CBSE Class 12 Physics Question Paper 2010 with Solution PDF-Delhi

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

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

General Instructions

(i) All questions are compulsory.

(ii) There are **30** questions in total. **Questions 1 to 8** carry **one** mark each, 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.

(iii) 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.

(iv) Use of calculators is **not permitted**.

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

$c = 3 \times 10^8 \text{ m s}^{-1}$

$h = 6.626 \times 10^{-34} \text{ J s}$

$e = 1.602 \times 10^{-19} \text{ C}$

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

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

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

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

Boltzmann's constant $k = 1.381 \times 10^{-23} \text{ J K}^{-1}$

Avogadro's number $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$

Radius of earth $= 6400 \text{ km}$

1. In which orientation, a dipole placed in a uniform electric field is in (i) stable, (ii) unstable equilibrium? [1 mark]

Solution:

Concept:

- The torque on a dipole is $\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$, where $\mathbf{p}$ is its electric dipole moment and $\mathbf{E}$ is the uniform electric field.
- Its potential energy is $U = -pE\cos\theta$, where θ is the angle between the dipole moment and the field.

Step 1: Locate equilibrium Equilibrium requires zero torque. Since $\tau = pE\sin\theta$, the possible orientations are $\theta = 0^\circ$ and 180°. Zero torque alone does not distinguish their stability.

Step 2: Test a small displacement At 0°, energy has its minimum value $-pE$, and a small rotation produces a restoring torque. At 180°, energy is maximum, $+pE$, and a small rotation makes the dipole turn farther away from that orientation.

Step 3: Conclusion (i) Stable equilibrium: $\mathbf{p}$ parallel to $\mathbf{E}$. (ii) Unstable equilibrium: $\mathbf{p}$ antiparallel to $\mathbf{E}$.

Quick Tip to Solve: Use minimum potential energy to identify stable equilibrium; zero torque occurs in both orientations.

2. Which part of electromagnetic spectrum has largest penetrating power? [1 mark]

Solution:

Concept:

- Electromagnetic radiation consists of photons with energy $E = h\nu$, where h is Planck's constant and ν is frequency.
- In the usual school-level ordering of the electromagnetic spectrum, gamma radiation occupies the highest-frequency, shortest-wavelength end.

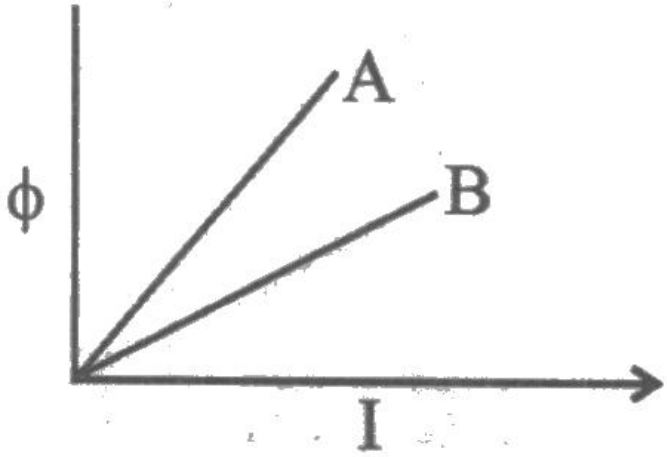
Step 1: Identify the relevant end of the spectrum The question asks about penetration through matter. In the standard comparison of spectral regions, the highly energetic photons at the gamma-ray end are associated with the greatest penetrating power.

Step 2: Name the radiation This region lies beyond X-rays in the usual electromagnetic-spectrum sequence. The required name is gamma rays; radio waves have the longest wavelengths, which is a different property from the penetration asked here.

Step 3: Conclusion Gamma rays (γ-rays) have the largest penetrating power in the standard electromagnetic-spectrum comparison.

Quick Tip to Solve: For this spectrum question, associate greatest penetration with the gamma-ray end, not the longest wavelength.

3. A plot of magnetic flux (ϕ) versus current (I) is shown in the figure for two inductors A and B. Which of the two has larger value of self inductance? [1 mark]

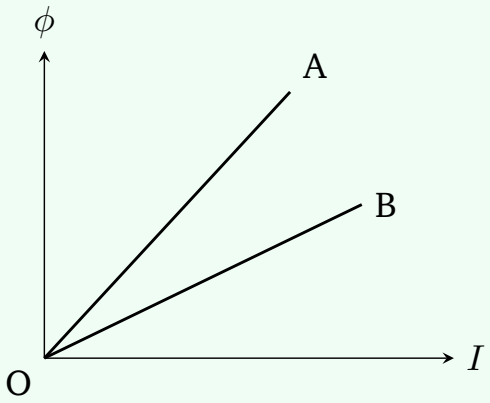


Solution:

Concept:

- The magnetic flux linkage of an inductor is proportional to its current: $\phi = LI$, with L the self inductance in the graph's flux convention.
- Consequently the slope of a plot with flux on the vertical axis and current on the horizontal axis is $L = \Delta\phi/\Delta I$.

Step 1: Read the axes and slopes The vertical axis shows magnetic flux ϕ, and the horizontal axis shows current I. Both straight lines pass through the origin. Line A rises more sharply than line B, so the flux increases more for a given increase in current in A.



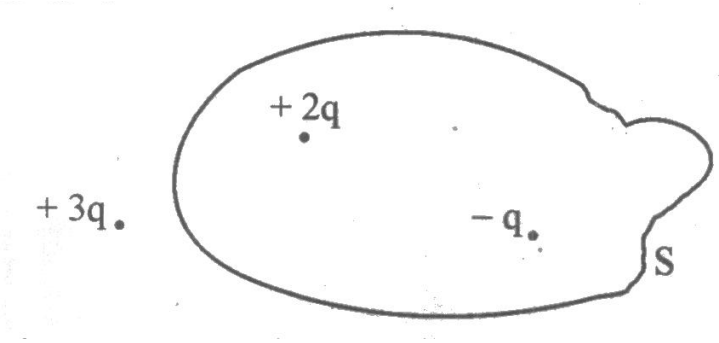
A has the greater slope on the flux-current graph.

Step 2: Compare the inductances At the same positive current, the ordinate for A is greater than that for B. Thus $\phi_A/I > \phi_B/I$, or equivalently $\tan\theta_A > \tan\theta_B$, where each angle is measured from the current axis.

Step 3: Conclusion Inductor A has the larger self inductance: $L_A > L_B$.

Quick Tip to Solve: Check the axes first: in a flux-versus-current graph, the steeper line represents the larger inductance.

4. Figure shows three point charges, $+2q$, $-q$ and $+3q$. Two charges $+2q$ and $-q$ are enclosed within a surface 'S'. What is the electric flux due to this configuration through the surface 'S'? [1 mark]



Solution:

Concept:

- Gauss's law gives the net outward electric flux through a closed surface: $\Phi_E = \oint_S \mathbf{E} \cdot d\mathbf{A} = Q_{\text{enclosed}}/\varepsilon_0$.
- Here Q_{enclosed} is the algebraic sum of charges inside the surface, and ε_0 is the permittivity of free space.

Step 1: Count only enclosed charge The charges $+2q$ and $-q$ lie inside S, so their algebraic sum is $Q_{\text{enclosed}} = 2q - q = q$. The charge $+3q$ is outside the closed surface and must not be included in this sum.

Step 2: Apply the flux law The external charge contributes to the electric field at points on S, but its net flux through S is zero: its entering and leaving contributions cancel. Substitution of the enclosed charge into Gauss's law therefore gives a positive net outward flux.

Step 3: Conclusion The electric flux through S is $\boxed{\Phi_E = q/\varepsilon_0}$, directed net outward.

Quick Tip to Solve: Add enclosed charges algebraically; an external charge changes the field but contributes zero net closed-surface flux.

5. A glass lens of refractive index 1.45 disappears when immersed in a liquid. What is the value of refractive index of the liquid? [1 mark]

Solution:

Concept:

- Refraction at a boundary depends on the relative refractive index n_g/n_l, where n_g and n_l are the indices of glass and liquid.
- Snell's law is $n_l \sin i = n_g \sin r$, with i and r measured from the normal.

Step 1: Interpret the disappearance For a transparent glass lens to disappear optically in the liquid, its boundary must cease to bend light. In this ideal index-matching situation, light propagates in the glass and liquid with the same speed.

Step 2: Match the refractive indices No deviation at the glass-liquid boundary requires $i = r$ for

Quick Tip to Solve: When a transparent lens disappears in a liquid, set their absolute refractive indices equal, not their difference to unity.

arbitrary incident rays. Snell's law then requires $n_l = n_g$. Equivalently, the relative index is unity and the lens has zero refracting power in that liquid.

Step 3: Conclusion The refractive index of the liquid is $\boxed{n_l = 1.45}$ (dimensionless).

Quick Tip to Solve: When a transparent lens disappears in a liquid, set their absolute refractive indices equal, not their difference to unity.

6. What is the ratio of radii of the orbits corresponding to first excited state and ground state in a hydrogen atom? [1 mark]

Solution:

Concept:

- For a hydrogen atom, Bohr's model gives $r_n = a_0 n^2$, where a_0 is the Bohr radius and n is the principal quantum number.
- The ground state corresponds to $n = 1$; the first excited state corresponds to $n = 2$.

Step 1: Assign the quantum numbers The first excited state is the state immediately above the ground state. Therefore use $n = 2$ for the numerator and $n = 1$ for the denominator, preserving the order requested in the question.

Step 2: Form the radius ratio The common constant a_0 cancels in the ratio. Squaring the principal quantum numbers, rather than using them directly, gives

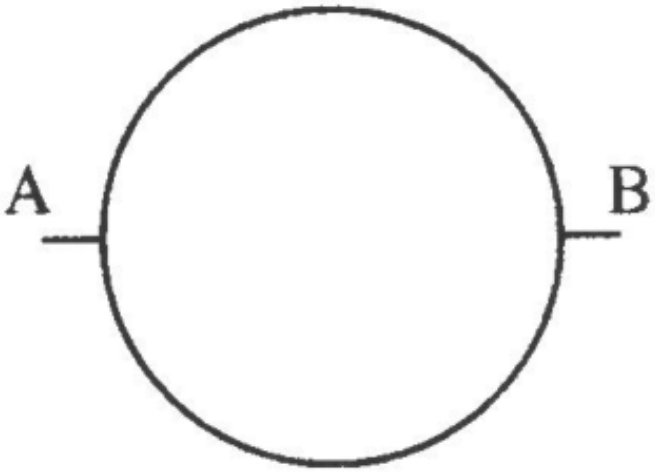
$$\frac{r_{\text{first excited}}}{r_{\text{ground}}} = \frac{a_0(2)^2}{a_0(1)^2} = 4.$$

The orbit radii are positive, so no negative energy sign enters this calculation.

Step 3: Conclusion The ratio of first-excited-state radius to ground-state radius is $\boxed{4:1}$.

Quick Tip to Solve: First excited means n equals 2; square the quantum numbers for a radius ratio and keep the requested order.

7. A wire of resistance $8R$ is bent in the form of a circle. What is the effective resistance between the ends of a diameter AB? [1 mark]



Solution:

Concept:

- For a uniform wire, resistance is proportional to its length: $R_{\text{wire}} = \rho L/A$, where ρ is resistivity and A is cross-sectional area.
- Two resistances connected between the same pair of points are in parallel, so $1/R_{\text{eq}} = 1/R_1 + 1/R_2$.

Step 1: Divide the wire at the diameter endpoints The points A and B divide the circular wire into two equal semicircles. Each semicircle therefore has half the resistance of the original wire, namely $8R/2 = 4R$.

Step 2: Combine the two paths in parallel Both semicircles connect A directly to B, so the applied potential difference is the same across them. Their equivalent resistance is

$$R_{\text{eq}} = \frac{(4R)(4R)}{4R + 4R} = \frac{16R^2}{8R}.$$

Step 3: Conclusion The effective resistance between the ends of the diameter is $\boxed{2R}$.

Quick Tip to Solve: At opposite points of a uniform circular wire, halve the wire resistance and then halve again for the two equal parallel paths.

8. State the conditions for the phenomenon of total internal reflection to occur. [1 mark]

Solution:

Concept:

- Total internal reflection is complete reflection back into the incident medium at a boundary with an optically rarer medium.

Quick Tip to Solve: State both conditions together: the correct direction across the boundary and the strict inequality $i > C$.

- The critical angle C is the incidence angle for which the refraction angle is 90°; for refractive indices $n_1 > n_2$, $\sin C = n_2/n_1$.

Step 1: Specify the direction of propagation Light must travel from an optically denser medium towards an optically rarer medium, so its incident-medium refractive index must exceed that of the second medium.

Step 2: Compare incidence with the critical angle The angle of incidence, measured from the normal, must be greater than the critical angle for the two media: $i > C$. At $i = C$, the refracted ray just grazes the interface; this limiting case is not the stated condition for total internal reflection.

Step 3: Conclusion The two conditions are denser-to-rarer propagation and an angle of incidence greater than the critical angle.

Quick Tip to Solve: State both conditions together: the correct direction across the boundary and the strict inequality $i > C$.

9. Explain the function of a repeater in a communication system. [2 marks]

Solution:

Concept:

- Attenuation is the reduction in signal strength as a signal propagates through a communication channel.
- A repeater combines a receiver and a transmitter at an intermediate location to relay a received signal onwards.

Step 1: Receive and strengthen the signal A signal arriving from a distant transmitting station becomes weak because energy is lost during propagation. The receiving section of a repeater picks up this incoming signal. Its amplifier raises the signal level so that it can be transmitted effectively over the next part of the link.

