CBSE Class 12 Physics 55/1/3 2025 Question Paper with Solutions

Time Allowed :3 Hours	**Maximum Marks :**80	**Total Questions :**33

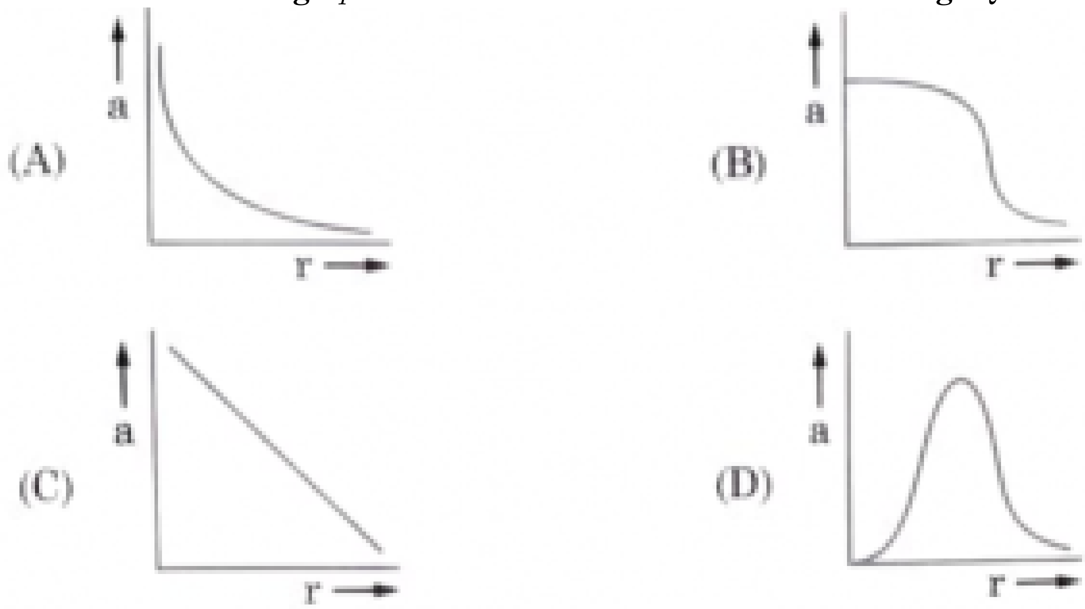
General Instructions

Read the following instructions very carefully and strictly follow them::

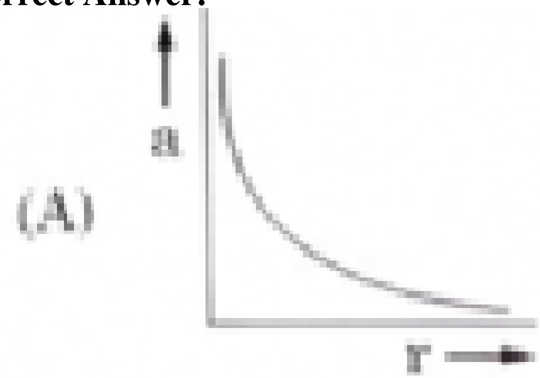
1. This question paper contains 33 questions. All questions are compulsory.
2. This question paper is divided into five sections Sections A, B, C, D and E.
3. In Section A Questions no. 1 to 16 are Multiple Choice type questions. Each question carries 1 mark.
4. In Section B Questions no. 17 to 21 are 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. A charge Q is fixed in position. Another charge q is brought near charge Q and released from rest. Which of the following graphs is the correct representation of the acceleration of the charge q as a function of its distance r from charge Q?



Correct Answer:



Solution: The force between the two charges is given by Coulomb's Law:

$$F = \frac{k \cdot Q \cdot q}{r^2}$$

where k is Coulomb's constant. The acceleration a is given by $a = \frac{F}{m}$, where m is the mass of the charge q. Therefore, the acceleration of the charge q as a function of distance r is proportional to $\frac{1}{r^2}$, which corresponds to option (1).

Quick Tip

For Coulomb's law, remember the force between two charges is inversely proportional to the square of the distance between them.

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2. Two conductors A and B of the same material have their lengths in the ratio 1:2 and radii in the ratio 2:3. If they are connected in parallel across a battery, the ratio $\frac{v_A}{v_B}$ of the drift velocities of electrons in them will be:

(1) 2

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

(3) $\frac{3}{2}$

(4) $\frac{8}{9}$

Correct Answer: (3) $\frac{3}{2}$

Solution: The drift velocity v is inversely proportional to the area of cross-section of the conductor, and directly proportional to the current and length. Since the conductors are in parallel, the voltage is the same across both. Hence, the ratio of drift velocities $\frac{v_A}{v_B}$ is:

$$\frac{v_A}{v_B} = \frac{r_B^2}{r_A^2} = \frac{3^2}{2^2} = \frac{9}{4}.$$

Thus, the correct ratio is $\frac{3}{2}$, corresponding to option (3).

Quick Tip

Drift velocity is related to the current and the area of cross-section. Smaller area of cross-section leads to larger drift velocity.

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

(1) $(2\hat{j} + 3\hat{k})$ mN

(2) $(-3\hat{j} + 2\hat{k})$ μN

(3) $(6\hat{j} + 4\hat{k})$ mN

(4) $(-4\hat{j} + 6\hat{k})$ μN

Correct Answer: (2) $(-3\hat{j} + 2\hat{k})$ μN

Solution: To determine the force acting on the segment of the wire, we can use the Lorentz force law for a current-carrying wire in a magnetic field:

$$\mathbf{F} = I\mathbf{L} \times \mathbf{B}$$

where:

$I = 0.5\,\mathrm{A}$ is the current,

$\mathbf{L} = 1\,\mathrm{cm}\,\hat{\imath} = 0.01\,\mathrm{m}\,\hat{\imath}$ is the length of the wire segment,

$\mathbf{B} = (0.4\,\mathrm{mT})\hat{\jmath} + (0.6\,\mathrm{mT})\hat{k} = (0.4 \times 10^{-3}\,\mathrm{T})\hat{\jmath} + (0.6 \times 10^{-3}\,\mathrm{T})\hat{k}$ is the magnetic field.

Now, compute the cross product $\mathbf{L} \times \mathbf{B}$:

$$\mathbf{L} \times \mathbf{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 0.01 & 0 & 0 \\ 0 & 0.4 \times 10^{-3} & 0.6 \times 10^{-3} \end{vmatrix}$$

$$\mathbf{L} \times \mathbf{B} = \hat{\imath}\left(0 \cdot 0.6 \times 10^{-3} - 0 \cdot 0.4 \times 10^{-3}\right) - \hat{\jmath}\left(0.01 \cdot 0.6 \times 10^{-3} - 0 \cdot 0\right) + \hat{k}\left(0.01 \cdot 0.4 \times 10^{-3} - 0 \cdot 0\right)$$

$$\mathbf{L} \times \mathbf{B} = -\hat{\jmath}\left(0.01 \cdot 0.6 \times 10^{-3}\right) + \hat{k}\left(0.01 \cdot 0.4 \times 10^{-3}\right)$$

$$\mathbf{L} \times \mathbf{B} = -\hat{\jmath}\left(6 \times 10^{-6}\right) + \hat{k}\left(4 \times 10^{-6}\right)$$

Now, multiply by the current $I = 0.5\,\mathrm{A}$:

$$\mathbf{F} = 0.5\left(-\hat{\jmath}\left(6 \times 10^{-6}\right) + \hat{k}\left(4 \times 10^{-6}\right)\right)$$

$$\mathbf{F} = -3 \times 10^{-6}\,\hat{\jmath} + 2 \times 10^{-6}\,\hat{k}$$

$$\mathbf{F} = (-3\hat{\jmath} + 2\hat{k})\,\mu\mathrm{N}$$

Thus, the correct answer is:

$$\boxed{(2)\,(-3\hat{\jmath} + 2\hat{k})\,\mu\mathrm{N}}$$

Quick Tip

The force on a current-carrying conductor in a magnetic field is calculated using $\mathbf{F} = I(\mathbf{L} \times \mathbf{B})$.

