmission and demodulation for reception.

Quick Tip to Solve: Expand modem as modulator-demodulator, then link each half to the transmitter and receiver respectively.

Step 3: State two advantages of digital communication First, digital communication has greater immunity to noise: small unwanted changes in pulse amplitude need not change the detected 0 or 1. Repeaters can identify the bit states and regenerate clean pulses, reducing the accumulation of noise along the transmission path. Second, digital data permit error detection and correction by adding suitable redundant check bits. These methods allow the receiver to identify, and within the code's capability correct, corrupted data, improving reliable recovery of the message. Neither advantage implies that arbitrarily strong noise can never cause errors.

Step 4: Conclusion A digital signal uses discrete levels, usually 0 and 1. A modem modulates digital data for transmission and demodulates the received signal to recover data. Two advantages are improved noise immunity with pulse regeneration, and the use of error-detection and correction codes.

Quick Tip to Solve: Expand modem as modulator-demodulator, then link each half to the transmitter and receiver respectively.

24. Explain, with the help of a schematic diagram, the principle and working of a Light Emitting Diode. What criterion is kept in mind while choosing the semi-conductor material for such a device? Write two advantages of Light Emitting Diode over conventional incandescent lamps. [3 marks]

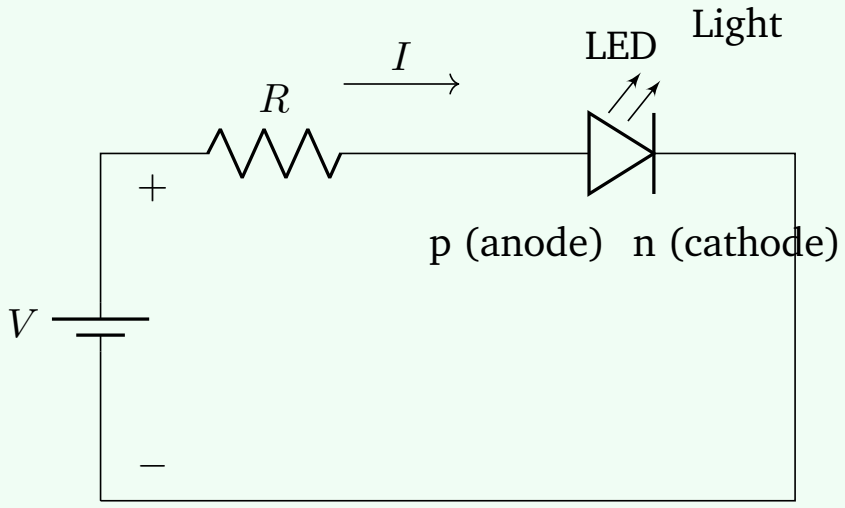
Solution:

Concept:

- An LED is a heavily doped p-n junction that emits light by radiative recombination when forward biased; this conversion of electrical energy into light is electroluminescence.
- An electron falling from the conduction band into a hole in the valence band releases energy approximately equal to the band gap: $h\nu \simeq E_g$, or $\lambda \simeq hc/E_g$.

Step 1: Forward bias and light emission Connect the p-region (anode) to the positive terminal and the n-region (cathode) to the negative terminal of a supply through a current-limiting resistor. Forward bias reduces the junction potential barrier. Electrons from the n-side and holes from the p-side are injected towards the junction. Their recombination near the junction releases energy as photons in a suitable semiconductor. A transparent window allows the light to emerge. The outgoing arrows in the schematic distinguish an LED from an ordinary junction diode.

Quick Tip to Solve: Show forward bias and two arrows pointing away from the diode; relate the chosen colour to $E_g = hc/\lambda$.



LED connected in forward bias through a current-limiting resistor.

Step 2: Choose the semiconductor material Choose a direct-band-gap semiconductor so that electron-hole recombination efficiently produces photons. Its band gap must correspond to the desired emission wavelength. For visible light, the band gap is approximately 1.8–3.1 eV. Compound semiconductors such as GaAsP can be used. Silicon and germanium are inefficient light emitters because most recombination energy becomes heat rather than visible photons.

Step 3: Two advantages over an incandescent lamp First, LEDs consume much less electrical power for a given useful light output because light is produced directly by recombination, without heating a filament to a high temperature. Second, they have a much longer working life because there is no hot filament to burn out; their solid-state construction also makes them robust.

Step 4: Conclusion A forward-biased LED emits photons by electron-hole recombination. Use a semiconductor with efficient radiative recombination and a band gap appropriate to the required colour. Low power consumption and long operating life are two advantages over incandescent lamps.

Quick Tip to Solve: Show forward bias and two arrows pointing away from the diode; relate the chosen colour to $E_g = hc/\lambda$.