Step 2: Retransmit towards the destination The transmitting section sends the amplified signal onwards to the next repeater or to the receiving station. Thus a repeater performs reception, amplification and retransmission while carrying the same information. Repeaters are placed at suitable intermediate positions to overcome the distance limitation caused by attenuation. A communication satellite can serve as a repeater station for signals exchanged between distant ground stations.

Step 3: Conclusion A repeater receives, amplifies and retransmits a communication signal, thereby extending the range of the communication link.

Quick Tip to Solve: Remember the three functions in order: receive, amplify, retransmit; then connect them to overcoming attenuation over long distances.

10. (i) Write two characteristics of a material used for making permanent magnets.
(ii) Why is core of an electromagnet made of ferromagnetic materials? [2 marks]

Solution:

Concept:

- Retentivity measures how strongly a material retains magnetisation after the magnetising field is removed; coercivity measures the reverse field needed to remove the residual magnetisation.
- Ferromagnetic materials have magnetic domains that align strongly in an applied field, producing large magnetisation and a high magnetic permeability.

Step 1: Select the properties for a permanent magnet (i) The material must have high retentivity, so that it retains substantial magnetisation after the external magnetising field is switched off. It must also have high coercivity, so that stray or opposing magnetic fields do not easily demagnetise it. These properties make a magnet strong and stable in ordinary use.

Step 2: Explain the choice of an electromagnet core (ii) A ferromagnetic core becomes strongly magnetised by the field produced by the current in the surrounding coil. Its aligned domains greatly increase the magnetic flux density compared with that of an air core for the same current. Hence it produces a strong electromagnet. In practice, a soft ferromagnetic material such as soft iron is preferred because it magnetises readily and loses most of its magnetisation when the current is switched off.

Step 3: Conclusion Permanent-magnet materials need high retentivity and high coercivity. A ferromagnetic electromagnet core provides high permeability and strong magnetisation, greatly strengthening the coil's magnetic field.

Quick Tip to Solve: Associate permanent magnets with retaining magnetisation and resisting demagnetisation; associate an electromagnet core with a large response to the coil's field.

OR

10. Draw magnetic field lines when a (i) diamagnetic, (ii) paramagnetic substance is placed in an external magnetic field. Which magnetic property distinguishes this behaviour of the field lines due to the two substances? [2 marks]

Solution:

Concept:

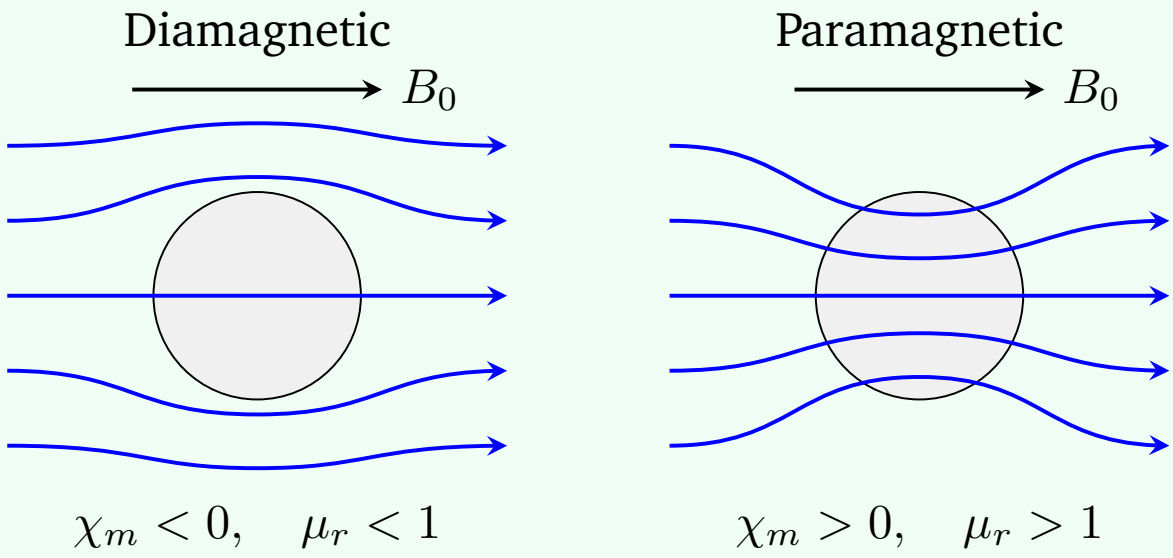
- Magnetic susceptibility χ_m relates magnetisation M to the applied magnetic field intensity H: $M = \chi_m H$.
- For a linear material, $\mu_r = 1 + \chi_m$, where μ_r is relative permeability. Field-line density represents magnetic flux density B.

Step 1: Draw the field through a diamagnetic substance (i) A diamagnetic substance develops magnetisation opposite to the applied field. Its susceptibility is small and negative, $\chi_m < 0$, and its relative permeability is slightly less than unity. The field is therefore slightly weaker inside it: the field

Quick Tip to Solve: Use the sign of χ_m: negative means an opposing response and sparser internal lines; positive means an aligned response and denser internal lines.

lines spread out and tend to avoid the substance. The sketch exaggerates this small change to make the behaviour visible.

Step 2: Draw the field through a paramagnetic substance (ii) A paramagnetic substance develops magnetisation along the applied field. Its susceptibility is small and positive, $\chi_m > 0$, and its relative permeability is slightly greater than unity. The magnetic field is slightly stronger within it, so field lines become more closely spaced as they pass through the substance. All arrows follow the external field direction in both sketches.



Field lines spread around a diamagnetic specimen and concentrate through a paramagnetic specimen; changes are exaggerated.

Step 3: Conclusion The distinguishing property is the sign of magnetic susceptibility: $\chi_m < 0$ for diamagnetic substances and $\chi_m > 0$ for paramagnetic substances. Equivalently, their relative permeabilities are below and above unity, respectively.

Quick Tip to Solve: Use the sign of χ_m: negative means an opposing response and sparser internal lines; positive means an aligned response and denser internal lines.

11. Draw the circuit diagram of an illuminated photodiode in reverse bias. How is photodiode used to measure light intensity? [2 marks]

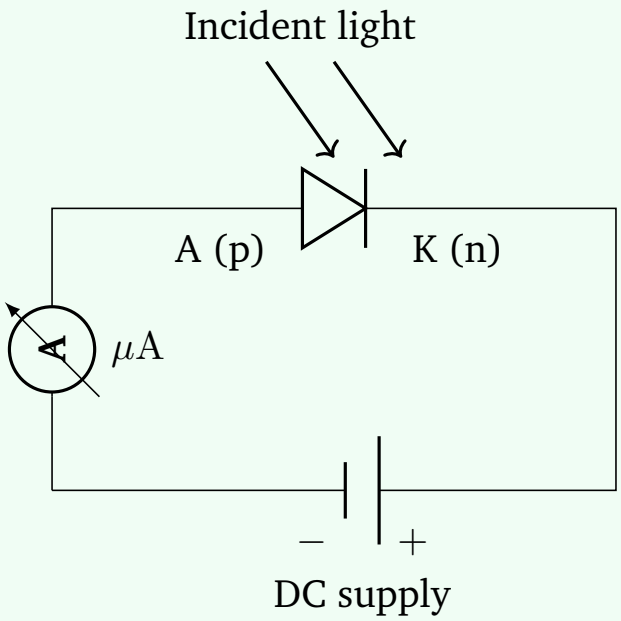
Solution:

Concept:

- A photodiode is a light-sensitive p-n junction operated in reverse bias: its p-side (anode) is connected to the negative terminal and its n-side (cathode) to the positive terminal.
- Incident photons generate electron-hole pairs near the depletion region. The junction electric field separates them, producing a reverse photocurrent proportional to incident light intensity at fixed wavelength.

Quick Tip to Solve: For reverse bias, connect the cathode bar to positive; draw the light arrows towards the diode, not away from it.

Step 1: Connect the reverse-biased detector Connect the photodiode and a sensitive microammeter in series with a DC supply as shown. The positive terminal is connected to the cathode K and the negative terminal, through the meter, to the anode A. The two arrows directed towards the junction represent incident light.



Illuminated photodiode with cathode connected to the positive DC terminal

Step 2: Use the current as an intensity reading First measure the small reverse current in darkness, called the dark current. On illumination, absorbed photons create additional charge carriers, so the magnitude of the reverse current increases. At fixed reverse voltage and wavelength, within the detector's linear operating range,

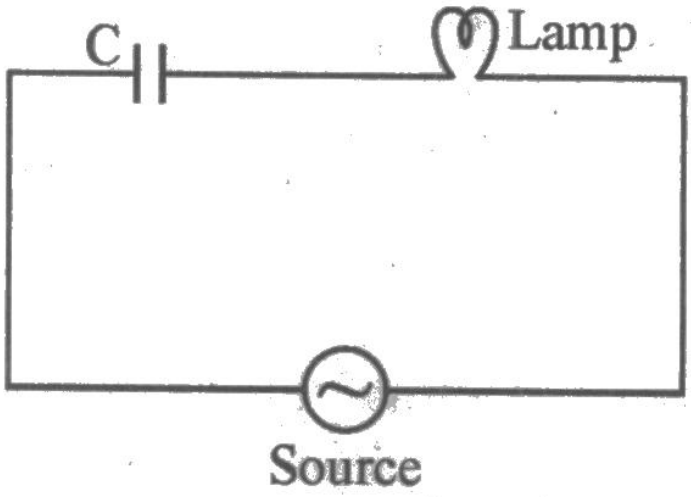
$$I_{\text{ph}} = I_{\text{illuminated}} - I_{\text{dark}} \propto \text{light intensity.}$$

Thus, a microammeter calibrated using known light intensities directly measures an unknown intensity. Stronger illumination gives a larger reading after subtracting the dark current.

Step 3: Conclusion The diagram shows a reverse-biased photodiode. Measure its reverse photocurrent with a calibrated microammeter; the photocurrent is proportional to the incident light intensity.

Quick Tip to Solve: For reverse bias, connect the cathode bar to positive; draw the light arrows towards the diode, not away from it.

12. An electric lamp having coil of negligible inductance connected in series with a capacitor and an AC source is glowing with certain brightness. How does the brightness of the lamp change on reducing the (i) capacitance, and (ii) the frequency? Justify your answer. [2 marks]



Solution:

Concept:

- With negligible lamp inductance, the series circuit contains lamp resistance R and capacitive reactance $X_C = 1/(2\pi fC)$, where f is frequency and C is capacitance.
- For a fixed rms supply voltage V, the current is $I = V/\sqrt{R^2 + X_C^2}$. The lamp's brightness depends on the average power dissipated, $P = I^2R$.

Step 1: Reduce the capacitance Keeping the source voltage and frequency unchanged, a decrease in C increases X_C. Hence the impedance $Z = \sqrt{R^2 + X_C^2}$ increases and the current decreases. The lamp receives less power and glows less brightly. In the standard constant-resistance model,

$$P = \frac{V^2 R}{R^2 + 1/(2\pi fC)^2}.$$

Decreasing C increases the denominator, explaining the decrease in brightness.

Step 2: Reduce the frequency Now keep the capacitance and rms supply voltage unchanged. Reducing f again increases the capacitive reactance because X_C is inversely proportional to f. The series current and the power dissipated in the lamp therefore decrease. Since inductance is negligible, there is no inductive reactance that could cancel this increase in capacitive reactance.

Step 3: Conclusion The lamp becomes dimmer in both cases: (i) on reducing capacitance and (ii) on reducing frequency. Each change increases capacitive reactance and reduces the current through the lamp.

Quick Tip to Solve: In a series RC circuit, reducing either factor in fC increases X_C; trace this through current to lamp power.

13. Arrange the following electromagnetic radiations in ascending order of their frequencies:

(i) Microwave

(ii) Radio wave

(iii) X-rays

(iv) Gamma rays

Write two uses of any one of these. [2 marks]

Solution:

Concept:

- All electromagnetic waves travel in vacuum with speed c, with $c = f\lambda$. Thus, a shorter wavelength λ corresponds to a higher frequency f.
- The conventional electromagnetic spectrum runs from radio waves through microwaves, infrared, visible light and ultraviolet to X-rays and gamma rays in increasing frequency.

Step 1: Compare the four spectral regions Radio waves occupy the low-frequency, long-wavelength end of the spectrum. Microwaves lie above ordinary radio waves in the conventional school classification. X-rays have much shorter wavelengths and higher frequencies than microwaves. Gamma rays are placed beyond X-rays at the high-frequency end of this standard ordering.

Step 2: State two uses of microwaves First, microwaves are used in radar: a transmitted microwave pulse is reflected by a target, and its returning signal helps determine the target's position or distance. Second, they are used in microwave ovens: absorption of microwave energy by food, especially through its water content, produces heating. Both are uses of the same requested spectral region.

Step 3: Conclusion In ascending order of frequency,

$$\text{Radio waves} < \text{Microwaves} < \text{X-rays} < \text{Gamma rays}.$$

Two uses of microwaves are radar and heating food in microwave ovens.

Quick Tip to Solve: Recall the spectrum from long wavelength to short wavelength; this is already the order of increasing frequency.

14. The radii of curvature of the faces of a double convex lens are 10 cm and 15 cm. If focal length of the lens is 12 cm, find the refractive index of the material of the lens. [2 marks]

Solution:

Concept:

- For a thin lens in air, the lens maker's formula is $1/f = (\mu - 1)(1/R_1 - 1/R_2)$, where μ is the refractive index of the lens material and R_1, R_2 are signed surface radii.
- Using the Cartesian convention with light travelling from left to right, a double convex lens has $R_1 > 0$, $R_2 < 0$ and positive focal length f.

