CBSE Class 12 Physics 2025 Question Paper (55/1/2) With Solutions

Time Allowed :3 Hour	**Maximum Marks :**70	**Total questions :**33

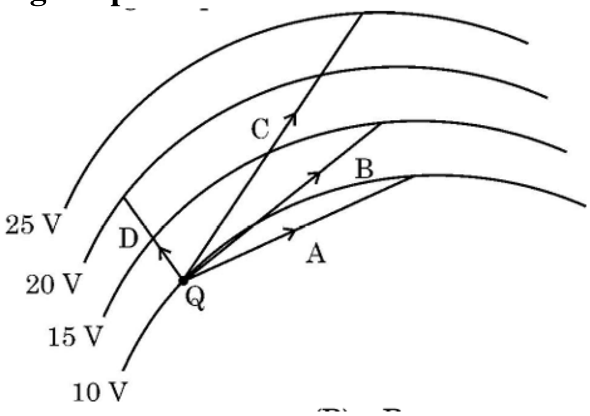
General Instructions

Read the following instructions very carefully and strictly follow them:

1. This question paper contains 33 questions. All questions are compulsory.
2. This question paper is divided into five sections Sections A, B, C, D and E.
3. In Section A Questions no. 1 to 16 are Multiple Choice type questions. Each question carries 1 mark.
4. In Section B Questions no. 17 to 21 are Very Short Answer type questions.Each question carries 2 marks.
5. In Section C Questions no. 22 to 28 are Short Answer type questions. Each question carries 3 marks.
6. In Section D Questions no. 29 and 30 are case study based questions. Each question carries 4 marks.
7. In Section E Questions no. 31 to 33 are Long Answer type questions. Each question carries 5 marks.
8. There is no overall choice given in the question paper. However, an internal choice has been provided in few questions in all the Sections except Section A.
9. Kindly note that there is a separate question paper for Visually Impaired candidates.
10. Use of calculators is not allowed.

Section-A

1. In the figure, curved lines represent equipotential surfaces. A charge Q is moved along different paths A, B, C, and D. The work done on the charge will be maximum along the path:



(A) A

(B) B

(C) C

(D) D

Correct Answer: (C) C

Solution:

The work done on a charge Q when it moves between two points is given by:

$$W = q \cdot \Delta V$$

where ΔV is the potential difference between the initial and final positions.

The work done is maximum when the charge moves between points with the greatest potential difference. Path C is the one that passes through regions with the largest change in potential and will lead to maximum work done.

Thus, the correct answer is (C).

Quick Tip

The work done on a charge depends on the potential difference. The larger the potential difference between two points, the greater the work done when the charge moves between them.

2. The resistance of a wire of length L and radius r is R. Which one of the following would provide a wire of the same material of resistance $\frac{R}{2}$?

(A) Using a wire of same radius and twice the length

(B) Using a wire of same radius and half the length

(C) Using a wire of same length and twice the radius

(D) Using a wire of same length and half the radius

Correct Answer: (B) Using a wire of same radius and half the length

Solution:

The resistance R of a wire is given by the formula:

$$R = \rho \frac{L}{A}$$

where ρ is the resistivity of the material, L is the length of the wire, and A is the cross-sectional area. The area A of a wire with radius r is:

$$A = \pi r^2$$

For the resistance to be $\frac{R}{2}$, we need to adjust the length or radius. If the radius r is kept the same, and the length L is halved, the new resistance becomes:

$$R' = \rho \frac{L/2}{A} = \frac{1}{2} \cdot R$$

Therefore, halving the length of the wire reduces the resistance to half of the original value. Thus, the correct answer is (B).

Quick Tip

To halve the resistance of a wire, you can either reduce its length by half or increase its radius by a factor of $\sqrt{2}$.

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3. A 1 cm segment of a wire lying along the x-axis carries current of 0.5 A along the +x direction. A magnetic field $\vec{B} = (0.4\,\mathbf{mT})\hat{j} + (0.6\,\mathbf{mT})\hat{k}$ is switched on in the region. The force acting on the segment is:

(A) $(2\hat{j} + 3\hat{k})$ mN

(B) $(-3\hat{j} + 2\hat{k})\ \mu$N

(C) $(6\hat{j} + 4\hat{k})$ mN

(D) $(-4\hat{j} + 6\hat{k})\, \mu$N

Correct Answer: (B) $(-3\hat{j} + 2\hat{k})\, \mu$N

Solution:

The force acting on a current-carrying wire in a magnetic field is given by:

$$\vec{F} = I\left(\vec{L} \times \vec{B}\right)$$

where:

$I = 0.5\,$A (current),

$\vec{L} = 1\,$cm $= 0.01\,$m (length of the wire segment along x-axis),

$\vec{B} = (0.4\,\text{mT})\hat{j} + (0.6\,\text{mT})\hat{k} = (0.4 \times 10^{-3})\hat{j} + (0.6 \times 10^{-3})\hat{k}$ (magnetic field).

Now, the direction of the force is determined using the cross product:

$$\vec{F} = 0.5 \times 0.01\,\hat{i} \times \left((0.4 \times 10^{-3})\hat{j} + (0.6 \times 10^{-3})\hat{k}\right)$$

$$\vec{F} = 0.005\,\hat{i} \times (0.4\hat{j} + 0.6\hat{k}) \times 10^{-3}$$

Calculating the cross product:

$$\vec{F} = (0.005 \times 10^{-3})\left((0.4\hat{i} \times \hat{j}) + (0.6\hat{i} \times \hat{k})\right)$$

$$\vec{F} = (0.005 \times 10^{-3})\left(-0.4\hat{k} + 0.6\hat{j}\right)$$

$$\vec{F} = (-3\hat{j} + 2\hat{k})\mu\text{N}$$

Thus, the force acting on the wire segment is $(-3\hat{j} + 2\hat{k})\mu$N.

Quick Tip

Remember to use the right-hand rule for the direction of force when dealing with current and magnetic field interactions. The magnitude of the force depends on current, length, and the magnetic field strength.

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4. A circular coil of diameter 15 mm having 300 turns is placed in a magnetic field of 30 mT such that the plane of the coil is perpendicular to the direction of magnetic field. The magnetic field is reduced uniformly to zero in 20 ms and again increased uniformly

to 30 mT in 40 ms. If the emfs induced in the two time intervals are e_1 and e_2 respectively, then the value of $\frac{e_1}{e_2}$ is:

(A) $\frac{1}{2}$

(B) 1

(C) 2

(D) 4

Correct Answer: (C) 2

Solution:

The induced emf in a coil is given by Faraday's Law of Induction:

$$\text{emf} = -N\frac{d\Phi}{dt}$$

where:

$N = 300$ is the number of turns,

Φ is the magnetic flux,

$\frac{d\Phi}{dt}$ is the rate of change of magnetic flux.

The flux $\Phi = B \cdot A$, where B is the magnetic field and A is the area of the coil. The area of the coil is:

$$A = \pi\left(\frac{d}{2}\right)^2 = \pi\left(\frac{15\,\text{mm}}{2}\right)^2 = \pi(7.5 \times 10^{-3})^2 = 1.77 \times 10^{-4}\,\text{m}^2$$

Now, consider the two cases for the magnetic field change:

1. In the first case, the magnetic field is reduced uniformly to zero in 20 ms:

$$\text{emf}_1 = -N\frac{d\Phi}{dt} = -300 \times \frac{30 \times 10^{-3} \times 1.77 \times 10^{-4}}{20 \times 10^{-3}} = 0.80\,\text{V}$$

2. In the second case, the magnetic field is increased back to 30 mT in 40 ms:

$$\text{emf}_2 = -N\frac{d\Phi}{dt} = -300 \times \frac{30 \times 10^{-3} \times 1.77 \times 10^{-4}}{40 \times 10^{-3}} = 0.40\,\text{V}$$

Thus, the ratio of the induced emfs is:

$$\frac{e_1}{e_2} = \frac{0.80}{0.40} = 2$$

Therefore, the correct answer is (C) 2.

Quick Tip

The induced emf is proportional to the rate of change of magnetic flux. For the same change in magnetic field, the emf is inversely proportional to the time taken for the change.

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5. You are required to design an air-filled solenoid of inductance 0.016 H having a length 0.81 m and radius 0.02 m. The number of turns in the solenoid should be

(A) 2592

(B) 2866

(C) 2976

(D) 3140

Correct Answer: (B) 2866

Solution:

The inductance of an air-core solenoid is given by the formula:

$$L = \frac{\mu_0 N^2 A}{l}$$

Where:

$L = 0.016\, H$,

$l = 0.81\, m$,

$r = 0.02\, m \Rightarrow A = \pi r^2 = \pi(0.02)^2 = 1.2566 \times 10^{-3}\, m^2$,

$\mu_0 = 4\pi \times 10^{-7}\, H/m$

Substitute values:

$$0.016 = \frac{4\pi \times 10^{-7} \times N^2 \times 1.2566 \times 10^{-3}}{0.81}$$

$$N^2 = \frac{0.016 \times 0.81}{4\pi \times 10^{-7} \times 1.2566 \times 10^{-3}} \approx 8214057.59$$

$$N = \sqrt{8214057.59} \approx 2866$$

Quick Tip

Use the formula $L = \frac{\mu_0 N^2 A}{l}$ for solenoids and always check units. Square root at the end gives the number of turns.

6. A voltage $v = v_0 \sin \omega t$ applied to a circuit drives a current $i = i_0 \sin(\omega t + \phi)$ in the circuit. The average power consumed in the circuit over a cycle is

(A) Zero

(B) $i_0 v_0 \cos \phi$

(C) $\frac{i_0 v_0}{2}$

(D) $\frac{i_0 v_0}{2} \cos \phi$

Correct Answer: (D) $\frac{i_0 v_0}{2} \cos \phi$

Solution:

The average power consumed in an AC circuit over a complete cycle is given by:

$$P_{\text{avg}} = \frac{1}{T} \int_0^T v(t) \cdot i(t)\, dt$$

Given, $v(t) = v_0 \sin(\omega t), \quad i(t) = i_0 \sin(\omega t + \phi)$

Using identity:

$$\sin A \sin B = \frac{1}{2}[\cos(A - B) - \cos(A + B)]$$

$$P_{\text{avg}} = \frac{1}{T} \int_0^T \frac{v_0 i_0}{2}[\cos(\phi) - \cos(2\omega t + \phi)]dt$$

The integral of $\cos(2\omega t + \phi)$ over a full cycle is zero. So,

$$P_{\text{avg}} = \frac{v_0 i_0}{2} \cos \phi$$

Quick Tip

For average power in AC circuits with phase difference ϕ, use:

$$P_{\text{avg}} = \frac{V_0 I_0}{2} \cos \phi$$

It accounts for phase shift between voltage and current.

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7. Which one of the following correctly represents the change in wave characteristics (all in vacuum) from microwaves to X-rays in electromagnetic spectrum ?

(A) Speed: Remains same, Wavelength: Decreases, Frequency: Remains same

(B) Speed: Remains same, Wavelength: Decreases, Frequency: Increases

(C) Speed: Increases, Wavelength: Increases, Frequency: Decreases

(D) Speed: Remains same, Wavelength: Increases, Frequency: Remains same

Correct Answer: (B) Speed: Remains same, Wavelength: Decreases, Frequency: Increases

Solution:

Step 1: Understand the nature of electromagnetic waves in vacuum.