Section D (15 marks)

25. Draw a labelled diagram of a moving coil galvanometer. State the principle on which it works. Deduce an expression for the torque acting on a rectangular current carrying loop kept in a uniform magnetic field. Write two factors on which the current sensitivity of a moving coil galvanometer depends. [5 marks]

Solution:

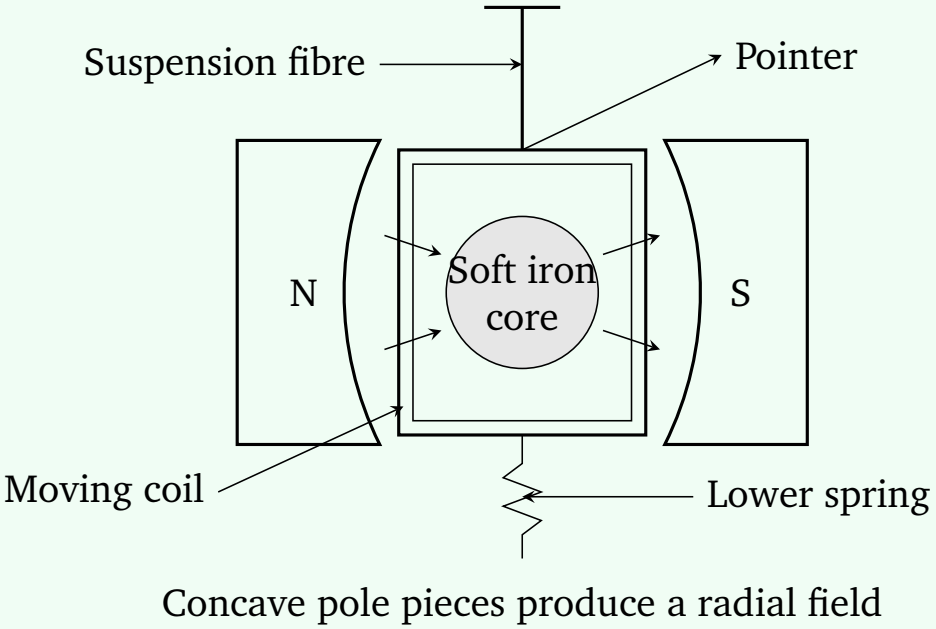
Concept:

- A current-carrying conductor in a magnetic field experiences $\vec{F} = I\vec{l} \times \vec{B}$. The forces on opposite sides of a loop can form a couple.

Quick Tip to Solve: Define θ as the angle between the coil normal and the field; the radial field makes this angle $90°$.

- A coil of N turns and area A has magnetic moment $\vec{m} = NIA\hat{n}$. Its magnetic torque is $\vec{\tau} = \vec{m} \times \vec{B}$.
- In a moving coil galvanometer a radial field keeps the coil's normal perpendicular to the field. At equilibrium the magnetic torque is balanced by restoring torque $k\phi$, where k is the torsional constant and ϕ the deflection.

Step 1: Construction and operating principle A light rectangular coil with many turns is suspended by a fine torsion fibre between concave pole pieces of a strong permanent magnet. A cylindrical soft iron core makes the field strong and radial. A lower spring provides the return current path and restoring torque; a pointer or mirror indicates the angular deflection. The core is fixed while the coil rotates around it. The instrument works because a current-carrying coil in a magnetic field experiences a torque. Larger current produces a larger equilibrium deflection.



Schematic of the moving coil galvanometer; the coil rotates around the fixed soft iron core.

Step 2: Forces on a rectangular loop Consider a single rectangular loop of length l, breadth b, and area $A = lb$. Let its normal make angle θ with a uniform field $\vec{B}$. Choose the two sides of length l perpendicular to the field. Each experiences force $F = BIl$. The forces are equal, opposite, and parallel, but act along different lines, so they form a couple. The perpendicular separation of these lines is $b\sin\theta$. The forces on the other pair of sides cancel and give no torque about the chosen rotation axis.

Step 3: Derive the torque and apply the radial field The torque of the couple is force multiplied by its perpendicular arm:

$$\tau = F(b\sin\theta) = BIlb\sin\theta = BIA\sin\theta.$$

For N turns, the torques add, giving

$$\tau = NBIA\sin\theta, \qquad \vec{\tau} = \vec{m} \times \vec{B}.$$

The torque tends to align the magnetic moment with the field. In the radial field of the galvanometer,

Quick Tip to Solve: Define θ as the angle between the coil normal and the field; the radial field makes this angle $90°$.

the field lies in the coil's plane for every permitted deflection, so $\theta = 90^\circ$ and $\tau = NBIA$. The torsion fibre and spring exert an opposing restoring torque $k\phi$. At equilibrium,

$$NBIA = k\phi, \qquad \phi = \frac{NBA}{k} I.$$

Thus the deflection is directly proportional to current, allowing a uniformly calibrated scale.