Step 1: Assign the surface signs Take the first surface radius as $R_1 = +10\,\text{cm}$ and the second as $R_2 = -15\,\text{cm}$. Their centres of curvature lie to the right and left of the respective surfaces. The lens is

Quick Tip to Solve: For a double convex lens in air, use opposite signs for the two radii, so their reciprocal magnitudes add.

converging, so $f = +12$ cm. All lengths are expressed in centimetres, which is consistent throughout the reciprocal-length equation.

Step 2: Apply the lens maker's formula Substituting the signed radii gives

$$\frac{1}{12} = (\mu - 1)\left(\frac{1}{10} - \frac{1}{-15}\right),$$
$$\frac{1}{12} = (\mu - 1)\left(\frac{3+2}{30}\right) = \frac{\mu - 1}{6},$$
$$\mu - 1 = \frac{6}{12} = \frac{1}{2}.$$

The negative sign of the second radius makes the two curvature magnitudes add. Reversing the lens swaps their magnitudes but leaves this sum, and hence the result, unchanged.

Step 3: Conclusion The refractive index of the lens material is $\boxed{\mu = 1.50}$. Refractive index is dimensionless.

Quick Tip to Solve: For a double convex lens in air, use opposite signs for the two radii, so their reciprocal magnitudes add.

15. An electron is accelerated through a potential difference of 100 volts. What is the de-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond? [2 marks]

Solution:

Concept:

- An electron accelerated from rest through a potential difference V gains kinetic energy $K = eV$, where e is the magnitude of its charge.
- The de-Broglie relation is $\lambda = h/p$. For a nonrelativistic electron, $p = \sqrt{2m_eK}$, where m_e is the electron mass and h is Planck's constant.

Step 1: Express wavelength in terms of accelerating voltage Equating the electrical work to the kinetic energy gives

$$\frac{p^2}{2m_e} = eV, \qquad \lambda = \frac{h}{\sqrt{2m_eeV}}.$$

At $V = 100$ V, the gained energy is only 100 eV, much smaller than the electron rest energy, so the nonrelativistic expression is appropriate.

Step 2: Substitute and compare the wavelength scale With $h = 6.63 \times 10^{-34}$ J s, $m_e = 9.1 \times 10^{-31}$ kg and $e = 1.6 \times 10^{-19}$ C,

$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2(9.1 \times 10^{-31})(1.6 \times 10^{-19})(100)}}\ \text{m} = 1.23 \times 10^{-10}\ \text{m}.$$

This is 0.123 nm, a wavelength lying in the X-ray region of the electromagnetic spectrum. The electron's associated wave is a matter wave; only its wavelength is being compared with that spectrum.

Quick Tip to Solve: For a nonrelativistic electron, use $\lambda(\text{nm}) \approx 1.227/\sqrt{V\,(\text{volts})}$; at 100 V, divide by 10.

Step 3: Conclusion The de-Broglie wavelength is $\boxed{\lambda \approx 1.23 \times 10^{-10}\,\text{m}}$, corresponding in wavelength to the $\boxed{\text{X-ray region}}$.

Quick Tip to Solve: For a nonrelativistic electron, use $\lambda(\text{nm}) \approx 1.227/\sqrt{V\,(\text{volts})}$; at 100 V, divide by 10.

16. A heavy nucleus X of mass number 240 and binding energy per nucleon 7.6 MeV is split into two fragments Y and Z of mass numbers 110 and 130. The binding energy of nucleons in Y and Z is 8.5 MeV per nucleon. Calculate the energy Q released per fission in MeV. [2 marks]

Solution:

Concept:

- Total binding energy equals the mass number A multiplied by binding energy per nucleon: $B = A(B/A)$.
- When the nucleons become more tightly bound in fission, their total rest energy decreases. The released energy is $Q = B_{\text{products}} - B_{\text{initial}}$.

Step 1: Calculate the binding energy of the parent nucleus The parent X has 240 nucleons, each contributing an average binding energy of 7.6 MeV. Its total binding energy is therefore

$$B_X = 240 \times 7.6 = 1824\,\text{MeV}.$$

Binding energy per nucleon must first be multiplied by the number of nucleons; the per-nucleon difference alone is not the energy of one fission event.

Step 2: Find the increase in total binding energy The fragment mass numbers add to $110 + 130 = 240$, so the same total number of nucleons is included before and after splitting. The two fragment binding energies are

$$B_Y = 110 \times 8.5 = 935\,\text{MeV}, \qquad B_Z = 130 \times 8.5 = 1105\,\text{MeV}.$$

Thus $B_Y + B_Z = 2040$ MeV, and the increase in binding energy is

$$Q = (B_Y + B_Z) - B_X = 2040 - 1824 = 216\,\text{MeV}.$$

This increase corresponds to an equal decrease in nuclear rest energy, which is available as the energy released.

Step 3: Conclusion The energy released in each fission is $\boxed{Q = 216\,\text{MeV}}$. The positive sign signifies an exoergic process.

Quick Tip to Solve: Since both fragments have the same binding energy per nucleon, calculate directly: $Q = 240(8.5 - 7.6)$ MeV.

17. (a) The bluish colour predominates in clear sky.

(b) Violet colour is seen at the bottom of the spectrum when white light is dispersed by a prism.

State reasons to explain these observations. [2 marks]

Solution:

Concept:

- For atmospheric molecules much smaller than the wavelength, Rayleigh scattering varies approximately as $I_s \propto 1/\lambda^4$, where λ is wavelength and I_s is scattered intensity for a fixed incident intensity.
- In ordinary prism glass, refractive index increases as wavelength decreases. A prism deviates light towards its base, and violet light undergoes greater deviation than red light.

Step 1: Explain the blue appearance of the clear sky Sunlight passing through the atmosphere is scattered by air molecules. Short-wavelength blue light is scattered much more strongly than long-wavelength red light, so the sunlight reaching our eyes from directions away from the Sun is rich in blue. Although violet is scattered strongly too, the eye is less sensitive to violet and sunlight contains less violet than blue; the resulting visual impression is predominantly blue.

Step 2: Explain the position of violet in the prism spectrum The refractive index of prism material is greatest for violet among the visible colours, so violet light bends most at the prism surfaces and has the greatest net deviation. In the usual arrangement with the prism's base downwards, all colours deviate downwards towards the base, but violet deviates the most. Consequently violet appears at the bottom and red, which deviates least, appears at the top. The word bottom refers to this prism orientation; the physical rule is deviation towards the base.

Step 3: Conclusion (a) The clear sky appears blue because short-wavelength blue light is strongly scattered by atmospheric molecules. (b) Violet appears at the bottom because it has the greatest deviation towards the downward-facing base of the prism.

Quick Tip to Solve: Use $1/\lambda^4$ for sky colour, but wavelength-dependent refractive index for prism dispersion; in a prism, violet deviates most towards the base.

18. Plot a graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$). On what factors does the (i) slope and (ii) intercept of the lines depend? [2 marks]

Solution:

Concept:

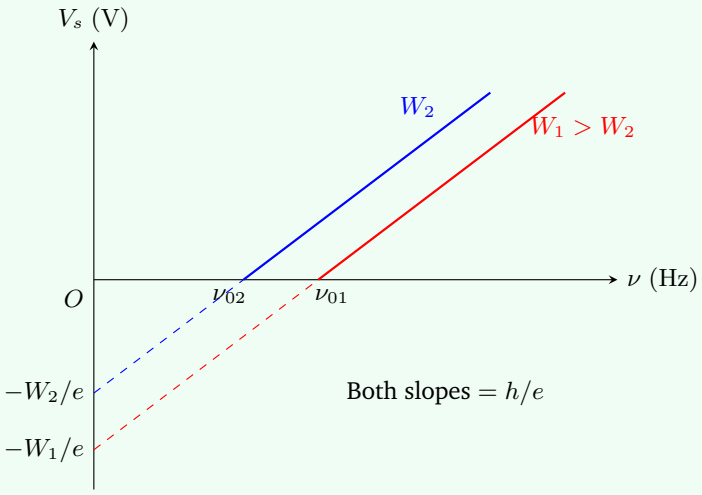
- Einstein's photoelectric equation is $eV_s = h\nu - W$, where V_s is the stopping potential, ν the incident frequency, W the work function, and e the positive elementary charge.
- A straight line $y = mx + c$ has slope m and vertical intercept c. Here $V_s = (h/e)\nu - W/e$, and photoemission begins at threshold frequency $\nu_0 = W/h$.

Quick Tip to Solve: Write $V_s = (h/e)\nu - W/e$ first: the coefficient of frequency fixes the slope, while increasing W shifts the line down and its threshold to the right.

Step 1: Draw the two stopping-potential lines For the two materials,

$$V_{s1} = \frac{h}{e}\nu - \frac{W_1}{e}, \qquad V_{s2} = \frac{h}{e}\nu - \frac{W_2}{e}.$$

Since $W_1 > W_2$, the thresholds obey $\nu_{01} = W_1/h > \nu_{02} = W_2/h$. The line for material 1 therefore starts farther to the right. At any frequency above both thresholds, its stopping potential is lower. The solid portions of the graph show physical stopping potentials; dashed portions are mathematical extrapolations below threshold, where there is no photoemission.



Stopping potential versus frequency; dashed segments indicate extrapolation, not negative physical stopping potentials.

Step 2: Identify the slope and intercepts Both straight lines have slope h/e, determined only by Planck's constant and the elementary charge. It is independent of the material and of incident intensity, so the lines are parallel. The vertical intercept is $-W/e$; it depends on the material's work function and is more negative for W_1. Equivalently, the horizontal intercept is W/h, the threshold frequency, which is larger for the material of larger work function.

Step 3: Conclusion The graph consists of parallel lines with common slope $\boxed{h/e}$. Their extrapolated vertical intercepts are $\boxed{-W_1/e \text{ and } -W_2/e}$, and their frequency-axis intercepts are $\boxed{W_1/h \text{ and } W_2/h}$, respectively.

Quick Tip to Solve: Write $V_s = (h/e)\nu - W/e$ first: the coefficient of frequency fixes the slope, while increasing W shifts the line down and its threshold to the right.

19. A parallel plate capacitor is charged by a battery. After sometime the battery is disconnected and a dielectric slab with its thickness equal to the plate separation is inserted between the plates. How will (i) the capacitance of the capacitor, (ii) potential difference between the plates and (iii) the energy stored in the capacitor be affected? Justify your answer in each case. [3 marks]

Solution:

Concept:

- A fully filled parallel-plate capacitor has capacitance $C = \varepsilon A/d$, where A is the plate area, d the separation and ε the permittivity between the plates.
- For an isolated charged capacitor, the free charge Q remains constant. Use $V = Q/C$ and $U = Q^2/(2C)$ to compare the voltage and stored electrostatic energy.

Step 1: Identify the quantity that remains fixed Let the initial capacitance, potential difference and energy be C_0, V_0 and U_0, respectively. The initial charge is $Q = C_0V_0$. Since the battery is disconnected before the dielectric is inserted, there is no conducting path for charge to enter or leave the plates. Thus the free charge remains Q; the potential difference is not held fixed by the battery.

Step 2: Compare the capacitances Let the slab's dielectric constant be $K > 1$. With the space between the plates completely filled, the permittivity changes from ε_0 to $K\varepsilon_0$, while the plate area and separation remain unchanged. Hence

$$C_0 = \frac{\varepsilon_0 A}{d}, \qquad C' = \frac{K\varepsilon_0 A}{d} = KC_0.$$

The capacitance increases by the factor K. Polarisation of the dielectric reduces the field for the same free charge, permitting a larger charge-to-voltage ratio.

Step 3: Compare the potential differences Applying $V = Q/C$ with the unchanged free charge gives

$$V' = \frac{Q}{C'} = \frac{Q}{KC_0} = \frac{V_0}{K}.$$

Thus the potential difference decreases to $1/K$ of its initial value, consistently with the reduced electric field between the plates.

Step 4: Compare the stored energies The appropriate energy expression at fixed charge is $U = Q^2/(2C)$. Therefore

$$U' = \frac{Q^2}{2KC_0} = \frac{U_0}{K}.$$

The stored electrical energy decreases. The decrease can appear as mechanical work as the dielectric is drawn into the capacitor; energy is not supplied by the disconnected battery.

Step 5: Conclusion For dielectric constant K, (i) $C' = KC_0$, (ii) $V' = V_0/K$, and (iii) $U' = U_0/K$. These results follow because the isolated capacitor retains its free charge.

Quick Tip to Solve: First circle the words "battery disconnected": keep Q fixed and compare both V and U using formulas with capacitance in the denominator.

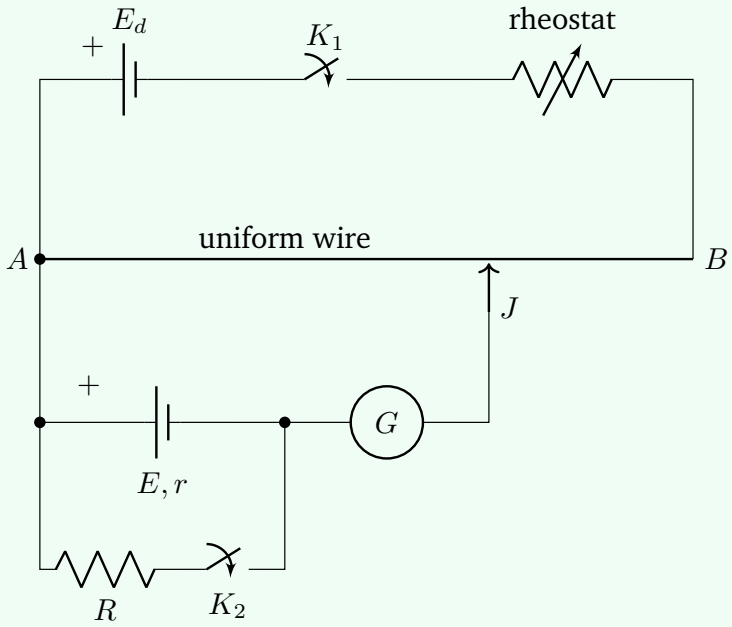
20. Write the principle of working of a potentiometer. Describe briefly, with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a given cell. [3 marks]

Solution:

Concept:

- Potentiometer principle: the potential drop across a uniform wire carrying a constant current is proportional to its length, $V = kl$, where k is the potential gradient.
- A cell of emf E and internal resistance r, supplying current through an external resistance R, has terminal voltage $V = ER/(R + r)$.