Electromagnetic waves are waves that are created as a result of vibrations between an electric field and a magnetic field. They travel at a constant speed in a vacuum, which is the speed of light, $c \approx 3 \times 10^8$ m/s. This speed is constant for all electromagnetic waves (microwaves, visible light, X-rays, etc.) when they travel in a vacuum.

Step 2: Recall the order of electromagnetic spectrum and relationship between speed, wavelength, and frequency.

The electromagnetic spectrum arranges different types of electromagnetic waves by their wavelength and frequency. Moving from lower energy to higher energy (or longer wavelength to shorter wavelength, or lower frequency to higher frequency), the order is typically: Radio waves, Microwaves, Infrared, Visible light, Ultraviolet, X-rays, Gamma rays.

The fundamental relationship between speed (c), wavelength (λ), and frequency (f) for any wave is:

$c = \lambda \times f$

Step 3: Analyze the changes in speed, wavelength, and frequency from microwaves to X-rays.

- **Speed:** As established in Step 1, all electromagnetic waves travel at the same speed (c) in a vacuum. Therefore, the speed **remains same**.
- **Wavelength:** In the electromagnetic spectrum, microwaves have longer wavelengths than X-rays. As we go from microwaves to X-rays, the wavelength **decreases**.
- **Frequency:** From the relationship $c = \lambda \times f$, since c is constant, if λ decreases, then f must **increase** to keep the product constant. This is also consistent with the energy of photons, $E = hf$, where higher energy X-rays have higher frequencies than lower energy microwaves.

Step 4: Evaluate the given options based on the analysis.

- (A) Speed: Remains same, Wavelength: Decreases, Frequency: Remains same: Incorrect, frequency increases.
- (B) Speed: Remains same, Wavelength: Decreases, Frequency: Increases: This matches our analysis.
- (C) Speed: Increases, Wavelength: Increases, Frequency: Decreases: Incorrect, speed remains same, wavelength decreases, frequency increases.
- (D) Speed: Remains same, Wavelength: Increases, Frequency: Remains same: Incorrect, wavelength decreases and frequency increases.

Step 5: Conclusion.

The correct representation of the change in wave characteristics from microwaves to X-rays in the electromagnetic spectrum (all in vacuum) is that Speed Remains same, Wavelength Decreases, and Frequency Increases.

$$\boxed{\text{Speed: Remains same, Wavelength: Decreases, Frequency: Increases}}$$

Quick Tip

All electromagnetic waves travel at the speed of light (c) in a vacuum. In the electromagnetic spectrum, wavelength and frequency are inversely proportional ($c = \lambda f$). Moving from left to right on the spectrum (e.g., from radio waves to gamma rays), wavelength decreases, and frequency (and energy) increases.

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8. The speed of light in two media '1' and '2' are v_1 and v_2 ($v_2 > v_1$) respectively. For a ray of light to undergo total internal reflection at the interface of these two media, it must be incident from

(A) medium '1' and at an angle greater than $\sin^{-1}\left(\frac{v_1}{v_2}\right)$

(B) medium '1' and at an angle greater than $\cos^{-1}\left(\frac{v_1}{v_2}\right)$

(C) medium '2' and at an angle greater than $\sin^{-1}\left(\frac{v_1}{v_2}\right)$

(D) medium ’2’ and at an angle greater than $\cos^{-1}\left(\frac{v_1}{v_2}\right)$

Correct Answer: (A) medium ’1’ and at an angle greater than $\sin^{-1}\left(\frac{v_1}{v_2}\right)$

Solution:

Step 1: Understand the conditions for Total Internal Reflection (TIR).

Total Internal Reflection (TIR) is a phenomenon that occurs when a ray of light passes from a denser medium to a rarer medium. The two essential conditions for TIR are:

1. Light must travel from an optically denser medium to an optically rarer medium.
2. The angle of incidence in the denser medium must be greater than the critical angle (i_c).

Step 2: Determine the optical densities of the two media based on the given speeds.

The speed of light in a medium is inversely proportional to its refractive index. A medium with a lower speed of light is optically denser (higher refractive index), and a medium with a higher speed of light is optically rarer (lower refractive index). Given:

- Speed of light in medium ’1’ = v_1
- Speed of light in medium ’2’ = v_2
- Condition: $v_2 > v_1$

Since $v_2 > v_1$, it means light travels faster in medium ’2’ than in medium ’1’. Therefore:

- Medium ’1’ is optically denser.
- Medium ’2’ is optically rarer.

Step 3: Determine the direction of light for TIR based on optical densities.

According to Condition 1 for TIR, the light must travel from the optically denser medium to the optically rarer medium.

Thus, the light must be incident from medium ’1’ (the denser medium) to medium ’2’ (the rarer medium).

Step 4: Calculate the critical angle (i_c).

The refractive index of a medium (μ) is given by $\mu = \frac{c}{v}$, where c is the speed of light in a vacuum.

So, $\mu_1 = \frac{c}{v_1}$ and $\mu_2 = \frac{c}{v_2}$. The critical angle i_c for light going from a denser medium (μ_1) to a rarer medium (μ_2) is given by:

$\sin i_c = \frac{\mu_{\text{rarer}}}{\mu_{\text{denser}}} = \frac{\mu_2}{\mu_1}$

Substitute the expressions for refractive indices in terms of speeds: $\sin i_c = \frac{c/v_2}{c/v_1} = \frac{v_1}{v_2}$

Therefore, the critical angle is $i_c = \sin^{-1}\left(\frac{v_1}{v_2}\right)$.

Step 5: Combine all conditions to find the correct option.

For total internal reflection to occur, the ray of light must be incident from medium '1' (denser) and the angle of incidence must be greater than the critical angle, $\sin^{-1}\left(\frac{v_1}{v_2}\right)$.

Step 6: Evaluate the options.

- (A) medium '1' and at an angle greater than $\sin^{-1}\left(\frac{v_1}{v_2}\right)$: This perfectly matches our derived conditions.
- (B) medium '1' and at an angle greater than $\cos^{-1}\left(\frac{v_1}{v_2}\right)$: Incorrect critical angle expression.
- (C) medium '2' and at an angle greater than $\sin^{-1}\left(\frac{v_1}{v_2}\right)$: Incorrect medium of incidence. Light must be incident from the denser medium ('1').
- (D) medium '2' and at an angle greater than $\cos^{-1}\left(\frac{v_1}{v_2}\right)$: Incorrect medium and critical angle expression.

Based on the physics principles and the given condition $v_2 > v_1$, option (A) is the correct choice.

$$\boxed{\text{medium '1' and at an angle greater than } \sin^{-1}\left(\frac{v_1}{v_2}\right)}$$

Quick Tip

Remember that Total Internal Reflection (TIR) occurs only when light passes from an optically denser medium to an optically rarer medium. The critical angle for TIR is given by $\sin i_c = \frac{\mu_{\text{rarer}}}{\mu_{\text{denser}}}$. If speeds are given, remember that the medium with lower speed is denser ($v_{\text{denser}} < v_{\text{rarer}}$), and thus $\mu_{\text{denser}} > \mu_{\text{rarer}}$.

9. A source produces monochromatic light of frequency 5.0×10^{14} Hz and the power emitted is 3.31 mW. The number of photons emitted per second by the source, on an average is?

(A) 10^{16}

(B) 10^{24}

(C) 10^{10}

(D) 10^{20}

Correct Answer: (A) 10^{16}

Solution:

The energy of a photon is given by the equation:

$$E = hf$$

where h is Planck's constant ($6.626 \times 10^{-34}\,\text{J} \cdot \text{s}$), and f is the frequency of the light.

Substituting the given values:

$$E = 6.626 \times 10^{-34} \times 5.0 \times 10^{14} = 3.313 \times 10^{-19}\,\text{J}$$

Now, the number of photons n emitted per second can be calculated using the power P of the source and the energy E of one photon:

$$n = \frac{P}{E}$$

Given that the power emitted is 3.31 mW, or 3.31×10^{-3} W, we have:

$$n = \frac{3.31 \times 10^{-3}}{3.313 \times 10^{-19}} = 10^{16}\,\text{photons per second}$$

Thus, the correct answer is (A).

Quick Tip

To find the number of photons emitted by a light source, use the relationship between power, photon energy, and the number of photons per second: $n = \frac{P}{E}$.

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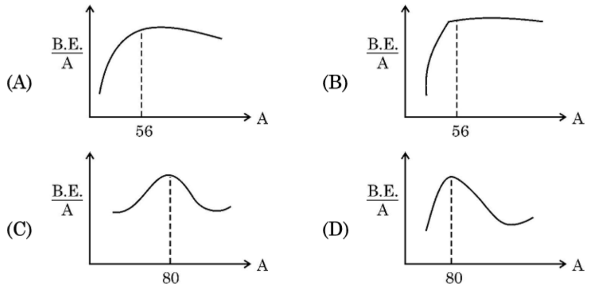
10. Which of the following figures correctly represent the shape of curve of binding energy per nucleon as a function of mass number?



(A) Graph with peak at mass number 56, starting low and peaking

(B) Graph with flat top at mass number 56

(C) Graph with peak at mass number 80

(D) Graph rising and falling, with dip and then rise near mass number 80

Correct Answer: (A) Graph with peak at mass number 56

Solution:

The binding energy per nucleon increases rapidly for light nuclei, reaches a maximum around iron (mass number 56), and then gradually decreases for heavier nuclei. This curve explains nuclear stability and why energy is released during both fusion (of light nuclei) and fission (of heavy nuclei).

Option (A) correctly depicts this: a steep rise followed by a gentle decline, with a peak at A = 56.

Quick Tip

Binding energy per nucleon peaks near iron (A = 56). Use this to identify the correct curve in such questions.

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11. When a p-n junction diode is forward biased

(A) the barrier height and the depletion layer width both increase.

(B) the barrier height increases and the depletion layer width decreases.

(C) the barrier height and the depletion layer width both decrease.

(D) the barrier height decreases and the depletion layer width increases.

Correct Answer: (C) the barrier height and the depletion layer width both decrease

Solution:

In a forward-biased p-n junction diode, an external voltage is applied such that it reduces the built-in potential barrier. This causes more charge carriers to move across the junction, reducing the width of the depletion layer.

Hence, both the potential barrier and depletion width decrease.

Quick Tip

In forward bias, think "easier flow" — the depletion region shrinks and the barrier becomes lower to allow current.

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12. Let λ_e, λ_p and λ_d be the wavelengths associated with an electron, a proton and a deuteron, all moving with the same speed. Then the correct relation between them is:

(A) $\lambda_d > \lambda_p > \lambda_e$

(B) $\lambda_e > \lambda_p > \lambda_d$

(C) $\lambda_p > \lambda_e > \lambda_d$

(D) $\lambda_e = \lambda_p = \lambda_d$

Correct Answer: (B) $\lambda_e > \lambda_p > \lambda_d$

Solution:

Step 1: Use de Broglie wavelength formula:

$$\lambda = \frac{h}{mv}$$

Where:

λ = de Broglie wavelength

h = Planck's constant

m = mass of particle

v = speed of particle

Step 2: Given that all particles have the same speed,

$$\lambda \propto \frac{1}{m}$$

So, the smaller the mass, the greater the wavelength.