Step 4: State two factors affecting current sensitivity Current sensitivity is deflection per unit current:

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

Two factors are the number of turns N and the torsional constant k: sensitivity increases when N increases and when k decreases. For completeness, increasing the coil area A or magnetic field B also increases sensitivity. The angle is measured in radians, so its unit is $\text{rad}\,\text{A}^{-1}$.

Step 5: Conclusion The moving coil galvanometer uses magnetic torque on a current-carrying coil. A rectangular N-turn loop has $\tau = NBIA\sin\theta$. In the radial field, $\phi/I = NBA/k$; increasing the number of turns or reducing the torsional constant increases current sensitivity.

Quick Tip to Solve: Define θ as the angle between the coil normal and the field; the radial field makes this angle 90°.

OR

25. State Biot-Savart law. Use it to derive an expression for the magnetic field at the centre of a circular loop of radius R carrying a steady current I. Sketch the magnetic field lines for such a current carrying loop. [5 marks]

Solution:

Concept:

- Biot-Savart law gives the field due to a small current element: $d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\, d\boldsymbol{\ell} \times \hat{\mathbf{r}}}{r^2}$. Here $d\boldsymbol{\ell}$ points along the current, $\mathbf{r}$ points from the element to the observation point, and μ_0 is the permeability of free space.
- In magnitude, $dB = \frac{\mu_0}{4\pi}\frac{I\, d\ell \sin\theta}{r^2}$, where θ is the angle between the current element and its displacement to the observation point. Fields from all elements add vectorially.
- The right-hand rule fixes the field direction: curl the fingers along the loop current; the thumb points along the field through the loop centre. Magnetic field lines are continuous closed curves.

Step 1: State the law and identify the geometry Biot-Savart law states that the magnetic field of a small steady-current element is directly proportional to its current, its length and the sine of the angle between the element and the displacement to the observation point, and inversely proportional to the square of their separation. Its direction is perpendicular to the plane containing these two vectors, as given by their cross product. For a circular loop of radius R, choose its centre O as the observation point. Every element is at distance R from O; its tangent is perpendicular to the inward radius. Hence

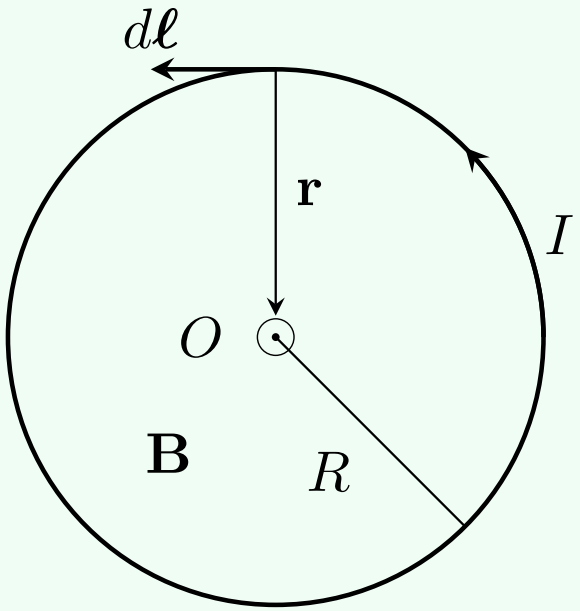
Quick Tip to Solve: At the centre, every tangent is perpendicular to its radius and every field contribution has the same direction; replace the line integral immediately by the circumference $2\pi R$.

$r = R$, $\theta = 90^\circ$, and $\sin\theta = 1$.

Step 2: Add the fields of the complete circular loop For every current element, the field at O is normal to the loop plane and has the same sense. Thus the contributions reinforce one another and their magnitudes can be integrated directly:

$$dB = \frac{\mu_0 I}{4\pi R^2}\, d\ell,$$
$$B = \frac{\mu_0 I}{4\pi R^2} \oint d\ell = \frac{\mu_0 I}{4\pi R^2}(2\pi R).$$