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4. The ratio of the number of turns of the primary to the secondary coils in an ideal transformer is 20:1. If 240 V AC is applied from a source to the primary coil of the transformer and a 6.0 Ω resistor is connected across the output terminals, then the current drawn by the transformer from the source will be:

(1) 4.0 A

(2) 3.8 A

(3) 0.97 A

(4) 0.10 A

Correct Answer: (4) 0.10 A

Solution: For an ideal transformer, the relationship between the primary and secondary voltages is given by:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s},$$

where V_p and V_s are the primary and secondary voltages, and N_p and N_s are the number of turns in the primary and secondary coils. Since the turns ratio is 20:1, the secondary voltage is:

$$V_s = \frac{V_p}{20} = \frac{240\,\mathrm{V}}{20} = 12\,\mathrm{V}.$$

The current in the secondary is:

$$I_s = \frac{V_s}{R} = \frac{12\,\mathrm{V}}{6.0\,\Omega} = 2.0\,\mathrm{A}.$$

Using the turns ratio, the primary current is:

$$I_p = \frac{I_s}{20} = \frac{2.0\,\mathrm{A}}{20} = 0.1\,\mathrm{A}.$$

Therefore, the current drawn by the transformer from the source is 0.1 A, corresponding to option (4).

Quick Tip

In transformers, the ratio of the primary to secondary voltage is equal to the ratio of the number of turns in the coils.

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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:

(1) 2592

(2) 2866

(3) 2976

(4) 3140

Correct Answer: (3) 2976

Solution: The inductance of a solenoid is given by the formula:

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

where:

$L = 0.016$ H (Inductance),

$\mu_0 = 4\pi \times 10^{-7}$ H/m (Permeability of free space),

$\mu_r = 1$ (for air-filled solenoid),

$A = \pi r^2 = \pi (0.02)^2$ m^2,

$l = 0.81$ m (Length),

N is the number of turns.

Rearranging for N:

$$N = \sqrt{\frac{Ll}{\mu_0 \mu_r A}}$$

Substituting values:

$$N = \sqrt{\frac{(0.016)(0.81)}{(4\pi \times 10^{-7})(1)(\pi (0.02)^2)}}$$

Solving this gives:

$$N \approx 2976$$

Thus, the correct answer is (3).

Quick Tip

For air-filled solenoids, permeability $\mu_r = 1$. Always check the unit consistency when using formulas.

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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:

(1) Zero

(2) $i_0 v_0 \cos \phi$

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

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

Correct Answer: (4) $\frac{i_0 v_0}{2} \cos \phi$

Solution: The average power consumed in an AC circuit is given by:

$$P_{\text{avg}} = V_{\text{rms}} I_{\text{rms}} \cos \phi$$

Since the peak voltage and current are related to their rms values as:

$$V_{\text{rms}} = \frac{v_0}{\sqrt{2}}, \quad I_{\text{rms}} = \frac{i_0}{\sqrt{2}}$$

Substituting these into the power formula:

$$P_{\text{avg}} = \left(\frac{v_0}{\sqrt{2}}\right)\left(\frac{i_0}{\sqrt{2}}\right) \cos \phi$$

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

Thus, the correct answer is (2).

Quick Tip

In AC circuits, the power factor $\cos \phi$ determines the actual power consumption. It accounts for phase differences between voltage and current.

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7. X-rays are more harmful to human beings than ultraviolet radiations because X-rays:

(1) have frequency lower than that of ultraviolet radiations.

(2) have wavelength smaller than that of ultraviolet radiations.

(3) move faster than ultraviolet radiations in air.

(4) are mechanical waves but ultraviolet radiations are electromagnetic waves.

Correct Answer: (2) have wavelength smaller than that of ultraviolet radiations.

Solution: X-rays and ultraviolet (UV) rays both belong to the electromagnetic spectrum, but X-rays have a much smaller wavelength and hence higher energy than UV rays. The energy of a photon is given by:

$$E = hf = \frac{hc}{\lambda}$$

where:

E is energy,

h is Planck's constant,

f is frequency,

c is the speed of light,

λ is the wavelength.

Since X-rays have a smaller wavelength (λ) than UV rays, they carry more energy per photon. This higher energy enables them to penetrate deeper into tissues, making them more harmful to living cells.

Thus, the correct answer is (2).

Quick Tip

X-rays are used in medical imaging but excessive exposure can damage tissues due to their high energy.

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8. A point source is placed at the bottom of a tank containing a transparent liquid (refractive index n) to a depth H. The area of the surface of the liquid through which light from the source can emerge out is:

(A) $\frac{\pi H^2}{(n-1)}$

(B) $\frac{\pi H^2}{(n^2-1)}$

(C) $\frac{\pi H^2}{\sqrt{n^2-1}}$

(D) $\frac{\pi H^2}{(n^2+1)}$

Correct Answer: (B) $\frac{\pi H^2}{(n^2-1)}$

Solution: The light from the point source will emerge out of the liquid surface within a circle of radius r due to total internal reflection. The critical angle θ_c for total internal reflection is given by:

$$\sin\theta_c = \frac{1}{n}$$

The radius r of the circle on the surface is:

$$r = H\tan\theta_c$$

Using $\tan\theta_c = \frac{\sin\theta_c}{\sqrt{1-\sin^2\theta_c}}$, we get:

$$r = H \cdot \frac{1}{\sqrt{n^2-1}}$$

The area A of the circle is:

$$A = \pi r^2 = \pi\left(\frac{H}{\sqrt{n^2-1}}\right)^2 = \frac{\pi H^2}{n^2-1}$$

Thus, the correct answer is (C).

Quick Tip

The phenomenon of total internal reflection is widely used in optical fibers, where light is confined within the core due to repeated reflections at the boundary.

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9. In a photoelectric experiment with a material of work function 2.1 eV, the stopping potential is found to be 2.5 V. The maximum kinetic energy of ejected photoelectrons is:

(A) 0.4 eV

(B) 2.1 eV

(C) 2.5 eV

(D) 4.6 eV

Correct Answer: (C) 2.5 eV

Solution: The maximum kinetic energy K_{max} of the ejected photoelectrons is given by:

$$K_{\text{max}} = eV_s$$

where V_s is the stopping potential. Given $V_s = 2.5\,\text{V}$:

$$K_{\text{max}} = 2.5\,\text{eV}$$

Thus, the correct answer is (C).

Quick Tip

The stopping potential is the minimum voltage required to stop the most energetic photoelectrons, and it directly measures their maximum kinetic energy.

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10. 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: When a p-n junction diode is forward biased, the applied voltage reduces the built-in potential (barrier height) and the width of the depletion layer decreases. This allows majority charge carriers to cross the junction more easily, resulting in current flow.

Thus, the correct answer is (C).

Quick Tip

Forward biasing a diode reduces the barrier to charge flow, enabling current to pass through the junction, which is the basis of diode operation in electronic circuits.

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11. 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:

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

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

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

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

Correct Answer: (2) $\lambda_e > \lambda_p > \lambda_d$

Solution: The de Broglie wavelength of a particle is given by:

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

where:

h is Planck's constant,

m is the mass of the particle,

v is the velocity of the particle.

