CBSE Class 12 Physics Question Paper 2006 with Solution PDF-Outside Delhi

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

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

General Instructions

(i) This question paper contains 27 questions. All questions are compulsory.

(ii) There is no overall choice. An internal choice is provided in 5 questions (Q10, Q18, Q25, Q26, Q27); attempt only one of the alternatives in such questions.

(iii) Marks for each question are indicated against it.

1. Define the term 'dielectric constant' of a medium in terms of capacitance of a capacitor. [1 mark]

Solution:

Concept:

- Capacitance is defined by $C = Q/V$, where Q is the charge on either plate and V is the potential difference.
- A dielectric increases capacitance by reducing the potential difference for the same stored charge.

Step 1: Specify the comparison Let C_0 be the capacitance with vacuum between the plates and C the capacitance when the space is completely filled with the medium. Keep the plate geometry unchanged.

Step 2: Form the ratio The dielectric constant is the ratio $K = C/C_0$. Since both numerator and denominator are capacitances, this ratio is dimensionless.

Step 3: Conclusion $\boxed{K = \frac{C}{C_0}}$: the capacitance with the medium divided by the capacitance with vacuum, for the same capacitor.

Quick Tip to Solve: Compare capacitances for identical plate area and separation, with the dielectric completely filling the gap.

2. Sketch a graph showing variation of resistivity of carbon with temperature. [1 mark]

Solution:

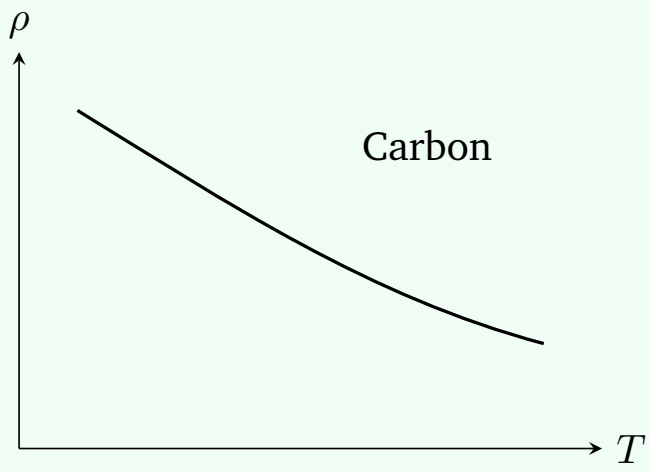
Concept:

- Resistivity ρ measures opposition to current independently of conductor dimensions.
- Carbon has a negative temperature coefficient of resistivity: $d\rho/dT < 0$.

Step 1: Choose the axes Take temperature T along the horizontal axis and resistivity ρ along the vertical axis. Resistivity stays positive in the temperature range represented.

Step 2: Show the variation As carbon is heated, its resistivity decreases. Thus the sketch slopes downwards from left to right. It is a qualitative graph; no numerical scale or precise functional dependence is required.

Quick Tip to Solve: For carbon, remember that heating lowers resistivity; draw a downward trend with both axes labelled.



Qualitative resistivity variation of carbon with temperature

Step 3: Conclusion The ρ-versus-T graph for carbon is a descending curve, showing its negative temperature coefficient.

Quick Tip to Solve: For carbon, remember that heating lowers resistivity; draw a downward trend with both axes labelled.

3. The vertical component of Earth's magnetic field at a place is $\sqrt{3}$ times the horizontal component. What is the value of angle of dip at this place? [1 mark]

Solution:

Concept:

- The angle of dip δ is the angle that Earth's magnetic field makes with the horizontal.
- Its vertical and horizontal components obey $B_V = B\sin\delta$ and $B_H = B\cos\delta$.

Step 1: Relate the components Dividing the vertical component by the horizontal component gives $\tan\delta = B_V/B_H$. The ratio specifies the inclination without requiring the total field magnitude.

Step 2: Substitute the given ratio Since $B_V = \sqrt{3}\,B_H$, we have $\tan\delta = \sqrt{3}$. The acute angle whose tangent is $\sqrt{3}$ is 60°.

Step 3: Conclusion The angle of dip is $\boxed{\delta = 60^\circ}$.

Quick Tip to Solve: Use vertical divided by horizontal for the tangent of dip; reversing that ratio gives the complementary angle.

4. With what purpose was famous Davisson-Germer experiment with electrons performed? [1 mark]

Solution:

Concept:

- De Broglie proposed that a moving particle has wavelength $\lambda = h/p$, where p is momentum.
- Diffraction is a characteristic wave phenomenon and can reveal the wave nature of electrons.

Step 1: Identify the observation Davisson and Germer scattered a beam of electrons from a nickel crystal. The regular atomic arrangement acted as a diffracting structure, giving intensity maxima at particular directions.

Step 2: Connect it to the purpose The electron diffraction pattern showed that electrons possess wave properties. The wavelength deduced from diffraction agreed with the de Broglie wavelength calculated from their momentum.

Step 3: Conclusion The experiment established the wave nature of electrons and experimentally verified de Broglie's matter-wave hypothesis.

Quick Tip to Solve: Associate Davisson–Germer with electron diffraction and de Broglie waves; diffraction identifies wave behaviour.

5. Name the type of communication in which the signal is a discrete and binary coded version of the message or information. [1 mark]

Solution:

Concept:

- In digital communication, information is represented using discrete symbols.
- Binary coding uses two symbols, 0 and 1, called bits, to represent the message.

Step 1: Recognise the signal form The question specifies a discrete signal rather than a signal that varies continuously. Its possible coded states are binary, so the information is expressed as a sequence of bits.

Step 2: Identify the communication type Transmission of a message represented by discrete binary-coded symbols is called digital communication. The binary sequence carries the encoded information from the transmitter to the receiver.

Step 3: Conclusion The required type is $\boxed{\text{Digital communication}}$.

Quick Tip to Solve: The combination of discrete values and binary coding directly identifies digital communication.

6. The electric field and electric potential at any point due to a point charge kept in air is $20\ \mathrm{NC}^{-1}$ and $10\ \mathrm{JC}^{-1}$ respectively. Compute the magnitude of this charge. [2 marks]

Solution:

Concept:

- For a point charge in air, $E = k|q|/r^2$, where r is the distance and $k = 1/(4\pi\varepsilon_0)$.
- Taking zero potential at infinity, $V = kq/r$. The given positive potential corresponds to a positive charge; its magnitude is required.

Step 1: Eliminate the charge to find distance For the positive values given, divide potential by field strength:

$$\frac{V}{E} = \frac{kq/r}{kq/r^2} = r.$$

Hence

$$r = \frac{10\,\mathrm{J\,C^{-1}}}{20\,\mathrm{N\,C^{-1}}} = 0.50\,\mathrm{m}.$$

The unit is metres because $\mathrm{J/N} = \mathrm{m}$.

Step 2: Calculate the charge magnitude Use $q = Vr/k$ with $k = 9.0 \times 10^9\ \mathrm{N\,m^2C^{-2}}$:

$$|q| = \frac{10 \times 0.50}{9.0 \times 10^9}\,\mathrm{C} = 5.56 \times 10^{-10}\,\mathrm{C}.$$

As a check, $k|q|/(0.50)^2 = 20\,\mathrm{N\,C^{-1}}$, which reproduces the specified field.

Step 3: Conclusion The magnitude of the point charge is $\boxed{|q| = 5.56 \times 10^{-10}\,\mathrm{C}}$, or approximately $0.56\,\mathrm{nC}$.

Quick Tip to Solve: For a single point charge, first use $r = |V|/E$; then obtain charge from $|q| = |V|r/k$.

7. Write the mathematical relation between mobility and drift velocity of charge carriers in a conductor. Name the mobile charge carriers responsible for conduction of electric current in (i) an electrolyte (ii) an ionised gas. [2 marks]

Solution:

Concept:

- Mobility μ is the magnitude of the average drift velocity acquired per unit applied electric field: $\mu = v_d/E$.
- Electric current is the directed motion of mobile charge carriers. The carriers depend on the medium and need not all be electrons.

Step 1: Relate mobility to drift velocity If E is the magnitude of the applied electric field and v_d is the magnitude of the drift velocity, then

$$v_d = \mu E, \qquad \mu = \frac{v_d}{E}.$$

Mobility has SI unit $\mathrm{m^2\,V^{-1}\,s^{-1}}$. This scalar relation uses speed; electrons drift opposite to the electric

Quick Tip to Solve: Use drift speed in $\mu = v_d/E$; remember that electrolytes conduct through ions, whereas an ionised gas also has free electrons.

field because their charge is negative.

Step 2: Identify the carriers in each medium (i) In an electrolyte, positive ions (cations) and negative ions (anions) carry current. They drift in opposite directions under the applied field, but their contributions to conventional current are in the same direction.

(ii) In an ionised gas, free electrons and positive ions carry current. Ionisation frees electrons from neutral atoms or molecules, leaving positive ions; both species can move in the electric field.

Step 3: Conclusion The required relation is $\boxed{v_d = \mu E}$. The mobile carriers are positive and negative ions in an electrolyte, and electrons and positive ions in an ionised gas.

Quick Tip to Solve: Use drift speed in $\mu = v_d/E$; remember that electrolytes conduct through ions, whereas an ionised gas also has free electrons.

8. State the principle of working of a cyclotron. Write two uses of this machine. [2 marks]

Solution:

Concept:

- A cyclotron accelerates charged particles using an alternating electric field while a uniform perpendicular magnetic field bends their paths into semicircles.
- For a non-relativistic particle of mass m and charge magnitude $|q|$, the cyclotron frequency is $f = |q|B/(2\pi m)$, independent of its speed and orbital radius.

Step 1: State the working principle A charged particle moving perpendicular to a uniform magnetic field follows a circular path because the magnetic force supplies the centripetal force:

$$|q|vB = \frac{mv^2}{r}, \qquad T = \frac{2\pi r}{v} = \frac{2\pi m}{|q|B}.$$

Thus its period is independent of speed in the non-relativistic regime. An alternating potential applied across two hollow D-shaped electrodes is adjusted to this frequency. Its polarity reverses during each semicircle, so the particle gains energy each time it crosses the gap and follows a spiral of increasing radius.

Step 2: Give two uses (i) A cyclotron produces energetic charged-particle beams for bombarding nuclei and studying nuclear reactions, including artificial transmutation.

(ii) It produces radioactive isotopes by bombarding suitable targets; these isotopes are used as tracers and in medical diagnosis or treatment. The magnetic field guides the particles, while the electric field supplies their energy.

Step 3: Conclusion A cyclotron works by resonant acceleration of charged particles with an alternating electric field in a perpendicular magnetic field. Two uses are nuclear-reaction studies and production of radioactive isotopes.

Quick Tip to Solve: State that the non-relativistic revolution frequency is independent of speed; the electric field accelerates and the magnetic field bends the path.