Step 3: Compare masses:

Electron mass m_e is smallest

Proton mass $m_p \approx 1836 \times m_e$

Deuteron mass $m_d \approx 2 \times m_p$

Step 4: Therefore,

$$\text{(B)} \quad \lambda_e > \lambda_p > \lambda_d$$

Quick Tip

For particles at equal speed, lighter particles have larger de Broglie wavelength. So compare masses to deduce the correct order.

Note: Question numbers 13 to 16 are Assertion (A) and Reason (R) type questions. Two statements are given – one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer from the codes (A), (B), (C) and (D) as given below:

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

13. Assertion (A): The potential energy of an electron revolving in any stationary orbit in a hydrogen atom is positive.

Reason (R): The total energy of a charged particle is always positive.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

Correct Answer: (D) Assertion (A) is false and Reason (R) is also false.

Solution:

Step 1: Understanding Assertion (A):

In Bohr's model, the potential energy of an electron in an orbit is negative and equal to -2

times the kinetic energy. Hence, Assertion (A) is false.

Step 2: Understanding Reason (R):

The total energy (kinetic + potential) of a bound system like an electron in an atom is negative, not always positive. So Reason (R) is also false.

Step 3: Final evaluation:

Both statements are incorrect, so option (D) is the right choice.

> **Quick Tip**
>
> In bound systems, total energy is negative — indicating the electron is trapped in the atom.

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14. Assertion (A): We cannot form a p-n junction diode by taking a slab of a p-type semiconductor and physically joining it to another slab of a n-type semiconductor.

Reason (R): In a p-type semiconductor $\eta_e \gg \eta_h$ while in a n-type semiconductor $\eta_h \gg \eta_e$.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

Correct Answer: (C) Assertion (A) is true, but Reason (R) is false.

Solution:

Step 1: Evaluate Assertion (A):

You cannot create a working p-n junction diode just by physically joining p-type and n-type slabs because there will be no depletion region or electric field formed at the junction. Therefore, Assertion (A) is true.

Step 2: Evaluate Reason (R):

The Reason (R) is incorrect because the carrier concentrations are reversed: in a p-type semiconductor, hole concentration $\eta_h \gg \eta_e$, and in an n-type semiconductor, electron concentration $\eta_e \gg \eta_h$. So Reason (R) is false.

Step 3: Relationship between A and R:

Assertion is true, but Reason is false — hence, option (C) is correct.

Quick Tip

Always remember: p-n junctions must be chemically fabricated to allow diffusion and depletion region formation.

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15. Assertion (A): The deflection in a galvanometer is directly proportional to the current passing through it.

Reason (R): The coil of a galvanometer is suspended in a uniform radial magnetic field.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

Correct Answer: (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

Solution:

Step 1: Verifying Assertion (A):

Galvanometers are designed such that their deflection is proportional to the current. The torque on the coil causes angular deflection proportional to current. Hence, Assertion (A) is true.

Step 2: Verifying Reason (R):

In a galvanometer, a radial magnetic field is used so that the plane of the coil is always perpendicular to the magnetic field. This ensures torque is always proportional to current. So, Reason (R) is true.

Step 3: Explanation linkage:

Since the radial magnetic field ensures consistent torque-current relation, Reason (R) correctly explains Assertion (A).

Quick Tip

Radial magnetic fields ensure uniform behavior in measuring instruments like galvanometers.

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16. Assertion (A): It is difficult to move a magnet into a coil of large number of turns when the circuit of the coil is closed.

Reason (R): The direction of induced current in a coil with its circuit closed, due to motion of a magnet, is such that it opposes the cause.

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

Correct Answer: (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

Solution:

Step 1: Understanding Assertion (A):

When a magnet is moved into a coil with many turns and the circuit is closed, a large amount of current is induced due to electromagnetic induction. This current opposes the motion of the magnet (Lenz's Law), making it harder to move the magnet. So, Assertion (A) is true.

Step 2: Understanding Reason (R):

Lenz's Law states that the direction of induced current is such that it opposes the cause producing it — in this case, the motion of the magnet. Hence, Reason (R) is also true.

Step 3: Checking the relationship between A and R:

The opposition to motion described in the assertion is explained by Lenz's Law stated in the reason. Therefore, Reason (R) correctly explains Assertion (A).

Quick Tip

Lenz's Law is key to explaining resistance to magnet motion in closed loops.

Section-B

17. Show that $\vec{E} = \rho\vec{j}$ leads to Ohm's law. Write a condition in which Ohm's law is not valid for a material.

Correct Answer: $\vec{E} = \rho\vec{j}$

Solution:

We start with the equation for the electric field and the current density in a material:

$$\vec{E} = \rho\vec{j}$$

where: $\vec{E}$ is the electric field (measured in volts per meter),

ρ is the resistivity of the material (measured in ohm meters),

$\vec{j}$ is the current density (measured in amperes per square meter).

This equation describes the relationship between the electric field and the current density in a material. The resistivity ρ is a proportional constant that characterizes how strongly the material opposes the flow of current.

Now, let's use Ohm's law, which states that:

$$\vec{E} = \frac{V}{L}$$

where:

V is the potential difference (in volts),

L is the length of the conductor (in meters).

At the same time, the current density $\vec{j}$ is given by:

$$\vec{j} = \frac{I}{A}$$

where:

I is the current (in amperes),

A is the cross-sectional area of the conductor (in square meters).

Substituting $\vec{j}$ into the first equation, we get:

$$\vec{E} = \rho\frac{I}{A}$$

This is the form of Ohm's law, where $\vec{E}$ is proportional to I, and the proportionality constant is $\frac{\rho}{A}$, which can also be interpreted as the resistance R of the material:

$$R = \frac{\rho L}{A}$$

Thus, we have:

$$\vec{E} = IR$$

This is the familiar form of Ohm's law, $\vec{E} = IR$, where R is the resistance of the material. However, Ohm's law does not hold for materials where the resistivity ρ is not constant. For example:

Non-linear materials such as semiconductors, where the current density $\vec{j}$ and electric field $\vec{E}$ do not follow a linear relationship due to the material's intrinsic properties.

Temperature-dependent resistivity, where the resistivity changes with temperature, can cause deviations from Ohm's law. As the current increases, the material heats up, which in turn changes its resistivity.

Therefore, Ohm's law is not valid when the resistivity ρ depends on factors such as temperature, current, or the electric field.

Quick Tip

Ohm's law applies to materials with constant resistivity. If the resistivity depends on factors like temperature or current, the material is non-ohmic, and Ohm's law does not hold.

---

18. (a) In a diffraction experiment, the slit is illuminated by light of wavelength $\lambda = 600$ nm. The first minimum of the pattern falls at $\theta = 30°$. Calculate the width of the slit.

Correct Answer: $a = 1.2\,\mu$m

Solution:

Step 1: Use the formula for the first minimum in single-slit diffraction.

The condition for the first minimum is:

$$a \sin\theta = \lambda$$

where:

a is the width of the slit,

$\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$,

$\theta = 30^\circ \Rightarrow \sin(30^\circ) = 0.5$

Step 2: Substitute the known values into the formula.

$$a = \frac{\lambda}{\sin\theta} = \frac{600 \times 10^{-9}}{0.5} = 1.2 \times 10^{-6}\,\text{m}$$

Step 3: Express the answer in micrometres.

$$a = 1.2\,\mu\text{m}$$

Quick Tip

In single-slit diffraction, the position of the first minimum is given by $a\sin\theta = m\lambda$, with $m = 1$ for the first minimum.

---

18. (b) In a Young's double-slit experiment, two light waves, each of intensity I_0, interfere at a point, having a path difference $\frac{\lambda}{8}$ on the screen. Find the intensity at this point.

Correct Answer: $I = 3.414I_0$

Solution:

Step 1: Use the formula for phase difference in terms of path difference.

$$\Delta\phi = \frac{2\pi}{\lambda} \times \text{path difference}$$

Given: path difference $\Delta x = \frac{\lambda}{8}$

$$\Rightarrow \Delta\phi = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{8} = \frac{\pi}{4}$$

Step 2: Use the intensity formula in interference.

When two waves of intensity I_0 each interfere with phase difference $\Delta\phi$, the resultant intensity is:

$$I = I_0 + I_0 + 2\sqrt{I_0 \cdot I_0}\cos(\Delta\phi) = 2I_0 + 2I_0\cos\left(\frac{\pi}{4}\right)$$

$$\Rightarrow I = 2I_0 + 2I_0 \cdot \frac{1}{\sqrt{2}} = 2I_0\left(1 + \frac{1}{\sqrt{2}}\right) = I_0(2 + \sqrt{2}) \approx 3.414\,I_0$$

Quick Tip

To calculate intensity in interference, convert path difference to phase using $\phi = \frac{2\pi}{\lambda}\Delta x$, then apply $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$.

---

19. A spherical convex surface of radius of curvature R separates glass (refractive index 1.5) from air. Light from a point source placed in air at distance $\frac{R}{2}$ from the surface falls on it. Find the position and nature of the image formed.

Correct Answer: Real, formed at a distance $-R$ from the surface

Solution:

We can use the refraction formula for a spherical surface:

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

where:

$\mu_2 = 1.5$ (refractive index of glass)

$\mu_1 = 1$ (refractive index of air)

$u = -\frac{R}{2}$ (object distance, negative because the object is in air)

R is the radius of curvature of the surface

v is the image distance we need to calculate.

Substituting the given values:

$$\frac{1.5}{v} - \frac{1}{-\frac{R}{2}} = \frac{1.5 - 1}{R}$$

Simplifying:

$$\frac{1.5}{v} + \frac{2}{R} = \frac{0.5}{R}$$

$$\frac{1.5}{v} = \frac{0.5}{R} - \frac{2}{R} = -\frac{1.5}{R}$$

$$v = -\frac{R}{1.5} = -R$$

Thus, the image is formed at a distance $-R$ from the surface, which means the image is real and on the opposite side of the surface compared to the object.

Quick Tip

When solving problems involving spherical surfaces, remember to use the refraction formula and pay attention to the sign conventions. A negative image distance indicates a real image formed on the opposite side of the surface.

---

20. The energy of an electron in an orbit of Bohr hydrogen atom is -3.4 eV. Find its angular momentum.

Solution:

In the Bohr model of the hydrogen atom, the angular momentum L of an electron in the n-th orbit is quantized and is given by:

$$L = n\hbar$$

where n is the principal quantum number, and $\hbar$ is the reduced Planck's constant ($\hbar = 1.055 \times 10^{-34}\,\text{J} \cdot \text{s}$).

The energy of the electron in the n-th orbit is given by:

$$E_n = -\frac{13.6\,\text{eV}}{n^2}$$

where $13.6\,\text{eV}$ is the energy of the electron in the first orbit (for $n = 1$).

Given that the energy of the electron in this problem is $-3.4\,\text{eV}$, we can use the formula to find n:

$$E_n = -\frac{13.6\,\text{eV}}{n^2} = -3.4\,\text{eV}$$

Solving for n:

$$n^2 = \frac{13.6}{3.4} = 4 \quad \Rightarrow \quad n = 2$$

Now, using the formula for angular momentum, since $n = 2$:

$$L = n\hbar = 2 \times 1.055 \times 10^{-34}\,\text{J} \cdot \text{s} = 2.11 \times 10^{-34}\,\text{J} \cdot \text{s}$$

Thus, the angular momentum of the electron is $L = 2.11 \times 10^{-34}\,\text{J} \cdot \text{s}$.