Since all three particles (electron, proton, and deuteron) have the same speed, the wavelength is inversely proportional to their masses:

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

The masses of the particles are:

m_e (electron) is the smallest,

m_p (proton) is larger,

m_d (deuteron) is the largest.

Thus, their wavelengths follow the relation:

$$\lambda_e > \lambda_p > \lambda_d$$

Hence, the correct answer is (2).

Quick Tip

The de Broglie wavelength is larger for lighter particles when moving at the same speed. Always compare the masses to determine the correct wavelength order.

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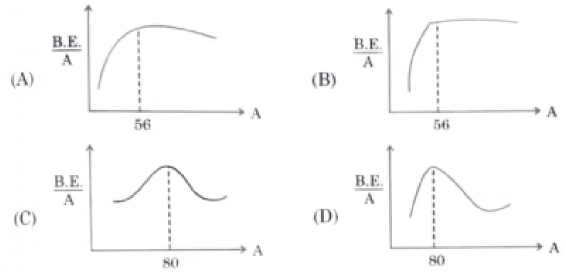
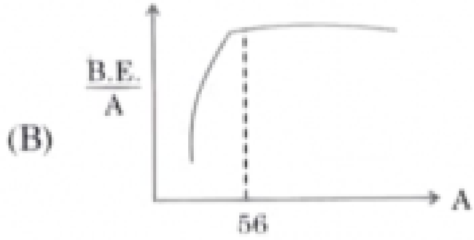
12. Which of the following figures correctly represents the shape of the curve of binding energy per nucleon as a function of mass number?



Correct Answer:



Solution: The binding energy per nucleon (B.E./A) curve as a function of mass number A follows a characteristic trend:

It rises steeply for light nuclei.

It reaches a maximum around $A \approx 56$ (Iron-56, the most stable nucleus).

It then slowly decreases for heavier nuclei.

The correct representation is Figure (B), which shows the binding energy per nucleon increasing and then flattening out around $A = 56$, consistent with experimental data.

Thus, the correct answer is (2).

Quick Tip

The peak in the binding energy curve around $A = 56$ (Iron-56) explains why nuclear fission and fusion release energy—lighter elements fuse to move towards iron, and heavier elements split to move towards iron.

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.

13. 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 an n-type semiconductor.

Reason (R): In a p-type semiconductor $\eta_e \gg \eta_h$ while in an 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 the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the 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: In a p-n junction diode, a p-type semiconductor and an n-type semiconductor must be physically joined together. However, the reasoning provided in the statement is incorrect. The ratio of electron and hole concentrations does not directly affect the ability to form a p-n junction diode, as the junction can still form despite differing carrier concentrations. Hence, Assertion (A) is true, but Reason (R) is false.

Quick Tip

In semiconductors, p-n junctions are formed by joining p-type and n-type materials, regardless of the hole and electron concentration ratios.

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14. 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 the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the 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: The potential energy of an electron in any stationary orbit in a hydrogen atom is negative, not positive. The total energy of the electron is negative due to the bound state of the electron in the atom. Hence, both Assertion (A) and Reason (R) are false.

Quick Tip

In atomic physics, the total energy of an electron in a hydrogen atom is negative, as it is a bound state.

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15. 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 the Assertion (A).

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

Solution: According to Lenz's Law, the induced current in the coil opposes the motion of the magnet. Therefore, the difficulty in moving the magnet into the coil is explained by the opposing force due to the induced current. Hence, both the Assertion and the Reason are true, and the Reason correctly explains the Assertion.

Quick Tip

Lenz's Law states that the direction of the induced current is always such that it opposes the change causing it.

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16. 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 the Assertion (A).

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

Solution: The deflection in a galvanometer is directly proportional to the current passing through it, as per the principle of a moving coil galvanometer. However, the reason provided is not directly related to the deflection, as the deflection is a result of the torque on the coil, which depends on the current. Therefore, both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

> **Quick Tip**
>
> In a moving coil galvanometer, deflection is proportional to the current passing through the coil.

SECTION - B

17. n **identical cells, each of e.m.f** E **and internal resistance** r**, are connected in series. Later on, it was found that two cells 'X' and 'Y' are connected in reverse polarities. Calculate the potential difference across the cell 'X'.**

Correct Answer: $2E$

Solution: When n identical cells are connected in series, the total effective e.m.f. is:

$$E_{\text{total}} = nE$$

If two cells are connected in reverse polarity, their individual e.m.f. will subtract from the total e.m.f.:

$$E'_{\text{total}} = (n-2)E$$

However, the potential difference across a single reversed cell 'X' is equal to the sum of the e.m.f. of the reversed cells, which is:

$$V_X = 2E$$

Thus, the potential difference across cell 'X' is $2E$.

> **Quick Tip**
>
> When a battery cell is reversed in a series circuit, its e.m.f. opposes the total e.m.f. of the circuit, reducing the overall voltage.

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

Correct Answer: $d = 1.2 \times 10^{-6}$ m

Solution: The condition for the first minimum in a single-slit diffraction pattern is given by:

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

For the first minimum, $m = 1$, so:

$$a \sin 30° = (1)(600 \times 10^{-9} \text{ m})$$

Since $\sin 30° = 0.5$, we get:

$$a \times 0.5 = 600 \times 10^{-9}$$

Solving for a:

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

Thus, the width of the slit is 1.2×10^{-6} m.

Quick Tip

The diffraction formula $a \sin \theta = m\lambda$ is useful for calculating the width of a slit when the wavelength and diffraction angle are known.

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: $I = I_0 \left(1 + \cos \frac{\pi}{4}\right)$

Solution: The resultant intensity in an interference pattern is given by:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \delta$$

Since $I_1 = I_2 = I_0$, we get:

$$I = 2I_0(1 + \cos \delta)$$

The phase difference δ is related to the path difference by:

$$\delta = \frac{2\pi}{\lambda} \times \frac{\lambda}{8} = \frac{\pi}{4}$$

Substituting this into the intensity formula:

$$I = 2I_0 \left(1 + \cos\frac{\pi}{4}\right)$$

Since $\cos\frac{\pi}{4} = \frac{1}{\sqrt{2}}$, we obtain:

$$I = I_0 \left(1 + \frac{1}{\sqrt{2}}\right)$$

Thus, the intensity at this point is $I_0 \left(1 + \cos\frac{\pi}{4}\right)$.

Quick Tip

In Young's double-slit experiment, the phase difference δ is related to the path difference by $\delta = \frac{2\pi}{\lambda} \times$ path difference.

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19. A double convex lens of glass has both faces of the same radius of curvature 17 cm. Find its focal length if it is immersed in water. The refractive indices of glass and water are 1.5 and 1.33 respectively.

Solution: The focal length f of a lens in a medium is given by the lens maker's formula:

$$\frac{1}{f} = (n_{\text{lens}} - n_{\text{medium}}) \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For a double convex lens, $R_1 = 17\,\text{cm}$ and $R_2 = -17\,\text{cm}$. The refractive index of glass $n_{\text{lens}} = 1.5$ and water $n_{\text{medium}} = 1.33$. Substituting these values:

$$\frac{1}{f} = (1.5 - 1.33) \left(\frac{1}{17} - \frac{1}{-17}\right)$$

$$\frac{1}{f} = 0.17 \left(\frac{2}{17}\right) = 0.17 \times \frac{2}{17} = 0.02\,\text{cm}^{-1}$$

$$f = \frac{1}{0.02} = 50\,\text{cm}$$

Thus, the focal length of the lens in water is $50\,\text{cm}$.