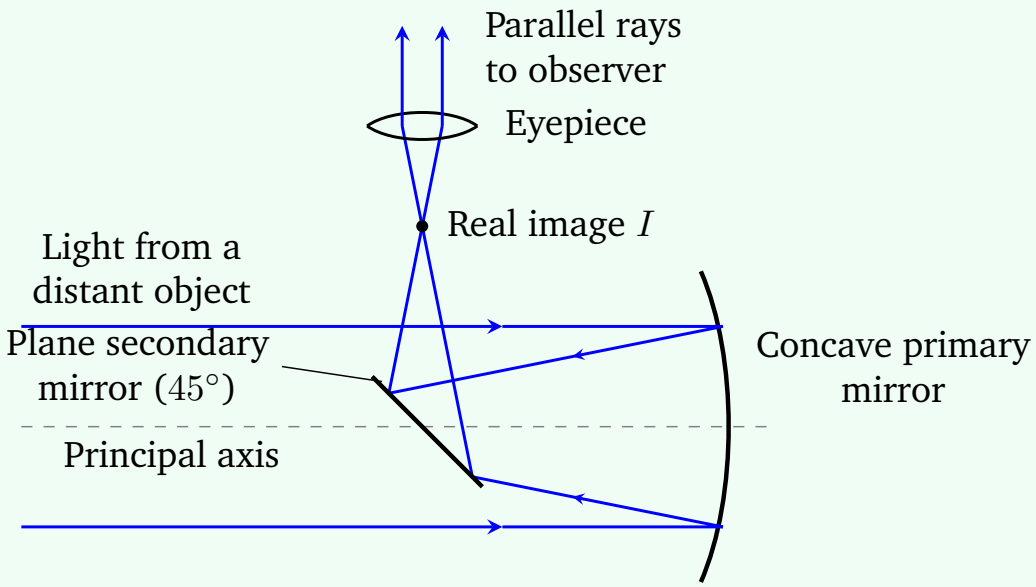
9. Draw a labelled ray diagram of a reflecting type telescope. Write its any one advantage over refracting type telescope. [2 marks]

Solution:

Concept:

- A reflecting telescope uses a concave primary mirror to collect light from a distant object and form a real image. An eyepiece magnifies this image.
- Reflection does not disperse light into its constituent colours, so a mirror objective avoids chromatic aberration.

Step 1: Draw the reflecting telescope The labelled diagram shows a Newtonian reflecting telescope. Parallel rays from a distant object fall on the concave primary mirror. The reflected rays converge, and a small plane mirror inclined at 45° redirects the converging beam towards the side of the telescope. The real image I lies at the first focal plane of the eyepiece; the eyepiece gives an enlarged angular view with parallel emergent rays for normal adjustment.



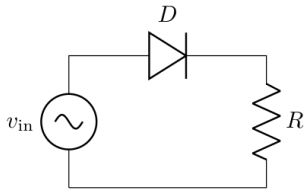
Newtonian reflecting telescope in normal adjustment (schematic)

Step 2: State an advantage over a refracting telescope A reflecting telescope is free from chromatic aberration at its objective. The law of reflection is the same for all colours, so the primary mirror brings different wavelengths to the same focus. In a refracting telescope, the refractive index of the objective lens varies with wavelength, giving different focal lengths for different colours unless corrective lens combinations are used.

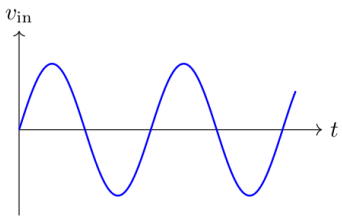
Step 3: Conclusion The Newtonian arrangement uses a concave primary mirror, a 45° plane secondary mirror and an eyepiece as shown. Its mirror objective is free from chromatic aberration.

Quick Tip to Solve: Draw the secondary before the primary focus and label the real image at the eyepiece's focal plane; cite absence of chromatic aberration.

10. Draw and explain the output waveform across the load resistor R, if the input waveform is as shown in the given figure. [2 marks]



Diode circuit



Input waveform

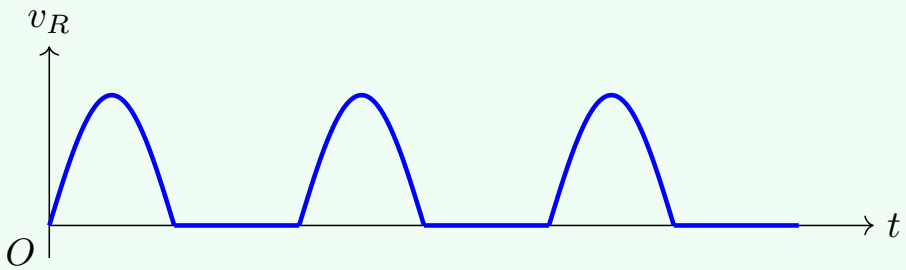
Solution:

Concept:

- A junction diode conducts when its anode is positive relative to its cathode (forward bias), and blocks current in reverse bias.
- The potential difference across the load is $v_R = iR$, where i is the current through resistance R. For an ideal conducting diode, the voltage drop across the diode is negligible.

Step 1: Follow the positive half-cycle During each positive half-cycle of the input, the upper terminal of the source is positive. The diode is forward biased, so current flows from the source through the diode and then downward through R. The upper end of the resistor is therefore positive. Since the diode offers negligible resistance, the output across R follows the positive half of the input waveform: $v_R = v_{in}$ when $v_{in} > 0$.

Step 2: Follow the negative half-cycle and plot the output During a negative half-cycle, the diode is reverse biased. Its resistance is very high and the circuit current is practically zero. Thus $v_R = iR = 0$ throughout that half-cycle. The same process repeats for each input cycle, producing positive pulses separated by zero-output intervals. The output is unidirectional but varies with time; it is a pulsating direct voltage, rather than a steady direct voltage.



Positive half-wave rectified voltage across the load resistor

Step 3: Conclusion The output waveform contains only the positive half-cycles of the input. Negative half-cycles are suppressed, so the circuit acts as a half-wave rectifier.

Quick Tip to Solve: Check the diode's anode and cathode for each half-cycle; draw the input shape only when the diode conducts and put the output on the time axis when it blocks.

OR

10. Explain how the width of depletion layer in a p-n junction diode changes when the junction is (i) forward biased (ii) reverse biased. [2 marks]

Solution:

Concept:

- The depletion layer consists of immobile ionised donors and acceptors near the junction, left behind when majority carriers diffuse and recombine. It has very few mobile charge carriers.
- The electric field of these fixed ions creates the built-in potential barrier, which opposes further majority-carrier diffusion. Applied bias changes the effective barrier and the depletion width.

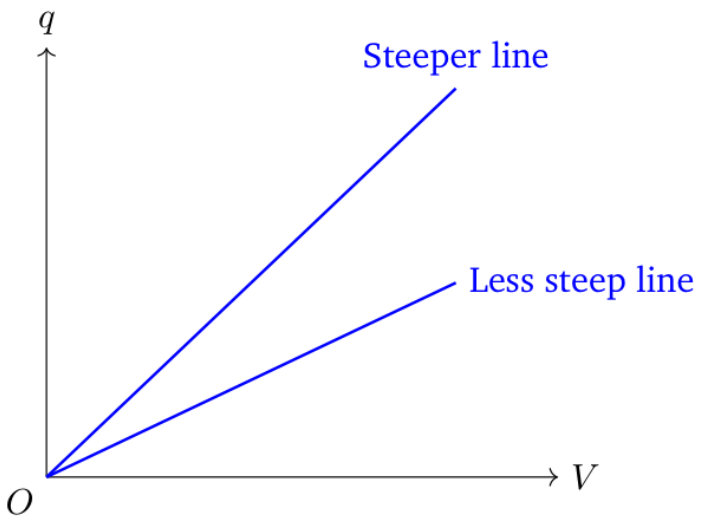
Step 1: Apply forward bias Connect the p-side to the positive terminal and the n-side to the negative terminal of the battery. The applied field opposes the junction's built-in field and lowers the potential barrier. Holes on the p-side and electrons on the n-side are driven towards the junction; the battery supplies these majority carriers. They reduce the region depleted of mobile carriers. Hence the depletion layer becomes narrower and majority carriers can cross the junction more readily, allowing a substantial forward current.

Step 2: Apply reverse bias Connect the p-side to the negative terminal and the n-side to the positive terminal. The applied field reinforces the built-in field and increases the effective barrier. Holes and electrons are pulled away from the junction towards their respective battery terminals. More immobile ions are exposed near the junction, extending the region with almost no mobile carriers. Therefore the depletion layer becomes wider and majority-carrier current is blocked; only a small minority-carrier current flows below breakdown.

Step 3: Conclusion (i) Forward bias decreases the depletion-layer width. (ii) Reverse bias increases the depletion-layer width.

Quick Tip to Solve: Remember the carrier motion: forward bias pushes majority carriers towards the junction and narrows the layer; reverse bias pulls them away and widens it.

11. The given graph shows the variation of charge q versus potential difference V for two capacitors C_1 and C_2. The two capacitors C_1 and C_2 have same plate separation but the plate area of C_2 is double than that of C_1. Which of the lines in the graph correspond to C_1 and C_2 and why? [2 marks]



Solution:

Concept:

- The charge stored by a capacitor is $q = CV$, where C is its capacitance and V is the potential difference across its plates. Thus the slope of a graph with charge on the vertical axis and voltage on the horizontal axis is $q/V = C$.
- For a parallel-plate capacitor, $C = \varepsilon A/d$, where A is plate area, d is plate separation and ε is the permittivity of the medium between the plates.

Step 1: Compare the capacitances from plate areas The two capacitors have equal plate separation and the same intervening medium. Hence capacitance is proportional to plate area. With $A_2 = 2A_1$,

$$\frac{C_2}{C_1} = \frac{\varepsilon A_2/d}{\varepsilon A_1/d} = \frac{A_2}{A_1} = 2.$$

Therefore the larger-area capacitor stores twice as much charge at the same applied potential difference.

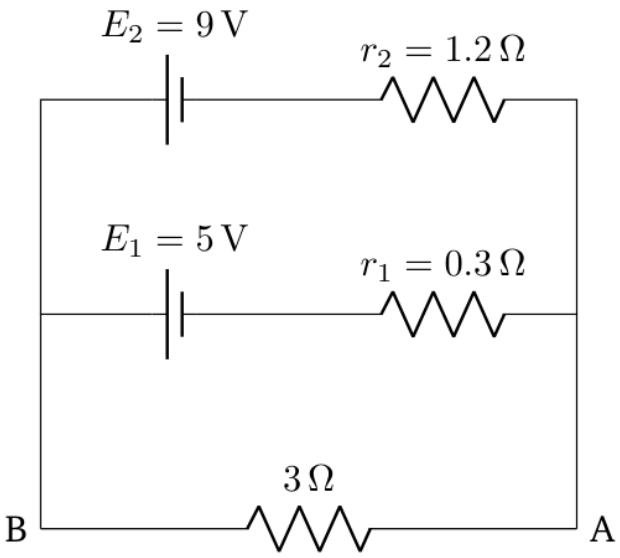
Step 2: Identify the lines using their slopes Since $q = CV$, both lines pass through the origin. A larger capacitance means a greater rise in charge for the same increase in voltage, so it gives the steeper line. Thus the steeper line represents C_2, while the less steep line represents C_1. In particular, at any common nonzero voltage, the ordinate on the C_2 line is twice the ordinate on the C_1 line; its slope is also twice as large.

Step 3: Conclusion The steeper line corresponds to C_2; the less steep line corresponds to C_1, because $C_2 = 2C_1$ and the slope of the q-versus-V graph equals capacitance.

Quick Tip to Solve: Read the axes before comparing slopes: on a charge-versus-voltage graph the steeper line means larger capacitance, while swapping the axes reverses that rule.

12. Two cells E_1 and E_2 in the given circuit diagram have an emf of 5 V and 9 V and internal resistance of $0.3\ \Omega$ and $1.2\ \Omega$ respectively. Calculate the value of current flowing through the resistance of $3\ \Omega$.

