CBSE Class 12 Physics Question Paper 2012 with Solution PDF-Delhi Set 1

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 are **30** questions in total. Questions **1 to 8** are very short answer type questions and carry **one** mark each.

(iii) Questions **9 to 18** carry **two** marks each, questions **19 to 27** carry **three** marks each and questions **28 to 30** carry **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 three questions of five marks each. You have to attempt only one of the choices in such questions.

(v) Use of calculators is **not** permitted. However, you may use log tables if necessary.

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

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

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

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

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

$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$

$m_e = 9.1 \times 10^{-31} \text{ kg}$

1. Two wires of equal length, one of copper and the other of manganin have the same resistance. Which wire is thicker? [1 mark]

Solution:

Concept:

- Resistance of a uniform wire is $R = \rho L/A$, where ρ is resistivity, L is length and A is cross-sectional area.
- Manganin has a higher resistivity than copper at the same temperature.

Step 1: Use the equal resistance and length For the two wires, $R_{\mathrm{m}} = R_{\mathrm{Cu}}$ and their lengths are equal. Thus

$$\frac{\rho_{\mathrm{m}}}{A_{\mathrm{m}}} = \frac{\rho_{\mathrm{Cu}}}{A_{\mathrm{Cu}}}, \qquad \frac{A_{\mathrm{m}}}{A_{\mathrm{Cu}}} = \frac{\rho_{\mathrm{m}}}{\rho_{\mathrm{Cu}}}.$$

Step 2: Compare their thickness Since $\rho_{\mathrm{m}} > \rho_{\mathrm{Cu}}$, the required area of manganin is larger. For a circular wire, $A = \pi d^2/4$, so a larger area means a larger diameter. A thin manganin wire of the same length would otherwise have a greater resistance.

Step 3: Conclusion The **manganin wire is thicker**, because its higher resistivity requires a greater cross-sectional area for the same resistance.

Quick Tip to Solve: When length and resistance are fixed, compare areas directly using $A \propto \rho$.

2. What are the directions of electric and magnetic field vectors relative to each other and relative to the direction of propagation of electromagnetic waves? [1 mark]

Solution:

Concept:

- An electromagnetic wave is transverse: its electric field $\mathbf{E}$ and magnetic field $\mathbf{B}$ are perpendicular to the direction of propagation.
- The propagation direction is given by $\mathbf{E} \times \mathbf{B}$, consistent with the direction of energy flow.

Step 1: Compare the two field vectors The electric and magnetic field vectors are mutually perpendicular: $\mathbf{E} \perp \mathbf{B}$. Their oscillations occur in two perpendicular planes and are in phase for a travelling electromagnetic wave.

Step 2: Relate the fields to propagation If the wave travels along the x-axis, one possible orientation is $\mathbf{E}$ along the y-axis and $\mathbf{B}$ along the z-axis. Both field vectors are perpendicular to the x-axis; the right-hand rule for $\mathbf{E} \times \mathbf{B}$ gives the wave direction.

Step 3: Conclusion $\mathbf{E}$ and $\mathbf{B}$ are **perpendicular to each other**, and **both are perpendicular to the direction of propagation**.

Quick Tip to Solve: Use a right-handed set of three axes: electric field, magnetic field, propagation.

3. How does the angular separation between fringes in single-slit diffraction experiment change when the distance of separation between the slit and screen is doubled? [1 mark]

Solution:

Concept:

- For slit width a and wavelength λ, diffraction minima obey $a \sin\theta_n = n\lambda$, where $n = 1, 2, \ldots$.
- In the small-angle limit, adjacent minima have angular separation approximately λ/a.

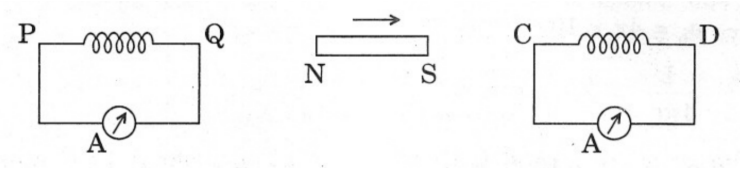
Step 1: Identify what fixes the angular pattern The slit width and wavelength determine each angular position through $\sin\theta_n = n\lambda/a$. The distance D between slit and screen does not appear in this equation, so moving the screen does not change the angular positions.

Step 2: Distinguish linear and angular separation On a distant screen, the linear separation is approximately $\Delta y = D\lambda/a$. Doubling D doubles Δy, but the angular separation is $\Delta\theta \simeq \Delta y/D = \lambda/a$. The increase in linear spacing is exactly compensated by the greater screen distance.

Step 3: Conclusion The angular separation **remains unchanged** when the slit-screen distance is doubled.

Quick Tip to Solve: Check whether the question asks for angular or linear spacing; only linear spacing depends on D.

4. A bar magnet is moved in the direction indicated by the arrow between two coils PQ and CD. Predict the directions of induced current in each coil. [1 mark]



Solution:

Concept:

- Lenz's law: an induced current creates a magnetic field that opposes the change in magnetic flux through the coil.
- A coil face is south when its current is clockwise as viewed from that face; it is north when the current is anticlockwise.

Step 1: Determine the polarity of the face of PQ The north pole of the magnet moves away from coil PQ. Coil PQ opposes this recession by attracting the departing north pole. Its face towards the magnet must therefore behave as a south pole. Viewed from the magnet looking towards PQ, the current is clockwise.

Step 2: Determine the polarity of the face of CD The south pole of the magnet approaches coil CD. Coil CD opposes this approach by repelling the incoming south pole. Its face towards the magnet must also behave as a south pole. Viewed from the magnet looking towards CD, the current is clockwise. The viewing directions for the two coils are opposite, since the magnet lies between them.

Step 3: Conclusion In **both coils the induced current is clockwise when each coil is viewed from**

Quick Tip to Solve: First decide whether the nearby pole approaches or recedes; then choose repulsion or attraction.

the magnet; the two faces towards the magnet become south poles.

Quick Tip to Solve: First decide whether the nearby pole approaches or recedes; then choose repulsion or attraction.

5. For the same value of angle of incidence, the angles of refraction in three media A, B and C are 15°, 25° and 35° respectively. In which medium would the velocity of light be minimum? [1 mark]

Solution:

Concept:

- Snell's law gives $n_0 \sin i = n \sin r$, where n_0 is the refractive index of the common incident medium.
- The speed of light in a medium of refractive index n is $v = c/n$, with c the vacuum speed.

Step 1: Compare the refractive indices For the same incident medium and angle of incidence, $n_0 \sin i$ is constant, so $n \propto 1/\sin r$. Since $\sin 15^\circ < \sin 25^\circ < \sin 35^\circ$, the refractive indices satisfy $n_A > n_B > n_C$.

Step 2: Compare the light speeds The speed is inversely proportional to the refractive index. Therefore the above order gives $v_A < v_B < v_C$. Equivalently, $v = c \sin r/(n_0 \sin i)$, so the smallest refracted angle gives the smallest speed for the stated common incidence.

Step 3: Conclusion The velocity of light is **minimum in medium A**, whose angle of refraction is 15°.

Quick Tip to Solve: For a common incident ray, stronger bending towards the normal means a larger index and lower speed.

6. A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why? [1 mark]

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is the Planck constant and p is momentum.
- For nonrelativistic motion, kinetic energy is $K = p^2/(2m)$, so $\lambda = h/\sqrt{2mK}$.

Step 1: Express wavelength at fixed kinetic energy Both particles have the same kinetic energy K. Combining the momentum-energy relation with the de Broglie relation gives

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

At fixed K, wavelength is inversely proportional to the square root of mass.

Step 2: Compare the electron with the proton The electron has much smaller mass than the proton, $m_e < m_p$. Hence its momentum $\sqrt{2m_eK}$ is smaller at the same kinetic energy. The wavelength ratio is $\lambda_e/\lambda_p = \sqrt{m_p/m_e} > 1$. Equal kinetic energy does not mean equal momentum or equal wavelength.

Step 3: Conclusion The **electron has the greater de Broglie wavelength**, because $\lambda \propto 1/\sqrt{m}$ for

Quick Tip to Solve: For equal kinetic energies compare $\sqrt{m}$; for equal momenta the wavelengths would be equal.

the same kinetic energy.

Quick Tip to Solve: For equal kinetic energies compare $\sqrt{m}$; for equal momenta the wavelengths would be equal.

7. Mention the two characteristic properties of the material suitable for making core of a transformer.

[1 mark]

Solution:

Concept:

- A transformer core must guide the changing magnetic flux efficiently between the primary and secondary coils.
- High magnetic permeability provides strong flux linkage; a small hysteresis-loop area gives small energy loss during repeated magnetisation.

Step 1: Choose a material that magnetises easily The core material should have **high magnetic permeability**. A relatively small magnetising field then produces a substantial magnetic flux, allowing most of the primary flux to link with the secondary winding.

Step 2: Choose a material with low cyclic loss The material should have **low hysteresis loss**, corresponding to a narrow hysteresis loop and low coercivity. The alternating current repeatedly magnetises and demagnetises the core, so a small loop area reduces the energy dissipated as heat in each cycle. Soft iron is a suitable example.

Step 3: Conclusion The two required properties are **high magnetic permeability** and **low hysteresis loss**.

Quick Tip to Solve: Associate permeability with effective flux linkage, and hysteresis-loop area with heat loss per cycle.

8. A charge q is placed at the centre of a cube of side l. What is the electric flux passing through each face of the cube?

[1 mark]

Solution:

Concept:

- Gauss's law gives the total outward electric flux through a closed surface: $\Phi = \oint \vec{E}\cdot d\vec{S} = q_{\text{enclosed}}/\varepsilon_0$, where ε_0 is the permittivity of free space.
- A charge at the centre of a cube is symmetrically located relative to all six identical faces, so their integrated fluxes are equal.

Step 1: Apply Gauss's law to the cube The cube encloses the single charge q. Thus its total signed outward flux is

$$\Phi_{\text{cube}} = \frac{q}{\varepsilon_0}.$$

The result depends on the enclosed charge, rather than the side length l.

Quick Tip to Solve: First find the closed-surface flux using Gauss's law, then divide by six only because the charge is at the cube's centre.

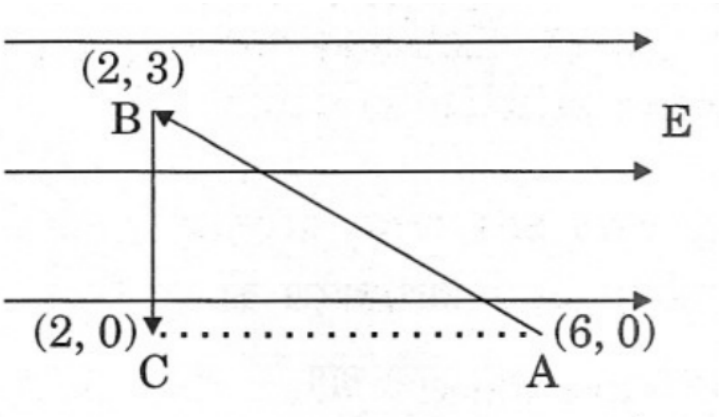
Step 2: Share the total flux among six faces By symmetry, each face receives the same flux. Although the electric field is not uniform over a face, the six surface integrals are identical. Hence

$$6\Phi_{\text{face}} = \Phi_{\text{cube}}.$$

Step 3: Conclusion The electric flux through each face, measured with its outward normal, is $\boxed{q/(6\varepsilon_0)}$, in N m^2 C^{-1}. Its sign follows the sign of q.

Quick Tip to Solve: First find the closed-surface flux using Gauss's law, then divide by six only because the charge is at the cube's centre.

9. A test charge 'q' is moved without acceleration from A to C along the path from A to B and then from B to C in electric field $\vec{E}$ as shown in the figure. (i) Calculate the potential difference between A and C. (ii) At which point (of the two) is the electric potential more and why? [2 marks]



Solution:

Concept:

- The potential difference is $V_C - V_A = -\int_A^C \vec{E} \cdot d\vec{l}$. Electrostatic potential difference depends on the endpoints, not the path.
- In a uniform field along the positive x-direction, $V_C - V_A = -E(x_C - x_A)$; displacement perpendicular to the field contributes no change of potential.

Step 1: Calculate the potential difference along the given path The printed coordinates are $A(6, 0)$, $B(2, 3)$ and $C(2, 0)$, and $\vec{E} = E\hat{x}$. On the oblique segment AB only the horizontal displacement contributes:

$$V_B - V_A = -E(2 - 6) = 4E.$$

On BC the horizontal coordinate remains 2, so $\vec{E} \cdot d\vec{l} = 0$ and $V_C - V_B = 0$. Adding the two changes gives

$$V_C - V_A = (V_C - V_B) + (V_B - V_A) = 4E.$$

This means E multiplied by four coordinate length units; if lengths are in metres and E is in V m^{-1}, the result is in volts. The test charge q cancels from potential difference.

Quick Tip to Solve: In a uniform horizontal field, use only the difference in x-coordinates; the vertical segment BC changes no potential.

Step 2: Identify the point at higher potential Potential decreases in the direction of the electric field, since $\vec{E} = -\vec{\nabla}V$. Point C lies to the left of A, opposite to the rightward field. A positive test charge must therefore be moved against the field to go from A to C. Moving it without acceleration requires external work $q(V_C - V_A)$, while the electric field does the opposite work.