Quick Tip

The focal length of a lens changes when immersed in a medium other than air due to the change in the relative refractive index.

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20. An electron in Bohr model of hydrogen atom makes a transition from energy level $-1.51\,$eV to $-3.40\,$eV. Calculate the change in the radius of its orbit. The radius of orbit of electron in its ground state is $0.53\,$Å.

Solution: The radius r_n of the electron's orbit in the Bohr model is given by:

$$r_n = r_1 n^2$$

where $r_1 = 0.53\,$Å is the radius of the ground state orbit, and n is the principal quantum number.

The energy levels are given by:

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

For $E_n = -1.51\,$eV:

$$-1.51 = -\frac{13.6}{n_1^2} \implies n_1^2 = \frac{13.6}{1.51} \implies n_1 = 3$$

For $E_n = -3.40\,$eV:

$$-3.40 = -\frac{13.6}{n_2^2} \implies n_2^2 = \frac{13.6}{3.40} \implies n_2 = 2$$

The radii of the orbits are:

$$r_{n_1} = r_1 n_1^2 = 0.53 \times 9 = 4.77\,\text{Å}$$

$$r_{n_2} = r_1 n_2^2 = 0.53 \times 4 = 2.12\,\text{Å}$$

The change in radius is:

$$\Delta r = r_{n_1} - r_{n_2} = 4.77 - 2.12 = 2.65\,\text{Å}$$

Thus, the change in the radius of the orbit is $2.65\,$Å.

Quick Tip

In the Bohr model, the radius of the electron's orbit is proportional to the square of the principal quantum number n.

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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.

Solution: The number density of silicon atoms is 5×10^{28} atoms/m^3. The doping ratio is 1 dopant atom per 5×10^7 silicon atoms. Therefore, the number of dopant atoms per cubic metre is:

$$\text{Dopant density} = \frac{5 \times 10^{28}}{5 \times 10^7} = 10^{21}\,\text{atoms/m}^3$$

Since each dopant atom creates one hole, the number of holes per cubic metre is 10^{21}. Converting to per cubic centimetre:

$$\text{Holes per cm}^3 = 10^{21} \times 10^{-6} = 10^{15}\,\text{holes/cm}^3$$

An example of such a dopant is Boron (B), which is a trivalent impurity and creates p-type semiconductors.

Quick Tip

Doping with trivalent impurities like Boron introduces holes in the semiconductor, making it p-type.

22(a). Two batteries of emf's 3V & 6V and internal resistances 0.2 & 0.4 are connected in parallel. This combination is connected to a 4 resistor. Find:

(i) the equivalent emf of the combination

(ii) the equivalent internal resistance of the combination

(iii) the current drawn from the combination

—

Correct Answer: (i) Equivalent emf = $4\,\text{V}$

(ii) Equivalent internal resistance = $0.133\,\Omega$

(iii) Current drawn = $0.968\,\text{A}$

—

Solution: For two batteries connected in parallel, the equivalent emf E_{eq} and equivalent internal resistance r_{eq} are given by:

$$E_{\text{eq}} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

$$r_{\text{eq}} = \frac{r_1 r_2}{r_1 + r_2}$$

Given:

$E_1 = 3\,\text{V}$, $r_1 = 0.2\,\Omega$

$E_2 = 6\,\text{V}$, $r_2 = 0.4\,\Omega$

(i) Equivalent emf:

$$E_{\text{eq}} = \frac{(3 \times 0.4) + (6 \times 0.2)}{0.2 + 0.4} = \frac{1.2 + 1.2}{0.6} = \frac{2.4}{0.6} = 4\,\text{V}$$

(ii) Equivalent internal resistance:

$$r_{\text{eq}} = \frac{0.2 \times 0.4}{0.2 + 0.4} = \frac{0.08}{0.6} = 0.133\,\Omega$$

(iii) Current drawn from the combination: The total resistance of the circuit is:

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

The current I is:

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

—

Quick Tip

When batteries are connected in parallel, the equivalent emf is a weighted average of the individual emfs, and the equivalent internal resistance is smaller than the smallest individual internal 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 gradually stretching it. If R and R' are initial and final values of resistance and v_d and v'_d are initial and final values of drift velocity, find the relation between:

(i) R' and R

(ii) v'_d and v_d

(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: (i) $R' = 4R$

(ii) $v_d' = 2v_d$

(iii) No, not all free electrons move in the same direction.

—

Solution:

(i) Relation between R' and R: Resistance R of a conductor is given by:

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

When the length is increased to $2l$, the cross-sectional area A decreases to $\frac{A}{2}$ (assuming volume remains constant). Thus:

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

So, $R' = 4R$.

(ii) Relation between v_d' and v_d: Drift velocity v_d is given by:

$$v_d = \frac{I}{neA}$$

When the length is doubled, the current I remains the same (since the cell is ideal), but the cross-sectional area A is halved. Thus:

$$v_d' = \frac{I}{ne(A/2)} = 2\frac{I}{neA} = 2v_d$$

So, $v_d' = 2v_d$.

(ii) Direction of free electrons: No, not all free electrons move in the same direction. Electrons move randomly due to thermal motion, but there is a net drift in the direction opposite to the electric field (from lower to higher potential).

—

Quick Tip

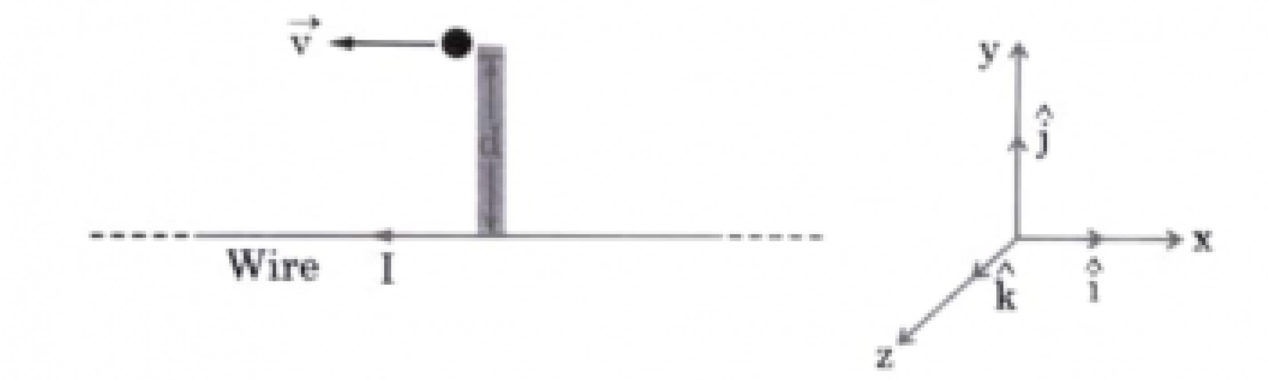
When a conductor is stretched, its resistance increases due to the increase in length and decrease in cross-sectional area, while the drift velocity increases due to the reduced cross-sectional area.

23. A particle of charge q is moving with a velocity $\vec{v}$ at a distance d from a long straight wire carrying a current I as shown in the figure. At this instant, it is subjected to a uniform electric field $\vec{E}$ such that the particle keeps moving undeviated. In terms of unit vectors $\hat{i}, \hat{j},$ and $\hat{k}$, find:

(a) the magnetic field $\vec{B}$,

(b) the magnetic force $\vec{F}_m$, and

(c) the electric field $\vec{E}$ acting on the charge.