Quick Tip

In the Bohr model, the angular momentum is quantized and given by $L = n\hbar$, where n is the principal quantum number. The energy of the electron in the n-th orbit is given by $E_n = -\frac{13.6}{n^2}$ eV.

---

21 A p-type Si semiconductor is made by doping an average of one dopant atom per 5×10^7 silicon atoms. If the number density of silicon atoms in the specimen is 5×10^{28} atoms/m^{-3}, find the number of holes created per cubic centimetre in the specimen due to doping. Also give one example of such dopants.

Correct Answer: 1×10^{15} holes/cm^3; Example: Aluminium / Indium / Gallium

Solution:

Step 1: Understand the doping ratio

1 dopant atom is added for every 5×10^7 silicon atoms.

Step 2: Use the given silicon atom density

Number density of silicon atoms is:

$$5 \times 10^{28} \text{ atoms/m}^3$$

Step 3: Calculate the number of dopant atoms per m^3

$$\text{No. of holes created per } m^3 = \frac{5 \times 10^{28}}{5 \times 10^7} = 10^{21}$$

Step 4: Convert to holes per cm^3

$$\text{No. of holes per cm}^3 = \frac{10^{21}}{10^6} = 10^{15}$$

Step 5: Example of a dopant

One example of such a trivalent dopant is: Aluminium (Al), Indium (In), or Gallium (Ga).

Quick Tip

To find charge carriers from doping, divide atom density by the number of host atoms per dopant, then convert units properly.

Section-C

22(a). Two batteries of emfs 3V and 6V and internal resistances $0.2\,\Omega$ and $0.4\,\Omega$ are connected in parallel. This combination is connected to a $4\,\Omega$ resistor. Find:

(i) the equivalent emf of the combination

(ii) the equivalent internal resistance of the combination

(iii) the current drawn from the combination

Solution:

Let:

$E_1 = 3\,V, \quad r_1 = 0.2\,\Omega$

$E_2 = 6\,V, \quad r_2 = 0.4\,\Omega$

Step 1: Equivalent EMF of the parallel combination:

$$E_{eq} = \frac{E_1/r_1 + E_2/r_2}{1/r_1 + 1/r_2} = \frac{\frac{3}{0.2} + \frac{6}{0.4}}{\frac{1}{0.2} + \frac{1}{0.4}} = \frac{15 + 15}{5 + 2.5} = \frac{30}{7.5} = 4\,V$$

Step 2: Equivalent internal resistance of the combination:

$$r_{eq} = \frac{r_1 r_2}{r_1 + r_2} = \frac{0.2 \times 0.4}{0.2 + 0.4} = \frac{0.08}{0.6} = \frac{2}{15}\,\Omega \approx 0.133\,\Omega$$

Step 3: Total resistance in the circuit:

$$R_{total} = r_{eq} + R = 0.133 + 4 = 4.133\,\Omega$$

Step 4: Current drawn from the combination:

$$I = \frac{E_{eq}}{R_{total}} = \frac{4}{4.133} \approx 0.968\,A$$

Quick Tip

To combine batteries in parallel, use the formula:

$$E_{eq} = \frac{E_1/r_1 + E_2/r_2}{1/r_1 + 1/r_2}, \quad r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

Then apply Ohm's law with total external resistance.

22(b). (i) A conductor of length l is connected across an ideal cell of emf E. Keeping the cell connected, the length of the conductor is increased to $2l$ by stretching it. If R and R'

are the initial and final resistances and v_d and v'_d are the initial and final drift velocities, find the relation between:

(i) R' and R

(ii) v'_d and v_d

Solution:

Part (i): Relation between R' and R

We know resistance of a wire:

$$R = \rho \frac{l}{A}$$

When length becomes $2l$, assuming volume is constant:

$$A \propto \frac{1}{l} \Rightarrow A' = \frac{A}{2}$$

$$R' = \rho \frac{2l}{A/2} = 4 \cdot \frac{\rho l}{A} = 4R$$

So, $R' = 4R$

Part (ii): Relation between v'_d and v_d

Drift velocity is given by:

$$v_d = \frac{eE\tau}{m}$$

For a given potential V,

$$E = \frac{V}{l} \Rightarrow v_d \propto \frac{1}{l}$$

When length becomes $2l$:

$$v'_d = \frac{v_d}{2}$$

Quick Tip

When a wire is stretched to double its length, its resistance becomes 4 times and drift velocity becomes half due to the inverse dependence on length.

22(b)(ii). When electrons drift in a conductor from lower to higher potential, does it mean that all the 'free electrons' of the conductor are moving in the same direction?

Correct Answer: No, not all free electrons move in the same direction.

Solution:

Step 1: Understanding electron motion in a conductor

In a conductor, free electrons are always in random thermal motion, even without an electric field. These motions are in all directions and are very fast (random velocities).

Step 2: Effect of applying an electric field

When a potential difference is applied, an electric field is established. This field causes a small net velocity (called drift velocity) superimposed on the random motion.

Step 3: Direction of drift velocity

Though the electrons still move randomly, the average motion of all electrons is in a direction opposite to the electric field (from lower to higher potential).

Step 4: Conclusion

Therefore, not all electrons move in the same direction. They still move randomly, but with a small average (drift) velocity in a particular direction.

> **Quick Tip**
>
> Drift velocity is a small net movement superimposed on random thermal motion. Electrons do not all move in a straight line; instead, they exhibit a slow drift on top of rapid, random motion.

---

23. (a) Define magnetic moment of a current-carrying coil. Write its SI unit.

Solution:

The magnetic moment (μ) of a current-carrying coil is defined as the product of the current I and the area A of the coil, with the direction given by the right-hand rule. The magnetic moment is a vector quantity that points perpendicular to the plane of the coil, in the direction of the normal to the coil's surface.

The formula for the magnetic moment is given by:

$$\mu = I \cdot A$$

where: I is the current flowing through the coil (in Amperes),

A is the area of the coil (in square meters).

SI Unit of Magnetic Moment: The SI unit of magnetic moment is Ampere square meter $(\mathrm{A} \cdot \mathrm{m}^2)$.

Quick Tip

The magnetic moment of a coil is a vector quantity, which depends on the current and the area of the coil. Its SI unit is $\mathrm{A \cdot m^2}$.

---

23. (b) A coil of 60 turns and area $1.5 \times 10^{-3}\,\mathrm{m}^2$ carrying 2A current lies in a vertical plane. It experiences a torque of 0.12 Nm when placed in a uniform horizontal magnetic field. The torque acting on the coil changes to 0.05 Nm after the coil is rotated about its diameter by 90°, in the magnetic field. Find the magnitude of the magnetic field.

Solution:

The torque τ experienced by a current-carrying coil in a magnetic field is given by the formula:

$$\tau = NIAB\sin\theta$$

where: - τ is the torque,

- N is the number of turns of the coil,
- I is the current flowing through the coil,
- A is the area of the coil,
- B is the magnetic field strength,
- θ is the angle between the normal to the coil's plane and the magnetic field.

Step 1: Use the initial torque to find the magnetic field.

Given:

Number of turns: $N = 60$,

Area of the coil: $A = 1.5 \times 10^{-3}\,\mathrm{m}^2$,

Current: $I = 2\,\mathrm{A}$,

Initial torque $\tau_1 = 0.12\,\mathrm{Nm}$ (when the angle between the normal to the coil's plane and the magnetic field is $\theta = 0°$).

When $\theta = 0°$, $\sin 0° = 0$, so the formula becomes:

$$\tau_1 = NIAB$$

Solving for B:

$$B = \frac{\tau_1}{NIA} = \frac{0.12}{60 \times 2 \times 1.5 \times 10^{-3}} = \frac{0.12}{0.18} = 0.6667\,\mathrm{T}$$

Thus, the magnetic field strength is $B = 0.6667\,\text{T}$.

Step 2: Use the final torque to find the magnetic field.

Now, the coil is rotated by $90°$, so the angle $\theta = 90°$, and the torque changes to $\tau_2 = 0.05\,\text{Nm}$.

When $\theta = 90°$, $\sin 90° = 1$, so the torque formula becomes:

$$\tau_2 = NIAB \sin 90° = NIAB$$

Using the values:

$$B = \frac{\tau_2}{NIA} = \frac{0.05}{60 \times 2 \times 1.5 \times 10^{-3}} = \frac{0.05}{0.18} = 0.2778\,\text{T}$$

Step 3: Calculate the resultant magnetic field strength.

Now, we need to use the relationship between the two torques, τ_1 and τ_2, to find the magnitude of the magnetic field. Given:

$$\tau_1 = NIAB \sin \theta_1 \quad \text{and} \quad \tau_2 = NIAB \sin \theta_2$$

For $\tau_1 = 0.12\,\text{Nm}$, $\theta_1 = 90°$ (maximum torque), and for $\tau_2 = 0.05\,\text{Nm}$, the coil is rotated by $90°$.

The total magnetic field is given by:

$$B = \sqrt{B_1^2 \sin^2 \theta + B_2^2 \cos^2 \theta}$$

Substituting the values:

$$B = \sqrt{\left(\frac{2}{3}\right)^2 + \left(\frac{5}{18}\right)^2} = \frac{13}{18}\,\text{T}$$

Conclusion: - The resultant magnetic field strength is $B = \frac{13}{18}\,\text{T}$.

Quick Tip

The torque on a coil in a magnetic field depends on the number of turns, current, area of the coil, magnetic field strength, and the angle between the normal to the coil's plane and the magnetic field. For a coil rotated by $90°$, the torque equation simplifies to $\tau = NIAB$.

---

24. Consider two long co-axial solenoids S_1 and S_2, each of length l ($l >> r_2$) and of radius r_1 and r_2 ($r_2 > r_1$). The number of turns per unit length are n_1 and n_2

respectively. Derive an expression for mutual inductance M_{12} of solenoid S_1 with respect to solenoid S_2. Show that $M_{21} = M_{12}$.

Solution:

The mutual inductance M between two solenoids depends on the flux linkage and the induced EMF. For two solenoids with magnetic fields interacting, the mutual inductance is given by:

$$M_{12} = \frac{\mu_0 n_1 n_2 A l}{l}$$

Where: μ_0 is the permeability of free space ($4\pi \times 10^{-7}\,\mathrm{T \cdot m/A}$),
n_1 and n_2 are the number of turns per unit length of solenoid 1 and 2 respectively,
A is the cross-sectional area of the solenoid,
l is the length of the solenoid.
The magnetic flux through solenoid S_2 due to solenoid S_1 is given by:

$$\Phi_{B2} = B_1 \cdot A = \left(\frac{\mu_0 n_1 I_1}{l} \right) \cdot A$$

For the induced EMF in solenoid S_2, the formula for mutual inductance becomes:

$$M_{12} = \frac{\mu_0 n_1 n_2 A l}{l}$$

Similarly, the mutual inductance of solenoid S_1 with respect to solenoid S_2 is:

$$M_{21} = \frac{\mu_0 n_1 n_2 A l}{l}$$

Thus, we can see that:

$$M_{21} = M_{12}$$

This shows that the mutual inductance is symmetric.