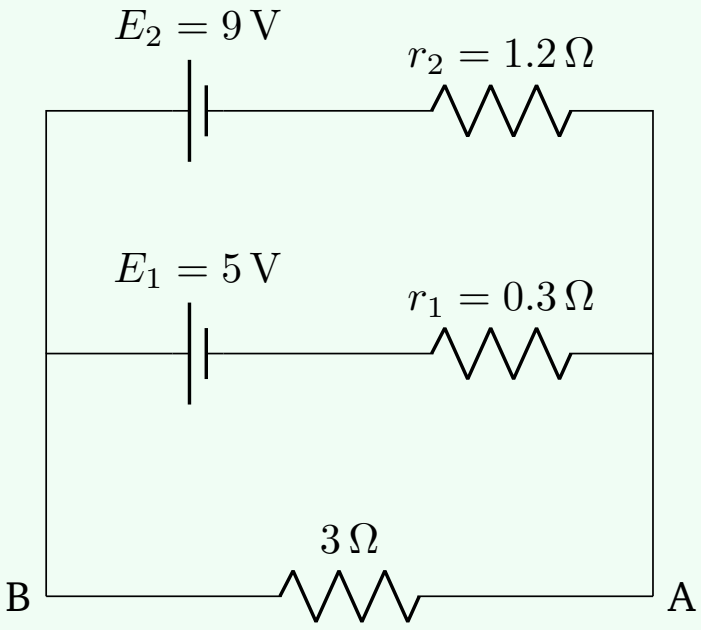
[2 marks]



Solution:

Concept:

- Kirchhoff's junction rule states that the algebraic sum of currents at a junction is zero. Let $V = V_B - V_A$ be the common terminal voltage and I the load current from B to A.
- For parallel cells of the same polarity, the current supplied by cell j is $I_j = (E_j - V)/r_j$. A negative value means that cell absorbs current. The external resistance obeys $V = IR$.



Parallel cells and the external resistance

Step 1: Apply the junction rule Take the currents in the cell branches from A to B as positive. The

Quick Tip to Solve: For unequal parallel cells, use their common terminal voltage; do not simply add their emfs.

two cells have a common terminal voltage because their branches connect the same junctions. With $R = 3\,\Omega$, Kirchhoff's rule gives

$$I_1 + I_2 = I, \qquad \frac{5 - V}{0.3} + \frac{9 - V}{1.2} = \frac{V}{3}.$$

The emf of a cell is not its terminal voltage when current passes through its internal resistance.

Step 2: Solve for the load current Multiply the equation by 6 to remove the denominators:

$$20(5 - V) + 5(9 - V) = 2V.$$

Thus $145 = 27V$, so $V = 145/27\,\text{V}$. Using Ohm's law for the load gives

$$I = \frac{V}{3} = \frac{145}{81}\,\text{A}.$$

As a consistency check, $I_1 = -1.235\,\text{A}$ and $I_2 = 3.025\,\text{A}$: the stronger cell supplies both the load and the weaker cell, and their algebraic sum agrees with the load current.

Step 3: Conclusion The current through the $3\,\Omega$ resistance is $\boxed{I \approx 1.79\,\text{A}}$, flowing from B to A in the diagram.

Quick Tip to Solve: For unequal parallel cells, use their common terminal voltage; do not simply add their emfs.

13. How is the mutual inductance of a pair of coils affected when:

(i) separation between the coils is increased?

(ii) the number of turns of each coil is increased?

(iii) a thin iron sheet is placed between the two coils, other factors remaining the same?

Explain your answer in each case. [3 marks]

Solution:

Concept:

- Mutual inductance M measures the flux linkage in one coil produced per unit current in the other: $N_2\Phi_{21} = MI_1$. Here Φ_{21} is the flux through each turn of coil 2 due to current I_1 in coil 1.
- For unchanged geometry and linear magnetic response, M is proportional to N_1N_2, the product of the turn counts, and increases with magnetic permeability and magnetic coupling.

Step 1: Increase the separation The magnetic field of the first coil becomes weaker at the second coil as the separation increases. Consequently a smaller fraction of the magnetic flux produced by the first coil links the second. At the same current I_1, the flux linkage $N_2\Phi_{21}$ decreases, so $M = N_2\Phi_{21}/I_1$ decreases. The separation changes the coupling between the coils rather than the number of turns.

Step 2: Increase the turns of both coils For the same current, increasing N_1 increases the magnetic field produced by the first coil. Increasing N_2 then increases the number of turns linked by that flux. Hence mutual inductance increases, with $M \propto N_1N_2$ when the other factors remain unchanged. If both turn counts are multiplied by the same factor a, the mutual inductance is multiplied by a^2.

Quick Tip to Solve: Compare the flux linkage at a fixed source current: more linked flux always means greater mutual inductance.

Step 3: Place an iron sheet between the coils Iron has a much greater magnetic permeability than air. It provides an easier magnetic path between the coils and enhances the magnetic flux linking them for a given current in the first coil. Therefore $N_2\Phi_{21}$, and hence the mutual inductance, increases. This explanation concerns the increased magnetic coupling due to the magnetic material, with the coil positions and turn counts kept unchanged.

Step 4: Conclusion Mutual inductance (i) decreases with increased separation, (ii) increases when the turns of each coil increase, and (iii) increases when the iron sheet is inserted.

Quick Tip to Solve: Compare the flux linkage at a fixed source current: more linked flux always means greater mutual inductance.

14. A convex lens made up of glass of refractive index 1.5 is dipped, in turn, in:

(i) medium A of refractive index 1.65

(ii) medium B of refractive index 1.33

Explain, giving reasons, whether it will behave as a converging lens or a diverging lens in each of these two media. [3 marks]

Solution:

Concept:

- The lens-maker formula in a surrounding medium is $\frac{1}{f} = \left(\frac{n_g}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$, where n_g and n_m are the indices of glass and medium.
- For a convex lens with light travelling left to right, $R_1 > 0$ and $R_2 < 0$; thus the curvature factor is positive. Positive f means convergence and negative f means divergence.

Step 1: Examine medium A The surrounding medium has $n_A = 1.65$, greater than the glass index $n_g = 1.5$. The relative index and its difference from unity are

$$\frac{n_g}{n_A} = \frac{1.5}{1.65} = \frac{10}{11}, \qquad \frac{n_g}{n_A} - 1 = -\frac{1}{11}.$$

Since the curvature factor of this convex lens is positive, its power $1/f$ is negative. Parallel incident rays therefore emerge diverging, with their backward extensions meeting at a virtual principal focus on the incident side.

Step 2: Examine medium B Here $n_B = 1.33$, smaller than the glass index. Thus

$$\frac{n_g}{n_B} = \frac{1.5}{1.33} = \frac{150}{133}, \qquad \frac{n_g}{n_B} - 1 = \frac{17}{133} > 0.$$

The positive refractive-index factor multiplied by the positive curvature factor gives positive power and positive focal length. Parallel incident rays emerge converging towards a real principal focus. The glass is optically denser than this medium, so the ordinary converging action of the convex lens is retained.

Step 3: Relate the result to refraction The shape alone does not determine whether a lens converges light. Its action depends on the refractive index relative to its surroundings. Moving from medium A

Quick Tip to Solve: For a convex lens, compare the glass index with the surrounding index before deciding the sign of its power.

to medium B changes the sign of the index factor while the radii remain fixed. No numerical focal length can be found from these indices alone, because the radii of curvature are not specified.

Step 4: Conclusion In medium A it is a diverging lens. In medium B it is a converging lens.

Quick Tip to Solve: For a convex lens, compare the glass index with the surrounding index before deciding the sign of its power.

15. Define the terms threshold frequency and stopping potential in relation to the phenomenon of photoelectric effect. How is the photoelectric current affected on increasing the (i) frequency (ii) intensity of the incident radiations and why? [3 marks]

Solution:

Concept:

- The work function ϕ is the minimum energy required to remove an electron from the metal surface. A photon of frequency ν supplies energy $h\nu$.
- Einsteiń s equation is $K_{\max} = h\nu - \phi = eV_s$, where e is the magnitude of electronic charge and V_s is the stopping-potential magnitude.
- Photoelectric current measures the charge collected per second; saturation current depends on the rate of emission of photoelectrons.

Step 1: Define threshold frequency Threshold frequency ν_0 is the minimum frequency of incident radiation that can cause photoelectric emission from a specified metal surface. Thus $h\nu_0 = \phi$. For $\nu < \nu_0$, no photoelectrons are emitted, however large the incident intensity.

Step 2: Define stopping potential Stopping potential is the minimum retarding potential applied between collector and emitter that reduces the photoelectric current to zero. It stops even the fastest emitted electrons, so $eV_s = K_{\max}$. The collector is negative relative to the emitting surface.

Step 3: Effect of increasing frequency For radiation already above threshold, the standard comparison at unchanged incident intensity and collecting conditions is that photoelectric current does not increase merely because the frequency increases: frequency determines the energy of each photoelectron rather than the number emitted. Increasing ν increases $K_{\max}$ and V_s. If the increase crosses ν_0, emission begins. Strictly, at fixed radiant power the photon arrival rate is $P/(h\nu)$, so the exact current also depends on photon flux and emission efficiency; the school-level statement refers to frequency affecting electron energy, not independently increasing emission rate.

Step 4: Effect of increasing intensity At a fixed frequency $\nu > \nu_0$, increasing intensity supplies more photons per second to the illuminated area. More electrons are therefore emitted per second and the photoelectric current increases; the saturation current is proportional to intensity. Since each photon still has the same energy, the maximum kinetic energy and stopping potential remain unchanged.

Step 5: Conclusion Threshold frequency satisfies $\nu_0 = \phi/h$; stopping potential satisfies $V_s = K_{\max}/e$. Above threshold, frequency primarily changes electron energy, while greater intensity at fixed frequency increases photoelectric current.

Quick Tip to Solve: First check whether the frequency exceeds threshold; then distinguish electron energy from the number of electrons collected per second.

16. Explain, with the help of a nuclear reaction in each of the following cases, how the neutron to proton ratio changes during (i) alpha-decay (ii) beta-decay. [3 marks]

Solution:

Concept:

- For a nucleus ${}^{A}_{Z}X$, proton number is Z, neutron number is $N = A - Z$, and its neutron-to-proton ratio is N/Z.
- An alpha particle is ${}^{4}_{2}\mathrm{He}$, containing two protons and two neutrons. In beta-minus decay a neutron converts into a proton, electron and electron antineutrino.

Step 1: Alpha-decay: track both nucleon numbers The general reaction is

$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\mathrm{He}. $$

The daughter has $Z' = Z - 2$ protons and $N' = (A - 4) - (Z - 2) = N - 2$ neutrons. Hence the ratio changes from N/Z to $(N - 2)/(Z - 2)$. The difference is

$$ \frac{N-2}{Z-2} - \frac{N}{Z} = \frac{2(N-Z)}{Z(Z-2)}. $$

Therefore the ratio increases for the usual heavy alpha-emitting nuclei, for which $N > Z$; removal of equal numbers makes the relative neutron excess larger.

Step 2: Illustrate alpha-decay with a reaction For example,

$$ {}^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}. $$

Uranium has $N = 146$, whereas thorium has $N = 144$. Its ratio increases from $146/92 \simeq 1.587$ to $144/90 = 1.600$. Both charge and total nucleon number are conserved.

Step 3: Beta-decay: conversion of a neutron In beta-minus decay,

$$ n \longrightarrow p + e^{-} + \bar{\nu}_e, \qquad {}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + e^{-} + \bar{\nu}_e. $$

Thus mass number stays constant, neutron number decreases by one and proton number increases by one. The ratio changes to $(N - 1)/(Z + 1)$, which is smaller than N/Z. For example,

$$ {}^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + e^{-} + \bar{\nu}_e. $$

The ratio falls from $8/6$ to $7/7 = 1$. The emitted electron is created in the decay, not removed from an atomic orbit. If beta-plus decay is considered instead, a proton converts into a neutron and N/Z increases to $(N + 1)/(Z - 1)$.