Step 3: Conclusion $\boxed{V_C - V_A = 4E}$ for the coordinate separation shown (equivalently, $V_A - V_C = -4E$). Point C has the higher potential because potential decreases along the rightward electric field.

Quick Tip to Solve: In a uniform horizontal field, use only the difference in x-coordinates; the vertical segment BC changes no potential.

---

10. An electric dipole is held in a uniform electric field.

(i) Show that the net force acting on it is zero.

(ii) The dipole is aligned parallel to the field. Find the work done in rotating it through the angle of $180°$. [2 marks]

Solution:

Concept:

- An electric dipole consists of charges $+q$ and $-q$ separated by a distance d, with dipole moment $\vec{p}$ directed from the negative to the positive charge and magnitude $p = qd$.
- A charge experiences force $\vec{F} = q\vec{E}$. The potential energy of a dipole in a uniform field is $U = -\vec{p} \cdot \vec{E} = -pE\cos\theta$, where θ is the angle between $\vec{p}$ and $\vec{E}$.

Step 1: Add the forces on the two charges Because the field is uniform, the field vector at both charges is the same. The positive charge experiences $\vec{F}_+ = q\vec{E}$, while the negative charge experiences $\vec{F}_- = -q\vec{E}$. Therefore

$$\vec{F}_{\text{net}} = q\vec{E} - q\vec{E} = \vec{0}.$$

This cancellation holds for every orientation. Equal and opposite forces can still form a couple, producing a torque $\vec{\tau} = \vec{p} \times \vec{E}$, so zero net force does not generally imply zero turning effect.

Step 2: Find the change in potential energy on rotation Initially the dipole is parallel to the field, so $\theta_i = 0$ and $U_i = -pE$. After rotation through $180°$, $\theta_f = \pi$ and $U_f = +pE$. The work supplied by an external agent in a slow rotation is

$$W_{\text{ext}} = U_f - U_i = pE - (-pE) = 2pE.$$

Equivalently, integrating the opposing torque gives $W_{\text{ext}} = \int_0^{\pi} pE\sin\theta\, d\theta$. The positive value indicates energy must be supplied to move from the stable parallel orientation to the unstable antiparallel orientation.

Step 3: Conclusion (i) $\boxed{\vec{F}_{\text{net}} = \vec{0}}$. (ii) Work required to rotate the dipole through $180°$ is $\boxed{2pE}$ joules. The work done by the electric field during this rotation is $-2pE$.

Quick Tip to Solve: For dipole rotation, subtract the endpoint energies using $U = -pE\cos\theta$; parallel to antiparallel always raises the energy by $2pE$.

11. State the underlying principle of a transformer. How is the large scale transmission of electric energy over long distances done with the use of transformers? [2 marks]

Solution:

Concept:

- A transformer works on mutual induction: changing current in the primary coil changes the magnetic flux linked with the secondary coil and induces an emf in it according to Faraday's law.
- For an ideal transformer, $V_s/V_p = N_s/N_p$ and $V_pI_p = V_sI_s$, where N, V and I denote turns, voltage and current, and subscripts p and s denote primary and secondary.

Step 1: State how mutual induction operates Alternating current in the primary coil produces a changing magnetic flux in the iron core. This flux links the secondary coil, inducing an alternating emf $\varepsilon_s = -N_s\, d\Phi/dt$. The primary and secondary are coupled magnetically. Using more secondary turns than primary turns increases the secondary voltage; using fewer secondary turns decreases it.

Step 2: Explain long-distance transmission at high voltage At the generating station a step-up transformer raises the voltage before power is sent through the transmission lines. For a given transmitted power P and power factor, raising the voltage reduces the current. With unity power factor, $I = P/V$, and the heating loss in a line of resistance R is

$$P_{\text{loss}} = I^2R = \frac{P^2R}{V^2}.$$

Thus high-voltage transmission greatly reduces line heating and energy loss. Near the consumers, step-down transformers lower the voltage in stages to the value required for distribution and domestic or industrial use. The supply is alternating, providing the changing flux needed for transformer action.

Step 3: Conclusion The transformer operates on mutual induction. Electric energy is transmitted over long distances after stepping up the AC voltage to reduce current and I^2R loss, then stepping it down near consumers.

Quick Tip to Solve: Link the transmission explanation in order: higher voltage, lower current for the same power, and lower I^2R heating loss.

12. A capacitor of capacitance 'C' is being charged by connecting it across a dc source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor. [2 marks]

Solution:

Concept:

- During charging, the charge Q on a capacitor changes, giving a conduction current in the connecting wires $I_c = dQ/dt$. For constant capacitance C, $Q = CV$.
- Maxwell's displacement current is $I_d = \varepsilon_0\, d\Phi_E/dt$, where Φ_E is electric flux. A changing electric field in the gap maintains current continuity even though charges do not cross an ideal insulating gap.

Quick Tip to Solve: Distinguish charge flow in the wires from changing electric flux in the gap; differentiating $Q = CV$ shows their currents are equal.

Step 1: Explain the transient ammeter deflection Yes. Immediately after connection to the DC source, charges flow through the wires onto the capacitor plates. This conduction current passes through the ammeter, causing a momentary deflection. As charge builds up, the capacitor voltage increases towards the source voltage and the charging current decreases. Once an ideal capacitor is fully charged, its charge and voltage become constant, so the conduction current and the ammeter deflection become zero.

Step 2: Account for current inside the capacitor No conduction charge passes through the insulating space between the plates. However, the accumulating plate charge produces a time-varying electric field there, giving displacement current. For parallel plates of area A in vacuum, neglecting fringing,

$$\Phi_E = EA = \frac{Q}{\varepsilon_0}.$$

Consequently,

$$I_d = \varepsilon_0 \frac{d\Phi_E}{dt} = \frac{dQ}{dt} = C\frac{dV}{dt} = I_c.$$

Here V is the instantaneous potential difference across the capacitor. Equality of displacement current in the gap and conduction current in the leads explains continuity of total current around the charging circuit. After charging stops the electric flux is constant, so displacement current also vanishes.

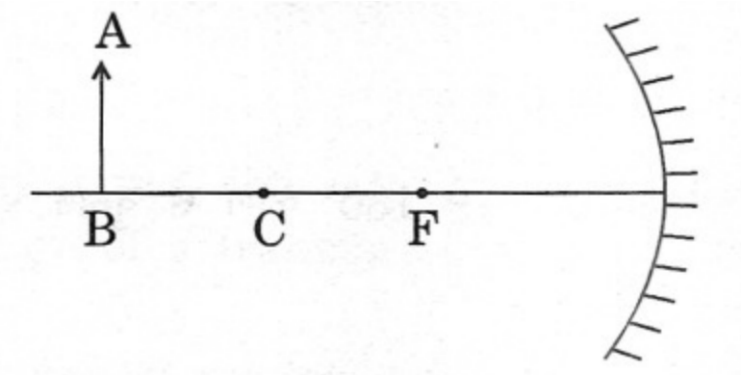
Step 3: Conclusion The ammeter shows a transient deflection during charging. Current inside the ideal capacitor is displacement current: $\boxed{I_d = \varepsilon_0\, d\Phi_E/dt = C\, dV/dt}$, equal to the conduction current in the connecting wires.

Quick Tip to Solve: Distinguish charge flow in the wires from changing electric flux in the gap; differentiating $Q = CV$ shows their currents are equal.

13. An object AB is kept in front of a concave mirror as shown in the figure.

(i) Complete the ray diagram showing the image formation of the object.

(ii) How will the position and intensity of the image be affected if the lower half of the mirror's reflecting surface is painted black? [2 marks]

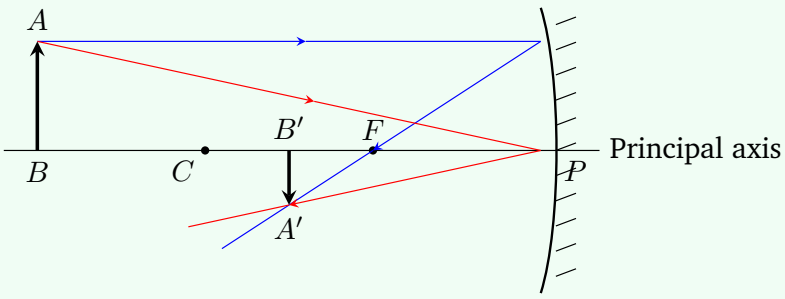


Solution:

Concept:

- For a concave mirror, a ray parallel to the principal axis is reflected through the principal focus F; a ray striking the pole P obeys the law of reflection.
- The intersection of reflected rays gives the image position. Reducing the reflecting area reduces the light collected, but does not change the mirror's focal length or the object distance.

Step 1: Complete the image-forming rays (i) The object AB lies beyond the centre of curvature C. Draw a ray from A parallel to the principal axis; after reflection it passes through F. Draw a second ray from A to the pole P; its reflected ray makes the same angle with the principal axis as the incident ray. The reflected rays meet at A'; its perpendicular projection onto the axis is B'.



Complete ray diagram for an object beyond the centre of curvature

Step 2: Determine the effect of blackening half the mirror (ii) Each unpainted portion can still reflect rays from every point of the object. The same mirror curvature and hence the same focal length remain. Since the object distance is unchanged, the mirror equation $1/f = 1/v + 1/u$ gives the same image distance v. The complete image stays at the same position and size, but receives fewer rays, so its intensity decreases.

Step 3: Conclusion The image is real, inverted and diminished, between C and F. Painting the lower half black leaves the complete image at the same position but makes it less bright.

Quick Tip to Solve: Locate the image using any two reflected rays; blocking part of a mirror changes brightness, while the curvature determines its focal length.

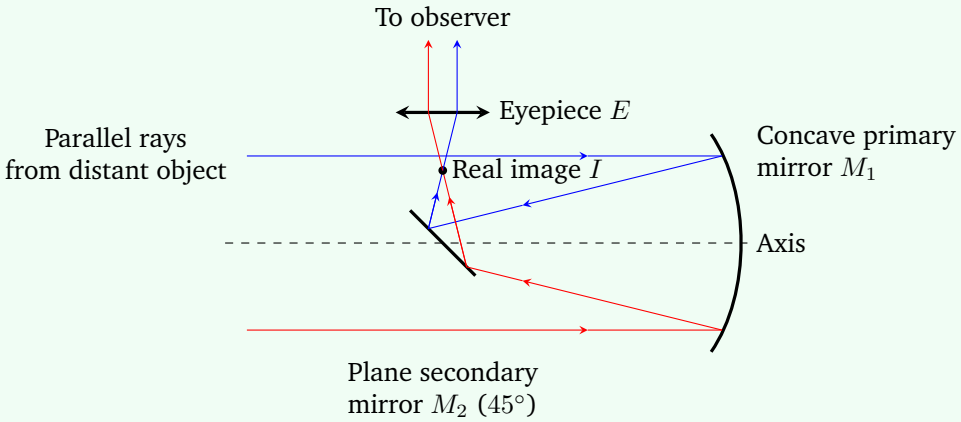
14. Draw a labelled ray diagram of a reflecting telescope. Mention its two advantages over the refracting telescope. [2 marks]

Solution:

Concept:

- A reflecting telescope uses a large concave primary mirror to collect parallel rays from a distant object and form a real image near its focus.
- A small secondary mirror diverts the converging rays towards an eyepiece, which magnifies the real image. Reflection does not disperse white light like refraction through a lens.

Step 1: Trace rays through a reflecting telescope The diagram shows the Newtonian arrangement. Parallel rays from a distant object strike the concave primary mirror M_1. They are reflected towards its principal focus. Before reaching that focus, a small plane mirror M_2, inclined at 45° to the principal axis, turns the converging beam through 90°. It forms a real image I beside the telescope tube. The eyepiece E is adjusted so that I lies in its focal plane; the emerging rays are then parallel for normal adjustment.



Newtonian reflecting telescope in normal adjustment (schematic)

Step 2: State two advantages over a refracting telescope First, the reflecting objective is free from chromatic aberration: the law of reflection is the same for all wavelengths, so different colours have the same focus. Second, a mirror can be supported over its back, allowing a much larger objective aperture than a large lens supported only at its edge. The larger aperture collects more light from faint objects and improves resolving power, enabling finer angular details to be distinguished.

Step 3: Conclusion A concave primary mirror and a secondary mirror send the image to an eyepiece. Its two advantages are freedom from chromatic aberration and the practical availability of a larger aperture for greater light gathering and resolution.

Quick Tip to Solve: Label the primary mirror, the tilted secondary, the real image and the eyepiece; explain the advantages through reflection and back support of the mirror.