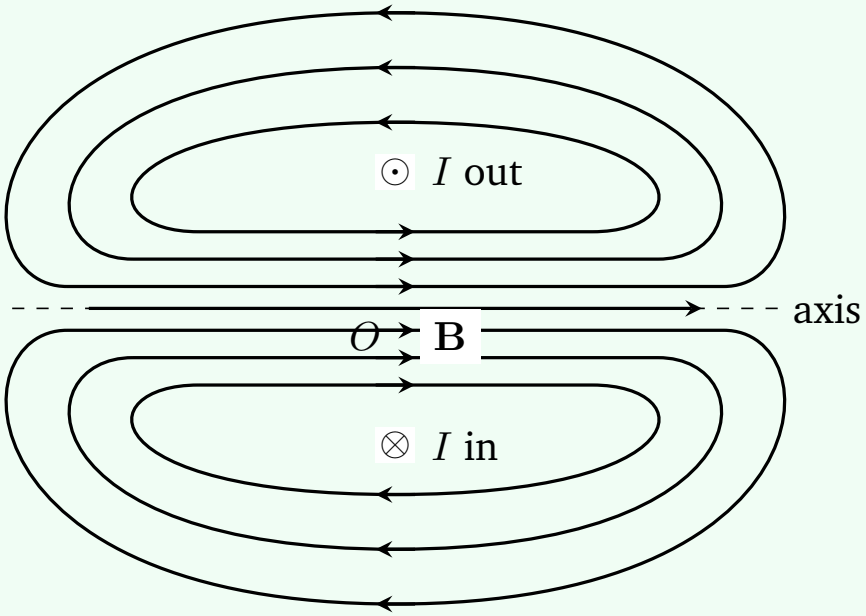
The integral is the circumference of the loop, not its area. For an anticlockwise current as viewed on the page, the central field is out of the page; reversing the current reverses the field. The following plan view shows the element, radius and field direction used in the derivation.



Plan view of the loop: anticlockwise current gives field out of the page at O.

Step 3: Sketch and explain the magnetic field lines The second sketch is a section through the loop axis. The upper dot represents current out of the page and the lower cross represents current into the page. With this current sense the field through the centre points to the right. The lines pass through the loop interior and curve back outside it, forming closed curves, as for a magnetic dipole. Near the centre the lines are nearly straight and parallel; their field direction is perpendicular to the plane of the circular loop. Outside the loop the return direction is opposite to the central direction. The sketch represents selected lines in one section of the three-dimensional field, so lines must not terminate on the wire or intersect each other.

Quick Tip to Solve: At the centre, every tangent is perpendicular to its radius and every field contribution has the same direction; replace the line integral immediately by the circumference $2\pi R$.



Axial section of the circular loop showing closed magnetic field lines.

Step 4: Conclusion The magnetic field at the centre of a single circular current loop is $\boxed{B = \frac{\mu_0 I}{2R}}$, directed along its axis according to the right-hand rule. Its field lines form closed curves passing through the loop and returning outside.

Quick Tip to Solve: At the centre, every tangent is perpendicular to its radius and every field contribution has the same direction; replace the line integral immediately by the circumference $2\pi R$.

26. What are coherent sources? Why are coherent sources required to produce interference of light? Give an example of interference of light in everyday life.

In Young's double slit experiment, the two slits are 0.03 cm apart and the screen is placed at a distance of 1.5 m away from the slits. The distance between the central bright fringe and fourth bright fringe is 1 cm. Calculate the wavelength of light used. [5 marks]

Solution:

Concept:

- Coherent sources emit waves of the same frequency with a constant phase difference. Coherence concerns the relative phase, not merely equal brightness.
- For two overlapping waves, intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$, where ϕ is their phase difference at the observation point.
- In Young's experiment, the bright-fringe position is $y_n = n\lambda D/d$, where n is the fringe order, d is slit separation and D is screen distance.

Step 1: Define coherent sources Two sources are coherent when they produce light of the same frequency and maintain a constant phase difference with time. They need not have zero phase difference or equal amplitudes. In practice, two coherent beams are obtained by splitting light from a

Quick Tip to Solve: Count bright fringes from the central fringe as order zero: central-to-fourth distance equals four fringe widths.

common source; in Young's arrangement, a single primary source illuminates both narrow slits.

Step 2: Explain why coherence is necessary Interference results from superposition. At a fixed point, a constant relative phase makes the interference term $2\sqrt{I_1 I_2}\cos\phi$ steady. Thus constructive and destructive interference occur at fixed positions and a stable pattern of bright and dark fringes is observable. Independent ordinary light sources have rapidly fluctuating relative phase: during the observation time the interference term averages to zero, giving $\langle I\rangle = I_1 + I_2$. Hence they do not produce a sustained visible fringe pattern.

Step 3: Give an everyday example The coloured bands seen on a thin soap bubble are an everyday example. Light reflected from the front and back surfaces of the thin film interferes. Different wavelengths reinforce at different film thicknesses and viewing angles, producing the observed colours.

Step 4: Identify the fourth bright fringe and convert units The central bright fringe has order $n = 0$, so the fourth bright fringe on either side has order $n = 4$. The given distance is therefore $y_4 = 4\beta$, not one fringe width. In SI units,

$$d = 0.03\,\text{cm} = 3.0 \times 10^{-4}\,\text{m}, \quad D = 1.5\,\text{m}, \quad y_4 = 1.0 \times 10^{-2}\,\text{m}.$$

The fringe spacing is $\beta = y_4/4 = 2.5 \times 10^{-3}\,\text{m}$.