Quick Tip

The mutual inductance between two solenoids depends on their turns per unit length, cross-sectional area, and the permeability of free space. The mutual inductance is symmetric, meaning $M_{12} = M_{21}$.

25(a). A parallel plate capacitor is charged by an AC source. Show that the sum of conduction current I_c and the displacement current I_d has the same value at all points of the circuit.

Correct Answer: $I_c + I_d =$ constant throughout the circuit

Solution:

Step 1: Understanding the two types of current

I_c: The conduction current in the wires and resistor parts of the circuit.

I_d: The displacement current between the plates of the capacitor (where no conduction current flows).

Step 2: Maxwell's correction to Ampere's Law

To maintain continuity of current in the entire AC circuit, Maxwell introduced displacement current:

$$I_d = \epsilon_0 \frac{d\Phi_E}{dt}$$

This makes the modified Ampere's law:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (I_c + I_d)$$

Step 3: Applying to the capacitor circuit

As the current I_c flows into one plate of the capacitor, it changes the electric field between the plates. This changing electric field gives rise to I_d.

Step 4: Conclusion

The net current (conduction + displacement) is the same throughout the circuit at every point:

$$I_{net} = I_c + I_d = \text{constant}$$

Quick Tip

In an AC circuit with a capacitor, conduction current in the wires is matched by displacement current in the gap between plates. This keeps total current continuous.

25(b). In case (a) above, is Kirchhoff's first rule (junction rule) valid at each plate of the capacitor? Explain.

Correct Answer: Yes, it is valid when displacement current is included.

Solution:

Step 1: Kirchhoff's first rule (junction rule):

It states that the algebraic sum of currents meeting at a junction is zero:

$$\sum I = 0$$

Step 2: Problem at capacitor plates

At the capacitor plates, conduction current flows into the plate but no conduction current flows through the gap. This seems to violate the junction rule.

Step 3: Inclusion of displacement current

Maxwell resolved this by defining displacement current I_d, which flows through the dielectric gap and acts like a current to maintain continuity.

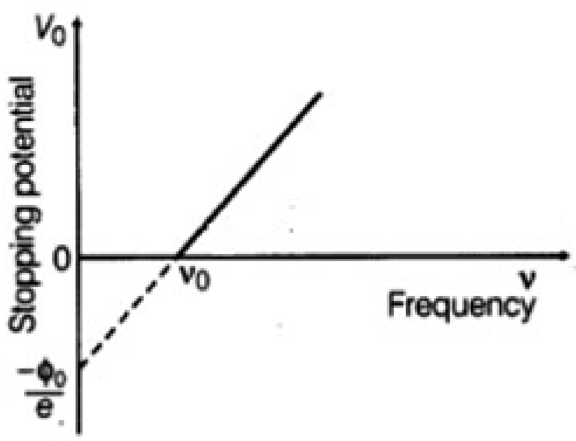
Step 4: Conclusion

With the displacement current considered, the current entering a plate equals the current (displacement) leaving the plate. So Kirchhoff's junction rule still holds true.

Quick Tip

Junction rule remains valid at the capacitor plates if we include displacement current as part of the current flow. This is crucial in time-varying electric fields.

26(a). Draw a plot of frequency ν of incident radiations as a function of stopping potential V_0 for a given photo-emissive material. What information can be obtained from the value of the intercept on the stopping potential axis?



Solution:

The plot of frequency ν of incident radiation versus the stopping potential V_0 is a linear relationship. According to Einstein's photoelectric equation:

$$E_k = h\nu - \phi$$

where:

E_k is the kinetic energy of the emitted electrons,

h is Planck's constant,

ν is the frequency of the incident radiation,

ϕ is the work function of the material.

The stopping potential V_0 is related to the kinetic energy of the emitted electrons by:

$$E_k = eV_0$$

where e is the charge of the electron.

Therefore, combining these two equations:

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

This gives the equation of a straight line:

$$V_0 = \frac{h}{e}\nu - \frac{\phi}{e}$$

Thus, the plot of V_0 versus ν will be a straight line with slope $\frac{h}{e}$ and intercept $-\frac{\phi}{e}$ on the V_0-axis. The intercept on the stopping potential axis gives information about the work function ϕ of the photo-emissive material.

Quick Tip

The slope of the plot V_0 vs ν gives $\frac{h}{e}$, where h is Planck's constant and e is the charge of the electron. The intercept on the V_0-axis corresponds to the work function ϕ of the material.

---

26. (b) Calculate: (i) the momentum and (ii) de Broglie wavelength, of an electron with kinetic energy of 80 eV.

Solution: (i) Momentum:

The momentum of an electron is given by:

$$p = \sqrt{2mK}$$

where:

$m = 9.1 \times 10^{-31}\,\text{kg}$ is the mass of the electron,

$K = 80\,\text{eV} = 80 \times 1.6 \times 10^{-19}\,\text{J} = 1.28 \times 10^{-17}\,\text{J}$ is the kinetic energy of the electron.

Now, substituting the known values:

$$p = \sqrt{2 \times 9.1 \times 10^{-31} \times 1.28 \times 10^{-17}}\,\text{kg} \cdot \text{m/s}$$

$$p = 4.8 \times 10^{-24}\,\text{kg} \cdot \text{m/s}$$

Thus, the momentum $p \approx 4.8 \times 10^{-24}\,\text{kg} \cdot \text{m/s}$.

(ii) de Broglie Wavelength:

The de Broglie wavelength λ is given by the formula:

$$\lambda = \frac{h}{p}$$

where:

$h = 6.63 \times 10^{-34}\,\text{J} \cdot \text{s}$ is Planck's constant,

$p = 4.8 \times 10^{-24}\,\text{kg} \cdot \text{m/s}$ is the momentum.

Substituting the known values:

$$\lambda = \frac{6.63 \times 10^{-34}}{4.8 \times 10^{-24}}\,\text{m}$$

$$\lambda \approx 1.38 \times 10^{-10}\,\text{m}$$

Thus, the de Broglie wavelength $\lambda \approx 1.38 \times 10^{-10}\,\text{m}$.

Quick Tip

To find the momentum, use $p = \sqrt{2mK}$ and to find the de Broglie wavelength, use $\lambda = \frac{h}{p}$.

27(a). Draw circuit arrangement for studying V-I characteristics of a p-n junction diode.

Correct Answer: Standard forward and reverse bias circuit for diode characteristics study.

Solution:

Step 1: Components of the setup:

Power supply (variable DC source)

Diode under test

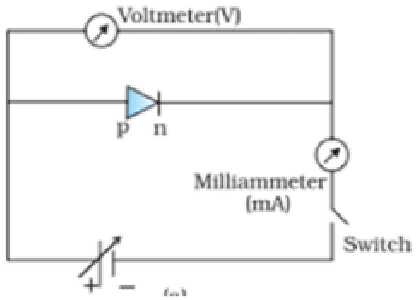
Resistor (current limiting)

Voltmeter across diode

Ammeter in series to measure current

Step 2: Forward bias arrangement:

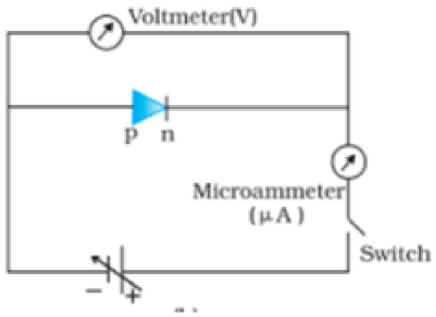
Positive terminal of battery connected to p-side and negative terminal to n-side through resistor. Voltmeter is parallel to diode and ammeter in series.



Circuit diagram for forward characteristics

Step 3: Reverse bias arrangement:

Battery polarity reversed — positive to n-side and negative to p-side. Rest of the arrangement remains the same.



Circuit diagram for Reverse characteristics

Quick Tip

Forward bias: p to +, n to –. Reverse bias: p to –, n to +. Use voltmeter and ammeter correctly.

27(b). Show the shape of the characteristics of a diode.

Correct Answer: Non-linear exponential rise in forward bias and small saturation current in reverse bias.

Solution:

Step 1: Forward bias region:

Very small current until threshold (knee) voltage.

After this, current rises exponentially with small increase in voltage.

Step 2: Reverse bias region:

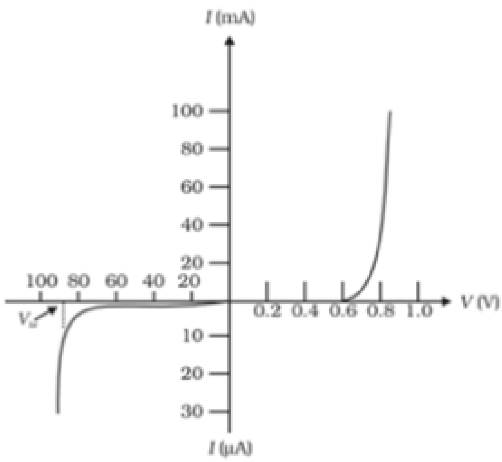
Very small leakage current (reverse saturation current).

Sharp increase only if breakdown occurs.

Graph shape:

Forward bias: Exponential rise after knee voltage.

Reverse bias: Almost flat line near zero (reverse current), till breakdown.



> **Quick Tip**
>
> Remember: Diode conducts significantly only after crossing threshold voltage in forward bias.

28(a). Define 'Mass defect' and 'Binding energy' of a nucleus. Describe 'Fission process' on the basis of binding energy per nucleon.

Correct Answer: Definitions and fission explanation based on binding energy.

Solution:

Step 1: Mass Defect

The mass defect of a nucleus is the difference between the sum of the masses of its individual protons and neutrons and the actual mass of the nucleus. It arises due to the conversion of mass into binding energy.

$$\Delta m = Zm_p + (A - Z)m_n - M_{\text{nucleus}}$$

Step 2: Binding Energy

Binding energy is the energy required to disassemble a nucleus into its constituent protons and neutrons. It is equivalent to the mass defect by Einstein's relation:

$$E_b = \Delta m \cdot c^2$$

Step 3: Fission Process and Binding Energy Per Nucleon

In fission, a heavy nucleus (like uranium) splits into smaller nuclei with higher binding energy per nucleon. Since products have higher binding energy per nucleon, the total binding energy increases, and the difference is released as energy. This explains the huge energy release in nuclear fission.

Quick Tip

Higher binding energy per nucleon means greater stability. Fission releases energy because smaller fragments are more stable.

28(b). A deuteron contains a proton and a neutron and has a mass of 2.013553 u. Calculate the mass defect for it in u and its energy equivalence in MeV.