Step 4: Conclusion Alpha-decay changes N/Z to $(N - 2)/(Z - 2)$, increasing it for heavy nuclei with $N > Z$. Beta-minus decay changes it to $(N - 1)/(Z + 1)$, decreasing the neutron-to-proton ratio.

Quick Tip to Solve: Write neutron and proton counts separately before taking their ratio; an unchanged mass number in beta decay does not mean an unchanged neutron number.

17. What is an intrinsic semiconductor? How can this material be converted into (i) P-type (ii) N-type extrinsic semiconductor? Explain with the help of energy band diagrams. [3 marks]

Solution:

Concept:

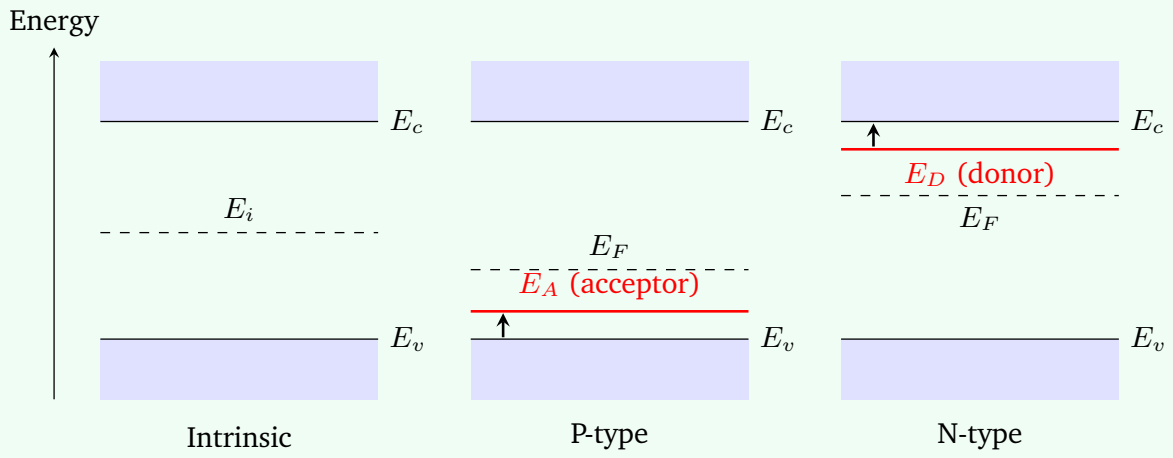
- An intrinsic semiconductor is a chemically pure semiconductor, such as pure silicon or germanium, whose conductivity arises from thermally generated electron-hole pairs.
- In an intrinsic material, electron and hole concentrations are equal: $n = p = n_i$. The valence-band edge is E_v, the conduction-band edge is E_c, and $E_g = E_c - E_v$.
- Doping adds a small controlled quantity of impurity. Acceptor levels lie just above the valence band; donor levels lie just below the conduction band.

Step 1: Describe the intrinsic material In pure silicon or germanium each atom forms four covalent bonds with its neighbours. At nonzero temperature, some electrons gain enough energy to reach the conduction band, leaving holes in the valence band. Every such excitation creates one electron and one hole, so neither carrier is a majority carrier. The intrinsic Fermi level E_i lies approximately midway across the forbidden energy gap.

Step 2: Produce a P-type semiconductor Dope the tetravalent crystal with a small amount of a trivalent impurity such as boron, aluminium or gallium. The impurity has only three valence electrons, leaving an electron deficiency in one bond. It can accept an electron from a neighbouring bond, creating a mobile hole. The acceptor energy level E_A is slightly above E_v, so a valence electron needs only a small thermal energy to occupy it. Holes are majority carriers and electrons are minority carriers; the Fermi level moves toward the valence band. The crystal remains electrically neutral because the mobile positive holes balance the negative ionised acceptors.

Step 3: Produce an N-type semiconductor Dope the crystal with a small amount of a pentavalent impurity such as phosphorus, arsenic or antimony. Four impurity electrons form covalent bonds, while the fifth is weakly bound. Its donor level E_D lies slightly below E_c, allowing a small thermal energy to promote it into the conduction band. Electrons are majority carriers and holes are minority carriers; the Fermi level moves toward the conduction band. Positive ionised donors balance the mobile electrons, so the crystal remains neutral. In both types, doping supplies additional carriers without making the forbidden gap disappear.

Quick Tip to Solve: Remember acceptors accept valence-band electrons, so their level lies just above that band; donors donate conduction electrons, so their level lies just below it.



Energy bands for intrinsic, P-type and N-type semiconductors (schematic, not to scale).

Step 4: Conclusion A pure semiconductor is intrinsic, with $n = p$. Trivalent acceptor doping produces P-type material with majority holes; pentavalent donor doping produces N-type material with majority electrons. Their impurity levels are shown close to the appropriate band edges.

Quick Tip to Solve: Remember acceptors accept valence-band electrons, so their level lies just above that band; donors donate conduction electrons, so their level lies just below it.

18. Why is the mass of a nucleus always less than the sum of the masses of its constituents, neutrons and protons?

If the total number of neutrons and protons in a nuclear reaction is conserved, how then is the energy absorbed or evolved in the reaction? Explain. [3 marks]

Solution:

Concept:

- A bound nucleus has a lower rest energy than its separated nucleons. Binding energy is the energy required to separate it completely into free neutrons and protons.
- For a nucleus with proton number Z and mass number A, the mass defect is $\Delta m = Zm_p + (A - Z)m_n - M$, and its binding energy is $B = \Delta mc^2$. Here M is its nuclear mass and c is the speed of light.

Step 1: Explain the mass defect When free nucleons combine to form a stable bound nucleus, energy is released as they enter a state of lower total energy. By mass-energy equivalence, this released binding energy corresponds to a decrease in rest mass. Thus

$$M = Zm_p + (A - Z)m_n - \frac{B}{c^2}.$$

Since $B > 0$ for a bound nucleus, its mass is smaller than the sum of the masses of its separated constituents. The missing mass is the mass equivalent of the binding energy; nucleons have not disappeared.

Quick Tip to Solve: Compare total binding energies on the two sides: greater final binding gives a positive reaction energy.

Step 2: Account for energy in a nuclear reaction Conservation of the numbers of protons and neutrons fixes the sum of their free masses, but does not fix how strongly they are bound in the reactant and product nuclei. Let B_i and B_f denote their respective total binding energies. Since the free-nucleon mass sum is the same on both sides,

$$Q = (M_i - M_f)c^2 = B_f - B_i.$$

If the products have greater total binding energy, their rest mass is smaller and $Q > 0$: the difference is released as kinetic energy or radiation. If the products have smaller binding energy, their rest mass is greater and $Q < 0$: energy must be supplied. Rest mass alone need not be conserved; total energy, including rest and kinetic energy and radiation, is conserved.

Step 3: Conclusion The nuclear mass deficit equals B/c^2. Nuclear reactions release energy when total binding energy increases, and absorb energy when it decreases, even though the nucleon numbers are conserved.

Quick Tip to Solve: Compare total binding energies on the two sides: greater final binding gives a positive reaction energy.

OR

18. Draw a graph showing the variation of binding energy per nucleon with mass number for different nuclei. Explain, with the help of this graph, the release of energy by the process of nuclear fusion.

[3 marks]

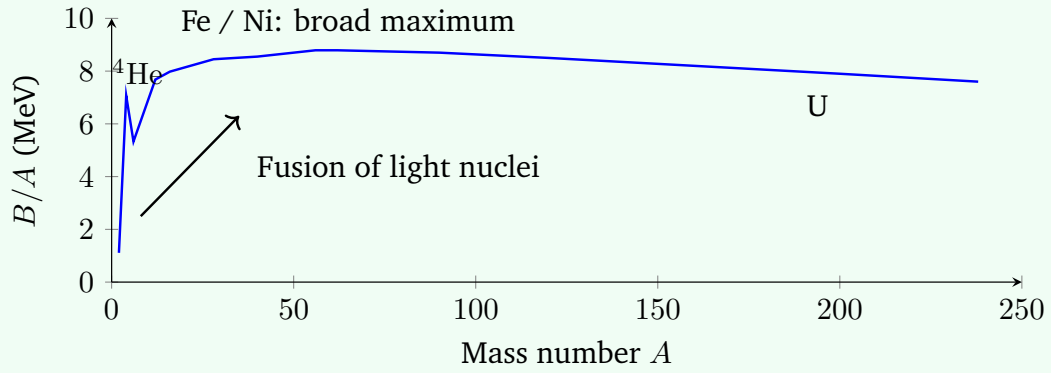
Solution:

Concept:

- The binding energy per nucleon is B/A, where B is the total binding energy and A is the mass number. It measures the average binding of a nucleon in the nucleus.
- Energy is released when a nuclear reaction increases the total binding energy: $Q = B_{\text{products}} - B_{\text{reactants}} = (M_i - M_f)c^2$.

Step 1: Describe the binding-energy curve The graph rises sharply for light nuclei, with some local irregularities, and reaches a broad maximum of about 8.8 MeV per nucleon near the iron and nickel region, $A \simeq 56$–62. For heavier nuclei it decreases slowly, reaching about 7.6 MeV per nucleon near uranium. The curve is schematic, with selected points indicating light-nucleus fluctuations.

Quick Tip to Solve: On the rising part of the curve, compare the total binding energy before and after fusion; the neutron has zero nuclear binding energy.



Schematic variation of binding energy per nucleon with mass number

Step 2: Explain energy release in fusion In fusion, suitably light nuclei combine to form a heavier nucleus on the rising part of the curve. For an energy-releasing fusion reaction, the products have a larger binding energy per nucleon, and hence a larger total binding energy for the conserved number of nucleons. Their total rest mass is therefore smaller than the initial rest mass. The difference

$$Q = (M_i - M_f)c^2 = B_f - B_i > 0$$

appears as kinetic energy of the products and, where applicable, radiation. For example, deuterium and tritium can fuse to give helium and a neutron:

$$^2_1\mathrm{H} + ^3_1\mathrm{H} \longrightarrow ^4_2\mathrm{He} + ^1_0\mathrm{n} + 17.6\,\mathrm{MeV}.$$

The helium nucleus is more tightly bound than the initial nuclei.

Step 3: Conclusion Fusion of suitable light nuclei releases energy because the products are more tightly bound: the gain in total binding energy equals the energy released.

Quick Tip to Solve: On the rising part of the curve, compare the total binding energy before and after fusion; the neutron has zero nuclear binding energy.

19. Define the term modulation. Name three different types of modulation used for a message signal using a sinusoidal continuous carrier wave. Explain the meaning of any one of these. [3 marks]

Solution:

Concept:

- A message signal carries information. A carrier is a high-frequency sinusoidal wave, written as $c(t) = A_c \cos(2\pi f_c t + \phi_c)$, with amplitude A_c, frequency f_c, and phase ϕ_c.
- Modulation makes a selected parameter of the carrier vary according to the instantaneous value of the message signal so that the information can be transmitted.