Step 5: Calculate the wavelength Using the small-angle Young's fringe relation,

$$\begin{aligned} y_4 &= \frac{4\lambda D}{d}, \\ \lambda &= \frac{y_4 d}{4D} \\ &= \frac{(1.0 \times 10^{-2})(3.0 \times 10^{-4})}{4(1.5)}\,\text{m} \\ &= 5.0 \times 10^{-7}\,\text{m}. \end{aligned}$$

Here $D \gg d$ and the fringe displacement is small compared with D, consistent with the approximation.

Step 6: Conclusion Coherent sources have the same frequency and a constant phase difference; they give a stable interference pattern. Soap-bubble colours illustrate interference. The wavelength used is $\boxed{\lambda = 5.0 \times 10^{-7}\,\text{m} = 500\,\text{nm}}$.

Quick Tip to Solve: Count bright fringes from the central fringe as order zero: central-to-fourth distance equals four fringe widths.

OR

26. State the condition under which the phenomenon of diffraction of light takes place. Derive an expression for the width of central maximum due to diffraction of light at a single slit.

A slit of width 'a' is illuminated by a monochromatic light of wavelength 700 nm at normal incidence. Calculate the value of 'a' for position of

(i) first minimum at an angle of diffraction of 30°.

(ii) first maximum at an angle of diffraction of 30°. [5 marks]

Solution:

Concept:

- Diffraction is the spreading of light into the geometrical shadow of an aperture or obstacle; it becomes appreciable when its size is comparable with the wavelength.
- For a single slit of width a, light from its different parts interferes. Minima occur when $a\sin\theta = m\lambda$, with nonzero integer m.
- The central maximum lies between the first minima on both sides. For a distant screen, its linear width is approximately $2D\lambda/a$. Secondary maxima approximately lie halfway between successive minima.

Step 1: State the condition for observable diffraction Diffraction occurs when light passes through an aperture or around an obstacle. Its spreading is appreciable when the aperture width or obstacle dimension is of the order of the wavelength of light. If the slit width is much greater than the wavelength, the diffraction angles are very small. Consider monochromatic light normally incident on a slit of width a, with the pattern observed on a distant screen at distance D.

Step 2: Derive the first minima by pairing the slit halves At an observation angle θ, the path difference between light from the two extreme edges of the slit is $a\sin\theta$. Divide the slit into two equal halves and pair each point in one half with the corresponding point in the other. Each pair has path difference $(a/2)\sin\theta$. When this equals $\lambda/2$, each pair cancels, giving the first minimum:

$$a\sin\theta_1 = \lambda.$$

An identical minimum occurs at $-\theta_1$. At $\theta = 0$, all contributions have equal phase and form the central maximum.

Step 3: Obtain the central maximum width The angular separation of the first minima is $2\theta_1$, so the exact angular width is

$$\Delta\theta = 2\sin^{-1}(\lambda/a).$$

For small diffraction angles, $\sin\theta_1 \simeq \theta_1 \simeq \tan\theta_1$, giving $\Delta\theta \simeq 2\lambda/a$. Each first minimum is at screen distance $y_1 = D\tan\theta_1 \simeq D\lambda/a$ from the centre. Thus the full linear width is

$$W = 2y_1 \simeq \frac{2D\lambda}{a}.$$

Without the small-angle approximation the width on a plane screen is $2D\tan[\sin^{-1}(\lambda/a)]$.

Step 4: Calculate slit width for the first minimum For part (i), use the exact minimum condition at

Quick Tip to Solve: For the first minimum use one wavelength across the slit; for the first secondary maximum use approximately three half-wavelengths.

30°. With $\lambda = 700\,\text{nm} = 700 \times 10^{-9}\,\text{m}$,

$$a = \frac{\lambda}{\sin 30^\circ} = \frac{700 \times 10^{-9}}{1/2}\,\text{m} = 1.4 \times 10^{-6}\,\text{m}.$$

A small-angle replacement is unnecessary here.

Step 5: Calculate slit width for the first secondary maximum For part (ii), the first maximum away from the central maximum is the first secondary maximum. The school-level approximate condition is $a \sin\theta \simeq 3\lambda/2$: the maximum lies approximately between the first and second minima. Hence

$$a \simeq \frac{3\lambda}{2\sin 30^\circ} = \frac{3(700 \times 10^{-9})}{2(1/2)}\,\text{m} = 2.1 \times 10^{-6}\,\text{m}.$$

This is an approximate maximum condition, unlike the exact minimum condition. More precisely, the single-slit intensity is proportional to $(\sin u/u)^2$, where $u = \pi a \sin\theta/\lambda$. Its first secondary maximum obeys $\tan u = u$, with $u \simeq 4.493$, giving $a \simeq 2.00 \times 10^{-6}\,\text{m}$. The usual CBSE approximation gives the stated $2.1\,\mu$m result.