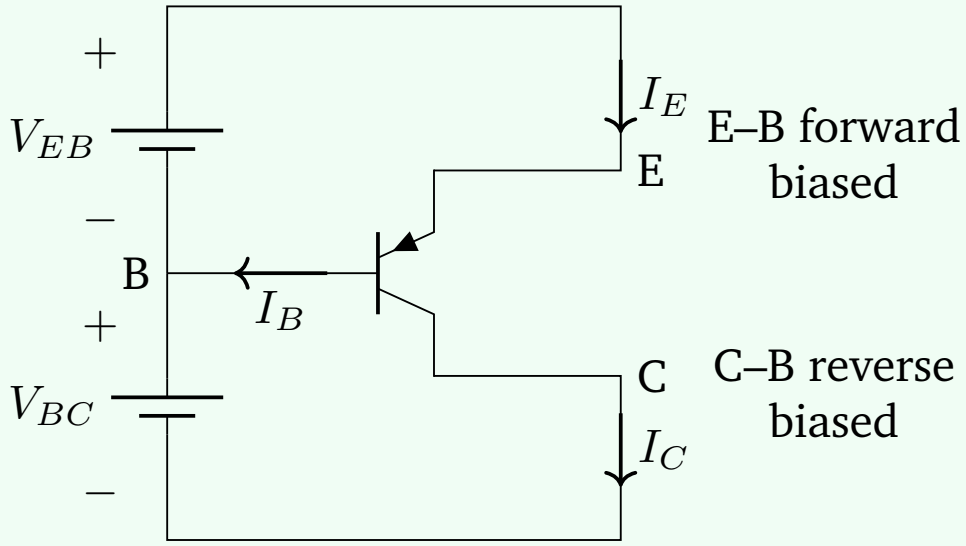
15. Describe briefly with the help of a circuit diagram, how the flow of current carriers in a p-n-p transistor is regulated with emitter-base junction forward biased and base-collector junction reverse biased. [2 marks]

Solution:

Concept:

- In a p-n-p transistor, holes are the majority carriers in the heavily doped p-type emitter. The n-type base is thin and lightly doped.
- Active operation requires $V_E > V_B > V_C$: the emitter-base junction is forward biased and the collector-base junction is reverse biased. Currents satisfy $I_E = I_B + I_C$.

Step 1: Bias the two junctions Connect the emitter to the positive terminal of the emitter supply and its negative terminal to the base. Connect the collector to the negative terminal of the collector supply, whose positive terminal is connected to the base. Thus the emitter-base barrier is reduced while the collector-base junction remains reverse biased, as shown below.



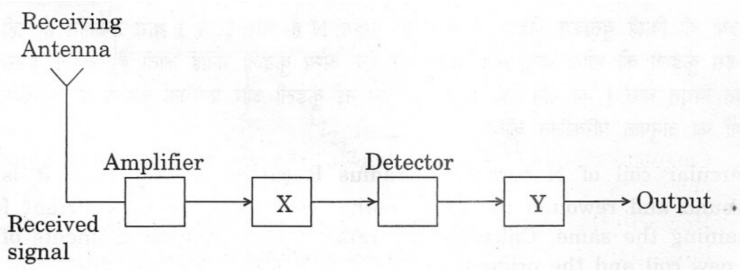
p-n-p transistor bias circuit: emitter positive and collector negative relative to the base; holes flow from emitter towards collector.

Step 2: Explain and control the carrier flow Forward bias injects holes from the emitter into the base. Only a small fraction recombines with base electrons, producing the small base current. Because the base is very thin, most holes reach the collector-base depletion region. Its electric field sweeps them into the collector, giving the collector current. Increasing the emitter-base forward bias increases hole injection and therefore increases I_C; reducing it decreases I_C. Hence a small change in base current regulates the much larger collector current, with $I_C \simeq \beta I_B$ in the active region. Conventional current enters the emitter and leaves through the base and collector.

Step 3: Conclusion The forward-biased emitter-base junction controls hole injection, while the reverse-biased collector-base junction collects most injected holes. A small base current therefore controls a large collector current, and $I_E = I_B + I_C$.

Quick Tip to Solve: For a p-n-p transistor remember E is most positive, C most negative, and the emitter arrow points towards the base.

16. In the given block diagram of a receiver, identify the boxes labelled as X and Y and write their functions. [2 marks]



Solution:

Concept:

- A radio receiver first amplifies the weak modulated signal received by its antenna. It then processes the carrier before recovering the information signal.
- Detection (demodulation) extracts the original low-frequency information from the modulated carrier; subsequent amplification raises the recovered signal to a useful output level.

Step 1: Identify X and explain its function X is the intermediate-frequency (IF) stage. It converts the carrier frequency of the received, amplified signal to a fixed, lower intermediate frequency, with the modulation retained. Frequency conversion is obtained by mixing with a local-oscillator signal. Working at a fixed IF makes selective amplification and subsequent detection convenient; this stage does not itself extract the original message.

Step 2: Identify Y and explain its function Y is the amplifier following the detector, that is, the audio-frequency amplifier for a radio receiver. The detector has recovered the information signal, but it is generally too weak to drive the output device. This amplifier increases its amplitude or power so that the recovered signal can operate a loudspeaker or other output device. The distinction from the first amplifier is that the first acts on the modulated high-frequency received signal, whereas Y acts on the recovered low-frequency signal.

Step 3: Conclusion $\boxed{X = \text{Intermediate-frequency stage}}$, which lowers the carrier frequency for convenient processing; $\boxed{Y = \text{Audio-frequency amplifier}}$, which amplifies the detected information signal for output.

Quick Tip to Solve: Locate each box relative to the detector: before it the carrier is still modulated; after it the amplifier boosts the recovered message.

17. A light bulb is rated 100 W for 220 V ac supply of 50 Hz. Calculate

(i) the resistance of the bulb;

(ii) the rms current through the bulb. [2 marks]

Solution:

Concept:

- The stated voltage of an ac supply is its rms value. For a resistive bulb, voltage and current are in phase, so the average power is $P = V_{\text{rms}} I_{\text{rms}} = V_{\text{rms}}^2 / R$.
- R is the filament resistance at its rated operating temperature; V_{rms} and I_{rms} are the effective ac voltage and current.

Step 1: (i) Calculate the resistance The rating gives $P = 100\,\text{W}$ when $V_{\text{rms}} = 220\,\text{V}$. Treating the filament as a pure resistance at its operating temperature,

$$R = \frac{V_{\text{rms}}^2}{P} = \frac{(220)^2}{100} = 484\,\Omega.$$

This is the hot-filament resistance, not its resistance at room temperature. There is no factor of two in this substitution because the supply rating already specifies an rms voltage.

Step 2: (ii) Calculate the rms current Use either the power relation or Ohm's law with the rms values:

$$I_{\text{rms}} = \frac{P}{V_{\text{rms}}} = \frac{100}{220} = 0.4545\,\text{A}.$$

As a check, $220/484 = 0.4545\,\text{A}$, giving the same current. The supplied frequency $50\,\text{Hz}$ does not enter these results because the ideal resistive filament has no inductive or capacitive reactance.

Step 3: Conclusion (i) The bulb's operating resistance is $\boxed{484\,\Omega}$. (ii) The rms current is $\boxed{0.455\,\text{A}}$ approximately.

Quick Tip to Solve: A bulb's ac voltage rating is already rms: use R = V squared / P and I = P / V directly, without dividing V by square root of two.

OR

17. An alternating voltage given by $V = 140 \sin 314t$ is connected across a pure resistor of $50\,\Omega$. Find

(i) the frequency of the source.

(ii) the rms current through the resistor. [2 marks]

Solution:

Concept:

- A sinusoidal voltage has the form $V(t) = V_0 \sin(\omega t)$, where V_0 is the peak voltage and $\omega = 2\pi f$ is the angular frequency.
- For a pure resistance R, current is in phase with voltage: $I_0 = V_0/R$ and $I_{\text{rms}} = I_0/\sqrt{2} = V_0/(\sqrt{2}R)$.

Step 1: (i) Find the source frequency Compare $V(t) = 140\sin(314t)$ with the standard sinusoidal

Quick Tip to Solve: In V = V0 sin(omega t), divide omega by 2 pi for frequency and divide V0 by square root of two before applying rms Ohm's law.

form. Its peak voltage is $V_0 = 140\,\text{V}$ and its angular frequency is $\omega = 314\,\text{rad s}^{-1}$. Therefore,

$$f = \frac{\omega}{2\pi} = \frac{314}{2\pi} \simeq 50\,\text{Hz}.$$

The coefficient of time gives angular frequency, not frequency in hertz; one complete cycle corresponds to a phase change of 2π radians.

Step 2: (ii) Calculate the rms current Across the pure resistor $R = 50\,\Omega$, Ohm's law gives

$$I(t) = \frac{140}{50}\sin(314t) = 2.8\sin(314t)\,\text{A}.$$

Thus $I_0 = 2.8\,\text{A}$. The rms value of a sinusoidal current is

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} = \frac{2.8}{\sqrt{2}} \simeq 1.98\,\text{A}.$$

Equivalently, $V_{\text{rms}} = 140/\sqrt{2}\,\text{V}$ and division by $50\,\Omega$ gives the same result. The coefficient 140 in the time-dependent voltage is a peak value, unlike the rms rating of a mains supply.

Step 3: Conclusion (i) The source frequency is $\boxed{50\,\text{Hz}}$ approximately. (ii) The rms current is $\boxed{1.98\,\text{A}}$ approximately.

Quick Tip to Solve: In V = V0 sin(omega t), divide omega by 2 pi for frequency and divide V0 by square root of two before applying rms Ohm's law.

18. A circular coil of N turns and radius R carries a current I. It is unwound and rewound to make another coil of radius $R/2$, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil. [2 marks]

Solution:

Concept:

- The magnetic moment of a circular coil is $m = NIA = NI\pi R^2$, where N is the number of turns, I the current and A the area of one turn.
- Rewinding the same wire conserves its length: the product of the number of turns and the circumference of each turn stays constant.

Step 1: Use the unchanged wire length Let the new number of turns be N'. The original wire length is $L = N(2\pi R)$. Since the new radius is $R/2$, the circumference per turn is halved. Therefore the same length of wire makes twice as many turns:

$$N(2\pi R) = N'\left(2\pi\frac{R}{2}\right) \quad \Rightarrow \quad N' = 2N.$$

Step 2: Compare the two magnetic moments The original moment is $m = NI\pi R^2$. In the new coil,

Quick Tip to Solve: For the same wire length and current, $N \propto 1/R$, so $m = NI\pi R^2 \propto R$; halving the radius halves the moment.

the current remains I, while the area of one turn becomes one quarter of its original value:

$$m' = N'I\pi\left(\frac{R}{2}\right)^2 = (2N)I\frac{\pi R^2}{4} = \frac{NI\pi R^2}{2}.$$

Thus the increase in the number of turns compensates for only half of the reduction due to the smaller turn area.

Step 3: Conclusion The ratio of the new magnetic moment to the original magnetic moment is $m'/m = 1/2$, or $\boxed{m' : m = 1 : 2}$.

Quick Tip to Solve: For the same wire length and current, $N \propto 1/R$, so $m = NI\pi R^2 \propto R$; halving the radius halves the moment.

19. Deduce the expression for the electrostatic energy stored in a capacitor of capacitance C and having charge Q.

How will the (i) energy stored and (ii) the electric field inside the capacitor be affected when it is completely filled with a dielectric material of dielectric constant K? [3 marks]

Solution:

Concept:

- At an intermediate charge q, a capacitor of capacitance C has potential difference $v = q/C$. The work to transfer an additional charge dq is $dW = v\,dq$.
- Electrostatic energy equals the total work done in charging: $U = \int_0^Q (q/C)\,dq$. For a dielectric filling the space completely, the new capacitance is $C' = KC$.
- For an isolated charged capacitor, its free charge Q remains fixed. For parallel plates separated by d, the field is $E = V/d$.

Step 1: Calculate the charging work Begin with an uncharged capacitor. When the charge already stored is q, its potential difference is q/C. Moving a small further charge dq against this potential requires work $dW = (q/C)\,dq$. Integrating from zero to the final charge Q, with C constant, gives

$$U = \int_0^Q \frac{q}{C}\,dq = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q = \frac{Q^2}{2C}.$$

Since $Q = CV$, equivalent expressions are $U = \frac{1}{2}QV = \frac{1}{2}CV^2$. The factor $1/2$ arises because the potential increases from zero to V during charging.

Step 2: Find the energy after inserting the dielectric Treat the capacitor with specified charge Q as isolated, so no charge can enter or leave its plates. Complete filling with the dielectric changes its capacitance to KC. Therefore,

$$U' = \frac{Q^2}{2C'} = \frac{Q^2}{2KC} = \frac{U}{K}.$$

The energy decreases to $1/K$ of its initial value; the decrease is $U(1 - 1/K)$. This lost electrostatic energy can appear as mechanical work as the dielectric is attracted into the capacitor.

Quick Tip to Solve: First decide whether charge or voltage is fixed. For the isolated charged capacitor here, keep Q fixed and replace C by KC in $Q^2/(2C)$.

