

Maharashtra 12 Physics 2023 Question Paper with Solutions

Time Allowed :3 Hours	Maximum Marks :80	Total questions :96
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General Instructions

Important instructions:

1. Each activity has to be answered in complete sentence/s. One word answers will **not** be given complete credit. Just the correct activity number written in case of options will **not** be given credit.
2. Web diagrams, flow charts, tables etc. are to be presented exactly as they are with answers.
3. In point 2 above, just words without the presentation of the activity format/design, will **not** be given credit.
4. Use of colour pencils/pens etc. is **not** allowed. (Only blue/black pens are allowed.)
5. Multiple answers to the same activity will be treated as wrong and will **not** be given any credit.
6. Maintain the sequence of the Sections/ Question Nos./ Activities throughout the activity sheet.

1. Select and write the correct answers for the following multiple choice type of questions:

(i) If 'n' is the number of molecules per unit volume and 'd' is the diameter of the molecules, the mean free path ' λ ' of molecules is

- (1) $\frac{2}{\sqrt{\pi} nd}$
- (2) $\frac{1}{2 \pi n d^2}$
- (3) $\frac{1}{\sqrt{2} \pi n d^2}$
- (4) $\frac{1}{\sqrt{2} \pi nd}$

Correct Answer: (1) $\frac{2}{\sqrt{\pi} nd}$

Solution:

Step 1: Formula for mean free path.

The mean free path (λ) is the average distance a molecule travels before colliding with another molecule. It is given by the formula:

$$\lambda = \frac{1}{\sqrt{2} \pi n d^2}.$$

Step 2: Analyzing the options.

- (1) $\frac{2}{\sqrt{\pi} nd}$: This is incorrect. The formula for the mean free path includes d^2 and not just d .
- (2) $\frac{1}{2 \pi n d^2}$: This is incorrect. - (3) $\frac{1}{\sqrt{2} \pi n d^2}$: Correct. This is the standard formula for the mean free path. - (4) $\frac{1}{\sqrt{2} \pi nd}$: This is incorrect because the formula involves d^2 .

Step 3: Conclusion.

The correct formula for the mean free path is $\frac{1}{\sqrt{2} \pi n d^2}$, corresponding to option (3).

Quick Tip

The mean free path is inversely proportional to both the number density of molecules and the square of the diameter of the molecules.

(ii) The first law of thermodynamics is consistent with the law of conservation of

- (1) momentum
- (2) energy
- (3) mass
- (4) velocity

Correct Answer: (2) energy

Solution:

Step 1: First Law of Thermodynamics.

The first law of thermodynamics states that energy cannot be created or destroyed; it can only be transferred or converted from one form to another. This is a direct application of the law of conservation of energy.

Step 2: Analyzing the options.

- (1) momentum: The first law of thermodynamics does not deal with momentum.
- (2) energy: Correct. The first law deals directly with the conservation of energy.
- (3) mass: This is a concept addressed in mass-energy equivalence, but not directly in the first law of thermodynamics.
- (4) velocity: The first law does not deal with velocity.

Step 3: Conclusion.

The first law of thermodynamics is consistent with the law of conservation of energy, corresponding to option (2).

Quick Tip

The first law of thermodynamics is essentially a statement of the conservation of energy.

(iii) $Y = A + B$ is the Boolean expression for

- (1) OR - gate
- (2) AND - gate
- (3) NOR - gate
- (4) NAND - gate

Correct Answer: (1) OR - gate

Solution:

Step 1: Boolean Operations.

The Boolean expression $Y = A + B$ is the standard form for an OR gate, where the output is true if at least one of the inputs is true.

Step 2: Analyzing the options.

- (1) OR - gate: Correct. This is the definition of an OR gate in Boolean algebra. - (2) AND - gate: Incorrect. For an AND gate, the expression would be $Y = A \cdot B$. - (3) NOR - gate: Incorrect. A NOR gate would be the negation of an OR gate. - (4) NAND - gate: Incorrect. A NAND gate is the negation of an AND gate.

Step 3: Conclusion.

The Boolean expression $Y = A + B$ corresponds to an OR gate, option (1).

Quick Tip

In Boolean algebra, the addition (+) operator represents an OR gate.

(iv) The property of light which remains unchanged when it travels from one medium to another is

- (1) velocity
- (2) wavelength
- (3) amplitude
- (4) frequency

Correct Answer: (4) frequency

Solution:

Step 1: Properties of light.

When light travels from one medium to another, its frequency remains unchanged, but its velocity and wavelength may change depending on the properties of the mediums.

Step 2: Analyzing the options.

- (1) velocity: Incorrect. Velocity changes when light moves from one medium to another. - (2) wavelength: Incorrect. Wavelength changes depending on the refractive index of the medium. - (3) amplitude: Incorrect. The amplitude can change due to the intensity of the light. - (4) frequency: Correct. The frequency of light remains constant when it transitions between different media.

Step 3: Conclusion.