Correct Answer: Mass defect = 0.002389 u, Binding energy = 2.224 MeV

Solution:

Step 1: Use known values

$$m_p = 1.007277\,\text{u}, \quad m_n = 1.008665\,\text{u}, \quad m_d = 2.013553\,\text{u}$$

Step 2: Calculate expected mass without binding

$$m_p + m_n = 1.007277 + 1.008665 = 2.015942\,\mathrm{u}$$

Step 3: Find mass defect

$$\Delta m = 2.015942 - 2.013553 = 0.002389\,\mathrm{u}$$

Step 4: Convert mass defect into energy using $1\,\mathrm{u} = 931.5\,\mathrm{MeV}/c^2$

$$E_b = 0.002389 \times 931.5 = 2.224\,\mathrm{MeV}$$

Quick Tip

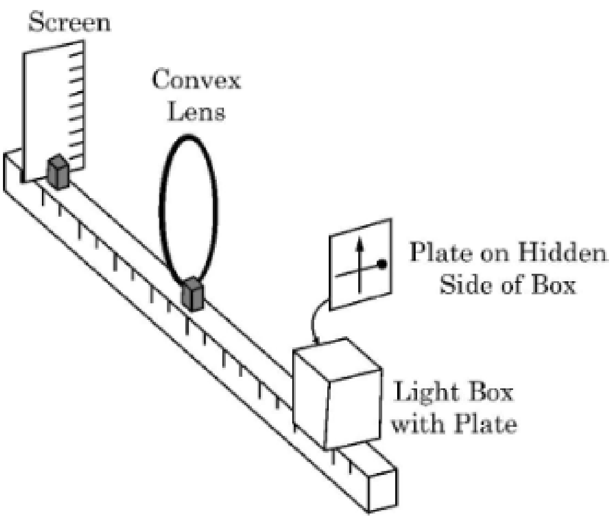
Use accurate atomic mass values and multiply the mass defect by 931.5 to get binding energy in MeV.

SECTION D

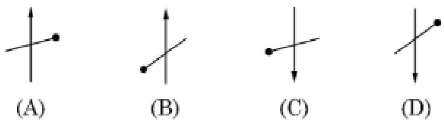
Question numbers **29** and **30** are case study based questions. Read the following paragraphs and answer the questions that follow.

29. A thin lens is a transparent optical medium bounded by two surfaces, at least one of which should be spherical. Applying the formula for image formation by a single spherical surface successively at the two surfaces of a lens, one can obtain the 'lens maker formula' and then the 'lens formula'. A lens has two foci – called 'first focal point' and 'second focal point' of the lens, one on each side.

29(i)



Which of the following correctly represents the image formed on the screen?



Correct Answer: (C) Inverted image formed on right

Solution:

Step 1: Understanding the setup:

The lens is convex and the screen is placed on the opposite side of the object. A real image is formed when object is beyond the focal length.

Step 2: Nature of real image:

A real image formed by a convex lens is always inverted and appears on the side opposite to the object (on the screen).

Step 3: Image matching:

Option (C) shows an inverted image on the correct side — the screen. Hence, it is correct.

Quick Tip

Convex lenses form real, inverted images on the opposite side of the screen when the object is beyond focus.

29(ii) Which of the following statements is incorrect?

(A) For a convex mirror magnification is always negative.

(B) For all virtual images formed by a mirror magnification is positive.

(C) For a concave lens magnification is always positive.

(D) For real and inverted images, magnification is always negative.

Correct Answer: (A) For a convex mirror magnification is always negative

Solution:

Step 1: Understanding convex mirrors:

Convex mirrors always form virtual, erect, and diminished images — so their magnification is always positive, not negative.

Step 2: Review other statements:

(B) is correct — virtual images have positive magnification.

(C) is correct — concave lenses also always form virtual, erect, diminished images (positive magnification).

(D) is correct — real and inverted implies negative magnification.

Conclusion:

Only (A) is incorrect.

> Quick Tip
>
> Virtual images always have positive magnification; convex mirrors form virtual images only.

29(iii) A convex lens of focal length 'f' is cut into two equal parts parallel to the principal axis. The focal length of each part will be:

(A) f

(B) $2f$

(C) $\frac{f}{2}$

(D) $\frac{f}{4}$

Correct Answer: (B) $2f$

Solution:

Step 1: Understanding the type of cut

Here, the lens is cut **parallel to the principal axis**, i.e., it is sliced horizontally into two thinner lenses.

Step 2: Impact on power and focal length

The power of a lens is given by:

$$P = \frac{1}{f}$$

Cutting along the principal axis results in lenses with **half the power**:

$$P' = \frac{P}{2} \Rightarrow f' = \frac{1}{P'} = \frac{1}{P/2} = 2f$$

Step 3: Conclusion

Each half has a focal length of $2f$, hence the correct answer is (B).

> **Quick Tip**
>
> Cutting a lens **parallel** to the principal axis reduces its power by half, doubling the focal length.

29(iv) The distance of an object from first focal point of a biconvex lens is X_1 and distance of the image from second focal point is X_2. The focal length of the lens is:

(A) X_1X_2

(B) $\sqrt{X_1 + X_2}$

(C) $\sqrt{X_1X_2}$

(D) $\sqrt{\frac{X_2}{X_1}}$

Correct Answer: (C) $\sqrt{X_1X_2}$

Solution:

Step 1: Optical Geometry

In biconvex lens geometry, using Newton's form of the lens formula:

$$X_1 \cdot X_2 = f^2$$

Step 2: Solve for f

$$f = \sqrt{X_1X_2}$$

Step 3: Final answer

So, focal length is the geometric mean of object and image distances from their respective focal points.

Quick Tip

Use Newton's lens formula: $X_1 X_2 = f^2$ to find focal length in such cases.

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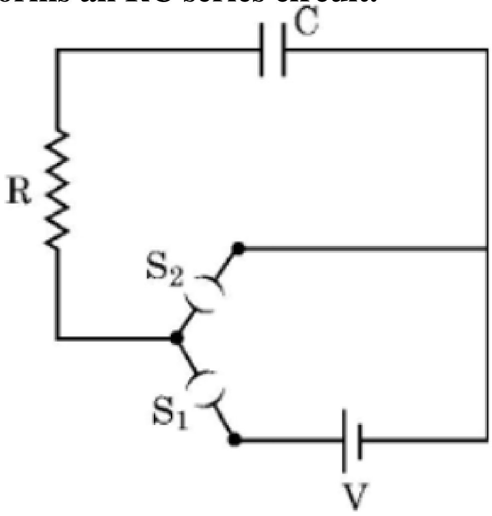
30. A circuit consisting of a capacitor C, a resistor R, and an ideal battery of emf V, forms an RC series circuit.



As soon as the circuit is completed by closing key S_1 (keeping S_2 open) charges begin to flow between the capacitor plates and the battery terminals. The charge on the capacitor increases and consequently the potential difference V_c (= Q/C) across the capacitor also increases with time. When this potential difference equals the potential difference across the battery, the capacitor is fully charged ($Q = VC$). During this process of charging, the charge q on the capacitor changes with time t as $q = Q[1 - e^{-t/RC}]$ The charging current can be obtained by differentiating it and using $\frac{d}{dx}(e^{mx}) = me^{mx}$. Consider the case when $R = 20$ kΩ, $C = 500$ μF and $V = 10$ V.

(i) The final charge on the capacitor, when key S_1 is closed and S_2 is open, is:

(A) 5 μC

(B) 5 mC

(C) 25 mC

(D) 0.1 C

Correct Answer: (C) 25 mC

Solution:

Step 1: Understand the circuit configuration and the condition for final charge.

The problem describes an RC series circuit. When key S_1 is closed and S_2 is open, the capacitor C is connected in series with the resistor R and the battery of emf V. The capacitor will charge through the resistor until it is fully charged.

Step 2: Identify the given numerical values.

From the last line of the preceding paragraph, we are given:

- Resistance, R $= 20\ \text{k}\Omega = 20 \times 10^3\Omega$
- Capacitance, C $= 500\ \mu\text{F} = 500 \times 10^{-6}$ F
- Voltage of the battery, V $= 10$ V

Step 3: Calculate the final charge (Q) on the capacitor.

When the capacitor is fully charged, the potential difference across it equals the battery voltage. The formula for the final charge (Q) on a capacitor is given by:

$Q = C \times V$

Substitute the given values into the formula:

$Q = (500 \times 10^{-6}\ \text{F}) \times (10\ \text{V})$

$Q = 5000 \times 10^{-6}$ C

$Q = 5 \times 10^3 \times 10^{-6}$ C

$Q = 5 \times 10^{-3}$ C

Step 4: Convert the final charge to appropriate units and evaluate the options.

The calculated final charge is 5×10^{-3} C.

We know that 1 millicoulomb (mC) = 10^{-3} C.

So, $Q = 5$ mC.

Now, let's compare this with the given options:

- (A) 5 μC = 5×10^{-6} C (Incorrect)
- (B) 5 mC = 5×10^{-3} C (Correct)

- (C) 25 mC = 25×10^{-3} C (Incorrect)

- (D) 0.1 C (Incorrect)

Step 5: Conclusion.

The final charge on the capacitor when key S_1 is closed and S_2 is open is 5 mC.

$$\boxed{5 \text{ mC}}$$

Quick Tip

Always use $Q = CV$ to find the maximum charge stored on a capacitor in a DC circuit.

30(ii). For sufficient time the key S_1 is closed and S_2 is open. Now key S_2 is closed and S_1 is open. What is the final charge on the capacitor?

(A) Zero

(B) 5 mC

(C) 2.5 mC

(D) 5 μC

Correct Answer: (A) Zero

Solution:

Step 1: Initial condition — key S_1 closed, S_2 open:

In this condition, the capacitor gets charged fully by the battery.

$$Q = C \cdot V = 500 \times 10^{-6} \cdot 10 = 5 \times 10^{-3} = 5 \text{ mC}$$

Step 2: Now S_2 is closed and S_1 is opened:

The capacitor is now connected across just the resistor (no battery). This leads to discharging of the capacitor through the resistor.

Step 3: Final condition after long time:

As time $t \to \infty$, the charge on the capacitor:

$$q(t) = Q \cdot e^{-t/RC} \to 0$$

So, the final charge on the capacitor is:

$$\boxed{0}$$

Quick Tip

When a charged capacitor is connected across a resistor without any battery, it discharges completely over time. Final charge becomes zero.

30(iii) The dimensional formula for RC is:

(A) $[ML^2T^{-3}A^{-2}]$

(B) $[M^0L^0T^{-1}A^0]$

(C) $[M^{-1}L^{-2}T^4A^2]$

(D) $[M^0L^0T^1A^0]$

Correct Answer: (D) $[M^0L^0T^1A^0]$

Solution:

Resistance: $[R] = [ML^2T^{-3}A^{-2}]$

Capacitance: $[C] = [M^{-1}L^{-2}T^4A^2]$

$$[RC] = [R] \cdot [C] = [T]$$

Quick Tip

Time constant RC always has the dimension of time $[T]$. Multiply units directly to confirm.

30(iv) The key S_1 is closed and S_2 is open. The value of current in the resistor after 5 seconds is:

(A) $\frac{1}{2\sqrt{e}}$ mA

(B) $\sqrt{e}$ mA

(C) $\frac{1}{\sqrt{e}}$ mA

(D) $\frac{1}{2e}$ mA

Correct Answer: (A) $\frac{1}{2\sqrt{e}}$ mA

Solution:

$$I(t) = \frac{V}{R} e^{-t/RC}$$

$$RC = 10\,s, \quad t = 5\,s \Rightarrow \frac{t}{RC} = \frac{1}{2}$$

$$I = \frac{10}{20000} \cdot e^{-1/2} = \frac{1}{2000} \cdot \frac{1}{\sqrt{e}} = \frac{1}{2\sqrt{e}} \text{ mA}$$

Quick Tip

Use $I(t) = \frac{V}{R} e^{-t/RC}$ to find current at any time t.