Step 3: Find the field after inserting the dielectric The voltage falls because the charge is fixed while the capacitance increases:

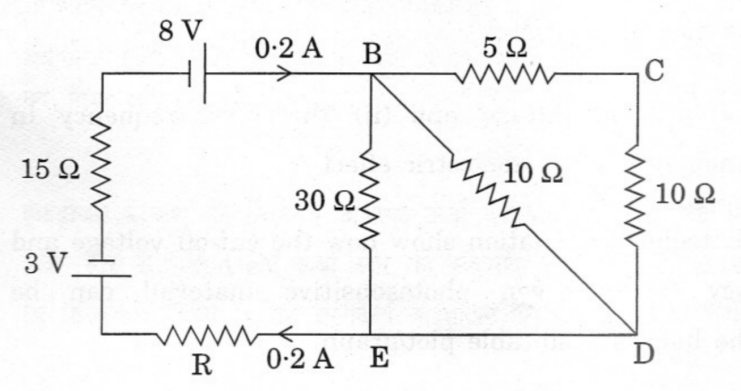
$$V' = \frac{Q}{KC} = \frac{V}{K}, \qquad E' = \frac{V'}{d} = \frac{E}{K}.$$

Polarisation of the dielectric produces a field opposing the original field, reducing the net field. The plate separation is unchanged. If a battery instead held V fixed, the result would differ: $U' = KU$ and $E' = E$, because additional charge would flow from the battery.

Step 4: Conclusion The stored energy is $\boxed{U = Q^2/(2C)}$. For the isolated capacitor after complete dielectric filling, $\boxed{U' = U/K}$ and $\boxed{E' = E/K}$.

Quick Tip to Solve: First decide whether charge or voltage is fixed. For the isolated charged capacitor here, keep Q fixed and replace C by KC in $Q^2/(2C)$.

20. Calculate the value of the resistance R in the circuit shown in the figure so that the current in the circuit is 0.2 A. What would be the potential difference between points B and E? [3 marks]



Solution:

Concept:

- Resistors in series add directly; parallel branches obey $1/R_{\text{eq}} = \sum_i 1/R_i$.
- Kirchhoff's loop rule equates net emf to total resistive drop. The longer cell plate is positive.
- Ohm's law gives $V = IR$, with I the current through resistance R.

Step 1: Reduce the network between B and E D and E are joined directly by a wire, so they are at the same potential. The path BCD has the $5\,\Omega$ and $10\,\Omega$ resistors in series, giving $15\,\Omega$. This path, the diagonal $10\,\Omega$ resistor and the vertical $30\,\Omega$ resistor form three parallel branches between B and E:

$$\frac{1}{R_{BE}} = \frac{1}{15} + \frac{1}{10} + \frac{1}{30} = \frac{2+3+1}{30} = \frac{1}{5}, \qquad R_{BE} = 5\,\Omega.$$

The outer $15\,\Omega$ resistor and the unknown R are in series with this equivalent resistance.

Step 2: Apply Kirchhoff's loop rule Follow the indicated clockwise current. Across the upper cell toward B, we move from negative to positive: a rise of 8 V. Up the left branch, the lower cell is crossed from its positive (lower) plate to negative: a drop of 3 V. The cells oppose, so the net emf is

Quick Tip to Solve: Identify D and E as one node first, then combine the three BE branches. Check both cell polarities before adding or subtracting their emfs.

$8 - 3 = 5\,\text{V}$.

$$8 - 3 - I(15 + R + 5) = 0.$$

Substituting the total current $I = 0.2\,\text{A}$,

$$5 = 0.2(20 + R), \qquad 20 + R = 25, \qquad R = 5\,\Omega.$$

Step 3: Calculate the voltage across B and E The total current entering the parallel network is $0.2\,\text{A}$. Use its equivalent resistance $5\,\Omega$, since this current splits among the individual branches:

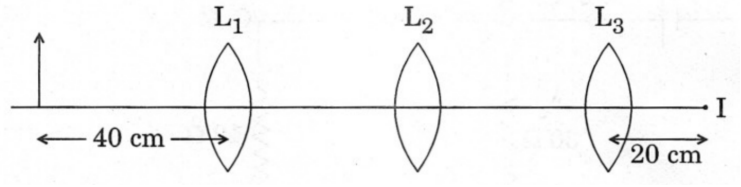
$$V_B - V_E = IR_{BE} = 0.2 \times 5 = 1.0\,\text{V}.$$

Since current flows through this resistive network from B toward E, B is at the higher potential.

Step 4: Conclusion The required resistance is $\boxed{R = 5\,\Omega}$. The potential difference is $\boxed{V_B - V_E = 1.0\,\text{V}}$, with B higher than E.

Quick Tip to Solve: Identify D and E as one node first, then combine the three BE branches. Check both cell polarities before adding or subtracting their emfs.

21. You are given three lenses L_1, L_2 and L_3 each of focal length $20\,\text{cm}$. An object is kept at $40\,\text{cm}$ in front of L_1, as shown. The final real image is formed at the focus 'I' of L_3. Find the separations between L_1, L_2 and L_3. [3 marks]



Solution:

Concept:

- For each thin convex lens, $1/f = 1/v - 1/u$, where u and v are signed distances measured from that lens. Take rightward distances as positive; here $f = +20\,\text{cm}$.
- An object at twice the focal length produces a real image at twice the focal length on the other side. An object at a convex lens's first focus produces parallel emergent rays, which a subsequent convex lens focuses at its second focus.

Step 1: Locate the image produced by the first lens For L_1, the object is on the left, so $u_1 = -40\,\text{cm}$. Substituting in the lens formula gives

$$\frac{1}{20} = \frac{1}{v_1} - \frac{1}{-40} \quad \Rightarrow \quad \frac{1}{v_1} = \frac{1}{40}.$$

Thus the first image I_1 lies $40\,\text{cm}$ to the right of L_1. This image becomes the object for L_2.

Step 2: Apply the condition imposed by the third lens The final image lies at the right-hand focus of

Quick Tip to Solve: Work backwards from a final image at a lens's focus: its incident beam must be parallel, so the preceding convex lens has its object at its first focus.

L_3, so $v_3 = f_3 = 20\,\text{cm}$. Consequently

$$\frac{1}{20} = \frac{1}{20} - \frac{1}{u_3} \quad \Rightarrow \quad \frac{1}{u_3} = 0.$$

The beam incident on L_3 must therefore be parallel. To supply this beam, L_2 must have its object I_1 at its first focus, $20\,\text{cm}$ to its left. Hence L_2 lies $20\,\text{cm}$ beyond the first image.

Step 3: Determine the separations allowed by the parallel beam Adding the distance from L_1 to I_1 and that from I_1 to L_2 gives

$$L_1L_2 = 40 + 20 = 60\,\text{cm}.$$

Between L_2 and L_3, the rays remain parallel. Moving L_3 along this beam does not change the fact that it forms an image at its own focus. Therefore the stated condition does not fix L_2L_3; any positive separation consistent with the shown order works. A unique numerical value for this second distance cannot be inferred from the schematic drawing.

Step 4: Conclusion $\boxed{L_1L_2 = 60\,\text{cm}}$. The separation $\boxed{L_2L_3 \text{ is arbitrary}}$, because L_2 sends parallel rays to L_3, which focuses them $20\,\text{cm}$ beyond itself.

Quick Tip to Solve: Work backwards from a final image at a lens's focus: its incident beam must be parallel, so the preceding convex lens has its object at its first focus.

22. Define the terms (i) 'cut-off voltage' and (ii) 'threshold frequency' in relation to the phenomenon of photoelectric effect.

Using Einstein's photoelectric equation show how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph. [3 marks]

Solution:

Concept:

- The photon energy is $h\nu$, where h is Planck's constant and ν is frequency. The work function is $\phi_0 = h\nu_0$.
- Einstein's equation gives $K_{\max} = h\nu - \phi_0 = eV_0$, with e the electron-charge magnitude and V_0 the stopping-potential magnitude.

Step 1: Define the two terms (i) The cut-off voltage is the minimum retarding potential between collector and emitter that stops even the fastest photoelectrons and makes the photocurrent zero for a given frequency. Its magnitude is V_0.

(ii) The threshold frequency ν_0 is the minimum frequency of incident radiation required to eject photoelectrons from a given material. For $\nu < \nu_0$, no photoemission occurs, irrespective of the incident intensity.

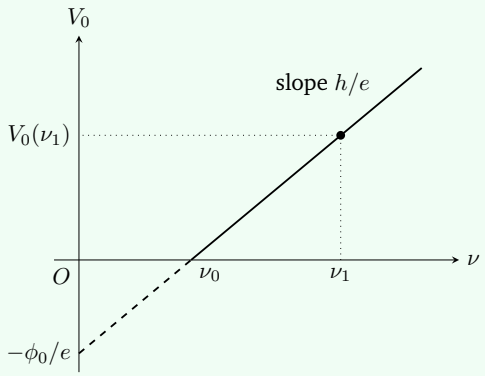
Step 2: Obtain the equation of the straight-line plot Using $\phi_0 = h\nu_0$ in Einstein's equation,

$$eV_0 = h\nu - h\nu_0,$$
$$V_0 = \frac{h}{e}\nu - \frac{h\nu_0}{e} = \frac{h}{e}(\nu - \nu_0).$$

Quick Tip to Solve: On a stopping-potential versus frequency graph, read the voltage vertically and the threshold where the fitted line meets the frequency axis.

Plot V_0 vertically against ν horizontally. This is a straight line with slope h/e, beginning at the threshold frequency.

Step 3: Read the required quantities from the graph At frequency $\nu_1 > \nu_0$, the ordinate of the line gives the cut-off voltage $V_0(\nu_1)$, as shown by the dotted guides. The frequency-axis intercept at $V_0 = 0$ gives ν_0. The dashed extension meets the voltage axis at $-\phi_0/e$. This is only extrapolation: below threshold there is no photoemission, so a negative stopping-potential magnitude is not physically measured.



Stopping potential versus frequency; dashed portion: extrapolation.

Step 4: Conclusion The straight-line plot $\boxed{V_0 = (h/e)(\nu - \nu_0)}$ gives the cut-off voltage as the ordinate at the incident frequency and the threshold frequency as its intercept on the frequency axis.

Quick Tip to Solve: On a stopping-potential versus frequency graph, read the voltage vertically and the threshold where the fitted line meets the frequency axis.

23. A series LCR circuit is connected to an ac source. Using the phasor diagram, derive the expression for the impedance of the circuit. Plot a graph to show the variation of current with frequency of the source, explaining the nature of its variation. [3 marks]

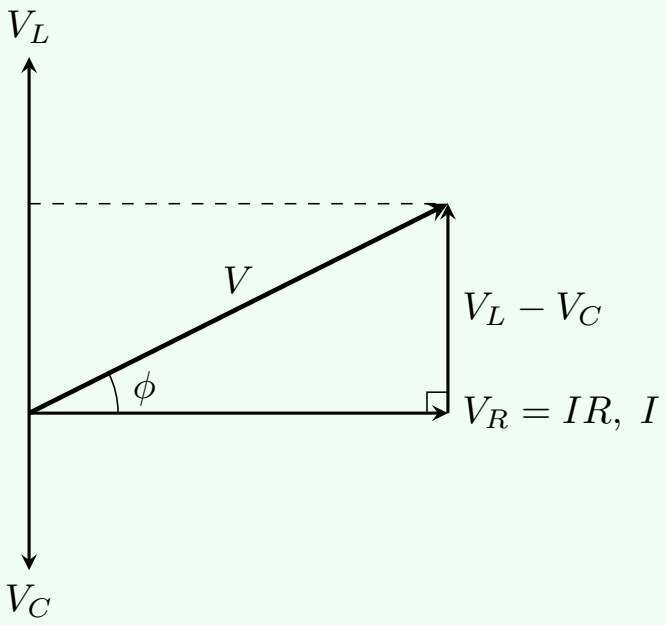
Solution:

Concept:

- In a series LCR circuit the same sinusoidal current flows through resistance R, inductance L and capacitance C. All phasor magnitudes below are rms values.
- The inductive and capacitive reactances are $X_L = \omega L$ and $X_C = 1/(\omega C)$, where $\omega = 2\pi f$. The resistor voltage is in phase with current; the inductor voltage leads it by 90°, and the capacitor voltage lags it by 90°.
- Resonance occurs when the two reactances cancel, so the impedance is minimum and current is maximum for a fixed source voltage.

Step 1: Construct the voltage phasors Take the current I as the horizontal reference. Then $V_R = IR$ lies along it, $V_L = IX_L$ points vertically upwards, and $V_C = IX_C$ points vertically downwards. The vertical resultant is therefore $V_L - V_C$. The diagram illustrates the inductive case $X_L > X_C$; in the capacitive case the resultant vertical component points downwards.

Quick Tip to Solve: Add the inductor and capacitor voltages with opposite signs before applying Pythagoras; their magnitudes must not be added.



Voltage phasors for a series LCR circuit, shown with $V_L > V_C$.