Step 6: Conclusion The central maximum has small-angle width $\boxed{W = 2D\lambda/a}$ and angular width $\boxed{2\lambda/a}$. At 30°, the slit width is $\boxed{1.4 \times 10^{-6}\,\text{m}}$ for the first minimum and approximately $\boxed{2.1 \times 10^{-6}\,\text{m}}$ for the first secondary maximum, using the standard school-level maximum condition.

Quick Tip to Solve: For the first minimum use one wavelength across the slit; for the first secondary maximum use approximately three half-wavelengths.

27. State the principle of working of p-n diode as a rectifier. Explain, with the help of a circuit diagram, the use of p-n diode as a full wave rectifier. Draw a sketch of the input and output waveforms.

[5 marks]

Solution:

Concept:

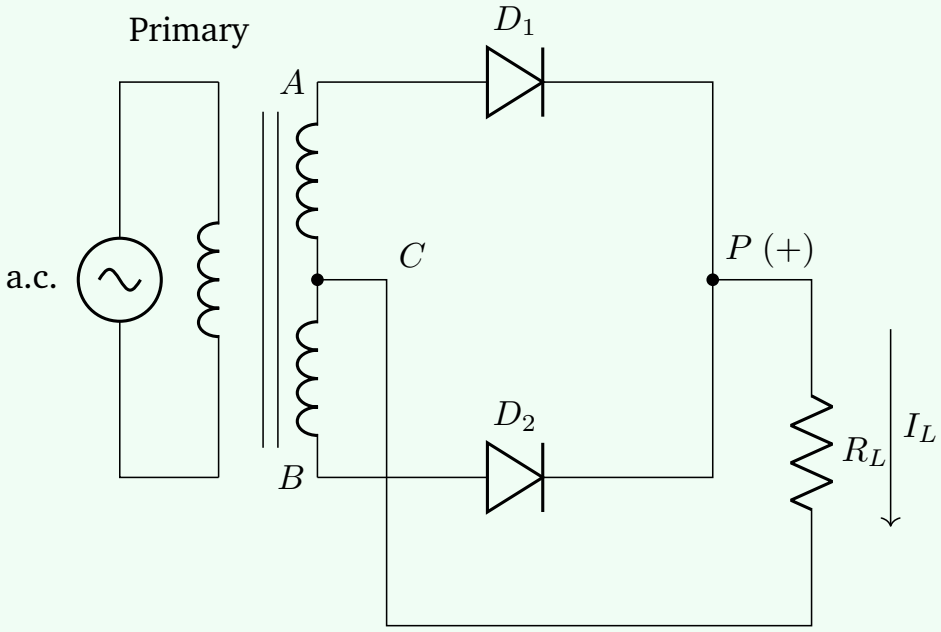
- A p-n junction diode conducts readily when forward biased and offers very high resistance when reverse biased. This asymmetric conduction allows it to rectify an alternating current.
- In a centre-tapped full-wave rectifier, two diodes conduct alternately, but the current through the load resistance R_L always flows in the same direction.
- For ideal diodes and a sinusoidal voltage across either half-secondary, the load voltage is $v_o = V_m|\sin\omega t|$. Its ripple frequency is $2f$, where f is the input frequency.

Step 1: Principle of rectification Forward bias reduces the depletion-layer barrier, so a diode permits a substantial current from its anode to its cathode. Reverse bias increases the barrier and the diode blocks current apart from a negligible leakage current. Therefore an alternating voltage can be converted into a unidirectional, pulsating voltage. Rectification alone does not give a perfectly steady direct voltage.

Step 2: Circuit of the full-wave rectifier Connect the alternating supply to the primary of a transformer

Quick Tip to Solve: Trace each conducting diode's path separately and check that both paths cross the load from its positive end to the centre tap.

having a centre-tapped secondary. Let its ends be A and B, and its centre tap be C. Connect the anodes of diodes D_1 and D_2 to A and B, respectively. Join their cathodes at P, and connect the load R_L between P and C. The two half-secondary voltages, measured relative to C, have equal magnitudes and opposite polarities. The circuit below shows the secondary and the diodes; the primary is driven by the a.c. input.



Centre-tapped full-wave rectifier; the transformer primary receives the a.c. input.

Step 3: Conduction during the first half-cycle When A is positive relative to C, B is negative relative to C. Diode D_1 is forward biased and D_2 is reverse biased. Current flows along $A \to D_1 \to P \to R_L \to C$, and returns through the upper half-secondary. Thus the upper end of the load is positive and the load current flows from P to C.