30(iv) (B). The key S_1 is closed and S_2 is open. The initial value of charging current in the resistor is:

(A) 5 mA

(B) 0.5 mA

(C) 2 mA

(D) 1 mA

Correct Answer: (B) 0.5 mA

Solution:

Step 1: Use formula for initial charging current:

$$I(0) = \frac{V}{R}$$

Step 2: Given values:

$V = 10\,V$

$R = 20\,k\Omega = 2 \times 10^4\,\Omega$

$$I(0) = \frac{10}{2 \times 10^4} = \frac{1}{2000} = 0.0005\,A = 0.5\,\text{mA}$$

Quick Tip

The initial charging current in an RC circuit is $I = \frac{V}{R}$. Be sure to convert resistance to ohms and express current in milliamperes.

Section-E

31(a)(i). (1) What are coherent sources? Why are they necessary for observing a sustained interference pattern?

Solution:

Coherent sources are sources of light that emit waves with a constant phase relationship. In other words, the phase difference between the waves from coherent sources remains constant over time. For sustained interference patterns, the waves need to maintain a fixed phase difference, which results in a stable constructive or destructive interference.

This constant phase relationship is necessary to observe sustained and stable interference patterns. Without coherence, the interference pattern would fade or change over time, making it impossible to observe clear and stable fringes.

(2) Lights from two independent sources are not coherent. Explain.

Solution:

When lights come from two independent sources, the phase difference between the waves from each source is random. These sources do not have a fixed phase relationship and therefore are not coherent. As a result, the interference pattern formed by two such sources would be irregular and would not sustain itself, as the random phase differences lead to fluctuating constructive and destructive interference.

> **Quick Tip**
>
> For sustained interference, coherence is key, ensuring that the phase difference between the waves remains constant.

31(a)(ii). Two slits 0.1 mm apart are arranged 1.20 m from a screen. Light of wavelength 600 nm from a distant source is incident on the slits.

(1) How far apart will adjacent bright interference fringes be on the screen?

Solution:

The distance between adjacent bright fringes (the fringe separation Δy) on the screen is given by the formula:

$$\Delta y = \frac{\lambda \cdot L}{d}$$

where:

λ is the wavelength of the light,

L is the distance from the slits to the screen,

d is the distance between the two slits.

Given:

$\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$

$L = 1.20\,\text{m}$

$d = 0.1\,\text{mm} = 0.1 \times 10^{-3}\,\text{m}$

Substituting the values:

$$\Delta y = \frac{600 \times 10^{-9} \cdot 1.20}{0.1 \times 10^{-3}} = 7.2 \times 10^{-3}\,\text{m} = 7.2\,\text{mm}$$

Thus, the adjacent bright fringes are $7.2\,\text{mm}$ apart.

(2) Find the angular width (in degrees) of the first bright fringe.

Solution:

The angular width of the first bright fringe θ is given by:

$$\theta = \frac{\lambda}{d}$$

where: λ is the wavelength of the light,

d is the distance between the slits.

Substituting the values:

$$\theta = \frac{600 \times 10^{-9}}{0.1 \times 10^{-3}} = 6^\circ$$

Thus, the angular width of the first bright fringe is 6°.

Quick Tip

The fringe separation is dependent on the wavelength of the light, the distance between the slits, and the distance to the screen. The angular width is related to the slit separation and wavelength.

31(b)(i) Define a wavefront. An incident plane wave falls on a convex lens and gets refracted through it. Draw a diagram to show the incident and refracted wavefront.

Solution:

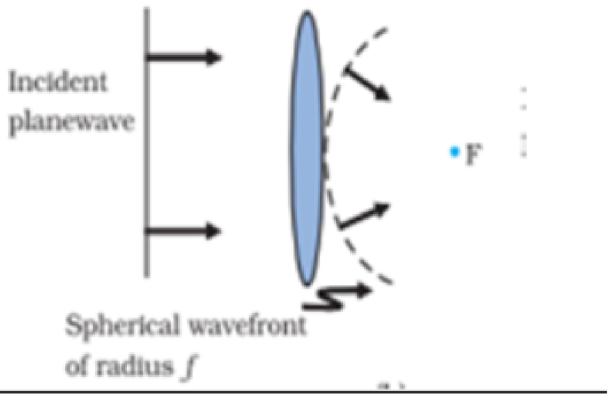
Step 1: Definition of a wavefront:

A wavefront is the locus of points in a medium that are all in phase, i.e., points where the waves have the same phase. For a plane wave, all points on the wavefront are at the same distance from the source and oscillate in unison.

Step 2: Incident and refracted wavefronts:

When a plane wave hits a convex lens, the wavefront bends as it passes through the lens. The part of the wavefront passing through the lens is refracted and converges towards the focal point of the lens, changing the curvature.

Step 3: Diagram for incident and refracted wavefronts:



Quick Tip

For a converging lens, the incident plane wavefront gets refracted and converges at the focal point, changing the curvature.

31(b)(ii) A beam of light coming from a distant source is refracted by a spherical glass ball (refractive index 1.5) of radius 15 cm. Draw the ray diagram and obtain the position of the final image formed.

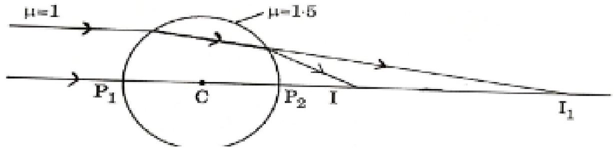
Solution:

Ray Diagram:

A parallel beam of light strikes the spherical glass ball.

The rays get refracted as they pass through the spherical surface.

The rays converge to form an image inside the sphere, depending on the radius and refractive index.



Step 1: Refraction at the first surface (from rarer to denser medium)

For refraction from the first surface, we use the formula:

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

Where:

$n_1 = 1$ (refractive index of air),

$n_2 = 1.5$ (refractive index of the glass),

$R = 15\,\text{cm}$ (radius of the sphere),

$u = \infty$ (object at infinity).

Substituting the values into the equation:

$$\frac{1.5}{v} - \frac{1}{\infty} = \frac{1.5 - 1}{15}$$
$$\frac{1.5}{v} = \frac{0.5}{15}$$
$$v = 45\,\text{cm}$$

Thus, the image formed by the first surface is at a distance of $v = 45\,\text{cm}$ inside the sphere.

Step 2: Refraction at the second surface (from denser to rarer medium)

Now, for the refraction at the second surface, we use the formula:

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

Where:

$n_1 = 1$ (refractive index of air),

$n_2 = 1.5$ (refractive index of the glass),

$R = -15\,\text{cm}$ (radius of curvature of the second surface),

$u' = 15\,\text{cm}$ (object distance from the second surface).

Substituting the values into the equation:

$$\frac{1}{v'} - \frac{1.5}{15} = \frac{1 - 1.5}{-15}$$
$$\frac{1}{v'} - \frac{0.1}{1} = \frac{-0.5}{-15}$$

$$\frac{1}{v'} - 0.1 = 0.0333$$

$$\frac{1}{v'} = 0.1333$$

$$v' = 7.5\,\text{cm}$$

Thus, the final image position after refraction through the second surface is at $7.5\,\text{cm}$ inside the sphere.

Step 3: Final Image:

The final image is formed at a distance of $7.5\,\text{cm}$ from the second surface. The image is real and formed inside the spherical glass ball.

Quick Tip

For spherical surfaces, the image formed depends on the object distance and the refractive index of the material.

32(a)(i). Two point charges $5\,\mu C$ and $-1\,\mu C$ are placed at points $(-3\,\textbf{cm}, 0, 0)$ and $(3\,\textbf{cm}, 0, 0)$ respectively. An external electric field

$$\vec{E} = \frac{3 \times 10^5}{r^2}\hat{r}$$

is switched on in the region. Calculate the change in electrostatic energy of the system due to the electric field.

Correct Answer: $\Delta U = 40\,\text{J}$

Solution:

Step 1: Electrostatic Potential Energy Without External Field

$$U_{\text{initial}} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r}$$

where $r = 6\,\text{cm} = 0.06\,\text{m}$. Substituting:

$$U_{\text{initial}} = \frac{1}{4\pi\epsilon_0} \cdot \frac{(5 \times 10^{-6})(-1 \times 10^{-6})}{0.06} = -\frac{5 \times 10^{-12}}{4\pi\epsilon_0 \times 0.06}$$

$$= -\frac{5 \times 10^{-12} \cdot 9 \times 10^9}{0.06} = -\frac{45 \times 10^{-3}}{0.06} = -0.75\,\text{J}$$

Step 2: Electrostatic Potential Energy Due to External Field

The electric potential due to the field is:

$$V(r) = -\int_{\infty}^{r} \vec{E} \cdot d\vec{r} = -\int_{\infty}^{r} \frac{3 \times 10^5}{r^2}\, dr = \frac{3 \times 10^5}{r}$$

$$U_{\text{ext}} = q_1 V(r_1) + q_2 V(r_2)$$

with $r_1 = r_2 = 3\,\text{cm} = 0.03\,\text{m}$:

$$U_{\text{ext}} = \left(5 \times 10^{-6} \cdot \frac{3 \times 10^5}{0.03}\right) + \left(-1 \times 10^{-6} \cdot \frac{3 \times 10^5}{0.03}\right)$$

$$= (5 - 1) \times 10^{-6} \cdot 10^7 = 4 \times 10^{-6} \cdot 10^7 = 40\,\text{J}$$

Step 3: Total Potential Energy With External Field

$$U_{\text{total}} = U_{\text{initial}} + U_{\text{ext}} = -0.75 + 40 = 39.25\,\text{J}$$

Quick Tip

To calculate the change in electrostatic energy due to an external field, use:

$$\Delta U = \sum q_i V(\vec{r}_i)$$

especially when mutual interaction remains constant.

32(a)(ii). A system of two conductors is placed in air and they have net charge of $+80\,\mu C$ and $-80\,\mu C$, which causes a potential difference of $16\,V$ between them.

(1) Find the capacitance of the system.

Correct Answer: $C = 5 \times 10^{-6}\,F = 5\,\mu F$

Solution:

$$C = \frac{Q}{V} = \frac{80 \times 10^{-6}}{16} = 5 \times 10^{-6}\,F$$

Quick Tip

Capacitance is defined by $C = \frac{Q}{V}$, where Q is the magnitude of charge on either conductor.

32(a)(ii). (2) If the air is replaced by a dielectric with $k = 3$, what is the new potential difference?

Correct Answer: $V' = \frac{16}{3}\,V \approx 5.33\,V$

Solution:

Capacitance increases by factor of k:

$$C' = kC = 3 \cdot C \Rightarrow V' = \frac{Q}{C'} = \frac{Q}{3C} = \frac{V}{3}$$

$$V' = \frac{16}{3} \approx 5.33\,V$$

Quick Tip

Inserting a dielectric increases capacitance $C \to kC$, so for same charge, potential reduces: $V \to \frac{V}{k}$.

32(a)(ii). (3) If charges are changed to $+160\,\mu C$ and $-160\,\mu C$, will the capacitance change? Explain.

Correct Answer: No, capacitance remains the same.