Step 1: Define modulation and name its types Modulation is the process of varying a characteristic of a high-frequency carrier wave in accordance with the instantaneous value of a low-frequency message signal. For a sinusoidal continuous carrier, the three different types are amplitude modulation (AM),

Quick Tip to Solve: Remember the three carrier parameters in order: amplitude, frequency and phase give AM, FM and PM respectively.

frequency modulation (FM), and phase modulation (PM). In AM the carrier amplitude changes, in FM its instantaneous frequency changes, and in PM its instantaneous phase changes according to the message. The choice identifies which characteristic carries the information.

Step 2: Explain amplitude modulation In amplitude modulation, the amplitude of the carrier is varied in proportion to the instantaneous value of the message signal, while the carrier frequency and carrier phase remain unchanged. For a sinusoidal message $m(t) = A_m \cos(2\pi f_m t)$, a standard AM wave is

$$s(t) = A_c[1 + \mu \cos(2\pi f_m t)] \cos(2\pi f_c t),$$

where μ is the modulation index and $f_c \gg f_m$. Its envelope follows the message: the carrier amplitude grows when the message value increases and falls when it decreases. For undistorted conventional AM, $0 \leq \mu \leq 1$, so the envelope does not reverse. Thus the slowly changing envelope contains the original information, which a receiver can recover by envelope detection. Only the amplitude is the intentionally varied carrier parameter in this type of modulation.

Step 3: Conclusion Modulation varies a carrier parameter according to the message. Its three continuous-wave types are AM, FM and PM; in AM, the carrier amplitude follows the message while its carrier frequency and phase remain fixed.

Quick Tip to Solve: Remember the three carrier parameters in order: amplitude, frequency and phase give AM, FM and PM respectively.

20. What is electric flux? Write its S.I. units.

Using Gauss's theorem, deduce an expression for the electric field at a point due to a uniformly charged infinite plane sheet. [3 marks]

Solution:

Concept:

- Electric flux measures the electric field passing normally through a surface: $\Phi_E = \int_S \vec{E} \cdot d\vec{A}$, where $d\vec{A}$ is the outward area vector for a closed surface.
- Gauss's theorem states that $\oint_S \vec{E} \cdot d\vec{A} = Q_{\text{enc}}/\varepsilon_0$, where Q_{enc} is the enclosed charge and ε_0 is the permittivity of free space.

Step 1: Define flux and its unit For a uniform electric field through a plane surface of area A, electric flux is $\Phi_E = EA\cos\theta$, where θ is the angle between the field and the surface normal. Thus it is the product of area and the normal component of the electric field. Since electric field has unit N C^{-1}, the S.I. unit of electric flux is N m^2 C^{-1}, equivalently V m. Flux is a signed scalar quantity.

Step 2: Choose a Gaussian surface using symmetry Let the infinite plane sheet have uniform surface charge density σ. Translational symmetry makes the electric field independent of position parallel to the sheet, while symmetry excludes any tangential component. The field is perpendicular to the sheet and has equal magnitude on both sides. Choose a cylindrical pillbox of face area A, with its axis perpendicular to the sheet and one flat face on each side. The enclosed charge is $Q_{\text{enc}} = \sigma A$.

Step 3: Apply Gauss's theorem For a positively charged sheet the field points away from the sheet. On both flat faces it is parallel to the outward normal, so each face contributes EA. On the curved

Quick Tip to Solve: A pillbox has two faces carrying flux; include both to obtain the factor of two in the field.

surface the field is tangent to the surface and its flux is zero. Therefore,

$$\oint_S \vec{E} \cdot d\vec{A} = EA + EA = 2EA,$$
$$2EA = \frac{\sigma A}{\varepsilon_0},$$
$$E = \frac{\sigma}{2\varepsilon_0}.$$

The area cancels, and the result is independent of distance from the ideal infinite sheet. For a negative sheet the field direction reverses.

Step 4: Conclusion The electric flux is $\Phi_E = \int_S \vec{E} \cdot d\vec{A}$, in N m^2 C^{-1}. The field magnitude is $\boxed{E = |\sigma|/(2\varepsilon_0)}$, normal to the sheet, away from positive charge and toward negative charge.

Quick Tip to Solve: A pillbox has two faces carrying flux; include both to obtain the factor of two in the field.

21. A 10 m long wire of uniform cross-section and resistance $20\ \Omega$ is used in a potentiometer. The wire is connected in series with a battery of 5 V along with an external resistance of $480\ \Omega$. If an unknown emf E is balanced at 6.0 m length of the wire, calculate:

(i) the potential gradient of the potentiometer wire,

(ii) the value of the unknown emf E. [3 marks]

Solution:

Concept:

- For a uniform potentiometer wire, the potential gradient is $k = V_{\text{wire}}/L$, where V_{wire} is the voltage across the wire and L is its total length.
- At balance, no current flows through the unknown cell branch, and its emf is $E = kl$, where l is the balance length.

Step 1: Find the current through the series circuit The potentiometer wire and the external resistor carry the same steady current because they are connected in series. The total resistance is

$$R_{\text{total}} = 20 + 480 = 500\,\Omega.$$

Taking the stated battery voltage as the voltage applied to these resistances, Ohmś law gives

$$I = \frac{5}{500} = 0.010\,\text{A}.$$

The external resistance limits the current and therefore must be included before finding the potential gradient.

Step 2: Calculate the potential gradient Only the voltage drop across the potentiometer wire is distributed over its length. Its resistance is $20\,\Omega$, so

$$V_{\text{wire}} = IR_{\text{wire}} = 0.010 \times 20 = 0.20\,\text{V}.$$

Quick Tip to Solve: First find the current using both series resistances; multiply it by the wire resistance before dividing by length.

The wire has a uniform cross-section and hence uniform resistance per unit length; with constant current, the potential falls uniformly along the wire. Thus

$$k = \frac{V_{\text{wire}}}{L} = \frac{0.20}{10} = 0.020\,\text{V m}^{-1}.$$

The entire $5\,\text{V}$ battery voltage is not across the wire: most of it is dropped across the external resistor.

Step 3: Use the null-balance condition At the balance point the galvanometer branch draws no current. Consequently the unknown emf equals the potential difference across the balancing length, without a loading correction. For $l = 6.0\,\text{m}$,

$$E = kl = 0.020 \times 6.0 = 0.12\,\text{V}.$$

As a check, this balance length is sixty percent of the full wire length, so the unknown emf is sixty percent of $0.20\,\text{V}$, which gives the same value.

Step 4: Conclusion (i) The potential gradient is $\boxed{k = 0.020\,\text{V m}^{-1}}$. (ii) The unknown emf is $\boxed{E = 0.12\,\text{V}}$.

Quick Tip to Solve: First find the current using both series resistances; multiply it by the wire resistance before dividing by length.

22. Draw a circuit diagram for use of NPN transistor as an amplifier in common emitter configuration. The input resistance of a transistor is $1000\ \Omega$. On changing its base current by $10\ \mu\text{A}$, the collector current increases by $2\ \text{mA}$. If a load resistance of $5\ \text{k}\Omega$ is used in the circuit, calculate:

(i) the current gain

(ii) voltage gain of the amplifier [3 marks]

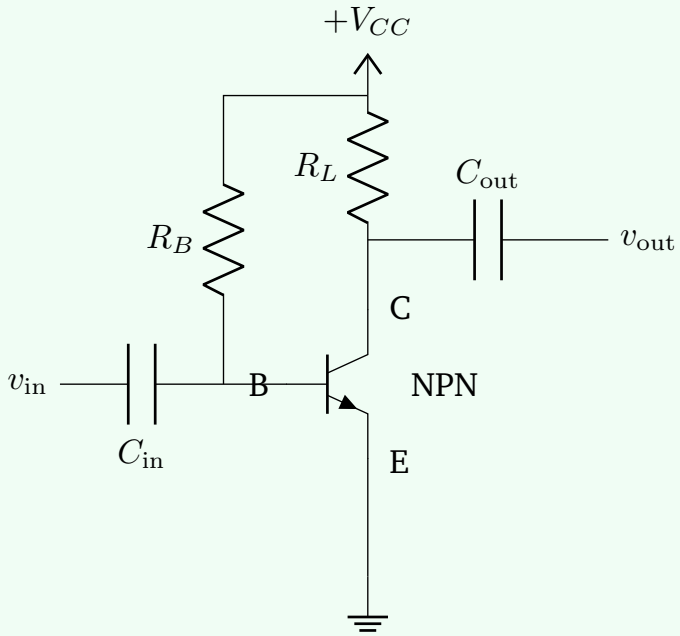
Solution:

Concept:

- In a common-emitter NPN amplifier the emitter is common to the input (base-emitter) and output (collector-emitter) circuits. The transistor is biased in its active region.
- The small-signal current gain is $\beta = \Delta I_C / \Delta I_B$. The voltage-gain magnitude is $|A_v| = \beta R_L / r_{\text{in}}$, where R_L is the collector load and r_{in} is the input resistance.

Step 1: Show the common-emitter amplifier circuit The circuit shows a positively biased base and a collector load connected to the positive supply. The emitter is connected to the common ground. The small input signal is coupled to the base through C_{in}, and the output is taken from the collector through C_{out}. The resistor R_B supplies the base bias; the NPN emitter arrow points outward. With suitable bias, the base-emitter junction is forward biased and the collector-base junction is reverse biased. Coupling capacitors pass the signal while separating the direct-current bias from the signal source and output.

Quick Tip to Solve: Convert both current changes to the same unit, then use current gain times the load-to-input resistance ratio.



NPN common-emitter amplifier with collector output

Step 2: Calculate the current gain The change in collector current is $\Delta I_C = 2\,\text{mA} = 2 \times 10^{-3}\,\text{A}$, and the change in base current is $\Delta I_B = 10\,\mu\text{A} = 10 \times 10^{-6}\,\text{A}$. Therefore,

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{2 \times 10^{-3}}{10 \times 10^{-6}} = 200.$$

This is a dimensionless incremental current gain, since it relates changes about the biased operating point.

Step 3: Calculate the voltage gain and phase The input voltage change is $\Delta V_{\text{in}} = r_{\text{in}} \Delta I_B = 1000 \times 10 \times 10^{-6} = 0.010\,\text{V}$. The magnitude of the collector voltage change is $R_L \Delta I_C = 5000 \times 2 \times 10^{-3} = 10\,\text{V}$. Hence

$$|A_v| = \frac{|\Delta V_{\text{out}}|}{\Delta V_{\text{in}}} = \frac{10}{0.010} = 1000.$$

Equivalently, $|A_v| = 200(5000/1000)$. An increased base current increases the collector current and the voltage drop across the load; the collector voltage therefore decreases. Thus the common-emitter output is inverted and the signed voltage gain is $A_v = -1000$.

Step 4: Conclusion (i) The current gain is $\boxed{\beta = 200}$. (ii) The voltage-gain magnitude is $\boxed{|A_v| = 1000}$; with the common-emitter phase inversion, $A_v = -1000$.

Quick Tip to Solve: Convert both current changes to the same unit, then use current gain times the load-to-input resistance ratio.

23. Define the term 'critical frequency' in relation to sky wave propagation of electromagnetic waves. On a particular day, the maximum frequency reflected from the ionosphere is 10 MHz. On another day, it was found to decrease to 8 MHz. Calculate the ratio of the maximum electron densities of the ionosphere on the two days. [3 marks]

Solution:

Concept:

- The ionosphere contains free electrons which respond to the electric field of an incident radio wave. Its maximum electron density determines the highest frequency returned at vertical incidence.
- The critical frequency is $f_c = 9\sqrt{N_{\max}}$, where f_c is in hertz and $N_{\max}$ is the maximum electron density in m^{-3}. Thus $N_{\max}$ is proportional to f_c^2.