Step 1: State the principle and connect the circuit For a wire of uniform cross-sectional area and resistivity, its resistance is proportional to length. At constant current and temperature, Ohm's law therefore gives $V \propto l$. Connect a driver battery, key K_1 and rheostat in series with potentiometer wire AB, with A at higher potential. Connect the positive terminal of the test cell to A and its negative terminal to galvanometer G, whose other terminal goes to jockey J. Connect known resistance R and key K_2 in series across the test cell. The driver must provide a potential drop along AB greater than the test-cell emf.



Potentiometer circuit: K_2 connects the known load across the test cell; J is the sliding contact.

Step 2: Measure the emf balance length Close K_1, adjust the rheostat, and keep K_2 open. Move J to obtain zero galvanometer deflection. If the balance length from A is l_1, no current is drawn from the test cell at balance, so no voltage is lost across its internal resistance. Thus

$$E = kl_1.$$

Step 3: Measure the terminal-voltage balance length Close K_2, allowing the cell to supply current through R. Without changing the primary current, find the new null point at length l_2. At this null point the galvanometer branch draws no current, while R remains connected across the cell. Hence

Quick Tip to Solve: Keep the driver current unchanged between readings, and put the shorter, loaded balance length l_2 in the denominator of the resistance formula.

its terminal voltage is

$$V = kl_2, \qquad \frac{E}{V} = \frac{l_1}{l_2}.$$

Since the loaded cell has a voltage drop inside it, normally $l_2 < l_1$.

Step 4: Derive the internal resistance If the cell current is I, then $I = V/R$ and $E = V + Ir$. Eliminating I gives

$$E - V = \frac{V}{R}r, \qquad r = R\left(\frac{E}{V} - 1\right).$$

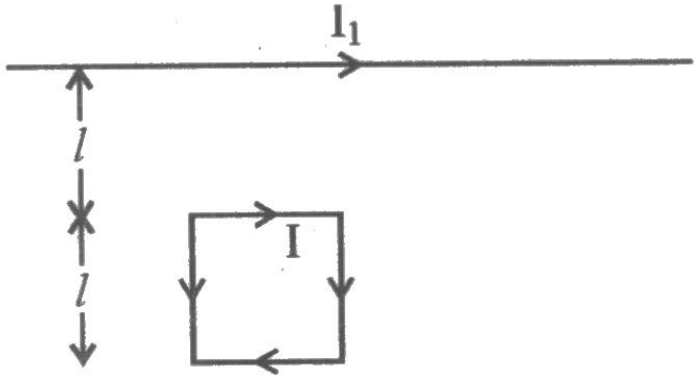
Substitute the ratio of the two measured balance lengths. The same potential gradient cancels because the primary current is kept unchanged.

Step 5: Conclusion The internal resistance is $r = R\dfrac{l_1 - l_2}{l_2}$, where l_1 is the open-circuit balance length and l_2 the balance length with R connected across the cell.

Quick Tip to Solve: Keep the driver current unchanged between readings, and put the shorter, loaded balance length l_2 in the denominator of the resistance formula.

21. Write the expression for the magnetic moment ($\vec{m}$) due to a planar square loop of side 'l' carrying a steady current I in a vector form.

In the given figure this loop is placed in a horizontal plane near a long straight conductor carrying a steady current I_1 at a distance l as shown. Give reasons to explain that the loop will experience a net force but no torque. Write the expression for this force acting on the loop. [3 marks]



Solution:

Concept:

- The magnetic moment of a planar current loop is $\vec{m} = IA\hat{n}$, where A is its area and $\hat{n}$ is the unit normal given by the right-hand rule.
- At perpendicular distance x from a long straight conductor, $B(x) = \mu_0 I_1/(2\pi x)$. A current element experiences force $d\vec{F} = I\,d\vec{l} \times \vec{B}$.

Step 1: Write the square loop's magnetic moment The loop has side l, so its area is l^2. Therefore

$$\vec{m} = Il^2\hat{n}.$$

Quick Tip to Solve: For a loop beside a straight wire, subtract the forces on the near and far parallel sides; the forces on the other two sides cancel point by point.

Curl the fingers of the right hand along the current; the thumb gives $\hat{n}$. The top, right and bottom arrows indicate clockwise circulation as viewed in the figure, giving a magnetic moment into the plane of the figure. The downward arrow printed on the left edge is inconsistent with steady current around a single loop; continuity requires upward current on that edge.

Step 2: Find the forces on the parallel sides The near side is at distance l from the wire and carries current parallel to I_1, so its force is attractive. The far side is at distance $2l$ and carries antiparallel current, so its force is repulsive. The corresponding force magnitudes are

$$F_{\text{near}} = Il\frac{\mu_0 I_1}{2\pi l} = \frac{\mu_0 I I_1}{2\pi},$$
$$F_{\text{far}} = Il\frac{\mu_0 I_1}{2\pi(2l)} = \frac{\mu_0 I I_1}{4\pi}.$$

Because the field is stronger near the wire, the attractive force exceeds the repulsive force.

Step 3: Cancel the transverse forces and examine the torque At corresponding points on the two sides perpendicular to the wire, the field has the same magnitude and direction, while the currents are opposite. Their elemental forces are equal, opposite and collinear, so they cancel pairwise and produce no resultant torque. Each parallel side experiences a uniform force whose resultant acts through that side's midpoint, along the common line through the loop's centre. These forces also exert zero torque about the centre. Thus the nonuniform magnetic field gives a net translational force but no turning effect on the loop.

Step 4: Combine the uncancelled forces Taking the direction towards the wire as positive, subtract the repulsive far-side force from the attractive near-side force:

$$F_{\text{net}} = F_{\text{near}} - F_{\text{far}} = \frac{\mu_0 I I_1}{4\pi}.$$

The dependence on l cancels because both the length of each parallel segment and its distance from the wire scale with l.

Step 5: Conclusion $\vec{m} = Il^2\hat{n}$. The loop experiences a net force of magnitude $\mu_0 I I_1/(4\pi)$ towards the straight conductor, and zero torque about its centre.

Quick Tip to Solve: For a loop beside a straight wire, subtract the forces on the near and far parallel sides; the forces on the other two sides cancel point by point.

22. (a) Depict the equipotential surfaces for a system of two identical positive point charges placed a distance 'd' apart.

(b) Deduce the expression for the potential energy of a system of two point charges q_1 and q_2 brought from infinity to the points $\vec{r}_1$ and $\vec{r}_2$ respectively in the presence of external electric field $\vec{E}$. [3 marks]

Solution:

Concept:

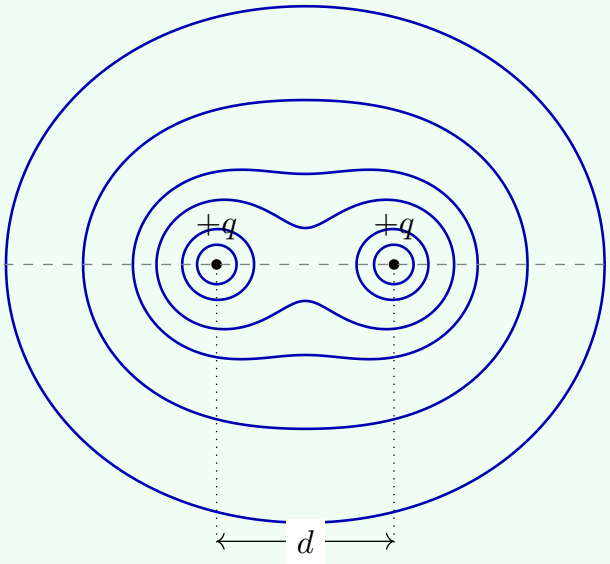
- An equipotential surface has the same electric potential at every point. For identical positive charges q, $V = kq(1/r_1 + 1/r_2)$, where $k = 1/(4\pi\varepsilon_0)$ and r_1, r_2 are distances from the charges.

Quick Tip to Solve: Add each charge's energy in the external potential, then add the mutual pair energy once; do not double-count the interaction.

- Electrostatic potential energy equals the external work required to assemble charges quasistatically. The external potential $V_{\text{ext}}(\vec{r})$ is due only to the fixed sources of the given field, with $\vec{E} = -\nabla V_{\text{ext}}$.

Step 1: (a) Sketch the equipotential surfaces The diagram shows plane sections of the surfaces through the line joining the charges. Near each charge the surfaces are nearly spherical and enclose that charge separately. Farther away a common surface encloses both charges; at very large distance it is nearly a sphere corresponding to total charge $2q$. Rotate the drawn sections about the charge axis to visualize the three-dimensional surfaces. The contours are symmetric about the midpoint and the charge axis, and the different constant-potential surfaces never intersect. Potential increases towards either positive charge; the electric field is normal to each surface wherever the field is nonzero.

$$V = kq(1/r_1 + 1/r_2) = \text{constant}$$



Plane sections of equipotential surfaces for two identical positive charges separated by d.

Step 2: (b) Bring the first charge from infinity Choose the external potential to be zero at infinity and let $V_1 = V_{\text{ext}}(\vec{r}_1)$. No second charge has yet been placed, so the work against the external field alone is

$$W_1 = q_1 V_1.$$

The prescribed external sources remain fixed during assembly. Their unchanged self-energy and the individual point-charge self-energies are excluded from the assembly energy being calculated.

Step 3: Bring the second charge into the combined potential Write $r_{12} = |\vec{r}_2 - \vec{r}_1|$ and $V_2 = V_{\text{ext}}(\vec{r}_2)$. The potential at the second position is the external potential plus that of the first charge. Therefore,

$$W_2 = q_2 \left(V_2 + \frac{kq_1}{r_{12}} \right).$$

Adding the successive work contributions counts the mutual interaction only once:

$$U = W_1 + W_2 = q_1 V_1 + q_2 V_2 + \frac{kq_1 q_2}{r_{12}}.$$

Quick Tip to Solve: Add each charge's energy in the external potential, then add the mutual pair energy once; do not double-count the interaction.

The external-field terms retain the signs of their charges and potentials. The mutual term is positive for like charges and negative for unlike charges. If the external potential cannot be referenced to infinity, the same assembly expression uses a specified finite reference instead.

Step 4: Conclusion The equipotentials consist of separate nearly spherical surfaces close to each positive charge and common enclosing surfaces farther away, as sketched. The assembly energy in the prescribed external field is

$$\boxed{U = q_1 V_{\text{ext}}(\vec{r}_1) + q_2 V_{\text{ext}}(\vec{r}_2) + \frac{q_1 q_2}{4\pi\varepsilon_0 |\vec{r}_2 - \vec{r}_1|}}.$$

Quick Tip to Solve: Add each charge's energy in the external potential, then add the mutual pair energy once; do not double-count the interaction.

23. What is an unpolarized light? Explain with the help of suitable ray diagram how an unpolarized light can be polarized by reflection from a transparent medium. Write the expression for Brewster angle in terms of the refractive index of denser medium. [3 marks]

Solution:

Concept:

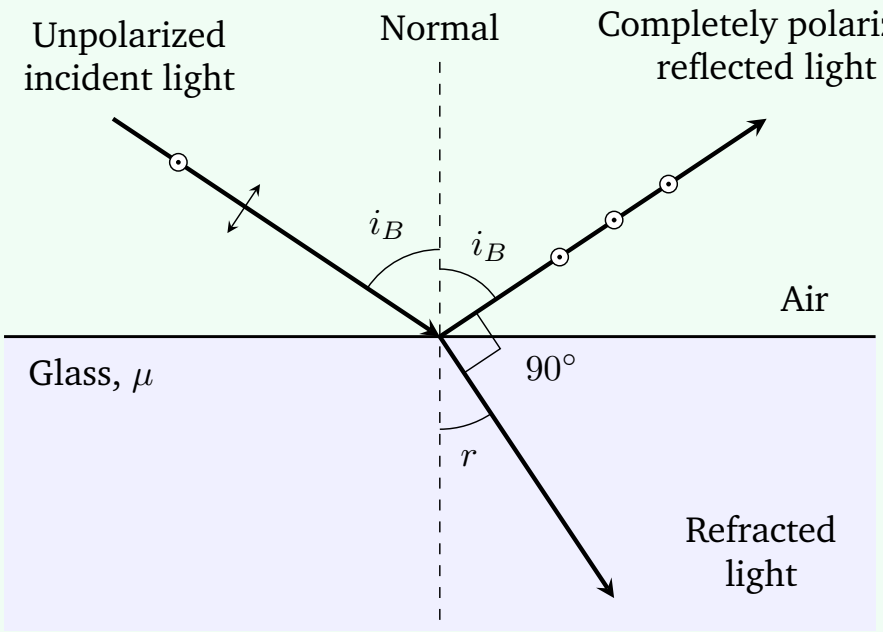
- In unpolarized light, the electric field vibrates randomly in all directions perpendicular to propagation, with no fixed preferred direction of vibration over time.
- At the polarizing or Brewster angle i_B, light reflected from a transparent dielectric is completely plane-polarized. The reflected and refracted rays are perpendicular.
- Snell's law is $n_1 \sin i_B = n_2 \sin r$, where n_1, n_2 are the refractive indices of the incident and transmitting media, and angles are measured from the normal.