Correct Answers: (a) $\vec{B} = \frac{\mu_0 I}{2\pi d}\hat{k}$

(b) $\vec{F}_m = qvB\hat{j}$

(c) $\vec{E} = -qvB\hat{j}$

Solution:

(a) Magnetic Field $\vec{B}$

The magnetic field due to a long straight current-carrying wire is given by Ampère's law:

$$B = \frac{\mu_0 I}{2\pi d}$$

The right-hand rule states that the direction of $\vec{B}$ at a distance d above the wire is along the positive $\hat{k}$-direction (out of the plane). Thus,

$$\vec{B} = \frac{\mu_0 I}{2\pi d}\hat{k}$$

(b) Magnetic Force $\vec{F}_m$

The force on a charged particle moving in a magnetic field is given by:

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

Given that:

$\vec{v} = v\hat{i}$ (along the x-axis),

$\vec{B} = B\hat{k}$ (along the z-axis),

Using the cross product:

$$\vec{v} \times \vec{B} = (v\hat{i}) \times (B\hat{k})$$

Using the vector identity $\hat{i} \times \hat{k} = -\hat{j}$, we get:

$$\vec{F}_m = qvB(-\hat{j})$$

Thus,

$$\vec{F}_m = -qvB\hat{j}$$

(c) Electric Field $\vec{E}$ Since the charge moves undeviated, the net force on the particle must be zero. This means that the electric force $\vec{F}_e = q\vec{E}$ must cancel out the magnetic force:

$$q\vec{E} = -\vec{F}_m$$

Substituting $\vec{F}_m = -qvB\hat{j}$:

$$q\vec{E} = qvB\hat{j}$$

Dividing by q:

$$\vec{E} = vB\hat{j}$$

Thus, the required electric field is:

$$\vec{E} = vB\hat{j}$$

Quick Tip

To find the direction of the magnetic field around a current-carrying wire, use the right-hand rule: Point your thumb in the direction of the current, and your fingers curl in the direction of $\vec{B}$.

---

24. An ac source of voltage $v = v_m \sin \omega t$ is connected to a series combination of LCR circuit. Draw the phasor diagram. Using it, obtain an expression for the impedance of the circuit and the phase difference between applied voltage and the current.

Solution:

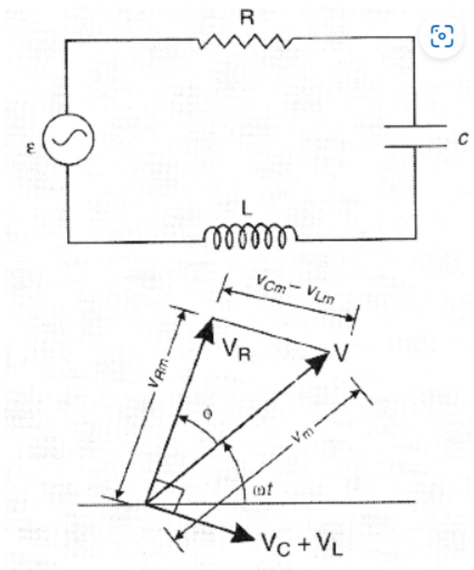
The impedance of the LCR circuit is given by:

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

where R is the resistance, L is the inductance, and C is the capacitance. The phase difference ϕ between the applied voltage and the current is given by:

$$\tan\phi = \frac{\omega L - \frac{1}{\omega C}}{R}$$

The current lags the voltage by the phase angle ϕ, which can be visualized in the phasor diagram.



Quick Tip

The phase difference between the voltage and current in an LCR circuit depends on the relative magnitudes of the inductive reactance (ωL) and capacitive reactance ($\frac{1}{\omega C}$).

---

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.

Solution:

In an AC circuit with a parallel plate capacitor, the conduction current I_c is the current through the resistor or conducting path, while the displacement current I_d arises due to the changing electric field between the plates of the capacitor. The displacement current is defined as:

$$I_d = \epsilon_0 A \frac{dE}{dt}$$

where A is the area of the plates, and $\frac{dE}{dt}$ is the rate of change of the electric field. In a steady AC circuit, the conduction current and the displacement current are equal, ensuring that the total current remains continuous at all points in the circuit.

Quick Tip

In AC circuits, displacement current is equal to the conduction current, which is why Kirchhoff's current law is still applicable in circuits with capacitors.

---

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

Solution:

Yes, Kirchhoff's first rule (junction rule) is valid at each plate of the capacitor. The junction rule states that the sum of currents entering a junction must equal the sum of currents leaving the junction. In the case of a capacitor, the conduction current and the displacement current contribute to the total current at the plates. The displacement current ensures the continuity of current in the capacitor, and thus Kirchhoff's current law remains valid even at the plates of the capacitor.

Quick Tip

Kirchhoff's current law is valid even in circuits with capacitors, as displacement current ensures the continuity of charge flow.

---

26. (a) Mention any three features of results of experiment on photoelectric effect which cannot be explained using the wave theory of light.

Solution:

The three features of the photoelectric effect that cannot be explained using the wave theory of light are:

1. The photoelectric effect occurs instantly when light of a frequency higher than the threshold frequency strikes the metal surface. The wave theory suggests a delay in the

emission of electrons.

2. The kinetic energy of the emitted electrons depends on the frequency of the incident light, not its intensity. Wave theory predicts that the energy should depend on the intensity of light.

3. The photoelectric effect cannot occur below a certain threshold frequency, regardless of the intensity of light. According to wave theory, there should be no threshold, and intensity should control the emission.

Quick Tip

Einstein's explanation of the photoelectric effect relies on the particle theory of light, where light is treated as quanta (photons).

---

26. (b) In his experiment on photoelectric effect, Robert A. Millikan found the slope of the cut-off voltage versus frequency of incident light plot to be 4.12×10^{-15} Vs. Calculate the value of Planck's constant from it.

Solution:

The relationship between the cut-off voltage V_{cut} and the frequency of light is given by:

$$eV_{\text{cut}} = hf - \phi$$

where:

e is the charge of the electron,

V_{cut} is the cut-off voltage,

h is Planck's constant,

f is the frequency of the incident light, and

ϕ is the work function of the metal.

The slope of the plot of V_{cut} versus frequency f is given by:

$$\text{Slope} = \frac{h}{e}$$

Given the slope is 4.12×10^{-15} Vs, we can calculate Planck's constant h using:

$$h = \text{Slope} \times e$$

Substituting the value of $e = 1.6 \times 10^{-19}$ C:

$$h = (4.12 \times 10^{-15}\,\text{Vs}) \times (1.6 \times 10^{-19}\,\text{C}) = 6.592 \times 10^{-34}\,\text{J}\cdot\text{s}$$

Quick Tip

The slope of the cut-off voltage versus frequency plot provides a direct way to calculate Planck's constant using the equation $eV_{\text{cut}} = hf - \phi$.

---

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

Solution:

The circuit arrangement for studying the V-I characteristics of a p-n junction diode consists of the following components:

1. A DC power supply to provide variable voltage.
2. A p-n junction diode connected in series with a resistor.
3. A voltmeter to measure the voltage across the diode.
4. An ammeter to measure the current flowing through the diode.

The power supply is adjusted to apply forward and reverse voltages to the diode, and the current is measured for different values of voltage to plot the V-I characteristics.

Quick Tip

In a typical V-I characteristic experiment, both forward and reverse biases are applied to observe how current behaves across the p-n junction.

---

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

Solution:

The V-I characteristics of a diode have the following shape:

1. In the forward bias region, when the applied voltage exceeds the threshold (typically 0.7 V for silicon), the current increases exponentially with increasing voltage.

2. In the reverse bias region, the current remains very small (ideally zero) until the reverse breakdown voltage is reached.