Step 1: Define critical frequency Critical frequency is the highest frequency of an electromagnetic wave that the ionosphere can return to the Earth when the wave is incident vertically on it. For vertical incidence, a frequency above this value penetrates the ionosphere instead of returning to the Earth. The critical frequency refers to the particular ionospheric layer and its electron density at the time of observation.

Step 2: Compare the maximum electron densities Let N_1 and N_2 denote the maximum electron densities on the first and second days. The given maximum reflected frequencies are $f_{c1} = 10\,\mathrm{MHz}$ and $f_{c2} = 8\,\mathrm{MHz}$. Applying the critical-frequency relation separately gives

$$\frac{N_1}{N_2} = \left(\frac{f_{c1}}{f_{c2}}\right)^2 = \left(\frac{10}{8}\right)^2 = \frac{100}{64} = \frac{25}{16}.$$

The frequency units cancel because both values are expressed in megahertz. The decrease in critical frequency therefore corresponds to a decrease in the maximum electron density; the density ratio must be greater than one in the order first day to second day.

Step 3: Conclusion Critical frequency is the highest frequency returned by the ionosphere at vertical incidence. The maximum electron densities on the two days are in the ratio $\boxed{N_1 : N_2 = 25 : 16}$.

Quick Tip to Solve: Square the critical-frequency ratio; electron density is proportional to frequency squared, not to frequency itself.

24. Draw a labelled diagram of Hertz's experimental set-up to produce electromagnetic waves. Explain the generation of electromagnetic waves using this set-up. [3 marks]

Solution:

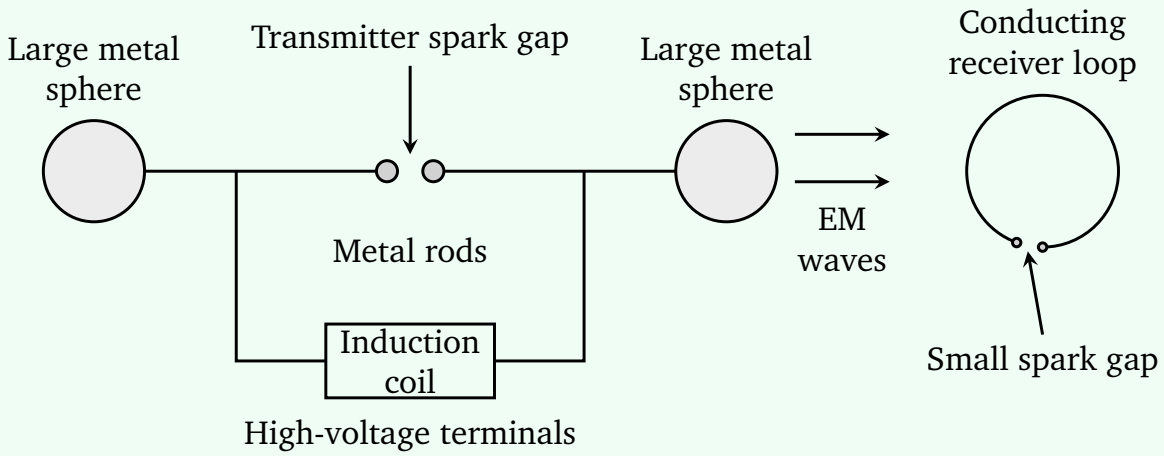
Concept:

- Accelerated charges emit electromagnetic radiation. An oscillating electric dipole produces time-varying electric and magnetic fields which propagate away from the source.
- A spark-gap oscillator combines the capacitance of its metal spheres with the inductance of its conductors. The discharge produces rapid, damped electrical oscillations.

Step 1: Describe the transmitter and receiver Hertz used two metal rods carrying large metal spheres

Quick Tip to Solve: Show both spark gaps and the induction-coil connections; link emission to the accelerated oscillating charges, and detection to induced emf.

at their outer ends and small spheres separated by a narrow spark gap at their inner ends. The rods were connected to the high-voltage terminals of an induction coil. A separate conducting loop with a small gap served as the receiver. The labelled arrangement is shown below; the loop is placed away from the transmitter.



Hertz's spark-gap transmitter and separate conducting-loop receiver

Step 2: Explain how radiation is produced The induction coil builds up a large potential difference across the transmitter gap, charging the metal spheres oppositely. When this potential difference is sufficient to break down the air in the gap, a spark provides a conducting path. The stored charge then discharges through the rods and spark gap. Because the arrangement has both capacitance and inductance, the current and the charges on the spheres oscillate rapidly, with their amplitudes decreasing as energy is lost. The oscillating charges are accelerated. They produce a changing electric field and a changing magnetic field, which spread through space as electromagnetic waves. The wave's electric and magnetic fields are mutually perpendicular and transverse to its direction of propagation.

Step 3: Explain the receiver spark When the waves reach the conducting loop, their varying fields induce an alternating emf in it. A sufficiently large potential difference appears across its small gap and produces tiny sparks. These receiver sparks demonstrate that electromagnetic energy has travelled from the transmitter to the receiver through space.

Step 4: Conclusion A spark discharge in Hertz's transmitter creates rapidly oscillating, accelerated charges which emit electromagnetic waves. Tiny sparks in the separate receiver gap reveal the arrival of these waves.

Quick Tip to Solve: Show both spark gaps and the induction-coil connections; link emission to the accelerated oscillating charges, and detection to induced emf.

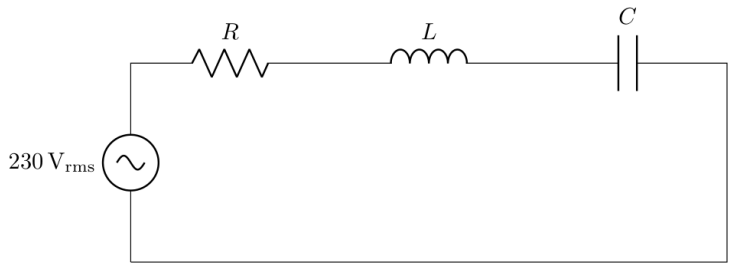
25. The given circuit diagram shows a series LCR circuit connected to a variable frequency 230 V source:

(a) Determine the source frequency which drives the circuit in resonance.

(b) Obtain the impedance of the circuit and the amplitude of current at the resonating frequency.

(c) Determine the rms potential drops across the three elements of the circuit.

(d) How do you explain the observation that the algebraic sum of the voltages across the three elements obtained in (c) is greater than the supplied voltage? [5 marks]



Variable frequency f

Solution:

Concept:

- In a series LCR circuit the same current flows through resistance R, inductance L and capacitance C. Their reactances are $X_L = \omega L$ and $X_C = 1/(\omega C)$, where $\omega = 2\pi f$.
- The impedance is $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Resonance occurs when the inductive and capacitive reactances are equal, making the impedance purely resistive.
- The source voltage 230 V is an rms value. A sinusoidal current has amplitude $I_0 = \sqrt{2} I_{\text{rms}}$. Voltages across reactive elements must be added as phasors because they differ in phase.

Step 1: (a) Determine the resonant frequency The resonance condition is

$$\omega_0 L = \frac{1}{\omega_0 C}.$$

Multiplying by $\omega_0 C$ gives $\omega_0^2 LC = 1$. Therefore the required source frequency, in hertz when L is in henry and C is in farad, is

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

At this frequency the net reactance vanishes; the applied voltage and current have zero phase difference.

Step 2: (b) Find impedance and current amplitude At resonance, substituting $X_L - X_C = 0$ into the impedance formula gives $Z_0 = R$. Consequently,

$$I_{\text{rms}} = \frac{230\,\text{V}}{R}, \qquad I_0 = \frac{230\sqrt{2}\,\text{V}}{R}.$$

With R in ohms these currents are in amperes. The factor $\sqrt{2}$ is essential because the question asks for amplitude rather than the rms current.

Quick Tip to Solve: Set $X_L = X_C$ first; use rms current for voltage drops and multiply by $\sqrt{2}$ only when finding current amplitude.

Step 3: (c) Calculate the three rms potential drops Ohm's law for the resistor and the reactance relations for the other elements give

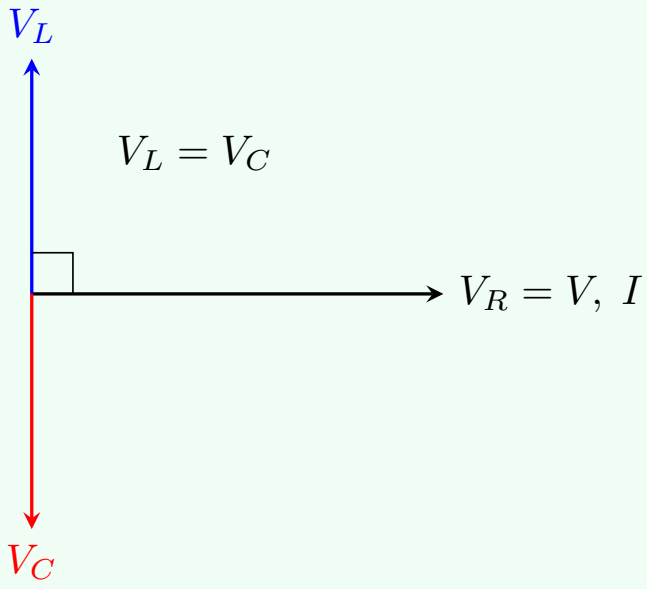
$$V_R = I_{\text{rms}} R = 230\,\text{V},$$
$$V_L = I_{\text{rms}} \omega_0 L = \frac{230\,\text{V}}{R}\sqrt{\frac{L}{C}},$$
$$V_C = \frac{I_{\text{rms}}}{\omega_0 C} = \frac{230\,\text{V}}{R}\sqrt{\frac{L}{C}}.$$

Thus the inductor and capacitor have equal rms voltage magnitudes at resonance. Their individual voltage magnitudes can exceed the source voltage when $\sqrt{L/C} > R$, although the source still supplies $230\,\text{V}$.

Step 4: (d) Explain the voltage sum using phase relations Taking current as the reference, the resistor voltage is in phase with it, the inductor voltage leads it by $90°$, and the capacitor voltage lags it by $90°$. Thus V_L and V_C are oppositely directed phasors. The source rms voltage obeys

$$V = \sqrt{V_R^2 + (V_L - V_C)^2} = V_R = 230\,\text{V}.$$

The positive scalar sum $V_R + V_L + V_C$ exceeds $230\,\text{V}$, but it does not represent the source voltage. Kirchhoff's voltage law applies to signed instantaneous voltages: $v_R(t) + v_L(t) + v_C(t) = v(t)$. At resonance the instantaneous reactive voltages cancel because they have equal amplitudes and opposite phase.



Resonance phasors: equal inductive and capacitive voltages cancel.

Step 5: Conclusion $f_0 = 1/(2\pi\sqrt{LC})$, $Z_0 = R$, and $I_0 = 230\sqrt{2}\,\text{V}/R$. The rms drops are $V_R = 230\,\text{V}$ and $V_L = V_C = (230\,\text{V}/R)\sqrt{L/C}$. The reactive voltage phasors cancel, so the source voltage equals V_R.

Quick Tip to Solve: Set $X_L = X_C$ first; use rms current for voltage drops and multiply by $\sqrt{2}$ only when finding current amplitude.