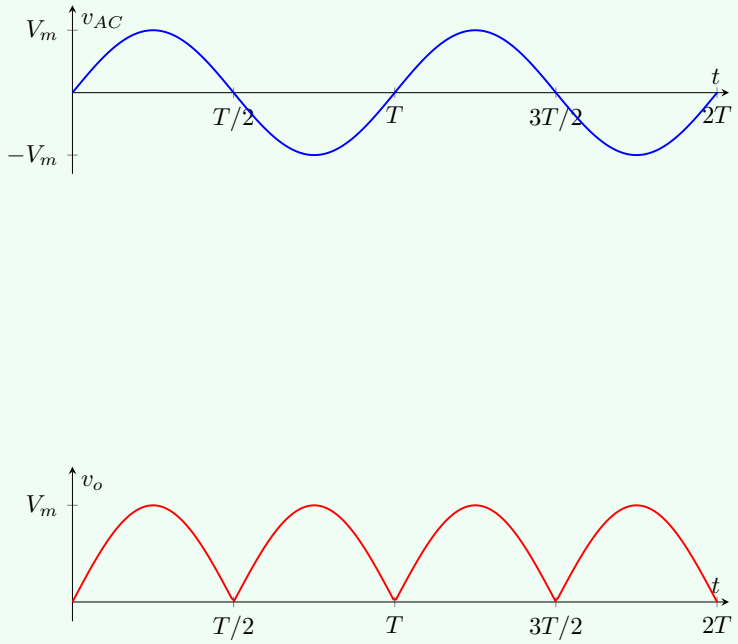
Step 4: Conduction during the second half-cycle When the supply reverses, B becomes positive and A negative relative to C. Now D_2 conducts and D_1 blocks. Current follows $B \to D_2 \to P \to R_L \to C$, returning through the lower half-secondary. Its direction through the load is again from P to C. Consequently both half-cycles contribute to the output.

Step 5: Input and output waveforms The input voltage alternates above and below zero. The output consists of successive positive half-sine pulses: the negative input half-cycle is reproduced as a positive load-voltage pulse by the second diode. Neglecting diode drops,

$$v_{AC} = V_m \sin \omega t, \qquad v_o = V_m |\sin \omega t|.$$

There are two output pulses per input cycle, so the output ripple frequency is twice the input frequency. A smoothing filter would be needed to obtain a nearly constant direct voltage; it is not part of the basic rectifier drawn here.

Quick Tip to Solve: Trace each conducting diode's path separately and check that both paths cross the load from its positive end to the centre tap.



Sinusoidal input and full-wave rectified output (ideal diodes).

Step 6: Conclusion A diode rectifies by conducting in forward bias and blocking in reverse bias. In the centre-tapped full-wave circuit, D_1 and D_2 conduct on alternate half-cycles and give a unidirectional pulsating load voltage during both halves of each cycle.

Quick Tip to Solve: Trace each conducting diode's path separately and check that both paths cross the load from its positive end to the centre tap.

OR

27. Draw the symbolic representation of a (i) p-n-p, (ii) n-p-n transistor. Why is the base region of a transistor thin and lightly doped? With a circuit diagram, show the biasing of a p-n-p transistor in common base configuration. Explain the movement of charge carriers through different parts of the transistor in such a configuration and show that $I_e = I_b + I_c$. [5 marks]

Solution:

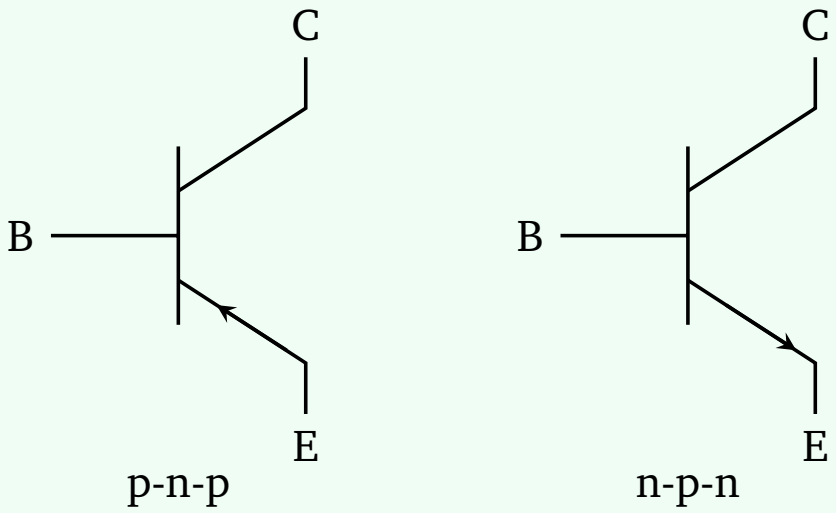
Concept:

- A transistor has emitter (E), base (B), and collector (C). The emitter arrow gives the direction of conventional current: inward for p-n-p and outward for n-p-n.
- In active operation, the emitter-base junction is forward biased and the collector-base junction is reverse biased. A p-n-p transistor conducts mainly by holes.
- A thin, lightly doped base permits most injected carriers to reach the collector. Conservation of charge relates the terminal currents.