Step 2: Obtain impedance from the right triangle The source voltage is the vector sum $\vec{V} = \vec{V}_R + \vec{V}_L + \vec{V}_C$. Since the horizontal and vertical components are perpendicular,

$$\begin{aligned} V^2 &= V_R^2 + (V_L - V_C)^2 \\ &= I^2 \left[R^2 + (X_L - X_C)^2\right]. \end{aligned}$$

On dividing by I^2, the impedance and phase angle follow:

$$Z = \frac{V}{I} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}, \qquad \tan\phi = \frac{X_L - X_C}{R}.$$

Step 3: Explain the current-frequency curve With the rms source voltage V held constant,

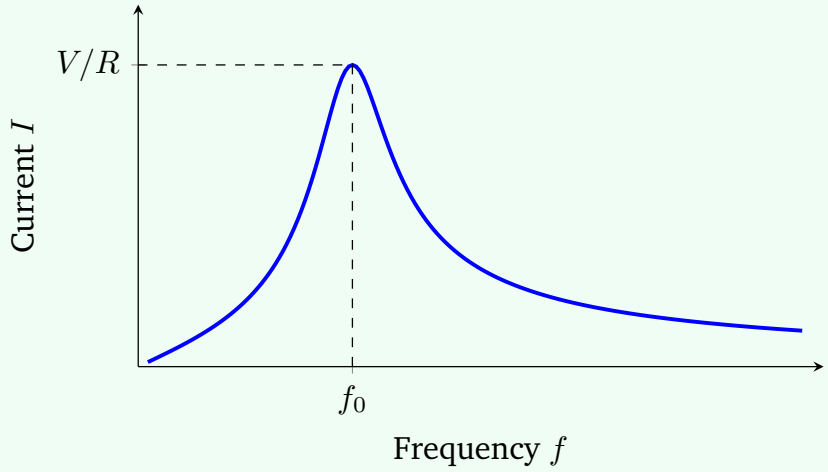
$$I(f) = \frac{V}{\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f C}\right)^2}}.$$

At low frequencies, X_C is large and current is small. As frequency increases towards resonance, the net reactance decreases and current rises. At

$$X_L = X_C, \qquad f_0 = \frac{1}{2\pi\sqrt{LC}},$$

the impedance equals R, current reaches $I_{\max} = V/R$, and voltage and current are in phase. Beyond f_0, inductive reactance dominates; impedance rises and current falls. For the same L and C, a smaller R gives a taller, sharper resonance peak.

Quick Tip to Solve: Add the inductor and capacitor voltages with opposite signs before applying Pythagoras; their magnitudes must not be added.



Current versus frequency for fixed rms source voltage.

Step 4: Conclusion Thus $Z = \sqrt{R^2 + (\omega L - 1/(\omega C))^2}$. The current has a resonance maximum V/R at $f_0 = 1/(2\pi\sqrt{LC})$, decreasing on either side of this frequency.

Quick Tip to Solve: Add the inductor and capacitor voltages with opposite signs before applying Pythagoras; their magnitudes must not be added.

24. Mention three different modes of propagation used in communication system. Explain with the help of a diagram how long distance communication can be achieved by ionospheric reflection of radio waves. [3 marks]

Solution:

Concept:

- Radio signals propagate by ground-wave, sky-wave and space-wave modes; the useful mode depends on frequency and the properties of the atmosphere and ground.
- The ionosphere contains free electrons and ions produced mainly by solar radiation. For suitable radio frequencies its changing refractive properties bend an upward travelling wave back towards the Earth.
- The bending back of radio waves by the ionosphere is conventionally called ionospheric reflection. It permits reception beyond the direct line of sight.

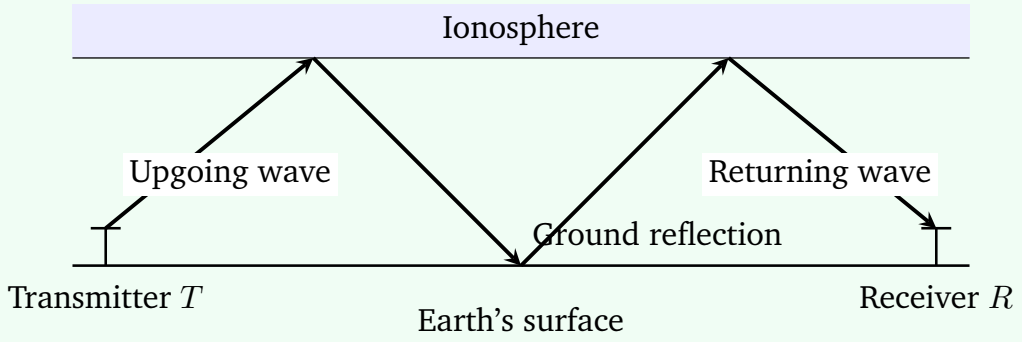
Step 1: State the three propagation modes **Ground-wave propagation:** Waves travel along the Earth's surface and follow its curvature; this mode is useful at low radio frequencies. **Sky-wave propagation:** Waves sent upwards return to the Earth after ionospheric reflection. **Space-wave propagation:** Waves travel directly from transmitter to receiver, with a possible ground-reflected component; this mode is used for line-of-sight communication, such as television and microwave links.

Step 2: Explain the role of the ionosphere To reach a distant receiver, the transmitting antenna radiates radio waves obliquely upwards towards an ionised atmospheric layer. In the ionosphere, the electron density generally varies with height. At an appropriate frequency and angle of incidence, the

Quick Tip to Solve: In a sky-wave sketch, label the Earth, ionosphere, transmitter and receiver, and add arrows showing the upward and returning rays.

wave undergoes progressive refraction and bends back to the Earth's surface. This return is represented as reflection in the schematic. Sky-wave propagation is commonly useful in the approximate frequency band 3–30 MHz; sufficiently high-frequency waves pass through the ionosphere instead of returning.

Step 3: Show how a long distance is covered The first returning ray reaches a point far beyond the transmitter's ordinary radio horizon. The distance between successive points at which a ray meets the ground is called a hop distance. Further reflections at the ground and further returns from the ionosphere allow several hops, carrying the signal over still greater distances. Thus sky-wave communication uses the ionosphere as a natural returning layer, without placing a physical repeater at each intermediate point. The schematic shows two successive hops from transmitter T to distant receiver R.



Schematic two-hop sky-wave communication by ionospheric reflection.

Step 4: Conclusion The three modes are ground-wave, sky-wave and space-wave propagation. Long-distance radio communication is achieved by sending suitable radio waves towards the ionosphere, which returns them to the Earth; repeated ground and ionospheric reflections extend the range.

Quick Tip to Solve: In a sky-wave sketch, label the Earth, ionosphere, transmitter and receiver, and add arrows showing the upward and returning rays.

25. Draw a plot of potential energy of a pair of nucleons as a function of their separations. Mark the regions where the nuclear force is (i) attractive and (ii) repulsive. Write any two characteristic features of nuclear forces. [3 marks]

Solution:

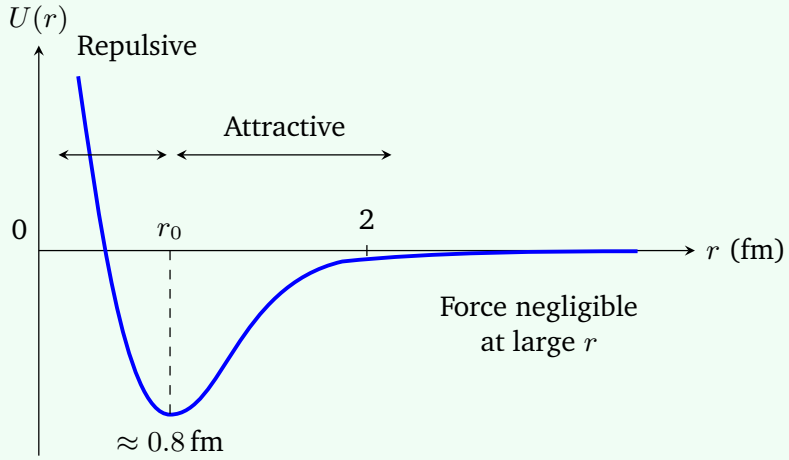
Concept:

- For two nucleons separated by r, the radial nuclear force is $F_r = -dU/dr$, where $U(r)$ is their potential energy. A positive force increases the separation; a negative force decreases it.
- The potential has a steep repulsive core, a negative minimum at a separation r_0 of roughly 0.8 fm, and approaches zero as the separation becomes a few femtometres. Here $1\,\text{fm} = 10^{-15}$ m.

Step 1: Draw and interpret the potential curve Choose $U = 0$ for nucleons far apart. At very small separations, the potential rises sharply to positive values. As r increases, it falls to a negative minimum at $r = r_0$, then rises towards zero. The minimum represents a stable equilibrium separation because a small displacement to either side produces a restoring force. The sketch is qualitative; the well depth

Quick Tip to Solve: Determine attraction or repulsion from minus the slope of the potential curve, not merely from whether the potential is positive or negative.

is not needed here.



Qualitative nucleon potential: repulsion for $r < r_0$, attraction for $r > r_0$ within the force range.

Step 2: Identify the two force regions from the slope For $r < r_0$, the curve has a negative slope: $dU/dr < 0$, hence $F_r > 0$. The force pushes the nucleons apart and is **repulsive**. For $r > r_0$ within the range of the interaction, $dU/dr > 0$, hence $F_r < 0$. The force pulls them together and is **attractive**. At the minimum, $dU/dr = 0$, so the force vanishes. At large separations the curve becomes flat and the force is negligible.

Step 3: State two characteristic features **Short range:** the nuclear force is appreciable only over distances of order 1–2 fm and becomes negligible beyond a few femtometres. Thus it does not act over macroscopic distances like gravitation or electrostatic force.

Approximate charge independence: after excluding the electrostatic contribution, the nuclear interaction between proton–proton, neutron–neutron and proton–neutron pairs is approximately the same in comparable states. It is therefore not an ordinary electric interaction.

Step 4: Conclusion The potential curve has a repulsive region to the left of its minimum and an attractive region to the right, before becoming nearly flat. Nuclear forces are short ranged and approximately charge independent.

Quick Tip to Solve: Determine attraction or repulsion from minus the slope of the potential curve, not merely from whether the potential is positive or negative.

26. In a Geiger-Marsden experiment, calculate the distance of closest approach to the nucleus of $Z = 80$, when an α-particle of $8\,\text{MeV}$ energy impinges on it before it comes momentarily to rest and reverses its direction.

How will the distance of closest approach be affected when the kinetic energy of the α-particle is doubled? [3 marks]

Solution:

Concept:

- In a head-on encounter, an alpha particle of charge $+2e$ is repelled by a nucleus of charge $+Ze$. At its closest approach the alpha particle is momentarily at rest.
- Taking the target nucleus as stationary and the initial electrostatic potential energy as zero, conservation of energy gives $K = (4\pi\varepsilon_0)^{-1}2Ze^2/r_{\min}$. Here K is the incident kinetic energy and $r_{\min}$ the closest separation.

Step 1: Apply energy conservation at the turning point The particle reverses its direction, so this is a head-on approach rather than a glancing collision. As it approaches the nucleus, its kinetic energy decreases and electrostatic potential energy increases. At the turning point all the initial kinetic energy has become electrostatic potential energy:

$$K = \frac{k(2e)(Ze)}{r_{\min}}, \qquad r_{\min} = \frac{2Zke^2}{K}, \qquad k = \frac{1}{4\pi\varepsilon_0}.$$

The relevant charge of the alpha particle is $2e$, not e, because it contains two protons.

Step 2: Substitute the incident energy and nuclear charge With $Z = 80$, $k = 9.0 \times 10^9\,\text{N m}^2\text{C}^{-2}$, and $e = 1.6 \times 10^{-19}\,\text{C}$, first convert the kinetic energy to joules:

$$K = 8 \times 10^6 \times 1.6 \times 10^{-19} = 1.28 \times 10^{-12}\,\text{J}.$$

Therefore,

$$r_{\min} = \frac{2 \times 80 \times 9.0 \times 10^9 \times (1.6 \times 10^{-19})^2}{1.28 \times 10^{-12}}$$
$$= 2.88 \times 10^{-14}\,\text{m} = 28.8\,\text{fm}.$$

This is the separation of the centres at the turning point, not the radius of the target nucleus.

Step 3: Double the alpha particle's kinetic energy The nuclear charge and alpha particle charge remain fixed, so $r_{\min} \propto 1/K$. If the initial kinetic energy becomes $K' = 2K = 16\,\text{MeV}$, then

$$r'_{\min} = \frac{2Zke^2}{2K} = \frac{r_{\min}}{2} = 1.44 \times 10^{-14}\,\text{m}.$$

The more energetic alpha particle penetrates closer before electrostatic repulsion brings it to rest.

Step 4: Conclusion The distance of closest approach is $\boxed{2.88 \times 10^{-14}\,\text{m}}$. Doubling the incident kinetic energy halves it to $\boxed{1.44 \times 10^{-14}\,\text{m}}$.

Quick Tip to Solve: For a head-on alpha-particle encounter, remember the charge product is $2Ze^2$ and the closest distance varies inversely with kinetic energy.

OR

26. The ground state energy of hydrogen atom is -13.6 eV. If an electron makes a transition from an energy level -0.85 eV to -3.4 eV, calculate the wavelength of the spectral line emitted. To which series of hydrogen spectrum does this wavelength belong? [3 marks]

Solution:

Concept:

- In hydrogen, the energy of level n is $E_n = -13.6/n^2$ eV, with $n = 1, 2, 3, \ldots$. The ground state corresponds to $n = 1$.
- When an electron moves from a higher to a lower energy level, it emits a photon with $E_\gamma = E_i - E_f = h\nu = hc/\lambda$. The spectral series is determined by the final principal quantum number.