The graph shows an exponential rise in current in the forward bias region and an almost flat response in the reverse bias region (until breakdown).

Quick Tip

The diode's V-I characteristic curve demonstrates rectification: it allows current to flow easily in the forward direction and blocks it in the reverse direction.

---

27. (c) Mention two information that you can get from these characteristics.

Solution:

From the V-I characteristics of a diode, you can obtain the following information:

1. The threshold voltage (or cut-off voltage), which is the minimum voltage required for the diode to start conducting in the forward direction.

2. The reverse breakdown voltage, which is the voltage at which the diode begins to conduct in the reverse direction, potentially damaging the diode.

Quick Tip

The threshold voltage is a critical characteristic for understanding when a diode starts to conduct in the forward direction, while the reverse breakdown voltage helps assess the diode's durability under reverse bias.

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

Solution:

Mass Defect: Mass defect (Δm) is the difference between the total mass of the individual nucleons (protons and neutrons) in a nucleus and the actual measured mass of the nucleus. It is given by:

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

where:

Z is the number of protons,

$A - Z$ is the number of neutrons,

m_p and m_n are the masses of a proton and a neutron, respectively,

m_{nucleus} is the actual nuclear mass.

Binding Energy: Binding energy (E_b) is the energy required to break a nucleus into its constituent protons and neutrons. It is given by Einstein's mass-energy equivalence:

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

where: c is the speed of light (3.0×10^8 m/s),

Δm is the mass defect.

Fission Process and Binding Energy Per Nucleon: Nuclear fission occurs when a heavy nucleus splits into two or more lighter nuclei, releasing a significant amount of energy. This is explained using the concept of binding energy per nucleon:

$$\text{Binding Energy per Nucleon} = \frac{E_b}{A}$$

For heavy nuclei (e.g., Uranium-235), the binding energy per nucleon is lower than that of medium-sized nuclei.

When a heavy nucleus splits, the resulting smaller nuclei have higher binding energy per nucleon, meaning energy is released in the process.

This released energy is the basis of nuclear power and atomic bombs.

Quick Tip

The higher the binding energy per nucleon, the more stable the nucleus. The most stable nucleus in nature is Iron-56.

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.

Given:

$m_p = 1.007277$ **u,** $m_n = 1.008665$ **u,** 1 **u =** 931.5 **MeV/**c^2**.**

Correct Answer: Mass defect $\Delta m = 0.002389$ u

Binding energy $E_b = 2.224$ MeV

Solution:

Step 1: Calculate the Mass Defect Mass defect is given by:

$$\Delta m = (m_p + m_n) - m_{\text{deuteron}}$$

Substituting values:

$$\Delta m = (1.007277 + 1.008665) - 2.013553$$

$$\Delta m = 2.015942 - 2.013553$$

$$\Delta m = 0.002389 \text{ u}$$

Step 2: Calculate the Binding Energy Binding energy is given by:

$$E_b = \Delta m \times 931.5 \text{ MeV}$$

Substituting $\Delta m = 0.002389$ u:

$$E_b = 0.002389 \times 931.5$$

$$E_b \approx 2.224 \text{ MeV}$$

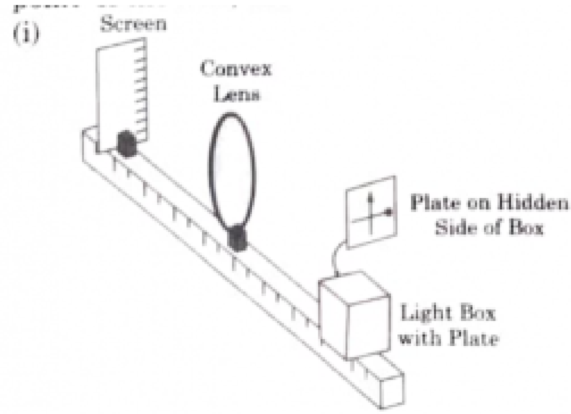
Thus, the mass defect is 0.002389 u, and the binding energy is 2.224 MeV.

Quick Tip

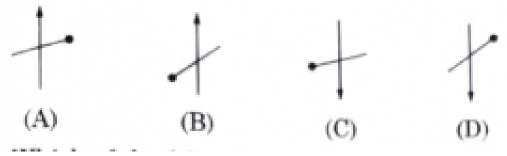
Mass defect arises due to the conversion of missing mass into energy, which holds the nucleus together. This is why nuclear reactions release enormous energy.

SECTION - D

29. (i) 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.



Consider the arrangement shown in figure. A black vertical arrow and a horizontal thick line with a ball are painted on a glass plate. It serves as the object. When the plate is illuminated, its real image is formed on the screen. Which of the following correctly represents the image formed on the screen?



Correct Answer: (B)

Solution:

The image formed by a thin lens can be obtained by applying the lens formula:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

where:

f is the focal length,

v is the image distance,

u is the object distance.

The lens has two focal points, one on each side of the lens, as the light converges or diverges depending on the type of lens (convex or concave).

Quick Tip

The lens formula is crucial for understanding the relationship between object distance, image distance, and focal length in lens systems.

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

Solution: For a concave lens, the magnification is always negative because the image formed by a concave lens is always virtual, erect, and diminished in size. Therefore, option (C) is incorrect. Other statements are true as they align with the behavior of mirrors and lenses.

Quick Tip

In mirrors and lenses, magnification sign conventions depend on whether the image is real or virtual, and whether it is upright or inverted.

---

29. (iii) A convex lens of focal length f is cut into two equal parts perpendicular 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: (C) $\frac{f}{2}$

Solution: When a convex lens is cut into two equal parts perpendicular to the principal axis, the focal length of each part is halved. The new focal length f' of each part is:

$$f' = \frac{f}{2}$$

This is because the lens curvature increases when it is cut in half, effectively reducing the focal length.

Quick Tip

Cutting a lens along its principal axis changes its curvature, and this reduces the focal length in this case by half.

OR

29(iii). If an object in case (i) above is 20 cm from the lens and the screen is 50 cm away from the object, the focal length of the lens used is:

(1) 10 cm

(2) 12 cm

(3) 16 cm

(4) 20 cm

Correct Answer: (2) 12 cm

Solution: We use the lens formula:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

where:

$u = -20$ cm (object distance, conventionally taken as negative),

$v = 50 - 20 = 30$ cm (image distance),

f is the focal length.

Substituting values:

$$\frac{1}{f} = \frac{1}{30} - \frac{1}{-20}$$

$$\frac{1}{f} = \frac{1}{30} + \frac{1}{20}$$

Taking LCM of 30 and 20:

$$\frac{1}{f} = \frac{2}{60} + \frac{3}{60} = \frac{5}{60}$$

$$f = \frac{60}{5} = 12 \text{ cm}$$

Thus, the focal length of the lens is 12 cm, so the correct answer is (2).

Quick Tip

In lens formula calculations, remember to use the sign conventions: object distance is negative for real objects in convex lenses.

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

(1) X_1X_2

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

(3) $\sqrt{X_1X_2}$

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

Correct Answer: (3) $\sqrt{X_1X_2}$

Solution: From the properties of a biconvex lens, the focal length f is given by the geometric mean of the distances X_1 and X_2:

$$f = \sqrt{X_1X_2}$$

This relation is derived from the lens formula and paraxial approximation when the object and image distances are measured from the focal points.

Thus, the correct answer is (3) $\sqrt{X_1X_2}$.

Quick Tip

The focal length of a biconvex lens can be estimated using the geometric mean of object and image distances when measured from their respective focal points.

---

30. A circuit consisting of a capacitor C, a resistor of resistance R and an ideal battery of emf V, as shown in figure is known as RC series circuit.