Solution:

Capacitance depends only on geometry and dielectric of the system, not on the amount of charge stored. Even if the charges are doubled, capacitance remains:

$$C = \frac{Q}{V} \quad \text{but both } Q \text{ and } V \text{ double}$$

Quick Tip

Capacitance is a geometric property and independent of charge. Changing the charge will change potential, but not capacitance.

32(b)(i). Consider three metal spherical shells A, B, and C, each of radius R. Each shell is having a concentric metal ball of radius $R/10$. The spherical shells A, B, and C are given charges $+6q$, $-4q$, and $+14q$ respectively. Their inner metal balls are also given charges $-2q$, $+8q$, and $-10q$ respectively. Compare the magnitude of the electric fields

due to shells A, B, and C at a distance $3R$ from their centres.

Correct Answer: The magnitude of the electric field due to each shell is the same at a distance of $3R$ from the center.

Solution:

For a spherical shell with a charge distributed over its surface, the electric field at a point outside the shell (at distance r from the center, where $r > R$) is given by Coulomb's Law:

$$E = \frac{KQ}{r^2}$$

where Q is the total charge on the shell, and r is the distance from the center.

At a distance $3R$ (which is outside all the shells), the electric field depends only on the total charge on the shell, and not on the distribution of charge inside. Therefore, for each shell at a distance $3R$, the electric field magnitude is given by:

$$E = \frac{KQ}{(3R)^2} = \frac{KQ}{9R^2}$$

So, for each shell at $3R$, the electric field magnitudes are:

For shell A: $E_A = \frac{K \cdot 6q}{9R^2}$

For shell B: $E_B = \frac{K \cdot (-4q)}{9R^2}$

For shell C: $E_C = \frac{K \cdot 14q}{9R^2}$

Since the magnitude depends only on the charge, the electric field magnitudes are proportional to the absolute values of the charges:

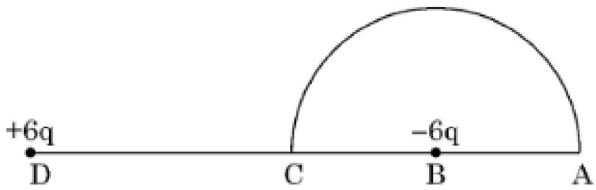
$$|E_A| = |E_B| = |E_C|$$

Thus, the electric field magnitudes at a distance of $3R$ are the same for all shells.

Quick Tip

For a spherical shell with charge Q, the electric field outside the shell depends only on the total charge and not on its internal charge distribution.

32(b)(ii). A charge $-6\,\mu C$ is placed at the centre B of a semicircle of radius 5 cm, as shown in the figure. An equal and opposite charge is placed at point D at a distance of 10 cm from B. A charge $+5\,\mu C$ is moved from point C to point A along the circumference. Calculate the work done on the charge.



Correct Answer: $W = -3.6\,\text{J}$

Solution:

We are calculating the work done on the charge $+5\,\mu C$ as it is moved from point C to point A along the semicircular path. The work done is given by:

$$W = q \cdot [V_A - V_C]$$

Step 1: Calculate the potential at point C (due to both charges at B and D)

$$V_C = \left[\frac{k \cdot 6 \times 10^{-6}}{5 \times 10^{-2}}\right] - \left[\frac{k \cdot 6 \times 10^{-6}}{5 \times 10^{-2}}\right]$$
$$V_C = 0$$

Step 2: Calculate the potential at point A:

$$V_A = \left[\frac{k \cdot 6 \times 10^{-6}}{15 \times 10^{-2}}\right] - \left[\frac{k \cdot 6 \times 10^{-6}}{5 \times 10^{-2}}\right]$$
$$V_A = \frac{k \cdot 6 \times 10^{-6}}{15 \times 10^{-2}}\left[1 - \frac{3}{15}\right]$$
$$V_A = \frac{9 \times 10^{9} \cdot 6 \times 10^{-6} \cdot 2}{15 \times 10^{-2}}$$
$$V_A = -7.2 \times 10^{5}\,\text{V}$$

Step 3: Calculate the work done:

$$W = q \cdot [V_A - V_C]$$

$$W = 5 \times 10^{-6} \cdot \left[-7.2 \times 10^{5} - 0\right]$$

$$W = -3.6\,\text{J}$$

Thus, the work done is $W = -3.6\,\text{J}$.

Quick Tip

When moving a charge in an electric field, the work done is the charge times the potential difference between the initial and final positions. The potential at a point due to multiple charges is the sum of the potentials due to each charge.

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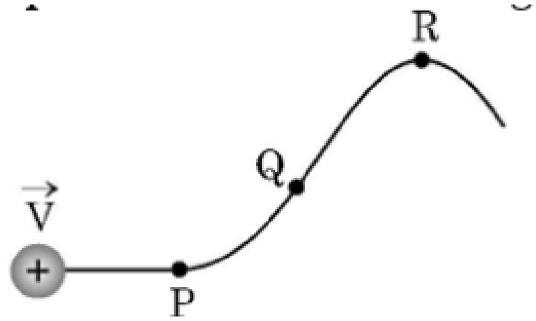
33 (a)(i) A proton moving with velocity $\vec{v}$ in a non-uniform magnetic field traces a path as shown in the figure.



The path followed by the proton is always in the plane of the paper. What is the direction of the magnetic field in the region near points P, Q, and R? What can you say about the relative magnitude of magnetic fields at these points?

Solution:

Step 1: Understanding proton motion in a magnetic field:

The proton is positively charged, and the force acting on it is given by the Lorentz force:

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

where q is the charge of the proton and $\vec{B}$ is the magnetic field.

Step 2: Determining the direction of magnetic field:

The proton moves in the plane of the paper, and the force is perpendicular to the velocity, which means the magnetic field is directed perpendicular to the paper.

At point P, the proton is moving along the curved path, and the force must be directed towards the center of the curve. Using the right-hand rule, the direction of $\vec{B}$ at point P is out of the paper (towards the viewer).

At point Q, since the proton is turning in the opposite direction, the magnetic field direction is into the paper.

At point R, as the proton is turning in the same direction again, the magnetic field direction is again out of the paper.

Step 3: Relative magnitude of magnetic fields:

The magnitude of the magnetic field depends on the curvature of the proton's path. Since the proton moves in a non-uniform magnetic field, the magnetic field strength is greater where the curvature is higher. Therefore, the magnetic field magnitude at point P (with sharp curvature) is greater than at point R (less curvature). The field at point Q, where the proton changes direction, could be comparable to point P.

> **Quick Tip**
>
> For charged particles in a magnetic field, the direction of the field is determined using the right-hand rule, and the field strength correlates with the curvature of the path.

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33 (a)(ii) A current carrying circular loop of area A produces a magnetic field B at its centre. Show that the magnetic moment of the loop is

$$\frac{2BA}{\mu_0}\sqrt{\frac{A}{\pi}}$$

Solution:

Step 1: Magnetic field at the center of a current-carrying loop:

The magnetic field B at the center of a circular loop of radius r carrying current I is given by:

$$B = \frac{\mu_0 I}{2r}$$

where μ_0 is the permeability of free space.

Step 2: Relating current to magnetic moment:

The magnetic moment $\vec{\mu}$ of a loop is given by:

$$\vec{\mu} = IA\hat{n}$$

where A is the area of the loop and $\hat{n}$ is the unit vector perpendicular to the plane of the loop. The magnetic moment is also related to the magnetic field at the center by:

$$B = \frac{\mu_0 \mu}{2\pi r^3}$$

Step 3: Substituting the expression for B:

We substitute $r = \sqrt{\frac{A}{\pi}}$ (from the area of the loop) into the equation for magnetic field:

$$B = \frac{2\mu_0\mu}{\mu_0 r}$$

$$\Rightarrow \mu = \frac{BA}{2\mu_0}$$

Thus, the magnetic moment is:

$$\mu = \frac{2BA}{\mu_0}\sqrt{\frac{A}{\pi}}$$

> **Quick Tip**
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> Magnetic moment of a current-carrying loop is proportional to both the current and the area of the loop. The magnetic field at the center of the loop is inversely proportional to the radius.

33(b)(i). Derive an expression for the torque acting on a rectangular current loop suspended in a uniform magnetic field.

Solution:

Let the current loop be a rectangle with dimensions l and w (length and width) carrying a current I. The loop is placed in a uniform magnetic field $\vec{B}$ with the plane of the loop perpendicular to the field.

The torque τ acting on the loop is given by:

$$\tau = \vec{\mu} \times \vec{B}$$

where μ is the magnetic dipole moment of the current loop, and $\vec{B}$ is the external magnetic field.

The magnetic dipole moment is defined as:

$$\mu = I \cdot A$$

where A is the area of the loop. For a rectangular loop, the area is:

$$A = l \cdot w$$

Thus, the magnetic moment becomes:

$$\mu = I \cdot l \cdot w$$

Now, the torque is given by:

$$\tau = \mu B \sin\theta$$

where θ is the angle between the magnetic moment and the magnetic field.
For the case where the magnetic moment is perpendicular to the field ($\theta = 90°$), the torque simplifies to:

$$\tau = I \cdot l \cdot w \cdot B$$

Thus, the expression for the torque acting on a rectangular current loop suspended in a uniform magnetic field is:

$$\tau = I \cdot A \cdot B \cdot \sin\theta$$

Quick Tip

The torque on a current loop in a magnetic field depends on the magnetic moment of the loop and the external field. When the loop is perpendicular to the field, the torque is maximized.

33(b)(ii). A charged particle is moving in a circular path with velocity $\vec{V}$ in a uniform magnetic field $\vec{B}$. It is made to pass through a sheet of lead and as a consequence, it loses one half of its kinetic energy without changing its direction. How will (1) the radius of its path (2) its time period of revolution change?

Solution:

Let the mass of the particle be m, the charge be q, and its velocity be v. The radius r of the circular path is related to the velocity by:

$$r = \frac{mv}{qB}$$

where B is the magnetic field strength.

Part (1) Change in Radius:

The particle loses half of its kinetic energy. The initial kinetic energy is:

$$K_i = \frac{1}{2}mv^2$$

After passing through the sheet of lead, the final kinetic energy is:

$$K_f = \frac{1}{2}K_i = \frac{1}{4}mv^2$$

The new velocity v' after the energy loss can be found by equating the final kinetic energy:

$$K_f = \frac{1}{2}mv'^2 \quad \Rightarrow \quad \frac{1}{4}mv^2 = \frac{1}{2}mv'^2$$

$$v' = \frac{v}{\sqrt{2}}$$

The new radius r' is given by:

$$r' = \frac{mv'}{qB} = \frac{m \cdot \frac{v}{\sqrt{2}}}{qB} = \frac{r}{\sqrt{2}}$$

Thus, the radius decreases by a factor of $\sqrt{2}$.

Part (2) Change in Time Period:

The time period T of revolution is given by:

$$T = \frac{2\pi r}{v}$$

Substituting the expression for r', the new time period T' is:

$$T' = \frac{2\pi r'}{v'} = \frac{2\pi \cdot \frac{r}{\sqrt{2}}}{\frac{v}{\sqrt{2}}} = T$$

Thus, the time period remains unchanged.

Quick Tip

When a charged particle moves through a material that reduces its kinetic energy, the radius of the path decreases because of the reduced velocity. However, the time period of revolution remains unchanged if only the velocity magnitude changes without altering the charge or magnetic field.