OR

25. The primary coil of an ideal step-up transformer has 100 turns and the transformation ratio is also 100. The input voltage and power are 220 V and 1100 W respectively. Calculate:

(i) number of turns in the secondary

(ii) the current in the primary

(iii) voltage across the secondary

(iv) the current in the secondary

(v) power in the secondary [5 marks]

Solution:

Concept:

- For an ideal transformer, the transformation ratio is $k = N_s/N_p = V_s/V_p$, where N_p, N_s are the primary and secondary turns and V_p, V_s are their voltages. A step-up transformer has $k > 1$.
- With no energy losses, the input and output powers are equal: $P_s = P_p$. In the ideal-transformer calculation, $P_p = V_p I_p$ and $P_s = V_s I_s$, so $I_s/I_p = 1/k$.

Step 1: (i) Calculate the secondary turns The given primary has $N_p = 100$ turns and the step-up transformation ratio is $k = 100$. Therefore,

$$N_s = kN_p = 100 \times 100 = 10\,000 \text{ turns.}$$

The ratio specifies how many times the secondary turns exceed the primary turns; it is not the secondary turn count itself.

Step 2: (ii) Calculate the primary current The input power is $P_p = 1100\,\text{W}$ and the primary voltage is $V_p = 220\,\text{V}$. Using the ideal-transformer power relation gives

$$I_p = \frac{P_p}{V_p} = \frac{1100}{220} = 5\,\text{A.}$$

This is the current drawn by the primary from the input source. The stated input power is used directly, without adding a loss term because the transformer is ideal.

Step 3: (iii) Calculate the secondary voltage The secondary-to-primary voltage ratio equals the turns ratio. Hence,

$$V_s = kV_p = 100 \times 220 = 22\,000\,\text{V.}$$

Thus the secondary voltage is $22\,\text{kV}$. Voltage rises by the same factor as the turn count because the induced emf per turn is equal in the two coils linked by the common magnetic flux.

Step 4: (iv) Calculate the secondary current Conservation of power requires the current to decrease as voltage increases. Using the inverse current ratio,

$$I_s = \frac{I_p}{k} = \frac{5}{100} = 0.05\,\text{A} = 50\,\text{mA.}$$

Equivalently, $I_s = P_p/V_s = 1100/22\,000\,\text{A}$, which gives the same value. Multiplying the primary current by 100 would violate conservation of energy.

Quick Tip to Solve: Multiply turns and voltage by the step-up ratio 100, divide current by 100, and check that the secondary voltage-current product remains 1100 W.

Step 5: (v) Calculate and verify the secondary power An ideal transformer has unit efficiency, so no input power is lost through winding resistance, eddy currents or hysteresis. The secondary power can also be checked using the calculated voltage and current:

$$P_s = V_s I_s = 22\,000 \times 0.05 = 1100\,\text{W} = P_p.$$

The increase in voltage is balanced by the decrease in current; a transformer transfers energy and does not increase the available power.

Step 6: Conclusion The required values are (i) $N_s = 10\,000$ turns, (ii) $I_p = 5\,\text{A}$, (iii) $V_s = 22\,000\,\text{V}$, (iv) $I_s = 0.05\,\text{A}$, and (v) $P_s = 1100\,\text{W}$.

Quick Tip to Solve: Multiply turns and voltage by the step-up ratio 100, divide current by 100, and check that the secondary voltage-current product remains 1100 W.

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26. What is interference of light? Write two essential conditions for sustained interference pattern to be produced on the screen.

Draw a graph showing the variation of intensity versus the position on the screen in Young's experiment when (a) both the slits are opened and (b) one of the slits is closed.

What is the effect on the interference pattern in Young's double slit experiment when:

(i) screen is moved closer to the plane of slits?

(ii) separation between two slits is increased. Explain your answer in each case. [5 marks]

Solution:

Concept:

- Interference is the redistribution of light intensity when two coherent light waves superpose, producing alternate regions of constructive and destructive interference.
- For slit intensities I_1 and I_2, the resultant intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$, where ϕ is their phase difference.
- In Young's experiment, $\phi = 2\pi dx/(\lambda D)$ and the fringe width is $\beta = \lambda D/d$, where λ is the wavelength, D the slit-to-screen distance, d the slit separation and x the displacement from the centre.

Step 1: Meaning and essential conditions When two waves overlap, their electric-field amplitudes add. At points where the waves arrive in phase, the resultant amplitude is large and a bright fringe forms. At points where they arrive in opposite phase, their amplitudes cancel for equal incident intensities and a dark fringe forms. This alternating enhancement and reduction of intensity constitutes interference; it redistributes energy over the screen. The two essential conditions for a sustained pattern are: (1) the sources must be coherent, maintaining a constant phase difference; and (2) they must emit light of the same frequency, or the same wavelength in a given medium. Independent ordinary lamps do not maintain a fixed relative phase, so their fringes average out. Young's slits are illuminated by the same source to obtain coherence. Comparable slit intensities give good contrast, and the interfering waves should have the same polarization.

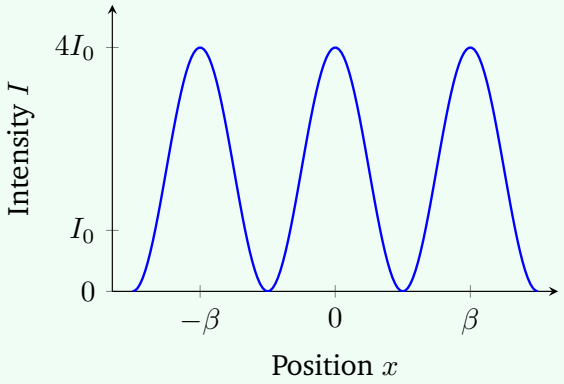
Quick Tip to Solve: Use $\beta = \lambda D/d$: decreasing the numerator or increasing the denominator crowds the fringes; one open slit removes the cosine interference term.

Step 2: Intensity with both slits open and with one slit closed Let each slit separately contribute intensity I_0 at the screen. With both slits open,

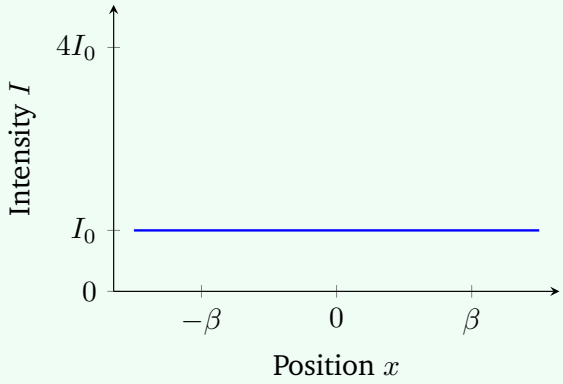
$$I(x) = 2I_0\left[1+\cos\left(\frac{2\pi dx}{\lambda D}\right)\right] = 4I_0\cos^2\left(\frac{\pi x}{\beta}\right).$$

Maxima occur at $x = n\beta$, with intensity $4I_0$; minima occur at $x = (n+\frac{1}{2})\beta$, with zero intensity. Adjacent maxima are separated by β. With one slit closed, the interference term disappears and the intensity is I_0, approximately constant over the small screen region shown. The graphs use the usual narrow-slit Young's approximation, neglecting the broad single-slit diffraction envelope. The one-slit intensity is one-quarter of the two-slit maximum, rather than half of that maximum.

(a) Both slits open



(b) One slit closed



Intensity versus screen position for equal narrow slits; β is the fringe width.

Step 3: Move the screen closer to the slits At fixed wavelength and slit separation, reducing the slit-to-screen distance from D to D' changes the fringe width to

$$\beta' = \frac{\lambda D'}{d}, \qquad \frac{\beta'}{\beta} = \frac{D'}{D} < 1.$$

Thus the fringes become narrower and closer together. The central bright fringe remains on the perpendicular bisector of the slits. This result applies while the usual Young's geometry and small-angle approximation remain valid.

Step 4: Increase the separation of the slits With D and λ fixed, increasing the separation from d to d' gives

$$\beta' = \frac{\lambda D}{d'}, \qquad \frac{\beta'}{\beta} = \frac{d}{d'} < 1.$$

Hence the fringes again become narrower and more closely spaced. A larger separation makes the path difference dx/D increase more rapidly with screen position; consequently, a smaller displacement is needed to change the path difference by one wavelength and reach the next bright fringe.

Step 5: Conclusion Sustained interference requires coherent sources of the same frequency. For equal slit intensities, both open slits give periodic maxima $4I_0$ and minima zero, whereas one open slit gives approximately uniform intensity I_0. Both moving the screen closer and increasing slit separation reduce the fringe width $\beta = \lambda D/d$.

Quick Tip to Solve: Use $\beta = \lambda D/d$: decreasing the numerator or increasing the denominator crowds the fringes; one open slit removes the cosine interference term.

OR

26. What is diffraction of light? Draw a graph showing the variation of intensity with angle in a single slit diffraction experiment. Write one feature which distinguishes the observed pattern from the double slit interference pattern.

How would the diffraction pattern of a single slit be affected when:

(i) the width of the slit is decreased?

(ii) the monochromatic source of light is replaced by a source of white light? [5 marks]

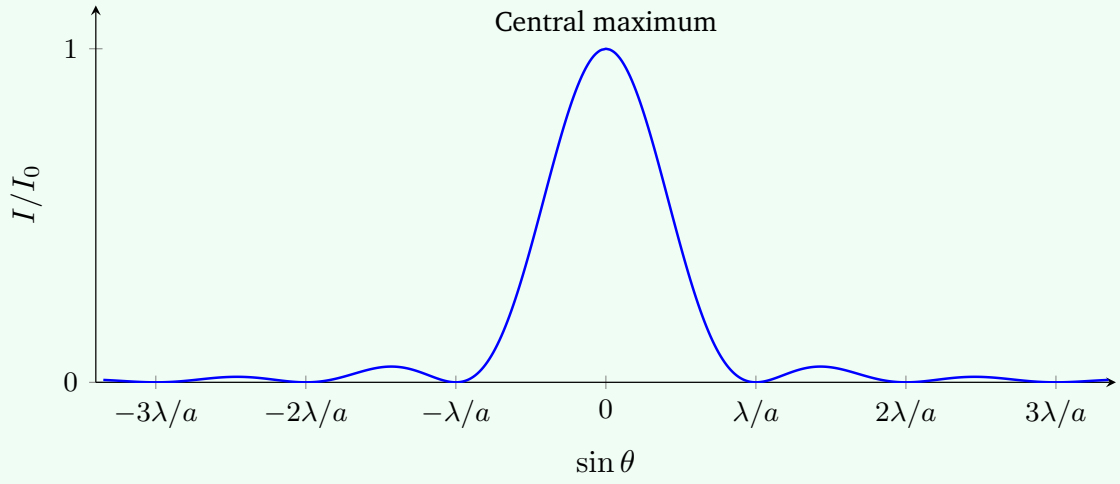
Solution:

Concept:

- Diffraction is the spreading or bending of light into the geometrical shadow when it passes through a narrow aperture or around an obstacle. It is appreciable when the aperture dimension is comparable with the wavelength.
- For a slit of width a, the intensity at angle θ is $I(\theta) = I_0(\sin\beta/\beta)^2$, where $\beta = \pi a \sin\theta/\lambda$, λ is the wavelength and I_0 is the central intensity.
- Dark fringes satisfy $a\sin\theta = m\lambda$, with $m = \pm1, \pm2, \ldots$. Thus, for small angles, the angular width of the central maximum is $2\lambda/a$.

Step 1: Explain the origin of diffraction Different points across the slit act as coherent secondary sources. Their waves overlap at the screen with path differences that depend on the observation angle. Along the axis their contributions are in phase and give the brightest maximum. Away from the axis, partial or complete cancellation produces alternate bright and dark regions. Hence light reaches points outside the geometrically projected slit, demonstrating diffraction.