As soon as the circuit is completed by closing key S (keeping S open) charges begin to flow between the capacitor plates and the battery terminals. The charge on the capacitor increases and consequently the potential difference Vc (= 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

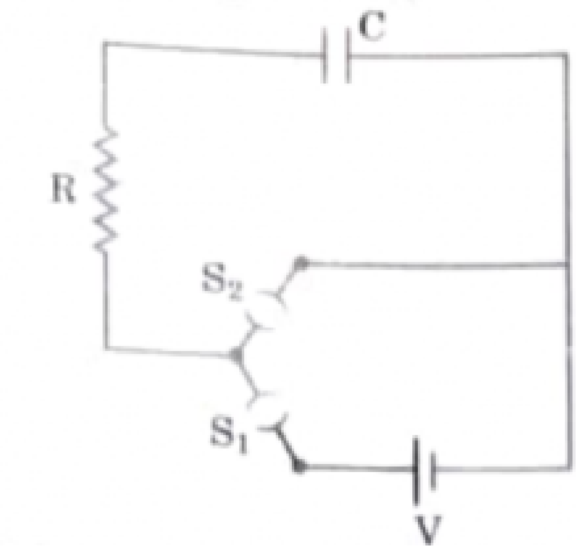
q = Q[1 - e$^{(}-t/RC)]$

The charging current can be obtained by differentiating it and using

d/dx (e$^{(}mx)) = me^{(}mx)$

Consider the case when R = 20 k, C = 500 F and V = 10 V.

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



(A) $5\,\mu C$

(B) $5\,mC$

(C) $25\,mC$

(D) $0.1\,C$

Correct Answer: (B) $5\,mC$

Solution: When key S_1 is closed and S_2 is open, the capacitor charges up fully and the final charge Q on the capacitor is given by:

$$Q = C \cdot V$$

where $C = 500\,\mu F = 500 \times 10^{-6}\,F$ and $V = 10\,V$. Therefore:

$$Q = 500 \times 10^{-6} \times 10 = 5\,mC$$

Quick Tip

The final charge on a capacitor is determined by the product of its capacitance and the voltage across it.

---

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) $5\,\mu C$

Correct Answer: (B) $5\,mC$

Solution: Once key S_1 is closed and S_2 is open, the capacitor is fully charged to the voltage $V = 10\,V$. When S_2 is closed, the charge on the capacitor remains the same, as it is disconnected from any other charge path. Hence, the final charge on the capacitor is $5\,mC$.

Quick Tip

In a fully charged capacitor, the charge remains the same unless connected to a discharge path or load.

---

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

Solution: The dimensional formula for RC can be derived as follows: - R (Resistance) has dimensions $[ML^2T^{-3}A^{-2}]$. - C (Capacitance) has dimensions $[M^{-1}L^{-2}T^4A^2]$.
Thus, the dimensional formula for RC is:

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

Quick Tip

Dimensional analysis helps in understanding the relationships between physical quantities, such as resistance and capacitance.

---

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

Solution: The current in the resistor during the charging process of the capacitor is given by:

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

After 5 seconds, the value of current will be:

$$I(5) = \frac{10}{20 \times 10^3}e^{-5/(RC)}$$

where $R = 20\,k\Omega$ and $C = 500\,\mu F$. Solving gives the final result of current after 5 seconds as $\frac{1}{\sqrt{e}}$ mA.

> **Quick Tip**
>
> During the charging of a capacitor, the current decays exponentially as the capacitor charges up.

OR

30. (iv) 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: The initial current when the capacitor begins charging is given by Ohm's Law:

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

where $V = 10\,V$ (battery voltage) and $R = 20\,k\Omega$. Therefore:

$$I(0) = \frac{10}{20 \times 10^3} = 0.5\,\text{mA}$$

Thus, the initial current is $0.5\,$mA.

Quick Tip

The initial current during the charging of a capacitor is determined by the battery voltage and the resistance in the circuit, calculated using Ohm's Law.

SECTION - E

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

Solution: Definition of Coherent Sources: Coherent sources are two or more sources of light that emit waves with a constant phase difference and the same frequency.

Importance for Interference:

For a sustained interference pattern:

The phase difference between the waves must remain constant over time.

If the sources are incoherent, the phase difference changes randomly, leading to the destruction of the interference pattern.

Thus, coherent sources are essential to produce stable and visible interference fringes.

Quick Tip

Laser light is an example of a coherent source, which is why it is commonly used in interference experiments.

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

Solution: Two independent sources of light are not coherent because:

They emit light waves independently, leading to random phase variations.

The atomic emissions of different sources are spontaneous and uncorrelated.

Even if they have the same frequency, their phase difference changes continuously.

As a result, two independent sources cannot produce sustained interference patterns.

Quick Tip

To obtain coherent sources, a single source is often split into two, such as in Young's double-slit experiment.

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?

Correct Answer: $y = 7.2$ mm

Solution: The fringe width in Young's double-slit experiment is given by:

$$y = \frac{\lambda D}{d}$$

where:

$\lambda = 600$ nm $= 600 \times 10^{-9}$ m (wavelength),

$D = 1.2$ m (distance to the screen),

$d = 0.1$ mm $= 1.0 \times 10^{-4}$ m (slit separation).

Substituting values:

$$y = \frac{(600 \times 10^{-9})(1.2)}{1.0 \times 10^{-4}}$$

$$y = \frac{7.2 \times 10^{-4}}{10^{-4}} = 7.2 \times 10^{-3} \text{ m} = 7.2 \text{ mm}$$

Thus, the fringe width is 7.2 mm.

Quick Tip

Fringe width increases with wavelength and distance to the screen but decreases with increasing slit separation.

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

Correct Answer: $\theta = 0.034°$

Solution: The angular width is given by:

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

Substituting values:

$$\theta = \frac{600 \times 10^{-9}}{1.0 \times 10^{-4}}$$

$$\theta = 6.0 \times 10^{-3} \text{ rad}$$

Converting to degrees:

$$\theta = 6.0 \times 10^{-3} \times \frac{180}{\pi}$$

$$\theta \approx 0.034^\circ$$

Thus, the angular width is 0.034°.

Quick Tip

Angular width is independent of the screen distance but depends on the wavelength and slit separation.

OR

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:

Definition of a Wavefront:

A wavefront is a surface of constant phase representing the positions of points in a wave that oscillate in unison.

Refraction through a Convex Lens:

A plane wavefront incident on a convex lens converges after refraction.

The refracted wavefront is spherical and converges towards the focal point of the lens.

Quick Tip

Wavefronts change shape according to Huygens' principle when passing through optical elements like lenses.

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: Using the lens-maker's formula for a spherical refracting surface:

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

where:

$n_1 = 1.0$ (air),

$n_2 = 1.5$ (glass),

$u = \infty$ (distant object),

$R = 15$ cm (radius of curvature),

v is the image distance.

Since $u = \infty$, the formula simplifies to:

$$\frac{1.5}{v} = \frac{0.5}{15}$$

$$v = \frac{1.5 \times 15}{0.5} = 45 \text{ cm}$$

Thus, the final image is formed at 45 cm inside the sphere.

Quick Tip

For refraction at a curved surface, use the lens-maker's equation, keeping sign conventions in mind.