Step 1: Describe the incident light and the plane of incidence Unpolarized light contains transverse electric-field vibrations whose directions change randomly. Resolve these vibrations into components parallel and perpendicular to the plane of incidence, the plane containing the incident ray and the normal to the surface. In the diagram this is the plane of the page; dots indicate electric-field vibrations perpendicular to that plane.

Step 2: Explain polarization at reflection Direct an unpolarized beam from air onto a transparent medium such as glass. In general the reflected beam is partially polarized. Adjust the incidence angle to i_B: the parallel component then has zero reflected amplitude, so the reflected beam contains only the component perpendicular to the plane of incidence. It is therefore completely plane-polarized, with its electric field parallel to the reflecting surface. The refracted beam generally remains partially polarized. At this angle the ray geometry gives

$$i_B + r = 90^\circ.$$

Quick Tip to Solve: Draw the reflected and refracted rays at right angles first; then use $r = 90^\circ - i_B$ in Snell's law to obtain $\tan i_B = \mu$.



Polarization by reflection at Brewster incidence; dots denote electric vibration perpendicular to the page.

Step 3: Derive Brewster's law For incidence from air, take $n_1 \simeq 1$ and write the denser medium's refractive index as $\mu = n_2$. Snell's law and the complementary angles give

$$\mu = \frac{\sin i_B}{\sin r} = \frac{\sin i_B}{\sin(90^\circ - i_B)} = \frac{\sin i_B}{\cos i_B} = \tan i_B.$$

Thus the required angle is measured with the surface normal, not with the surface. More generally, when the incident medium is not air, the index entering this law is the relative index n_2/n_1.

Step 4: Conclusion Unpolarized light has randomly oriented transverse electric-field vibrations. Its reflected beam is completely plane-polarized perpendicular to the plane of incidence at the Brewster angle

$$\boxed{i_B = \tan^{-1}\mu}$$

for incidence from air into a medium of refractive index μ.

Quick Tip to Solve: Draw the reflected and refracted rays at right angles first; then use $r = 90^\circ - i_B$ in Snell's law to obtain $\tan i_B = \mu$.

24. (i) Define 'activity' of a radioactive material and write its S.I. unit.

(ii) Plot a graph showing variation of activity of a given radioactive sample with time.

(iii) The sequence of stepwise decay of a radioactive nucleus is

$D \xrightarrow{\alpha} D_1 \xrightarrow{\beta^-} D_2$

If the atomic number and mass number of D_2 are 71 and 176 respectively, what are their corresponding values for D? [3 marks]

Solution:

Concept:

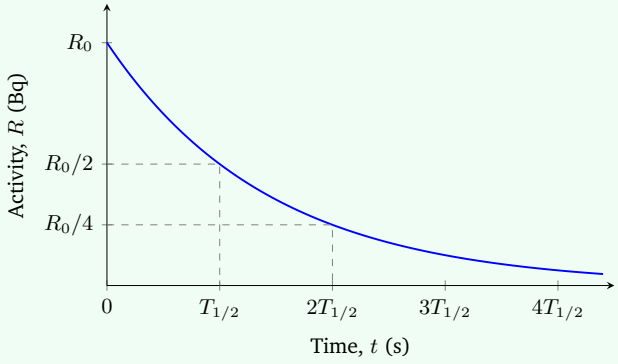
- Activity is the disintegration rate: $R = -dN/dt = \lambda N$, where N is the number of undecayed nuclei and λ is the decay constant. Thus $R = R_0 e^{-\lambda t}$.
- Alpha decay reduces mass number by four and atomic number by two. Beta-minus decay increases atomic number by one without changing mass number.

Step 1: Define activity and its unit (i) Activity is the number of radioactive disintegrations per unit time. It is positive because $R = -dN/dt$ and the number of undecayed nuclei decreases. Its SI unit is the becquerel: 1 Bq means one disintegration per second.

Step 2: Draw the activity-time graph (ii) Using $N = N_0 e^{-\lambda t}$ in $R = \lambda N$ gives

$$R(t) = \lambda N_0 e^{-\lambda t} = R_0 e^{-\lambda t}.$$

The graph starts at R_0 and decreases exponentially towards zero. At one half-life $T_{1/2} = \ln 2/\lambda$, activity is $R_0/2$; at two half-lives it is $R_0/4$. The curve approaches the time axis asymptotically.



Exponential decrease of activity with time; $T_{1/2}$ is the half-life.

Step 3: Apply both nuclear changes (iii) Let D have atomic number Z and mass number A. After alpha emission, D_1 has atomic number $Z - 2$ and mass number $A - 4$. Beta-minus emission then gives D_2 atomic number $Z - 1$, while its mass number remains $A - 4$. Therefore

$$Z - 1 = 71 \;\Rightarrow\; Z = 72, \qquad A - 4 = 176 \;\Rightarrow\; A = 180.$$

Step 4: Conclusion Activity is the disintegration rate in Bq and decreases exponentially as plotted. The parent nucleus D has $\boxed{Z = 72,\ A = 180}$.

Quick Tip to Solve: Reverse beta-minus decay first: subtract one from atomic number. Then reverse alpha decay: add two to atomic number and four to mass number.

25. A long straight wire of a circular cross-section of radius 'a' carries a steady current 'I'. The current is uniformly distributed across the cross-section. Apply Ampere's circuital law to calculate the magnetic field at a point 'r' in the region for (i) $r < a$ and (ii) $r > a$. [3 marks]

Solution:

Concept:

- Ampere's circuital law for steady currents is $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_{\text{enc}}$, where I_{enc} is the current enclosed by the closed path.
- For a long straight circular wire, cylindrical symmetry makes B constant on a coaxial circle and tangent to it. The circulation is therefore $B(2\pi r)$.
- Uniform current density means $J = I/(\pi a^2)$. The enclosed current is the current density multiplied by the cross-sectional area within the chosen path.

Step 1: Choose a circular Amperian path Take a circle of radius r, centred on the wire's axis, in a plane perpendicular to the wire. Symmetry makes the magnetic field tangent to this circle, with equal magnitude at every point. Choose its sense of traversal by the right-hand thumb rule relative to the current. Then

$$\oint \mathbf{B} \cdot d\mathbf{l} = B \oint dl = 2\pi r B = \mu_0 I_{\text{enc}}.$$

Here r is measured from the wire's axis, not from its surface.

Step 2: Calculate the field inside the wire (i) For $r < a$, only the current crossing the inner area πr^2 is enclosed. Because the current density is uniform,

$$I_{\text{enc}} = J\pi r^2 = I\frac{r^2}{a^2}.$$

Substituting this into Ampere's law gives

$$2\pi r B = \mu_0 I\frac{r^2}{a^2} \quad \Rightarrow \quad B = \frac{\mu_0 I r}{2\pi a^2}.$$

The field is zero at the axis and increases linearly with radial distance inside the wire.

Step 3: Calculate the field outside the wire (ii) For $r > a$, the entire current I lies within the Amperian circle. Thus

$$2\pi r B = \mu_0 I \quad \Rightarrow \quad B = \frac{\mu_0 I}{2\pi r}.$$

The field falls inversely with radial distance outside the wire. Both expressions give $\mu_0 I/(2\pi a)$ at the surface, so the result is continuous there.

Step 4: Conclusion The magnetic field magnitude is

$$\boxed{B(r) = \begin{cases} \dfrac{\mu_0 I r}{2\pi a^2}, & r < a, \\ \dfrac{\mu_0 I}{2\pi r}, & r > a. \end{cases}}$$

In both regions the field circles the wire's axis, with direction given by the right-hand thumb rule.

Quick Tip to Solve: First find enclosed current: inside the wire use the area fraction r^2/a^2; outside use the full current. Check that both fields agree at $r = a$.

OR

25. State the underlying principle of working of a moving coil galvanometer. Write two reasons why a galvanometer can not be used as such to measure current in a given circuit. Name any two factors on which the current sensitivity of a galvanometer depends. [3 marks]

Solution:

Concept:

- A current-carrying coil in a magnetic field experiences a torque. In the radial field of a moving coil galvanometer, the magnetic torque is $\tau_m = NBIA$.
- The suspension provides restoring torque $\tau_r = k\theta$, where k is the torsional constant and θ is the angular deflection in radians. At equilibrium, $NBIA = k\theta$.
- Current sensitivity is the angular deflection per unit current: $S_I = \theta/I = NBA/k$. Here N is the number of turns, B the magnetic field and A the area of each turn.

Step 1: State the working principle The galvanometer works on the principle that a current-carrying coil placed in a magnetic field experiences a torque. Its radial magnetic field keeps the plane of the coil parallel to the field as the coil turns, giving magnetic torque $NBIA$. The coil rotates until this torque balances the restoring torque of the suspension:

$$NBIA = k\theta \quad \Rightarrow \quad \theta = \frac{NBA}{k} I.$$

The deflection is therefore directly proportional to the current through the coil.

Step 2: Explain the two limitations for current measurement First, the galvanometer has appreciable resistance. Connecting it directly in series with a circuit adds resistance and changes the current being measured; an ideal ammeter should have negligible resistance.

Second, its fine coil can carry only a small current safely. Ordinary circuit currents may exceed its full-scale range, produce excessive deflection and heat or damage the coil. A low-resistance shunt connected in parallel diverts most of the current and converts the galvanometer into a suitable ammeter.

Step 3: Identify two factors controlling current sensitivity From $S_I = \theta/I = NBA/k$, two factors are the number of turns N in the coil and the magnetic field strength B. With other quantities fixed, current sensitivity is directly proportional to each: increasing either N or B gives a greater deflection for the same current. The formula also shows the roles of coil area and torsional constant.

Step 4: Conclusion A moving coil galvanometer uses magnetic torque on a current-carrying coil. Its appreciable resistance and small safe current range prevent direct use as an ammeter. Two factors governing current sensitivity are $\boxed{N \text{ and } B}$, with $S_I = NBA/k$.

Quick Tip to Solve: Obtain current sensitivity by balancing $NBIA$ with $k\theta$, then divide by I. Keep the two ammeter limitations distinct: circuit loading and the coil's small current capacity.

26. What is space wave propagation? Give two examples of communication systems which use space wave mode.

A TV tower is 80 m tall. Calculate the maximum distance upto which the signal transmitted from the tower can be received. [3 marks]

Solution:

Concept:

- Space waves travel through the lower atmosphere from the transmitting antenna to the receiving antenna, chiefly along a direct line of sight; a ground-reflected component can also reach the receiver.
- The approximate horizon distance of an antenna of height h is $d = \sqrt{2R_E h}$, where R_E is Earth's radius and $h \ll R_E$.

Step 1: Describe the mode and give examples In space wave propagation, radio waves pass through the troposphere from the transmitter to the receiver. Because they travel approximately in straight lines, the direct signal requires line of sight between the antennas. Earth's curvature therefore limits the coverage of a terrestrial transmitter. Television broadcasting and microwave point-to-point communication are two systems that use this mode.

Step 2: Relate tower height to the horizon distance At the limiting range, the ray from the top of the tower is tangent to Earth's surface. The Earth radius drawn to the point of tangency is perpendicular to this ray. Pythagoras' theorem gives

$$(R_E + h)^2 = R_E^2 + d^2 \quad \Rightarrow \quad d^2 = 2R_E h + h^2.$$

Since the tower height is extremely small compared with Earth's radius, the h^2 term is negligible. No receiver height is specified, so the receiver is taken to be at ground level.

Step 3: Substitute the tower height in SI units Use $h = 80\,\text{m}$ and $R_E = 6.4 \times 10^6\,\text{m}$. Thus

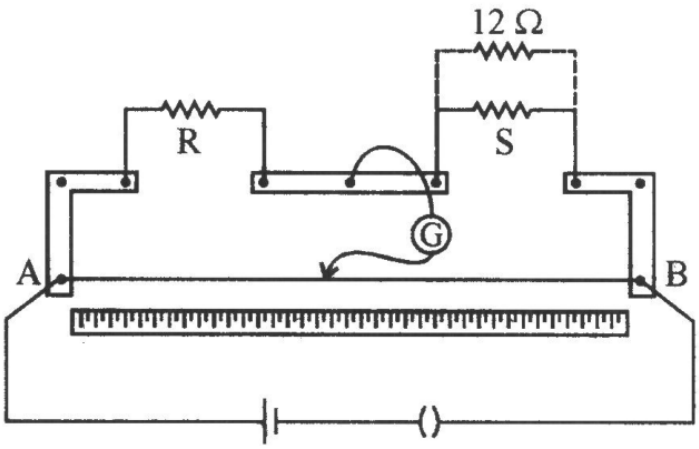
$$\begin{aligned} d &= \sqrt{2(6.4 \times 10^6)(80)}\,\text{m} \\ &= \sqrt{1.024 \times 10^9}\,\text{m} = 3.2 \times 10^4\,\text{m}. \end{aligned}$$

This is the ideal geometrical range; a raised receiving antenna would add its own horizon distance.

Step 4: Conclusion Space wave propagation is radio transmission through the lower atmosphere, principally along the line of sight. Television broadcasting and microwave links use it. The maximum ground-level reception distance for the $80\,\text{m}$ tower is $\boxed{32\,\text{km}}$.

Quick Tip to Solve: Put both Earth's radius and tower height in metres before taking the square root; convert the resulting metres to kilometres only at the end.