Step 1: Identify the initial and final energy levels Both energies are negative because the electron is bound. The state -0.85 eV has a higher energy than -3.4 eV, so the transition releases energy. Using the given ground-state energy,

$$n_i^2 = \frac{13.6}{0.85} = 16, \quad n_i = 4; \qquad n_f^2 = \frac{13.6}{3.4} = 4, \quad n_f = 2.$$

Thus the electron makes a downward transition from the fourth level to the second level.

Step 2: Calculate the emitted photon energy Subtract the final energy from the initial energy, keeping both negative signs:

$$\begin{aligned} E_\gamma &= (-0.85) - (-3.4) = 2.55\,\text{eV} \\ &= 2.55 \times 1.602 \times 10^{-19}\,\text{J} \\ &= 4.0851 \times 10^{-19}\,\text{J}. \end{aligned}$$

The positive energy difference is carried away by the emitted photon; the electron's own energy decreases by the same amount.

Step 3: Find the wavelength and identify the series With $h = 6.626 \times 10^{-34}$ J s and $c = 3.00 \times 10^8$ m s^{-1},

$$\begin{aligned} \lambda = \frac{hc}{E_\gamma} &= \frac{6.626 \times 10^{-34} \times 3.00 \times 10^8}{4.0851 \times 10^{-19}} \\ &\simeq 4.87 \times 10^{-7}\,\text{m} = 487\,\text{nm}. \end{aligned}$$

Since the final level is $n_f = 2$, the emitted line belongs to the **Balmer series**. In particular, the $4 \to 2$ transition is the visible H_β line.

Step 4: Conclusion The emitted wavelength is approximately $\boxed{4.87 \times 10^{-7}\,\text{m}}$ (about 487 nm). It belongs to the $\boxed{\text{Balmer series}}$, because the transition ends at $n = 2$.

Quick Tip to Solve: Subtract the two signed energies to obtain the positive photon energy, then use the final level alone to name the spectral series.

27. Define relaxation time of the free electrons drifting in a conductor. How is it related to the drift velocity of free electrons? Use this relation to deduce the expression for the electrical resistivity of the material. [3 marks]

Solution:

Concept:

- Relaxation time τ is the mean time interval between successive collisions of a conduction electron with the ions of the conductor.
- An electron has charge $-e$ and mass m. In an electric field $\vec{E}$, its acceleration is $\vec{a} = -e\vec{E}/m$.
- If n is the number of free electrons per unit volume, current density has magnitude $J = nev_d$. Resistivity ρ is defined by $E = \rho J$.

Step 1: Define relaxation time and obtain drift velocity Electrons have random thermal velocities in a conductor. Without an applied field, their average velocity is zero, so there is no net current. When an electric field is applied, electrons acquire a small average velocity opposite to the field, called drift velocity. Collisions interrupt their acceleration. The average interval between successive collisions is the relaxation time τ. Averaging the field-induced change in velocity over this interval gives

$$\vec{v}_d = \vec{a}\tau = -\frac{e\tau}{m}\vec{E}, \qquad v_d = \frac{eE\tau}{m}.$$

The minus sign indicates that electron drift is opposite to the electric field; v_d denotes its magnitude.

Step 2: Relate electron drift to current In a conductor of cross-sectional area A, the electrons crossing a section in time dt occupy a cylinder of length $v_d dt$. Their number is $nAv_d dt$, giving current magnitude

$$I = \frac{neAv_d dt}{dt} = neAv_d, \qquad J = \frac{I}{A} = nev_d.$$

Conventional current flows opposite to electron drift and therefore along the applied field.

Step 3: Deduce the material resistivity Substituting the drift-speed expression into current density gives

$$J = ne\left(\frac{eE\tau}{m}\right) = \frac{ne^2\tau}{m}E.$$

Comparison with $J = \sigma E = E/\rho$ identifies the conductivity as $\sigma = ne^2\tau/m$. Thus resistivity is the reciprocal of this conductivity and depends on the electron density and the mean collision interval, rather than on the conductor's length or area.

Step 4: Conclusion Relaxation time is the mean interval between successive electron collisions. Its relation to drift velocity is $\vec{v}_d = -e\tau\vec{E}/m$, and the resistivity is $\boxed{\rho = m/(ne^2\tau)}$, measured in Ω m.

Quick Tip to Solve: Start with $v_d = eE\tau/m$, substitute into $J = nev_d$, and read resistivity from E/J; keep the electron-direction minus sign separate from the positive current magnitude.

28. (a) In Young's double slit experiment, derive the condition for (i) constructive interference and (ii) destructive interference at a point on the screen.

(b) A beam of light consisting of two wavelengths, 800 nm and 600 nm is used to obtain the interference fringes in a Young's double slit experiment on a screen placed 1.4 m away. If the two slits are separated by 0.28 mm, calculate the least distance from the central bright maximum where the bright fringes of the two wavelengths coincide. [5 marks]

Solution:

Concept:

- Interference is the superposition of coherent waves. The two slits must maintain a fixed phase difference and emit light of the same frequency for a stationary fringe pattern of each wavelength.
- A path difference Δ produces phase difference $\phi = 2\pi\Delta/\lambda$, where λ is the wavelength. In Young's experiment, $\Delta = d\sin\theta \simeq dy/D$, with slit separation d, screen distance D, and transverse displacement y.
- For equal slit intensities I_0, the resultant intensity is $I = 4I_0\cos^2(\phi/2)$. Bright-fringe positions are $y_m = m\lambda D/d$.

Step 1: (a) Obtain the resultant intensity Let the disturbances arriving at a point P on the screen be $a\sin\omega t$ and $a\sin(\omega t+\phi)$. Since the two slits are illuminated by the same source, they act as coherent secondary sources. Adding the disturbances gives

$$u = 2a\cos(\phi/2)\sin(\omega t+\phi/2),$$
$$I = 4I_0\cos^2(\phi/2) = 2I_0(1+\cos\phi).$$

Here intensity is proportional to the square of the resultant amplitude. A difference of one complete wavelength corresponds to a phase difference of 2π, so $\phi = 2\pi\Delta/\lambda$.

Step 2: (a)(i) Derive the condition for constructive interference At a bright fringe, the arriving waves are in phase and their amplitudes add. The intensity is maximum when $\cos\phi = 1$, giving

$$\phi = 2m\pi \quad\Longrightarrow\quad \Delta = m\lambda, \qquad m = 0, \pm1, \pm2, \ldots.$$

Since $\Delta = d\sin\theta \simeq dy/D$, the positions of constructive interference are $y_m = m\lambda D/d$. The central bright fringe is the case $m = 0$, where the paths from both slits are equal.

Step 3: (a)(ii) Derive the condition for destructive interference At a dark fringe, the arriving waves are in opposite phase. For equal amplitudes they cancel, and the intensity vanishes when $\cos\phi = -1$. Hence

$$\phi = (2k+1)\pi \quad\Longrightarrow\quad \Delta = \left(k+\frac{1}{2}\right)\lambda, \qquad k\in\mathbb{Z}.$$

The dark-fringe positions are therefore $y = (k+1/2)\lambda D/d$. Thus an integral wavelength path difference gives a maximum, whereas an odd half-wavelength path difference gives a minimum.

Step 4: (b) Find the first coincident bright-fringe orders Each wavelength produces its own interference pattern. Their bright fringes coincide at the same displacement if

$$\frac{m_1\lambda_1 D}{d} = \frac{m_2\lambda_2 D}{d} \quad\Longrightarrow\quad 800m_1 = 600m_2.$$

Quick Tip to Solve: For coincident bright fringes, first reduce the wavelength ratio to obtain the smallest integer orders; here $800:600 = 4:3$, so use orders 3 and 4 before substituting into $y = m\lambda D/d$.

Thus $4m_1 = 3m_2$. Excluding the central maximum, the smallest positive integer orders are $m_1 = 3$ for 800 nm and $m_2 = 4$ for 600 nm. The smallest common nonzero path difference is consequently $3(800) = 4(600) = 2400$ nm.

Step 5: (b) Calculate the distance on the screen Convert the supplied dimensions to SI units: $D = 1.4$ m, $d = 0.28 \times 10^{-3}$ m, and $\lambda_1 = 800 \times 10^{-9}$ m. Substitution gives

$$y = \frac{3(800 \times 10^{-9})(1.4)}{0.28 \times 10^{-3}} \text{ m}$$
$$= 1.2 \times 10^{-2} \text{ m} = 12 \text{ mm}.$$

As a check, the individual fringe widths are $\beta_{800} = 4$ mm and $\beta_{600} = 3$ mm; their third and fourth bright fringes respectively occur at 12 mm. The same coincidence occurs symmetrically on either side of the centre.

Step 6: Conclusion Constructive interference requires $\boxed{\Delta = m\lambda}$, and destructive interference requires $\boxed{\Delta = (k + 1/2)\lambda}$. The least nonzero distance of coincident bright fringes from the central maximum is $\boxed{12 \text{ mm} = 1.2 \text{ cm}}$.

Quick Tip to Solve: For coincident bright fringes, first reduce the wavelength ratio to obtain the smallest integer orders; here $800 : 600 = 4 : 3$, so use orders 3 and 4 before substituting into $y = m\lambda D/d$.

OR

28. (a) How does an unpolarized light incident on a polaroid get polarized?

Describe briefly, with the help of a necessary diagram, the polarization of light by reflection from a transparent medium.

(b) Two polaroids 'A' and 'B' are kept in crossed position. How should a third polaroid 'C' be placed between them so that the intensity of polarized light transmitted by polaroid B reduces to $\frac{1}{8}$th of the intensity of unpolarized light incident on A? [5 marks]

Solution:

Concept:

- Unpolarized light has electric-field vibrations in all directions perpendicular to its direction of propagation. A polaroid transmits only the component parallel to its transmission axis.
- At Brewster's angle i_B, the reflected light is completely plane polarized and the reflected and refracted rays are perpendicular. For incidence from air, $\mu = \tan i_B$, where μ is the refractive index of the transparent medium.
- Malus's law gives $I = I_p \cos^2\theta$, where I_p is the incident polarized intensity and θ is the angle between its polarization direction and the next polaroid's transmission axis. An ideal first polaroid transmits half the incident unpolarized intensity.

Step 1: Explain polarization by a polaroid in part (a) A polaroid is a dichroic material: it absorbs the electric-field component along one direction much more strongly than the perpendicular component. Resolve each incident electric-field vibration into components parallel and perpendicular to its

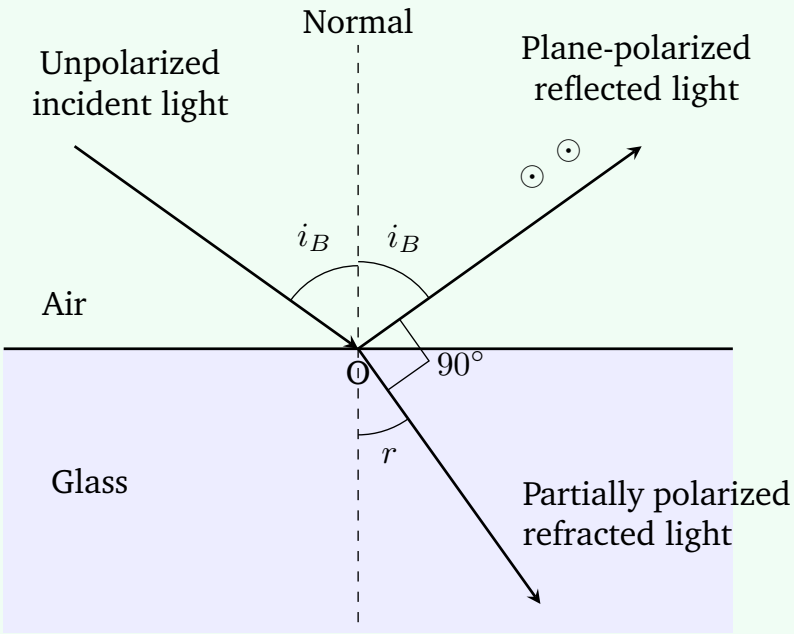
Quick Tip to Solve: Include the initial factor of $1/2$ for unpolarized light. For crossed outer polaroids, use $I_B/I_0 = \sin^2(2\theta)/8$; the required $1/8$ is reached when the middle axis bisects their axes.

transmission axis. The parallel component is transmitted, while the perpendicular component is absorbed. Therefore, all transmitted vibrations are along the same axis, and the emerging light is plane polarized. For uniformly distributed incident vibration directions, the average value of $\cos^2\theta$ is $1/2$; thus the transmitted intensity is $I_0/2$ for an ideal polaroid, with I_0 the unpolarized incident intensity.

Step 2: Describe polarization by reflection in part (a) Direct unpolarized light onto the plane surface of a transparent medium, such as glass. The reflected light is generally partially polarized. At the particular angle of incidence i_B, called the polarizing or Brewster angle, the reflected beam becomes completely plane polarized. Its electric-field vibrations are perpendicular to the plane of incidence, which is the plane containing the incident ray and the normal. In the diagram this plane is the page, so the reflected electric field is perpendicular to the page. The refracted light remains partially polarized. At this incidence, the reflected and refracted rays are at right angles, giving $i_B + r = 90^\circ$. Applying Snell's law for incidence from air gives

$$\mu = \frac{\sin i_B}{\sin r} = \frac{\sin i_B}{\cos i_B} = \tan i_B.$$

This is Brewster's law. Merely reflecting at an arbitrary incidence angle does not give complete polarization.