Step 1: Symbols of the two transistors The symbols below label all three terminals. The arrow is always on the emitter lead. In the p-n-p symbol it points towards the base; in the n-p-n symbol it

Quick Tip to Solve: For p-n-p active bias, remember the potential order $V_E > V_B > V_C$; then check that conventional emitter current enters and both other currents leave.

points away from the base. It represents conventional current, not necessarily the direction of electron motion. The collector lead has no arrow. Thus the emitter arrow distinguishes the two types even when their terminal layout is identical.

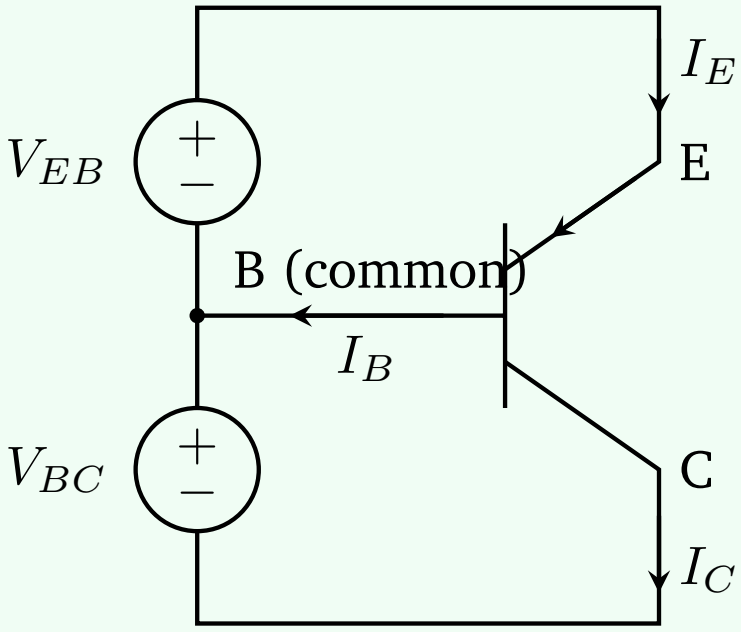


Transistor symbols with emitter arrows.

Step 2: Why the base is thin and lightly doped The emitter injects majority carriers into the base. In a p-n-p transistor these carriers are holes, which become minority carriers in the n-type base. A thin base gives them a short distance to travel, while light doping gives relatively few electrons with which they can recombine. Consequently only a small fraction of injected holes recombines in the base, producing a small base current. Most holes cross the base and are collected by the collector. This is essential for transistor action and for a collector current nearly equal to the emitter current.

Step 3: Common-base bias circuit for a p-n-p transistor The base is the terminal common to the input emitter-base circuit and the output collector-base circuit. The circuit below shows two d.c. supplies with their polarities labelled explicitly. The emitter is positive relative to the base, so the p-emitter/n-base junction is forward biased. The collector is negative relative to the base, so the p-collector/n-base junction is reverse biased. With the base chosen as zero potential, the required ordering is $V_E > V_B > V_C$. The magnitudes of the supplies need not be equal.

Quick Tip to Solve: For p-n-p active bias, remember the potential order $V_E > V_B > V_C$; then check that conventional emitter current enters and both other currents leave.



Common-base p-n-p circuit: emitter positive and collector negative relative to the common base.

Step 4: Motion of carriers and the current relation Forward bias reduces the emitter-base barrier and injects holes from the heavily doped p-type emitter into the n-type base. A much smaller electron flow occurs from base to emitter. Within the thin base, a few injected holes recombine with electrons. Electrons supplied through the base connection replace those lost in recombination; the corresponding conventional base current flows out of the base of a p-n-p transistor. Most holes diffuse across the base and reach the collector-base depletion region. Its reverse-bias electric field sweeps them into the p-type collector, giving the collector current flowing out of the collector.

At steady state there is no accumulation of charge in the transistor. During a time interval Δt, the charge entering through the emitter equals the charges leaving through the base and collector:

$$I_E \Delta t = I_B \Delta t + I_C \Delta t.$$

Dividing by Δt gives $I_E = I_B + I_C$, where the currents denote positive magnitudes in the directions indicated. Since base recombination is small, $I_B \ll I_E$ and I_C is nearly equal to I_E.

Step 5: Conclusion The p-n-p emitter arrow points inward and the n-p-n emitter arrow outward. A thin, lightly doped base minimizes recombination. In the p-n-p common-base circuit the emitter-base junction is forward biased and the collector-base junction reverse biased; conservation of charge gives $\boxed{I_E = I_B + I_C}$.

Quick Tip to Solve: For p-n-p active bias, remember the potential order $V_E > V_B > V_C$; then check that conventional emitter current enters and both other currents leave.