27. In a meter bridge, the null point is found at a distance of 40 cm from A. If a resistance of 12 Ω is connected in parallel with S, the null point occurs at 50.0 cm from A. Determine the values of R and S. [3 marks]



Solution:

Concept:

- At balance a metre bridge has zero galvanometer current. With R next to A and S next to B, $R/S = l/(100 - l)$, where l is the balance length in centimetres from A along the uniform wire.
- Connecting $12\,\Omega$ in parallel with S gives $S' = (12\,\Omega)S/(S + 12\,\Omega)$. This decreases the right-gap resistance while the left-gap resistance is unchanged.

Step 1: Use the initial balance length The wire lengths on the two sides of the null point are 40 cm and 60 cm. The printed circuit has R in the left gap, so

$$\frac{R}{S} = \frac{40}{60} = \frac{2}{3}, \qquad R = \frac{2S}{3}.$$

Step 2: Use the new midpoint balance After adding the parallel resistor, both wire segments are 50.0 cm long. Their resistances are equal, so the gap resistances must now also be equal:

$$R = S' = \frac{(12\,\Omega)S}{S + 12\,\Omega}.$$

Substitute the first relation and cancel the nonzero resistance S:

$$\frac{2}{3} = \frac{12\,\Omega}{S + 12\,\Omega} \quad \Rightarrow \quad 2S + 24\,\Omega = 36\,\Omega.$$

Thus $S = 6\,\Omega$, and $R = 2S/3 = 4\,\Omega$. For verification, $6\,\Omega$ in parallel with $12\,\Omega$ is $4\,\Omega$, giving the observed central balance. Initially, $4/6 = 40/60$, so both observations are satisfied.

Step 3: Conclusion The required resistances are $\boxed{R = 4\,\Omega}$ and $\boxed{S = 6\,\Omega}$.

Quick Tip to Solve: A midpoint null means equal gap resistances. Pair the resistance next to A with the wire length measured from A to avoid reversing the initial ratio.

28. Describe briefly, with the help of a labelled diagram, the basic elements of an A.C. generator. State its underlying principle. Show diagrammatically how an alternating emf is generated by a loop of wire rotating in a magnetic field. Write the expression for the instantaneous value of the emf induced in the rotating loop. [5 marks]

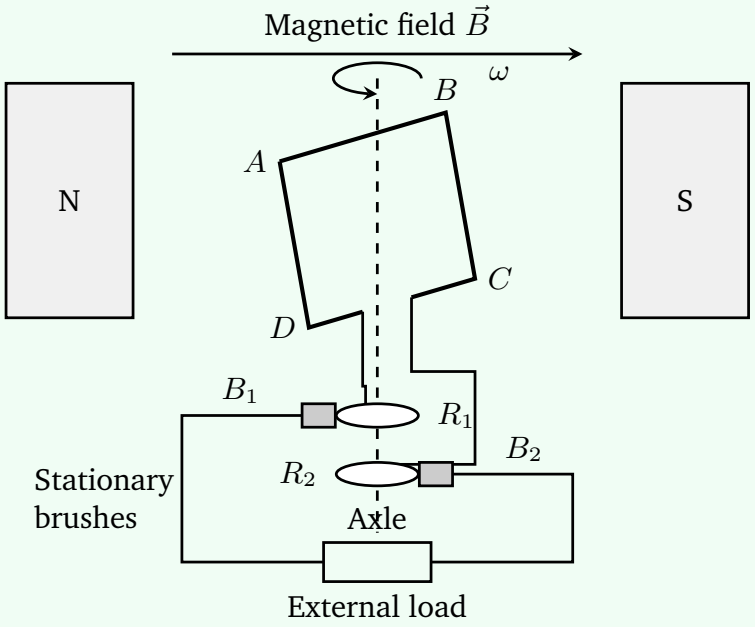
Solution:

Concept:

- An A.C. generator converts mechanical energy into electrical energy by electromagnetic induction. Faraday's law gives $\varepsilon = -d(N\Phi)/dt$, where $N\Phi$ is the magnetic flux linkage of an N-turn coil.
- For a plane coil of area A in a uniform magnetic field B, $\Phi = BA\cos\theta$, where θ is the angle between the field and the normal to the coil. Uniform rotation gives $\theta = \omega t$ when the normal is initially parallel to the field.

Step 1: Identify the basic elements A rectangular insulated copper coil $ABCD$, called the armature, is mounted on an axle between the north and south poles of a strong magnet. The field is directed from N to S. A mechanical drive rotates the axle and coil about an axis perpendicular to the magnetic field.

The two ends of the coil are connected separately to two mutually insulated metallic slip rings R_1 and R_2, which rotate with the axle. Stationary carbon brushes B_1 and B_2 press against the rings and connect them to the external load. Each ring maintains contact with the same end of the coil throughout the rotation, allowing an alternating output to reach the load.



A.C. generator with separate coil-end connections to slip rings; brushes remain stationary.

Step 2: Apply the principle of electromagnetic induction As the armature rotates, the angle between its normal and the magnetic field changes continuously. Therefore the magnetic flux linked with the coil changes and an emf is induced according to Faraday's law. When the external circuit is closed, this emf drives a current through the brushes and the load. Its direction can be found using Fleming's right-hand rule; it reverses after every half-turn because the motion of each active side relative to the

Quick Tip to Solve: Measure the angle from the coil's normal: maximum flux means zero emf, whereas zero flux means maximum emf. Slip rings preserve the alternating output.

field reverses. Lenz's law accounts for the minus sign and the opposing torque that the mechanical drive must overcome.

Step 3: Derive the instantaneous induced emf Let the coil contain N turns, each of area A, and rotate with uniform angular speed ω. Choose $t = 0$ when the normal to the coil is parallel to $\vec{B}$. The flux linkage is

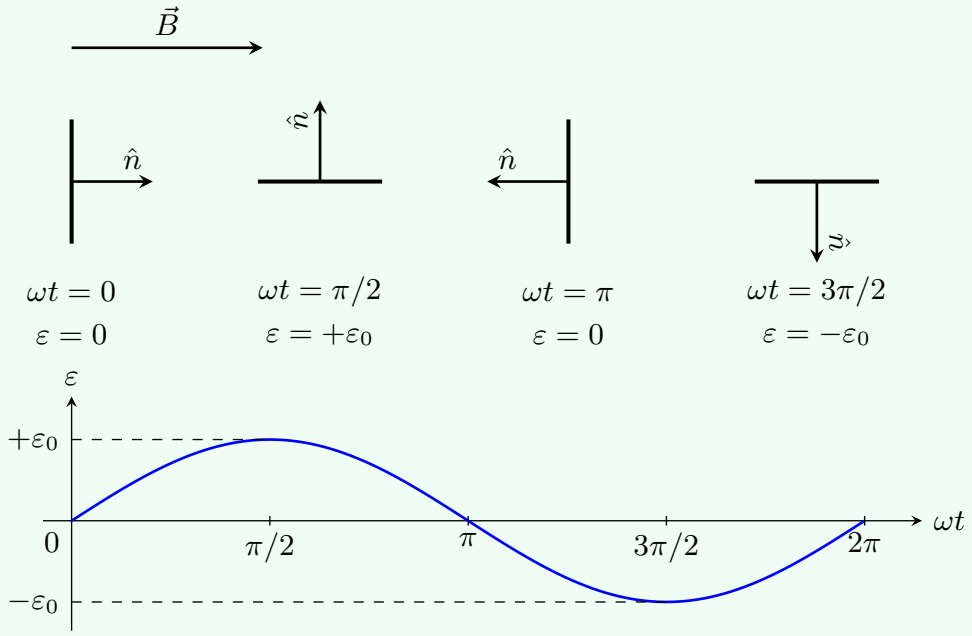
$$N\Phi = NBA\cos\omega t.$$

Differentiating with respect to time gives

$$\varepsilon = -\frac{d}{dt}(NBA\cos\omega t) = NBA\omega\sin\omega t.$$

The peak emf is $\varepsilon_0 = NBA\omega$, and the frequency is $f = \omega/(2\pi)$. For the single loop specified in the question, put $N = 1$. The sign is measured with a fixed choice of terminals; reversing that choice reverses all signs without changing the alternating nature of the output.

Step 4: Follow one complete revolution diagrammatically The small sketches below are end views along the rotation axis: the thick segment represents the plane of the loop, and the arrow $\hat{n}$ is its normal. At $\omega t = 0$, the plane is perpendicular to the field, the flux is maximum and its instantaneous rate of change is zero. At $\pi/2$, the plane is parallel to the field, the flux is zero and the positive emf is maximum. At π, the flux has reversed and again has zero rate of change. At $3\pi/2$, the emf is maximum in the negative direction. After 2π, the initial position returns. Thus the emf completes one sinusoidal cycle per revolution.



Loop orientations and the corresponding sinusoidal emf, with the magnetic field directed to the right.

Step 5: Conclusion A rotating coil, magnetic field, slip rings and brushes form the basic A.C. generator. Its induced emf alternates because its flux linkage varies sinusoidally:

$$\boxed{\varepsilon(t) = NBA\omega\sin\omega t = \varepsilon_0\sin\omega t.}$$

Quick Tip to Solve: Measure the angle from the coil's normal: maximum flux means zero emf, whereas zero flux means maximum emf. Slip rings preserve the alternating output.

For one loop, $\varepsilon_0 = BA\omega$. This phase convention takes the coil normal parallel to the field at $t = 0$.

Quick Tip to Solve: Measure the angle from the coil's normal: maximum flux means zero emf, whereas zero flux means maximum emf. Slip rings preserve the alternating output.

OR

28. A series LCR circuit is connected to an ac source having voltage $v = v_m \sin \omega t$. Derive the expression for the instantaneous current I and its phase relationship to the applied voltage.
Obtain the condition for resonance to occur. Define 'power factor'. State the conditions under which it is (i) maximum and (ii) minimum. [5 marks]

Solution:

Concept:

- In a series circuit the same instantaneous current flows through the resistance R, inductance L and capacitance C. Kirchhoff's voltage law gives $v = Ri + L\,di/dt + q/C$, where $i = dq/dt$.
- The inductive and capacitive reactances are $X_L = \omega L$ and $X_C = 1/(\omega C)$. Their voltage contributions are opposite in phase, so the net reactance is $X = X_L - X_C$.
- For sinusoidal voltage and current, average power is $P = V_{\text{rms}} I_{\text{rms}} \cos\phi$, where ϕ is the phase by which voltage leads current. The power factor is $\cos\phi$.

Step 1: Write the steady-state voltage equation Let the current be $i = i_m \sin(\omega t - \phi)$, and put $\theta = \omega t - \phi$. In sinusoidal steady state,

$$\frac{di}{dt} = \omega i_m \cos\theta, \qquad q = -\frac{i_m}{\omega}\cos\theta.$$

Substituting into Kirchhoff's law gives

$$v = i_m R \sin\theta + i_m \left(\omega L - \frac{1}{\omega C}\right)\cos\theta.$$

Here the resistor voltage is in phase with the current, while the inductor and capacitor voltages are respectively ahead of and behind it by $\pi/2$.

Step 2: Compare coefficients to obtain current and phase The applied voltage can also be written as

$$v = v_m \sin(\theta + \phi) = v_m \cos\phi \sin\theta + v_m \sin\phi \cos\theta.$$

Equating the coefficients of the two independent sinusoidal terms,

$$v_m \cos\phi = i_m R, \qquad v_m \sin\phi = i_m (X_L - X_C).$$

Squaring and adding gives $v_m^2 = i_m^2[R^2 + (X_L - X_C)^2]$. Therefore the impedance and current amplitude

Quick Tip to Solve: Subtract the reactances before combining with resistance: $X_L - X_C$ fixes both the impedance and whether current leads or lags. At resonance this difference vanishes, not the individual reactances.

are

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}, \qquad i_m = \frac{v_m}{Z}.$$

Dividing the coefficient equations gives

$$\tan\phi = \frac{X_L - X_C}{R}, \qquad i(t) = \frac{v_m}{Z}\sin(\omega t - \phi).$$

For $X_L > X_C$, $\phi > 0$ and current lags voltage. For $X_C > X_L$, $\phi < 0$ and current leads voltage by $|\phi|$. For equal reactances they are in phase.

Step 3: Obtain the resonance condition Series resonance occurs when the opposing reactive voltages cancel:

$$X_L = X_C \quad \Rightarrow \quad \omega_0 L = \frac{1}{\omega_0 C} \quad \Rightarrow \quad \omega_0 = \frac{1}{\sqrt{LC}}.$$

Thus $f_0 = 1/(2\pi\sqrt{LC})$. At resonance, $Z = R$ is minimum, the current amplitude $i_m = v_m/R$ is maximum for a fixed source amplitude, and $\phi = 0$. The inductor and capacitor can each have nonzero voltage, but those voltages cancel in the series sum.

Step 4: Define the power factor and its limiting values The power factor is the cosine of the phase difference between applied voltage and current, equivalently the ratio of average power to apparent power:

$$\cos\phi = \frac{P}{V_{\text{rms}} I_{\text{rms}}} = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}}.$$

(i) Its maximum value is 1, when $\phi = 0$: the circuit is purely resistive in its net behaviour. A series LCR circuit with $R > 0$ attains this at resonance, $X_L = X_C$.

(ii) Its minimum value is 0, when $|\phi| = \pi/2$: the circuit is purely reactive, such as an ideal inductor or capacitor, with no resistance and nonzero net reactance. Energy is stored and returned each cycle, so average power is zero. For a series LCR circuit with a fixed nonzero R, the power factor remains positive at finite frequency and approaches zero when $|X_L - X_C|$ becomes much greater than R.

Step 5: Conclusion The current is $i = (v_m/Z)\sin(\omega t - \phi)$, with impedance Z as derived above and $\tan\phi = (X_L - X_C)/R$. Resonance requires $\omega_0 = 1/\sqrt{LC}$. The power factor R/Z is unity for zero net reactance and zero for an ideal purely reactive circuit.