Polarization by reflection at Brewster's angle; the reflected electric field is perpendicular to the page.

Step 3: Apply Malus's law to the three polaroids in part (b) Let A's transmission axis define 0°. Since A and B are crossed, B's axis is at 90°. Place C between them with its axis at an angle θ to A's axis; its angle to B's axis is $90^\circ - \theta$. The first polaroid A converts the unpolarized input into polarized light, so

Quick Tip to Solve: Include the initial factor of $1/2$ for unpolarized light. For crossed outer polaroids, use $I_B/I_0 = \sin^2(2\theta)/8$; the required $1/8$ is reached when the middle axis bisects their axes.

the successive transmitted intensities are

$$I_A = \frac{I_0}{2},$$
$$I_C = \frac{I_0}{2}\cos^2\theta,$$
$$I_B = \frac{I_0}{2}\cos^2\theta\cos^2(90^\circ - \theta)$$
$$= \frac{I_0}{2}\cos^2\theta\sin^2\theta = \frac{I_0}{8}\sin^2(2\theta).$$

C changes the polarization direction to its own axis; consequently a component can pass through B even though A and B remain crossed.

Step 4: Impose the required transmitted intensity The question requires $I_B = I_0/8$. Substituting this into the preceding expression gives

$$\sin^2(2\theta) = 1.$$

Taking the angle between the crossed axes in the range $0^\circ \le \theta \le 90^\circ$, this requires $2\theta = 90^\circ$, or $\theta = 45^\circ$. The resulting sequence is $I_A = I_0/2$, $I_C = I_0/4$, and $I_B = I_0/8$. Thus C's axis must bisect the right angle between A's and B's axes; either equivalent bisector direction gives the same intensity.

Step 5: Conclusion (a) A polaroid selects one electric-field vibration direction by selective absorption. Reflection at Brewster's angle produces completely plane-polarized reflected light, with vibrations perpendicular to the plane of incidence and $\mu = \tan i_B$. (b) Place C between A and B with its transmission axis at 45° to each of their axes; then B transmits $I_0/8$.

Quick Tip to Solve: Include the initial factor of $1/2$ for unpolarized light. For crossed outer polaroids, use $I_B/I_0 = \sin^2(2\theta)/8$; the required $1/8$ is reached when the middle axis bisects their axes.

29. (a) Describe briefly, with the help of a diagram, the role of the two important processes involved in the formation of a p-n junction.

(b) Name the device which is used as a voltage regulator. Draw the necessary circuit diagram and explain its working. [5 marks]

Solution:

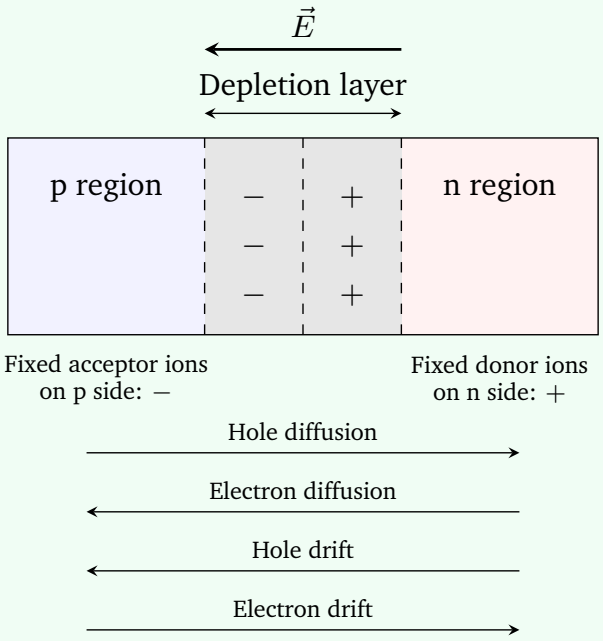
Concept:

- Diffusion is the motion of carriers from higher to lower concentration: electrons diffuse from the n region to the p region, while holes diffuse from p to n.
- Drift is carrier motion under the junction electric field. The depletion layer contains fixed negative acceptor ions on the p side and positive donor ions on the n side.
- A Zener diode maintains an approximately constant reverse voltage V_Z in its breakdown region. A series resistor limits the current, and the load is connected in parallel with the diode.

Step 1: (a) Diffusion establishes the depletion layer When p-type and n-type semiconductor regions are joined, there is a large carrier concentration difference across the junction. Majority electrons diffuse from n to p and majority holes diffuse from p to n. Near the junction these carriers recombine.

Quick Tip to Solve: In the regulator sketch, put the Zener cathode at the positive output node and the load in parallel with the Zener; draw the junction field from n to p.

The n side is consequently left with immobile positively charged donor ions, while the p side is left with immobile negatively charged acceptor ions. The region depleted of mobile majority carriers is the depletion layer. These fixed charges produce an electric field directed from the n side towards the p side and establish a potential barrier that opposes further majority-carrier diffusion.

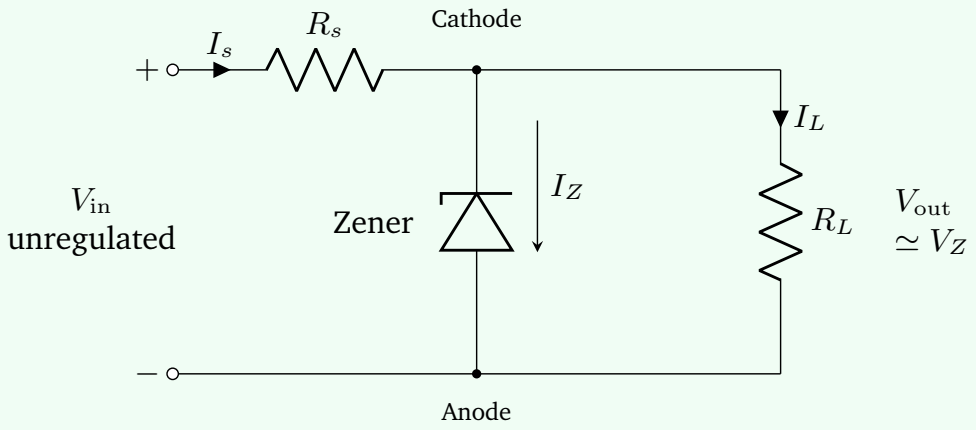


Unbiased junction: fixed ions, depletion layer and opposing carrier motions

Step 2: (a) Drift balances diffusion at equilibrium The junction field drives electrons towards the n region and holes towards the p region, opposite to their respective diffusion directions. This field-driven carrier motion produces the drift current, due mainly to minority carriers. As the depletion layer and potential barrier develop, the diffusion current decreases. At thermal equilibrium, with no applied voltage, drift and diffusion currents are equal in magnitude and opposite in direction, so the net current through the junction is zero. The two processes continue microscopically; equilibrium does not mean that all carrier motion stops.

Step 3: (b) Connect a Zener diode as a voltage regulator The device is a Zener diode. Connect it in reverse bias across the load R_L, with its cathode connected to the positive output terminal and its anode to the negative terminal. Connect a suitable resistor R_s in series with the unregulated supply. Choose the supply and resistor so that the diode operates in reverse breakdown without exceeding its permissible current or power. In this region a substantial change in reverse current produces only a small change in voltage, hence the load voltage is approximately V_Z.

Quick Tip to Solve: In the regulator sketch, put the Zener cathode at the positive output node and the load in parallel with the Zener; draw the junction field from n to p.



Zener shunt regulator with the diode reverse biased across the load

Step 4: (b) Explain regulation for supply and load changes The series current splits into the load current and Zener current:

$$I_s = \frac{V_{\text{in}} - V_Z}{R_s} = I_L + I_Z, \qquad I_L = \frac{V_Z}{R_L}.$$

If the input voltage rises, the extra current flows mainly through the Zener diode and the additional voltage is dropped across R_s; the output remains nearly constant. If the input falls, I_Z decreases. Similarly, when the load draws more current, the diode current decreases, and when the load draws less current, the diode current increases. Regulation holds provided the Zener remains in its breakdown operating range and below its maximum power rating. The resistor is essential because it limits the diode current.

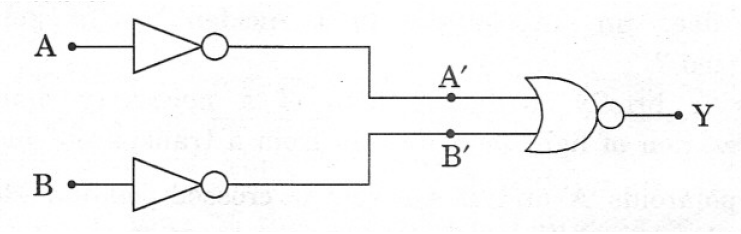
Step 5: Conclusion The two processes are diffusion and drift; their opposing currents balance in an unbiased p-n junction. A reverse-biased Zener diode operating in breakdown, connected across the load with a series current-limiting resistor, gives $V_{\text{out}} \simeq V_Z$.

Quick Tip to Solve: In the regulator sketch, put the Zener cathode at the positive output node and the load in parallel with the Zener; draw the junction field from n to p.

OR

29. (a) Explain briefly the principle on which a transistor-amplifier works as an oscillator. Draw the necessary circuit diagram and explain its working.

(b) Identify the equivalent gate for the following circuit and write its truth table. [5 marks]



Solution:

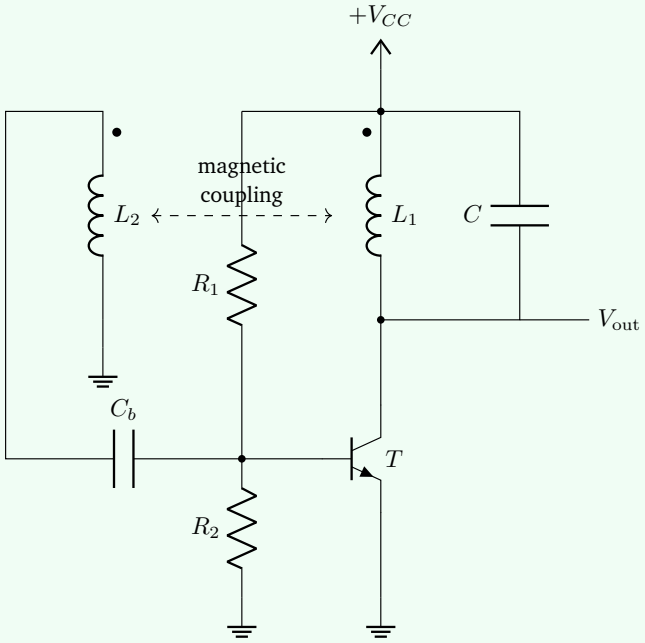
Concept:

- An oscillator converts energy from a d.c. supply into a sustained a.c. signal without an externally applied periodic input. Positive feedback returns a suitable fraction of the output to the amplifier input in phase with the input.
- For sustained oscillation, the loop gain satisfies $A\beta = 1$ in magnitude and the total phase change around the loop is 0° or an integral multiple of 360°, where A is amplifier gain and β is the feedback fraction.
- An ideal LC tank exchanges energy between the capacitor's electric field and the inductor's magnetic field at frequency $f_0 = 1/(2\pi\sqrt{L_1 C})$. The transistor supplies the energy lost in the real circuit.
- De Morgan's theorem gives $\overline{\overline{A} + \overline{B}} = AB$. A NOT gate on each input followed by a NOR gate is therefore equivalent to an AND gate.

Step 1: (a) Principle and circuit of the transistor oscillator A transistor amplifier acts as an oscillator when part of its output is fed back with the phase required to reinforce its input. The diagram shows an inductively coupled LC oscillator using an npn transistor in the common-emitter arrangement. The parallel combination L_1C forms the collector tank circuit; L_2 is magnetically coupled to L_1 and supplies feedback to the base through the coupling capacitor C_b. Resistors R_1 and R_2 provide base bias, while C_b prevents the feedback winding from disturbing the d.c. bias.

A common-emitter amplifier introduces a phase reversal of 180°. The winding connections provide the additional reversal needed for the voltage returned to the base to reinforce the original base signal. The winding polarity is chosen for positive feedback; reversing one winding would give negative feedback and prevent sustained oscillations.

Quick Tip to Solve: For an oscillator, check both the feedback phase and replacement of tank losses. For the logic circuit, write the NOR expression with one outer bar before applying De Morgan's theorem.



Common-emitter LC oscillator with inductive positive feedback; the dots show winding polarity.

Step 2: (a) Start-up and sustained working On switching on the supply, a small transient or electrical noise starts a change in collector current. This excites the LC tank. As the capacitor discharges through L_1, its electric-field energy becomes magnetic-field energy in the coil. The collapsing magnetic field then charges the capacitor with the opposite polarity. This repeated interchange produces alternating voltage and current.

The changing flux in L_1 induces an alternating emf in L_2. With the indicated feedback polarity, that emf changes the base current so that the resulting amplified collector-current variation reinforces the oscillation. The transistor draws energy from the d.c. source and restores the energy dissipated by circuit resistance. Thus the oscillations do not die away as they would in an isolated practical LC circuit.