Step 2: Draw and interpret the intensity distribution The graph has its highest peak at $\theta = 0$. The first minima are at $\sin\theta = \pm\lambda/a$; subsequent minima occur at integer multiples of λ/a in $\sin\theta$. The secondary maxima are much weaker than the central maximum and decrease in intensity farther from the centre. The curve is symmetric about the slit axis. The horizontal coordinate below uses $\sin\theta$, retaining the exact positions of the minima.



Single-slit diffraction intensity; angular positions are shown through $\sin\theta$.

Step 3: Distinguish diffraction from double-slit interference In single-slit diffraction, the central bright

Quick Tip to Solve: Use $a\sin\theta = m\lambda$: a smaller slit spreads the pattern, and longer wavelengths spread farther from the central white maximum.

maximum has twice the width of each secondary bright maximum, approximately in the small-angle region. In the ideal double-slit interference pattern, the bright fringes have equal widths. Also, diffraction maxima become progressively weaker, whereas equal coherent slits give equal interference maxima when their diffraction envelope is neglected.

Step 4: Reduce the slit width From $\sin\theta_1 = \lambda/a$, decreasing a increases the angle of the first minimum on each side. Therefore the central maximum broadens and the whole diffraction pattern spreads out: the dark fringes move farther from the centre. At a fixed screen distance D, its width is approximately $2D\lambda/a$. With the same incident illumination, a narrower slit transmits less light, so the pattern also becomes less bright.

Step 5: Replace monochromatic light by white light Every constituent wavelength forms its own diffraction pattern. At $\theta = 0$, all wavelengths have zero path difference and their maxima coincide, producing a white central maximum. Away from the centre, the fringe positions depend on wavelength. Red light, having the greater wavelength, spreads farther than violet light. The secondary regions therefore show coloured fringes, with violet nearer the centre and red farther out. These patterns overlap increasingly away from the centre, so the coloured secondary fringes become indistinct.

Step 6: Conclusion Diffraction is the spreading of light at a narrow slit. Its broad, intense central maximum distinguishes it from equally spaced, equal-width ideal double-slit fringes. Decreasing slit width broadens the pattern; white light gives a white central maximum and overlapping coloured secondary fringes.

Quick Tip to Solve: Use $a\sin\theta = m\lambda$: a smaller slit spreads the pattern, and longer wavelengths spread farther from the central white maximum.

27. With the help of a neat and labelled diagram, explain the underlying principle and working of a moving coil galvanometer. What is the function of:

(i) uniform radial field

(ii) soft iron core

in such a device? [5 marks]

Solution:

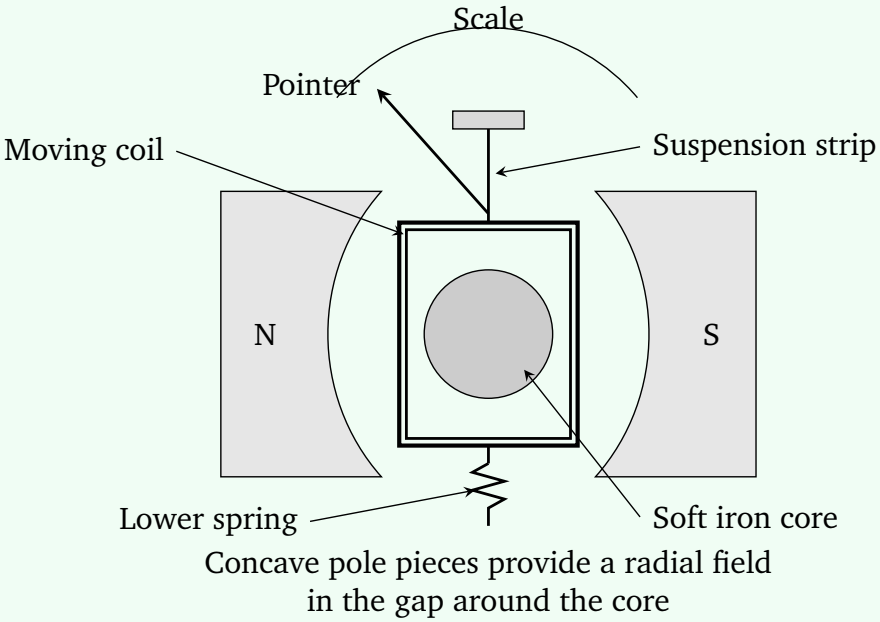
Concept:

- A current-carrying coil in a magnetic field experiences a torque. For a coil of N turns and area A, the torque is $\tau_m = NIAB\sin\alpha$, where α is the angle between the coil's normal and the field.
- In a radial field, the field lies in the plane of the coil for every allowed position, so $\alpha = 90^\circ$ and $\tau_m = NIAB$.
- The suspension or spring provides a restoring torque $\tau_r = C\theta$, where C is its torsional constant and θ is the angular deflection in radians.

Step 1: Construction and labelled diagram A light rectangular coil of many turns of insulated copper wire is wound on an aluminium frame and placed between the concave pole pieces of a strong permanent magnet. A cylindrical soft iron core is placed inside the coil without touching it. A fine suspension strip supports the coil and carries current into it; a lower spring carries current out and

Quick Tip to Solve: Begin with $NIAB = C\theta$: the radial field removes the sine factor, while the core increases B and hence θ/I.

supplies restoring torque. A pointer attached to the coil moves over a calibrated scale. The diagram shows the pole pieces and coil schematically; the coil can rotate about its vertical suspension axis.



Schematic moving coil galvanometer with concave pole pieces and a soft iron core.

Step 2: Principle and production of deflecting torque When current I passes through the coil, its two opposite vertical sides experience equal magnetic forces in opposite directions. These forces form a couple and rotate the coil. The magnetic torque for a general uniform field is $NIAB\sin\alpha$. The specially shaped pole pieces and the cylindrical core make the field radial, keeping the field parallel to the coil's plane throughout its motion. Consequently,

$$\tau_m = NIAB.$$

Reversing the current reverses the couple and hence the direction of deflection. Thus the galvanometer can indicate both the presence and direction of a small current.

Step 3: Equilibrium and measurement of current As the coil rotates, the suspension and spring twist and develop an opposing restoring torque $C\theta$. The coil comes to rest when the two torques balance:

$$\begin{aligned} NIAB &= C\theta, \\ I &= \frac{C}{NAB}\theta, \\ \frac{\theta}{I} &= \frac{NAB}{C}. \end{aligned}$$

Since N, A, B and C are fixed for the instrument, deflection is directly proportional to current. The scale can therefore have equally spaced divisions. The aluminium frame also provides electromagnetic damping through induced eddy currents, helping the pointer settle promptly without prolonged oscillations.

Step 4: Function of the uniform radial field The radial field keeps the angle between the coil's normal

Quick Tip to Solve: Begin with $NIAB = C\theta$: the radial field removes the sine factor, while the core increases B and hence θ/I.

and the magnetic field equal to 90° as the coil turns. Thus the magnetic torque has its maximum value $NIAB$ and contains no angle-dependent sine factor. A field of constant magnitude over the working region makes the deflection proportional to current, giving a linear scale and constant current sensitivity.

Step 5: Function of the soft iron core Soft iron has high magnetic permeability. The cylindrical core strengthens the field in the air gap, increasing B and therefore increasing the current sensitivity NAB/C. Together with the concave pole pieces, its shape also produces the radial field required for linear response. Its low retentivity prevents it from retaining appreciable magnetisation after removal of the magnetising field.

Step 6: Conclusion A moving coil galvanometer works by balancing magnetic torque against restoring torque: $I = (C/NAB)\theta$. The uniform radial field gives maximum torque and a linear scale; the soft iron core strengthens the field and helps make it radial, thereby improving sensitivity.

Quick Tip to Solve: Begin with $NIAB = C\theta$: the radial field removes the sine factor, while the core increases B and hence θ/I.

OR

27. Derive a mathematical expression for the force per unit length experienced by each of the two long current carrying conductors placed parallel to each other in air. Hence define one ampere of current.

Explain why two parallel straight conductors carrying current in the opposite direction kept near each other in air repel? [5 marks]

Solution:

Concept:

- A long straight conductor carrying current I produces a magnetic field $B = \mu_0 I/(2\pi r)$ at perpendicular distance r in air; its direction follows the right-hand thumb rule.
- A straight conductor of length l, carrying current I in a field B, experiences force $F = IlB\sin\theta$. The vector direction is given by $\mathbf{F} = I\boldsymbol{l} \times \mathbf{B}$.
- Each wire experiences a force due to the magnetic field produced by the other wire. For parallel wires, this field is perpendicular to the current, so $\theta = 90^\circ$.

Step 1: Find the magnetic field of the first conductor Let two very long, straight parallel conductors A and B be separated by distance d, and carry currents I_1 and I_2, respectively. Neglect end effects and take the permeability of air as μ_0. By Ampere's circuital law, a circular path of radius d centred on A gives

$$B_1(2\pi d) = \mu_0 I_1, \qquad B_1 = \frac{\mu_0 I_1}{2\pi d}.$$

This is the magnetic field at B due to A. Its direction is tangential to the circular magnetic field lines around A, and hence perpendicular to B's length.

Step 2: Obtain the force on each conductor Consider length l of conductor B. Since its current is

Quick Tip to Solve: First find the field of one wire at the other, then use $F = IlB$; check force direction separately with the right-hand rule.

perpendicular to B_1, the magnitude of its magnetic force is

$$F_B = I_2 l B_1 \sin 90^\circ = \frac{\mu_0 I_1 I_2 l}{2\pi d}.$$

Thus $F_B/l = \mu_0 I_1 I_2/(2\pi d)$. Similarly, B produces field $B_2 = \mu_0 I_2/(2\pi d)$ at A. Therefore $F_A = I_1 l B_2$, which gives exactly the same force per unit length. These forces act along the line joining the wires and have opposite directions. Currents in the same direction give attraction; currents in opposite directions give repulsion.

Step 3: Define one ampere using the force between wires In the force-based definition required here, one ampere is that constant current which, when maintained in each of two straight parallel conductors of infinite length and negligible circular cross-section placed one metre apart in vacuum, produces between them a force of 2×10^{-7} N per metre of length. To verify this, put $I_1 = I_2 = 1$ A, $d = 1$ m and $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{N\,A^{-2}}$ in the expression:

$$\frac{F}{l} = \frac{4\pi \times 10^{-7} \times 1 \times 1}{2\pi \times 1} = 2 \times 10^{-7}\,\mathrm{N\,m^{-1}}.$$

Step 4: Explain repulsion for opposite currents For a definite direction check, place A to the left of B, with current in A upwards and current in B downwards in the plane of the page. The right-hand thumb rule gives A's field at B into the page. Applying $\mathbf{F} = I\boldsymbol{l} \times \mathbf{B}$, the downward current in B in this inward field experiences force to the right, away from A. At A, the field due to B is also into the page; the upward current in A therefore experiences force to the left, away from B. Both conductors are pushed apart, explaining the repulsion. Reversing just one current reverses the magnetic force relative to the same-direction attractive case.

Step 5: Conclusion Each conductor experiences equal and opposite forces with magnitude per unit length $F/l = \mu_0 I_1 I_2/(2\pi d)$. Equal currents of one ampere in the specified conductors one metre apart in vacuum give $2 \times 10^{-7}\,\mathrm{N\,m^{-1}}$. Oppositely directed currents repel because the magnetic forces on the two wires point away from each other.

Quick Tip to Solve: First find the field of one wire at the other, then use $F = IlB$; check force direction separately with the right-hand rule.