Quick Tip to Solve: Subtract the reactances before combining with resistance: $X_L - X_C$ fixes both the impedance and whether current leads or lags. At resonance this difference vanishes, not the individual reactances.

29. State Huygens's principle. Show, with the help of a suitable diagram, how this principle is used to obtain the diffraction pattern by a single slit.

Draw a plot of intensity distribution and explain clearly why the secondary maxima become weaker with increasing order (n) of the secondary maxima. [5 marks]

Solution:

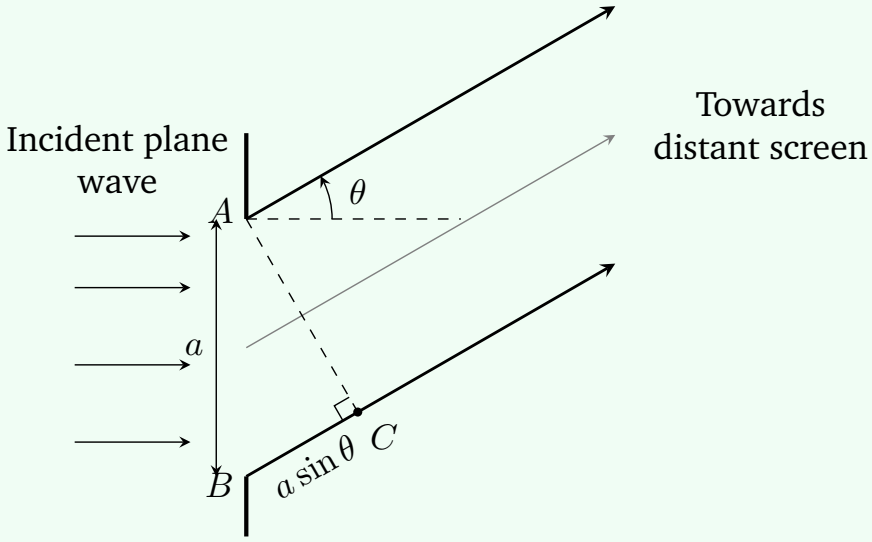
Concept:

- Huygens's principle: every point of a wavefront acts as a source of secondary wavelets that spread with the speed of light in that medium. The forward envelope of these wavelets gives the new wavefront.
- For a uniformly illuminated slit of width a, secondary wavelets from all points across the opening superpose. At angle θ to the slit normal, the path difference between the extreme rays is $a\sin\theta$.
- With wavelength λ, define $\beta = \pi a\sin\theta/\lambda$. The intensity is $I = I_0(\sin\beta/\beta)^2$, where I_0 is the central intensity.

Step 1: Apply Huygens's principle at the slit Let monochromatic plane waves fall normally on the narrow slit AB, of width a. All points in its opening are coherent secondary sources, initially in phase. Observe the Fraunhofer pattern on a distant screen, or in the focal plane of a convex lens. Rays going in one direction θ contribute to the same observation point. Draw AC perpendicular to the ray from B. The rays have equal remaining optical paths after this reference wavefront, so their initial path difference is

$$\Delta = BC = AB\sin\theta = a\sin\theta.$$

Along the normal, $\theta = 0$, all wavelets arrive in phase and produce the bright central maximum.



Parallel diffracted rays towards a distant point at angle θ. The perpendicular AC gives $BC = a\sin\theta$.

Step 2: Obtain the dark bands by pairwise cancellation At $a\sin\theta = \lambda$, divide the slit into two equal halves. Every point in one half has a partner displaced by $a/2$ in the other. Each pair has path difference $(a/2)\sin\theta = \lambda/2$, hence phase difference π, and cancels. This gives the first minimum on either side. More generally, if $a\sin\theta = m\lambda$, divide the slit into $2m$ equal strips. Adjacent strips cancel

Quick Tip to Solve: For slit minima, pair points separated by $a/(2m)$. Do not apply the minimum formula at $m = 0$: the centre has all wavelets in phase and is the brightest point.

in pairs because their corresponding wavelets differ in path by $\lambda/2$. Therefore

$$a \sin\theta_m = m\lambda, \qquad m = \pm 1, \pm 2, \ldots$$

Between consecutive minima the cancellation is incomplete and a secondary maximum occurs. For small angles on a screen at distance D, $y_m = m\lambda D/a$; thus the central maximum extends from $-\lambda D/a$ to $+\lambda D/a$, twice the spacing between adjacent minima outside it.

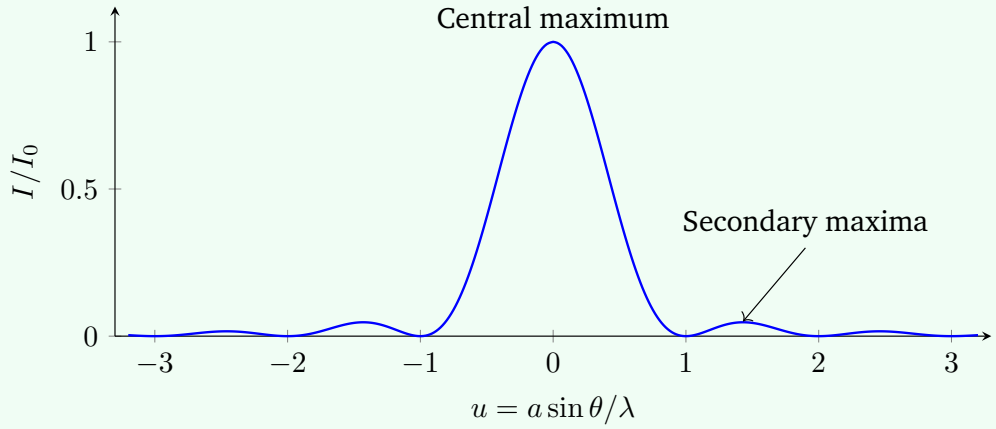
Step 3: Obtain and plot the intensity distribution To express the superposition quantitatively, take a small strip at transverse coordinate y, measured from the slit centre. Its phase relative to the centre is $2\pi y \sin\theta/\lambda$. If the amplitude contribution per unit width is c, symmetry cancels the sine components and gives

$$\begin{aligned} A(\theta) &= c\int_{-a/2}^{a/2} \cos\left(\frac{2\pi y \sin\theta}{\lambda}\right) dy \\ &= ca\frac{\sin\beta}{\beta}, \qquad \beta = \frac{\pi a \sin\theta}{\lambda}. \end{aligned}$$

Since intensity is proportional to amplitude squared and $A(0) = ca$,

$$\frac{I(\theta)}{I_0} = \left(\frac{\sin\beta}{\beta}\right)^2.$$

At $\beta = 0$, use $\sin\beta/\beta \to 1$, so the central intensity is I_0, not zero. The graph is symmetric, with zero intensity at nonzero integer values of $a\sin\theta/\lambda$, a broad central peak and weaker side peaks.



Normalised single-slit intensity: the central peak spans two minimum spacings; the side peaks rapidly weaken.

Step 4: Explain the decreasing secondary maxima As the observation angle increases, phase changes more rapidly across the opening and more of the wavelets cancel. Only a smaller resultant amplitude remains. Approximately, at $a\sin\theta = (2n+1)\lambda/2$, divide the slit into $2n+1$ equal strips: $2n$ strips cancel in pairs, leaving one strip. Its fractional width decreases as the order n increases. The intensity formula gives the same result precisely. Nonzero maxima satisfy $\tan\beta = \beta$. At these roots,

$$\frac{I_n}{I_0} = \frac{1}{1+\beta_n^2}.$$

Thus larger $|\beta_n|$ means a weaker maximum. The familiar approximate positions $\beta_n \simeq (n + \frac{1}{2})\pi$, for

Quick Tip to Solve: For slit minima, pair points separated by $a/(2m)$. Do not apply the minimum formula at $m = 0$: the centre has all wavelets in phase and is the brightest point.

$n = 1, 2, \ldots$, give

$$\frac{I_n}{I_0} \simeq \frac{1}{(n + \frac{1}{2})^2 \pi^2}.$$

These approximate positions are slightly displaced from the true maxima; the diminishing intensity follows from increasing destructive interference across the slit.

Step 5: Conclusion Huygens wavelets from a single slit interfere to produce a broad central maximum, minima at $a \sin\theta = m\lambda$ and secondary maxima between them. The distribution $I = I_0(\sin\beta/\beta)^2$ shows that the secondary maxima weaken with increasing order because cancellation becomes more complete.

Quick Tip to Solve: For slit minima, pair points separated by $a/(2m)$. Do not apply the minimum formula at $m = 0$: the centre has all wavelets in phase and is the brightest point.

OR

29. Draw a ray diagram to show the working of a compound microscope. Deduce an expression for the total magnification when the final image is formed at the near point.

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

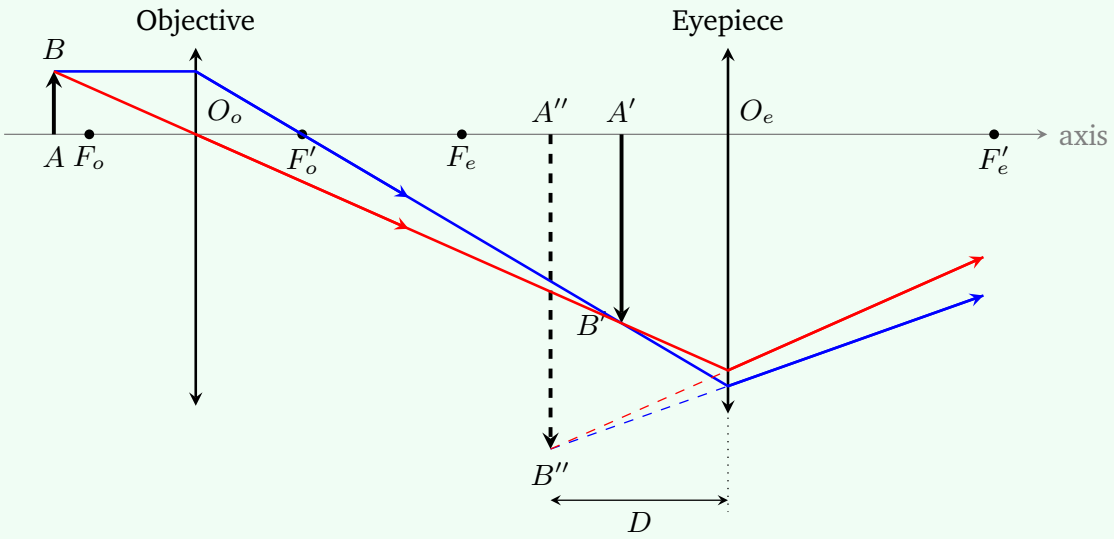
Solution:

Concept:

- A compound microscope combines the objective's linear magnification with the eyepiece's angular magnification: $M = m_o M_e$.
- With Cartesian distances, $1/f = 1/v - 1/u$ and $m_o = v_o/u_o$. The least distance of distinct vision is $D = 25\,\text{cm}$.
- For a final virtual image at the near point, the eyepiece acts as a simple microscope with $M_e = 1 + D/f_e$.

Step 1: Trace the formation of the two images Place the small object AB just beyond the objective's principal focus F_o. The objective forms a real, inverted and enlarged intermediate image $A'B'$. Adjust the eyepiece so that this image lies between its first focus F_e and its optical centre O_e. Rays emerging from the eyepiece diverge; their backward extensions meet at B''. The final image $A''B''$ is virtual, enlarged and inverted relative to AB, at distance D from the eyepiece. The diagram is schematic; dashed rays are backward extensions.

Quick Tip to Solve: First find the objective's actual image distance using the lens formula; then multiply its magnification by $1 + D/f_e$, retaining the extra 1 for near-point viewing.



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

Step 2: Derive the eyepiece magnification Let the intermediate image height have magnitude h', and put its distance from the eyepiece equal to $s = |u_e|$. For near-point viewing, $v_e = -D$ and $u_e = -s$. Thus

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

In the small-angle approximation the angle subtended through the eyepiece is $\beta \simeq h'/s$; viewing this intermediate image directly at the near point would subtend h'/D. Their ratio is therefore $M_e = D/s = 1 + D/f_e$.

Step 3: Combine the objective and eyepiece factors If the original object has height h, viewing it directly at D gives angle $\alpha \simeq h/D$. Since $h'/h = |v_o/u_o|$, the total angular magnification has magnitude

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

Retaining the inversion sign gives $M = (v_o/u_o)(1 + D/f_e)$. For an object very close to the objective focus and an intermediate-image distance approximately equal to the tube length L, the familiar estimate is $M \simeq -(L/f_o)(1 + D/f_e)$. The given object distance allows the exact thin-lens objective factor to be used here.

Step 4: Calculate the objective image distance Use $u_o = -1.5\,\text{cm}$ and $f_o = +1.25\,\text{cm}$:

$$\frac{1}{v_o} = \frac{1}{f_o} + \frac{1}{u_o} = \frac{1}{1.25} - \frac{1}{1.5} = \frac{2}{15}\,\text{cm}^{-1}.$$

Hence $v_o = 7.5\,\text{cm}$, and the signed objective magnification is $m_o = 7.5/(-1.5) = -5$. Its negative sign confirms that the intermediate image is inverted.

Step 5: Evaluate the eyepiece factor For $f_e = 5\,\text{cm}$ and $D = 25\,\text{cm}$,

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

Quick Tip to Solve: First find the objective's actual image distance using the lens formula; then multiply its magnification by $1 + D/f_e$, retaining the extra 1 for near-point viewing.

The intermediate image must be $s = f_e D/(D + f_e) = 25/6$ cm in front of the eyepiece, which is less than its focal length. This verifies the near-point arrangement used in the derivation.