At start-up the small-signal loop gain must exceed unity for the oscillation to grow. As its amplitude grows, the effective gain settles to the value that just compensates losses, giving sustained oscillation. Approximately,

$$f_0 = \frac{1}{2\pi\sqrt{L_1 C}}.$$

No periodically varying external input is required: the feedback itself supplies the input signal.

Step 3: (b) Identify the equivalent logic gate The two triangular input gates with output bubbles are NOT gates, so their outputs are $\overline{A}$ and $\overline{B}$. These signals enter an OR-shaped gate with an output bubble, which is a NOR gate. Therefore,

$$\begin{aligned} Y &= \overline{\overline{A} + \overline{B}} \\ &= \overline{\overline{A}}\,\overline{\overline{B}} = AB. \end{aligned}$$

The equivalent gate is an AND gate. Its truth table, including intermediate values for the given circuit,

Quick Tip to Solve: For an oscillator, check both the feedback phase and replacement of tank losses. For the logic circuit, write the NOR expression with one outer bar before applying De Morgan's theorem.

is

A	B	$\overline{A}$	$\overline{B}$	$Y = AB$
0	0	1	1	0
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

Thus either low input makes at least one input of the NOR gate high, forcing its output low. Only when both original inputs are high are both inverted inputs low, so the NOR output becomes high.

Step 4: Conclusion (a) A transistor oscillator uses positive feedback and energy from its d.c. supply to sustain the LC tank oscillations, approximately at $f_0 = 1/(2\pi\sqrt{L_1 C})$. (b) The given logic circuit is equivalent to an AND gate: $Y = AB$, with outputs $0, 0, 0, 1$ for inputs $00, 01, 10, 11$, respectively.

Quick Tip to Solve: For an oscillator, check both the feedback phase and replacement of tank losses. For the logic circuit, write the NOR expression with one outer bar before applying De Morgan's theorem.

---

30. (a) Write the expression for the force, $\vec{F}$, acting on a charged particle of charge 'q', moving with a velocity $\vec{v}$ in the presence of both electric field $\vec{E}$ and magnetic field $\vec{B}$. Obtain the condition under which the particle moves undeflected through the fields.

(b) A rectangular loop of size $l \times b$ carrying a steady current I is placed in a uniform magnetic field $\vec{B}$. Prove that the torque $\vec{\tau}$ acting on the loop is given by $\vec{\tau} = \vec{m} \times \vec{B}$, where $\vec{m}$ is the magnetic moment of the loop. [5 marks]

Solution:

Concept:

- The Lorentz force on charge q moving with velocity $\vec{v}$ is $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$, where $\vec{E}$ and $\vec{B}$ are the electric and magnetic fields.
- A straight current-carrying segment in a uniform magnetic field experiences $\vec{F} = I\vec{L} \times \vec{B}$, with $\vec{L}$ along conventional current and of magnitude equal to the segment length.
- The magnetic moment of a single planar loop is $\vec{m} = IA\hat{n}$, where $A = lb$ and $\hat{n}$ is the unit normal given by the right-hand rule for the current. A couple has torque equal to either force times the perpendicular separation of its lines of action.

Step 1: (a) Write the force and impose zero deflection The electric force is $q\vec{E}$, and the magnetic force is $q\vec{v} \times \vec{B}$. Their vector sum is

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}.$$

For a charged particle to continue with its original velocity through the fields, the net transverse force must vanish; the standard force-free condition is

$$\vec{E} + \vec{v} \times \vec{B} = \vec{0}.$$

Thus the electric and magnetic forces must be equal in magnitude and opposite in direction. In the

Quick Tip to Solve: In a velocity selector check both force directions before using $v = E/B$. For a loop, measure θ from the area normal and use the separation of the force lines, not the full edge length, as the couple arm.

usual crossed-field arrangement, $\vec{E}$, $\vec{B}$ and the incident $\vec{v}$ are mutually perpendicular. Consequently,

$$|q|E = |q|vB, \qquad v = \frac{E}{B}.$$

The direction must also satisfy $\vec{v} \times \vec{B} = -\vec{E}$; equality of magnitudes alone is insufficient. The selected speed is independent of the charge magnitude and mass, and reversing the sign of the charge reverses both forces, preserving their cancellation. More generally, cancellation requires $\vec{E} \cdot \vec{B} = 0$, and the selected perpendicular velocity is $\vec{v}_\perp = \vec{E} \times \vec{B}/B^2$; any velocity component parallel to $\vec{B}$ adds no magnetic force.

Step 2: (b) Identify the forces on the rectangular loop Let θ be the angle between the area normal $\hat{n}$ and $\vec{B}$. First take the length-l sides perpendicular to $\vec{B}$, so that the two length-b sides lie in the plane containing $\hat{n}$ and $\vec{B}$. The uniform field produces equal and opposite forces of magnitude

$$F = IlB$$

on the length-l sides. These two forces have distinct parallel lines of action and constitute a couple. The forces on the other pair are also equal and opposite, but act along the same line, so their torque is zero. The total force on the closed loop is therefore zero, although its couple can rotate it.

Step 3: Find the couple arm and the torque magnitude The separation of the length-l sides is b. Its component perpendicular to their force direction is $b\sin\theta$. Therefore the torque of this pair is

$$\begin{aligned}\tau &= F(b\sin\theta)\\ &= (IlB)b\sin\theta\\ &= IAB\sin\theta = mB\sin\theta.\end{aligned}$$

The angle here is measured from the normal, not from the plane of the loop. The torque is zero when the normal is parallel or antiparallel to the field and maximum when the normal is perpendicular to the field.

Step 4: Establish the vector direction and general form The couple rotates the magnetic moment toward alignment with the field. Its direction follows $\hat{n} \times \vec{B}$. For an explicit check, take $\vec{B} = B\hat{z}$ and $\hat{n} = \sin\theta\,\hat{x} + \cos\theta\,\hat{z}$. Let the separation direction of the length-l sides be $\hat{u} = \cos\theta\,\hat{x} - \sin\theta\,\hat{z}$. With current along $+\hat{y}$ on the side at $+b\hat{u}/2$, its force is $+IlB\hat{x}$; the opposite side has the opposite force. Summing their moments gives

$$\vec{\tau} = bIlB(\hat{u} \times \hat{x}) = -IAB\sin\theta\,\hat{y} = IA\hat{n} \times \vec{B}.$$

The result does not depend on which edge is perpendicular to the field. For any planar closed loop in a uniform field, $d\vec{F} = I\,d\vec{r} \times \vec{B}$, and integration gives

$$\vec{\tau} = I\oint \vec{r} \times (d\vec{r} \times \vec{B}) = I\vec{A} \times \vec{B},$$

where $\vec{A} = \frac{1}{2}\oint \vec{r} \times d\vec{r} = A\hat{n}$ is its oriented area. Thus the rectangular-loop result holds for any

Quick Tip to Solve: In a velocity selector check both force directions before using $v = E/B$. For a loop, measure θ from the area normal and use the separation of the force lines, not the full edge length, as the couple arm.

orientation.

Step 5: Conclusion (a) $\boxed{\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})}$. Undeflected, force-free motion requires $\vec{E} = -\vec{v} \times \vec{B}$; for mutually perpendicular crossed fields, $v = E/B$ with the correct direction. (b) For $\vec{m} = Il\hat{bn}$, $\boxed{\vec{\tau} = \vec{m} \times \vec{B}}$, and $\tau = IlbB \sin\theta$.

Quick Tip to Solve: In a velocity selector check both force directions before using $v = E/B$. For a loop, measure θ from the area normal and use the separation of the force lines, not the full edge length, as the couple arm.

OR

30. (a) Explain, giving reasons, the basic difference in converting a galvanometer into (i) a voltmeter and (ii) an ammeter.

(b) Two long straight parallel conductors carrying steady currents I_1 and I_2 are separated by a distance d. Explain briefly, with the help of a suitable diagram, how the magnetic field due to one conductor acts on the other. Hence deduce the expression for the force acting between the two conductors. Mention the nature of this force. [5 marks]

Solution:

Concept:

- A galvanometer of resistance G gives full-scale deflection at current I_g. A voltmeter measures potential difference in parallel; an ammeter measures current in series.
- The magnetic field at perpendicular distance d from a long straight conductor carrying current I_1 is $B_1 = \mu_0 I_1/(2\pi d)$, where μ_0 is the permeability of free space.
- A length L of a conductor carrying current I_2 experiences magnetic force $\vec{F} = I_2\vec{L} \times \vec{B}$, with $\vec{L}$ directed along its current.

Step 1: (a)(i) Convert the galvanometer into a voltmeter Connect a high resistance R in series with the galvanometer. If the required voltage range is V, full-scale deflection occurs when the current through both series elements is I_g:

$$V = I_g(G + R), \qquad R = \frac{V}{I_g} - G.$$

The resulting voltmeter has high resistance $G + R$. When connected in parallel across a component, it draws very little current and therefore makes only a small change to the potential difference being measured. The series resistance also limits the galvanometer current to its safe full-scale value.

Step 2: (a)(ii) Convert the galvanometer into an ammeter Connect a small resistance S, called a shunt, in parallel with the galvanometer. For an ammeter range I, only I_g passes through the galvanometer and the remaining current $I - I_g$ passes through the shunt. Since the parallel branches

Quick Tip to Solve: Remember the instrument connections first: a voltmeter must draw little current, while an ammeter must produce little voltage drop. For wire forces, apply the right-hand rule for the field before applying the cross product for force.

have equal potential differences,

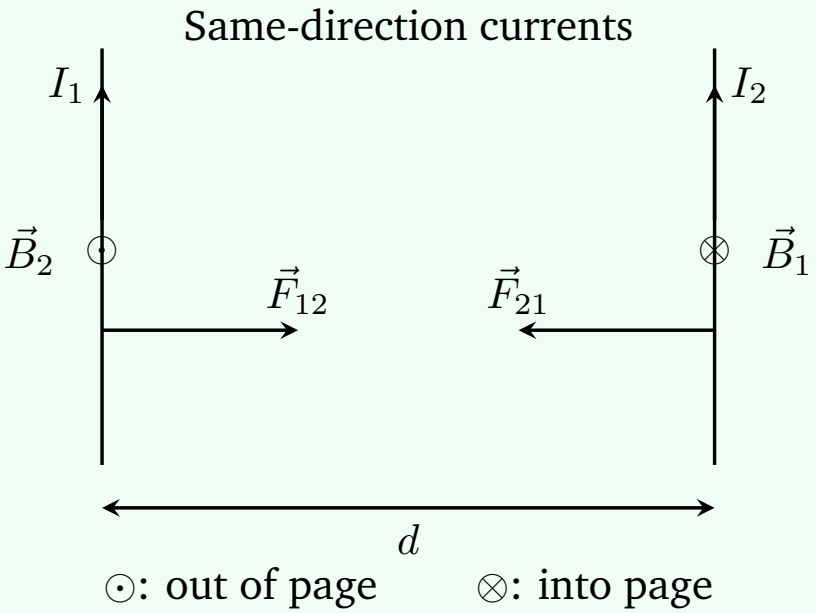
$$I_g G = (I - I_g)S, \qquad S = \frac{I_g G}{I - I_g}.$$

The ammeter resistance is $R_A = GS/(G+S)$, which is very small. Thus, when inserted in series, it causes little voltage drop and makes only a small change to the circuit current. The basic difference is therefore a high series resistance for voltage measurement and a low parallel resistance for current measurement.

Step 3: (b) Determine the field produced by the first conductor Take two long straight parallel conductors in air or vacuum, separated by d, with both currents directed upward as shown. By the right-hand thumb rule, the field $\vec{B}_1$ produced by the left conductor at the right conductor points into the page. Its magnitude is

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

Similarly, the field $\vec{B}_2$ produced by the right conductor at the left conductor points out of the page. Each conductor experiences a force due to the magnetic field of the other conductor.



Parallel currents in the same direction attract: the field at each wire is produced by the other wire.

Step 4: (b) Deduce the force and its direction Since the second conductor is perpendicular to $\vec{B}_1$, the magnitude of the force on its length L is

$$F_{21} = I_2 L B_1 \sin 90^\circ = \frac{\mu_0 I_1 I_2 L}{2\pi d}.$$

The direction from $I_2\vec{L} \times \vec{B}_1$, or Fleming's left-hand rule, is toward the first conductor. Applying the same reasoning to the first conductor gives an equal force directed toward the second conductor. Thus parallel currents in the same direction attract. If one current is reversed, the corresponding magnetic

Quick Tip to Solve: Remember the instrument connections first: a voltmeter must draw little current, while an ammeter must produce little voltage drop. For wire forces, apply the right-hand rule for the field before applying the cross product for force.

force directions reverse and currents in opposite directions repel. The force is magnetic, acts along the line joining the conductors, and is equal and opposite on corresponding equal lengths.

Step 5: Conclusion A galvanometer becomes a voltmeter with a high resistance in series and an ammeter with a low-resistance shunt in parallel. The force per unit length between two long parallel conductors is $F/L = \mu_0 I_1 I_2/(2\pi d)$. Currents in the same direction attract; currents in opposite directions repel.

Quick Tip to Solve: Remember the instrument connections first: a voltmeter must draw little current, while an ammeter must produce little voltage drop. For wire forces, apply the right-hand rule for the field before applying the cross product for force.