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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** $\vec{E} = \frac{A}{r^2}\hat{r}$ **where** $A = 3 \times 10^5$ **V/m is switched on in the region. Calculate the change in electrostatic energy of the system due to the electric field.**

Solution:

The electrostatic potential energy U of a system of point charges is given by the formula:

$$U = \frac{1}{4\pi\epsilon_0} \sum_{i<j} \frac{q_i q_j}{r_{ij}}$$

where q_i and q_j are the point charges, and r_{ij} is the distance between them.
The change in energy due to the external electric field $\vec{E}$ is given by the work done by the electric field on the system, which is:

$$\Delta U = -\sum_i q_i \vec{E} \cdot \vec{r_i}$$

Here, the charges are placed at $(-3\,\text{cm}, 0, 0)$ and $(3\,\text{cm}, 0, 0)$, and the electric field $\vec{E} = \frac{A}{r^2}\hat{r}$ is acting on them.
The calculations will involve evaluating the work done on each charge and summing them up.

Quick Tip

When an external electric field is applied, the change in electrostatic energy can be calculated by finding the work done by the electric field on the system of charges.

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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.
(2) If the air between the capacitor is replaced by a dielectric medium of dielectric constant 3, what will be the potential difference between the two conductors?
(3) If the charges on two conductors are changed to $+160\,\mu C$ and $-160\,\mu C$, will the capacitance of the system change? Give reason for your answer.
Solution:
The capacitance C of the system can be calculated using the formula for capacitance:

$$C = \frac{Q}{V}$$

where:
$Q = 80\,\mu C = 80 \times 10^{-6}\,C$,
$V = 16\,\text{V}$.
Therefore, the capacitance is:

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

(ii) When the dielectric constant $k = 3$ is inserted, the capacitance increases by a factor of k.

The new capacitance C' becomes:

$$C' = kC = 3 \times 5\,\mu F = 15\,\mu F$$

Since $Q = C'V'$, and the charge Q remains the same, the new potential difference V' is:

$$V' = \frac{Q}{C'} = \frac{80 \times 10^{-6}}{15 \times 10^{-6}} = 5.33\,\text{V}$$

(iii) The capacitance of the system depends only on the geometry of the conductors and the dielectric constant of the medium between them, not the charges. Therefore, if the charges are doubled, the capacitance remains unchanged. The capacitance will still be $5\,\mu F$, because capacitance is independent of the charge.

Quick Tip

Capacitance depends on the geometry of the conductors and the dielectric material, not the amount of charge.

OR

32(b)(i). Consider three metal spherical shells A, B, and C, each of radius R. Each shell has 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 centers.

Solution: The electric field at a distance $3R$ from the center of a spherical shell depends only on the net charge enclosed and is given by Gauss's law:

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q_{\text{net}}}{r^2}$$

where Q_{net} is the total charge enclosed by each shell.

Step 1: Calculate Net Charge on Each Shell - For Shell A:

$$Q_A = 6q + (-2q) = 4q$$

- For Shell B:

$$Q_B = -4q + 8q = 4q$$

- For Shell C:

$$Q_C = 14q + (-10q) = 4q$$

Since the total charge enclosed for all three shells is the same ($4q$), the magnitude of the electric field at a distance $3R$ is identical for all:

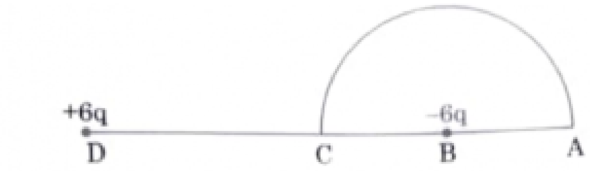
$$E_A = E_B = E_C = \frac{1}{4\pi\epsilon_0}\frac{4q}{(3R)^2}$$

Thus, the electric fields due to shells A, B, and C at a distance $3R$ are equal.

Quick Tip

According to Gauss's law, the electric field outside a spherical shell behaves as if all the charge were concentrated at its center.

32(b)(ii). A charge $-6\mu C$ is placed at the center 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.



Solution:

Work done in moving a charge in an electrostatic field depends only on the potential difference between the initial and final positions. The work done is given by:

$$W = q\Delta V$$

where: - W is the work done, - $q = 5\mu C = 5 \times 10^{-6} C$, - $\Delta V = V_A - V_C$ (potential difference between points A and C).

Since both C and A are on the same equipotential surface (same radial distance from the center B), their potential is the same:

$$V_A = V_C$$

Thus, the potential difference:

$$\Delta V = V_A - V_C = 0$$

$$W = (5 \times 10^{-6}) \times 0 = 0$$

Thus, no work is done on the charge.

Quick Tip

Work done in moving a charge along an equipotential surface is always zero because there is no change in electric potential.

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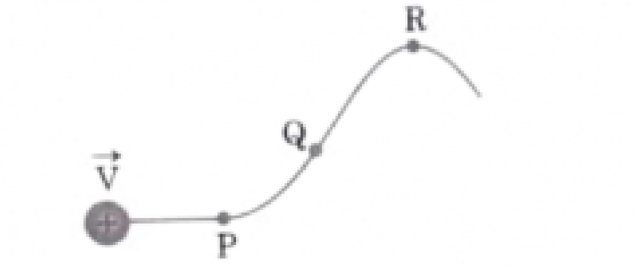
33. (a)(i) A proton moving with velocity V in a non-uniform magnetic field traces a path as shown in the figure. The path followed by the proton is always in the plane of the paper. What is the direction of the magnetic field in the region near points P, Q, and R? What can you say about relative magnitude of magnetic fields at these points?



Solution:

The direction of the magnetic field at points P, Q, and R can be determined using the right-hand rule for the motion of charged particles in a magnetic field. The proton experiences a force that is always perpendicular to both its velocity and the magnetic field.

At point P, the magnetic field is directed into the page.

At point Q, the magnetic field is directed out of the page.

At point R, the magnetic field is again directed into the page.

The relative magnitude of the magnetic fields increases as the proton moves from point P to point Q, and decreases again as it moves from Q to R.

Quick Tip

Use the right-hand rule to determine the direction of the magnetic field based on the direction of motion of a positively charged particle.

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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:

The magnetic moment μ of a current loop is defined as:

$$\mu = I \cdot A$$

where I is the current and A is the area of the loop. The magnetic field at the centre of the loop due to the current is given by:

$$B = \frac{\mu_0 I A}{2R^2}$$

where R is the radius of the loop. Using the relationship between current and magnetic moment, we can express the current I in terms of the magnetic moment:

$$I = \frac{\mu}{A}$$

Substituting this into the equation for B, we obtain the desired expression for the magnetic moment.

Quick Tip

The magnetic moment of a current loop is directly proportional to both the current and the area of the loop.

OR

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

Solution:

The torque τ on a current loop in a magnetic field is given by:

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

where:

μ is the magnetic moment of the loop,

B is the magnetic field strength,

θ is the angle between the magnetic moment and the magnetic field.

For a rectangular loop, the magnetic moment μ is:

$$\mu = I \cdot A$$

where I is the current and A is the area of the loop. The torque acts to rotate the loop until the magnetic moment aligns with the magnetic field.

Quick Tip

Torque on a current loop in a magnetic field is maximum when the angle between the magnetic moment and the field is 90 degrees.

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

Solution:

(1) The radius of the path will decrease. Since the kinetic energy is reduced by half, the velocity decreases. The radius of a charged particle's path in a magnetic field is given by:

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

Since the velocity v is halved, the radius will also be halved.

(2) The time period of revolution will remain unchanged. The time period of revolution T for a charged particle moving in a magnetic field is given by:

$$T = \frac{2\pi m}{qB}$$

Since the magnetic field B and the charge q are constant, the time period is independent of the kinetic energy, and hence remains the same.

Quick Tip

A reduction in kinetic energy affects the velocity and radius of a charged particle's circular path but does not change its time period of revolution.