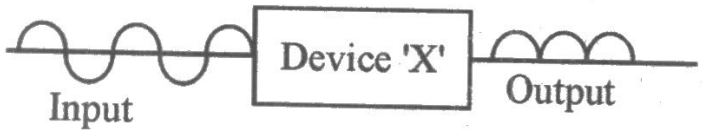
Step 6: Conclusion For the final image at the near point, $M = (v_o/u_o)(1 + D/f_e)$. Numerically, $M = (-5)(6) = -30$: the magnifying power is 30, and the final virtual image is inverted relative to the object.

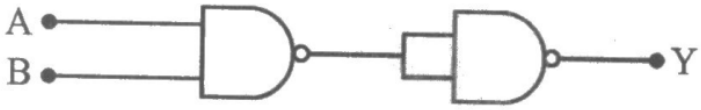
Quick Tip to Solve: First find the objective's actual image distance using the lens formula; then multiply its magnification by $1 + D/f_e$, retaining the extra 1 for near-point viewing.

30. (a) Explain the formation of depletion layer and potential barrier in a p-n junction.

(b) In the figure given below the input waveform is converted into the output waveform by a device 'X'. Name the device and draw its circuit diagram.

(c) Identify the logic gate represented by the circuit as shown and write its truth table. [5 marks]





Solution:

Concept:

- Majority carriers diffuse across a newly formed p-n junction because of their concentration gradient. The uncovered, immobile ions produce a depletion region and an electric field.
- A full-wave rectifier converts both half-cycles of an alternating voltage into a unidirectional, pulsating output across a load resistance R_L.
- A NAND gate gives $\overline{AB}$. Joining its two inputs makes it an inverter, since $\overline{Z \cdot Z} = \overline{Z}$.

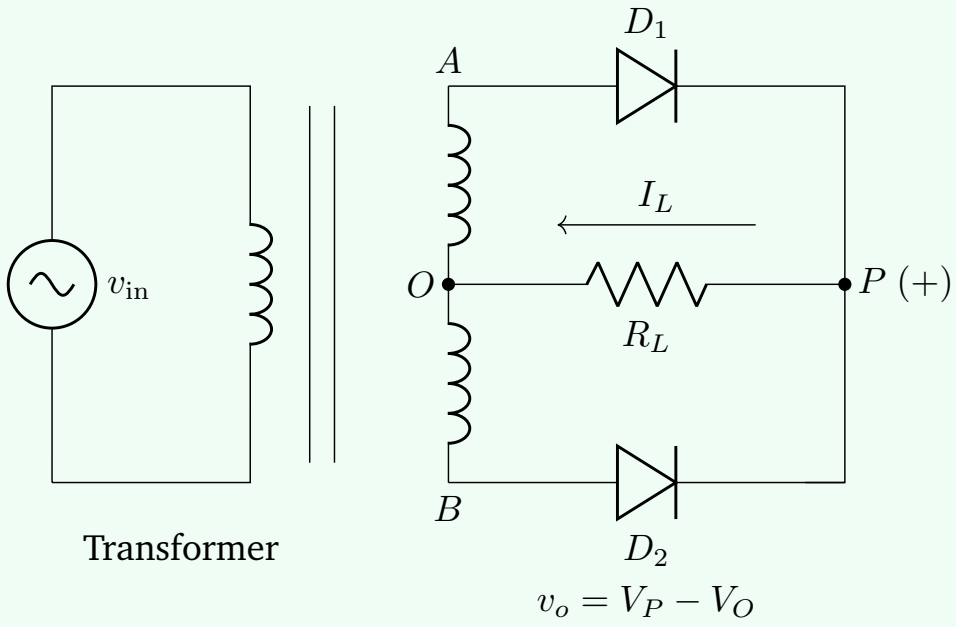
Step 1: (a) Formation of the depletion layer When p-type and n-type semiconductors are joined, electrons diffuse from the n-side, where their concentration is large, into the p-side. Holes similarly diffuse from the p-side into the n-side. Near the junction these electrons and holes recombine. The n-side is therefore left with positively charged donor ions, while the p-side is left with negatively charged acceptor ions. These ions are fixed in the crystal lattice and cannot carry current. The thin region on both sides of the junction is depleted of mobile majority carriers and is called the depletion layer.

Step 2: (a) Establishment of the potential barrier The uncovered ions create an electric field directed from the positive donor ions on the n-side towards the negative acceptor ions on the p-side. This field opposes the further diffusion of both electrons and holes. It establishes a potential difference across the junction, called the potential barrier. As the layer forms, the field increases until the drift current caused by this field balances the diffusion current. Thus, at thermal equilibrium, there is no

Quick Tip to Solve: If every input half-cycle becomes an output pulse of the same sign, identify full-wave rectification. For the logic circuit, replace a NAND with tied inputs by a NOT gate first.

net current across an unbiased junction; this does not mean that all microscopic carrier motion ceases.

Step 3: (b) Identify the device and draw its circuit The negative input half-cycles appear as positive pulses in the output, while the positive half-cycles are retained. Thus device X performs full-wave rectification. A two-diode circuit using a centre-tapped transformer secondary is shown below. The ends A and B have equal and opposite instantaneous voltages relative to the centre tap O; the diode cathodes are joined at P. The load is connected between P and O, and $v_o = V_P - V_O$.



Centre-tapped full-wave rectifier: the load current flows from P to O in both half-cycles.

Step 4: (b) Explain the rectifier operation During the half-cycle in which A is positive relative to O, diode D_1 is forward biased and D_2 is reverse biased. Conventional current follows $A \to D_1 \to P \to R_L \to O$. In the next half-cycle, B is positive relative to O, so D_2 conducts and D_1 blocks; current follows $B \to D_2 \to P \to R_L \to O$. The current through the load therefore has the same direction in both half-cycles. The output is pulsating dc with twice the input frequency; no smoothing capacitor is needed to produce the waveform shown.

Step 5: (c) Reduce the logic circuit and write the truth table The first gate is NAND, giving $Z = \overline{AB}$. Both inputs of the second NAND are connected to Z, so its output is

$$Y = \overline{Z \cdot Z} = \overline{Z} = \overline{\overline{AB}} = AB.$$

Consequently, the output is high only when both inputs are high. The complete truth table, including the intermediate signal, is

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

Step 6: Conclusion (a) Recombination exposes fixed ions, forming a depletion layer; their electric field

Quick Tip to Solve: If every input half-cycle becomes an output pulse of the same sign, identify full-wave rectification. For the logic circuit, replace a NAND with tied inputs by a NOT gate first.

establishes the potential barrier that opposes further diffusion. (b) Device X is a full-wave rectifier. (c) The combination represents an AND gate, with $Y = AB$.

Quick Tip to Solve: If every input half-cycle becomes an output pulse of the same sign, identify full-wave rectification. For the logic circuit, replace a NAND with tied inputs by a NOT gate first.

OR

30. (a) With the help of the circuit diagram explain the working principle of a transistor amplifier as an oscillator.

(b) Distinguish between a conductor, a semiconductor and an insulator on the basis of energy band diagrams. [5 marks]

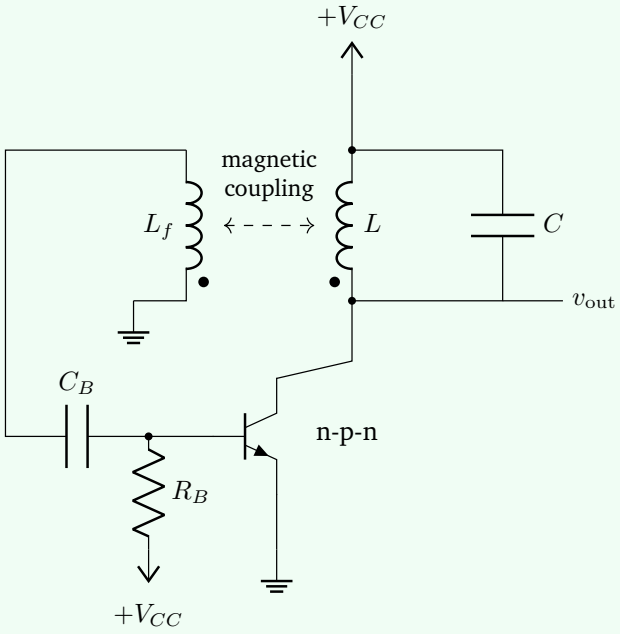
Solution:

Concept:

- An oscillator uses positive feedback: a fraction of the output is returned in phase with the input. The d.c. supply provides the energy of the alternating output.
- An ideal inductance L and capacitance C exchange magnetic and electric energy at $f_0 = 1/(2\pi\sqrt{LC})$. Amplification compensates the losses of a real resonant circuit.
- The forbidden energy gap is $E_g = E_C - E_V$, where E_C is the conduction-band bottom and E_V the valence-band top. Available empty states and the gap determine electrical conduction.

Step 1: Connect the amplifier with positive feedback Use an n-p-n transistor in the common-emitter configuration, with its emitter grounded and its collector connected to the parallel LC tank. The resistor R_B supplies base bias. The feedback winding L_f is magnetically coupled to L; C_B couples its alternating voltage to the base while blocking d.c. The supply terminal is an a.c. ground. The winding polarity, indicated by the dots, is chosen to give a further 180° reversal between the collector voltage and the returned base voltage. Together with the 180° inversion of the common-emitter amplifier, the total loop phase shift is 360°: the feedback reinforces the original input. No external alternating input is needed.

Quick Tip to Solve: Check both loop phase and loop gain when explaining an oscillator. In band sketches, draw and label the gap between the top of the valence band and the bottom of the conduction band.



Common-emitter oscillator with inductive positive feedback; dots specify winding polarity.

Step 2: Explain how oscillations start and persist A small switching transient or electrical noise produces an initial variation of base current. The amplified collector-current variation excites the tank circuit. Its capacitor repeatedly charges and discharges through the inductor, so electric energy $CU^2/2$ and magnetic energy $LI^2/2$ interchange. The alternating tank voltage induces a voltage in L_f, which returns through C_B to increase the original base-current variation. Thus the oscillations build up. Their approximate frequency is

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

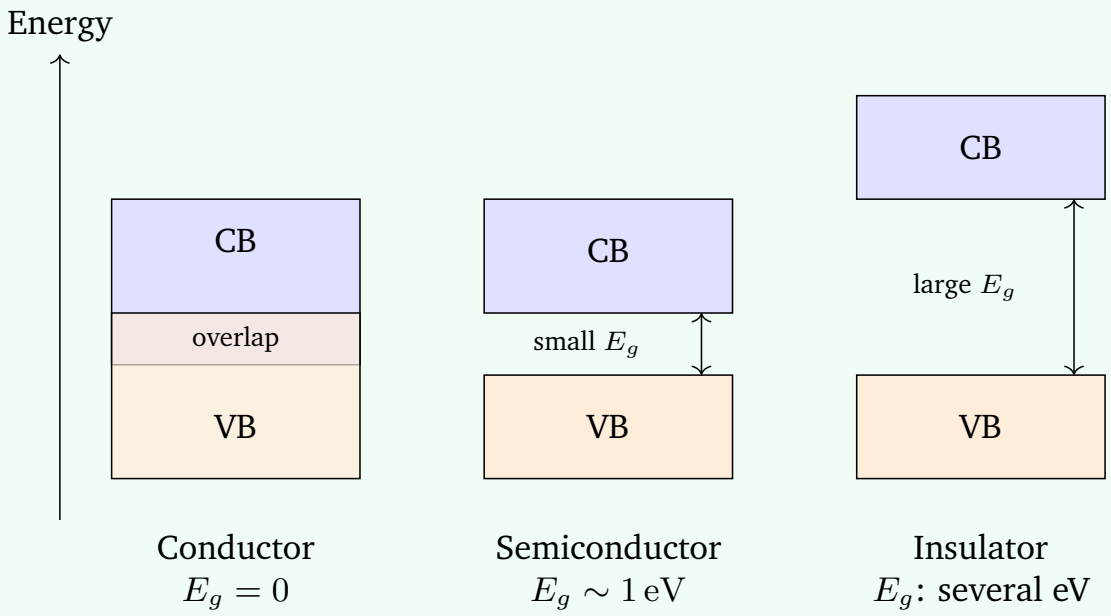
Let A denote amplifier gain and β the fraction fed back. Starting requires loop-gain magnitude slightly greater than unity. As amplitude grows, the effective gain settles so that $|A\beta| = 1$ with zero net phase shift modulo 360°. The transistor then replaces exactly the energy lost per cycle, giving sustained oscillations; the energy comes from the d.c. source.

Step 3: Compare the three types of energy-band structure In a conductor, the valence and conduction bands overlap, or the highest occupied band is partially filled. Empty states are therefore available close to occupied states, and an applied field can readily move electrons into them. There is no forbidden gap obstructing conduction.

In an intrinsic semiconductor, the valence band is full and the conduction band empty at $0\,\text{K}$. A small forbidden gap, typically of order $1\,\text{eV}$, separates them. At ordinary temperatures some electrons acquire enough thermal energy to enter the conduction band, leaving holes in the valence band; both contribute to conduction.

In an insulator, the valence band is full and the conduction band empty, separated by a large gap, usually several electron-volts. Ordinary thermal energy cannot excite appreciable numbers of electrons across it, so the conductivity is extremely small. The schematic diagrams compare band separation; their vertical dimensions are not to scale.

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Schematic band comparison; CB denotes conduction band and VB denotes valence band.

Step 4: Conclusion Positive feedback with compensation for tank losses sustains oscillations. Conductors have overlapping or partially filled bands; semiconductors and insulators have small and large forbidden gaps, respectively.

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