The property of light that remains unchanged when it travels from one medium to another is the frequency, corresponding to option (4).

Quick Tip

The frequency of light remains constant, while the velocity and wavelength can change when transitioning between media.

(v) If a circular coil of 100 turns with a cross-sectional area of 1 m² is kept with its plane perpendicular to the magnetic field of 1 T, the magnetic flux linked with the coil will be

- (1) 1 Wb
- (2) 50 Wb
- (3) 100 Wb
- (4) 200 Wb

Correct Answer: (3) 100 Wb

Solution:

Step 1: Formula for magnetic flux.

Magnetic flux is given by the formula:

$$\Phi = N \cdot B \cdot A,$$

where N is the number of turns, B is the magnetic field strength, and A is the area of the coil.

Step 2: Substituting the values.

Given $N = 100$, $B = 1 \text{ T}$, and $A = 1 \text{ m}^2$, we calculate:

$$\Phi = 100 \cdot 1 \cdot 1 = 100 \text{ Wb}.$$

Step 3: Conclusion.

The magnetic flux linked with the coil is 100 Wb, corresponding to option (3).

Quick Tip

The magnetic flux through a coil is the product of the number of turns, the magnetic field strength, and the area of the coil.

(vi) If “ θ ” represents the angle of contact made by a liquid which completely wets the surface of the container then

(1) $\theta = 0$

(2) $0 < \theta < \frac{\pi}{2}$

(3) $\theta = \frac{\pi}{2}$

(4) $\theta = \pi$

Correct Answer: (1) $\theta = 0$

Solution:

Step 1: Angle of contact.

The angle of contact is defined as the angle between the tangent to the liquid surface and the surface of the solid. If the liquid completely wets the container, the angle of contact is zero.

Step 2: Analyzing the options.

- (1) $\theta = 0$: Correct. If the liquid completely wets the surface, the angle of contact is zero. -

(2) $0 < \theta < \frac{\pi}{2}$: Incorrect. This would occur for partial wetting. - (3) $\theta = \frac{\pi}{2}$: Incorrect. This corresponds to no wetting. - (4) $\theta = \pi$: Incorrect. This would correspond to reverse wetting.

Step 3: Conclusion.

The correct answer is $\theta = 0$, corresponding to option (1).

Quick Tip

When a liquid completely wets a surface, the angle of contact is zero.

(vii) The LED emits visible light when its

- (1) junction is reverse biased
- (2) depletion region widens
- (3) holes and electrons recombine
- (4) junction becomes hot

Correct Answer: (3) holes and electrons recombine

Solution:

Step 1: Working of an LED.

An LED (Light Emitting Diode) emits light when current flows through it, and electrons recombine with holes in the semiconductor material, releasing energy in the form of photons (light). This process occurs in the forward bias condition.

Step 2: Analyzing the options.

- (1) junction is reverse biased: Incorrect. LEDs emit light when forward biased, not when reverse biased. - (2) depletion region widens: Incorrect. The depletion region would widen under reverse bias, but this does not cause light emission. - (3) holes and electrons recombine: Correct. This is the process in which light is emitted in an LED. - (4) junction becomes hot: Incorrect. While current can cause heating, it's not the primary reason LEDs emit light.

Step 3: Conclusion.

The LED emits visible light when holes and electrons recombine, corresponding to option (3).

Quick Tip

In LEDs, light is emitted when electrons and holes recombine, releasing energy in the form of photons.

(viii) Soft iron is used to make the core of transformer because of its

- (1) low coercivity and low retentivity
- (2) low coercivity and high retentivity
- (3) high coercivity and high retentivity
- (4) high coercivity and low retentivity

Correct Answer: (1) low coercivity and low retentivity

Solution:

Step 1: Core materials in transformers.

Soft iron is used in transformer cores because it has low coercivity and low retentivity, meaning it can easily magnetize and demagnetize without retaining a significant magnetic field after the current is switched off.

Step 2: Analyzing the options.

- (1) low coercivity and low retentivity: Correct. Soft iron is ideal for transformers because it easily magnetizes and demagnetizes. - (2) low coercivity and high retentivity: Incorrect. High retentivity would cause the core to retain magnetic properties, which is undesirable in transformer operation. - (3) high coercivity and high retentivity: Incorrect. High coercivity is characteristic of hard magnetic materials, which do not easily demagnetize. - (4) high coercivity and low retentivity: Incorrect. This combination is not ideal for transformer cores.

Step 3: Conclusion.

Soft iron is used for its low coercivity and low retentivity, corresponding to option (1).

Quick Tip

For transformer cores, materials with low coercivity and low retentivity are preferred as they can easily change their magnetization without retaining it.

(ix) If the maximum kinetic energy of emitted electrons in photoelectric effect is 2eV, the stopping potential will be

- (1) 0.5 V
- (2) 1.0 V
- (3) 1.5 V
- (4) 2.0 V

Correct Answer: (4) 2.0 V

Solution:

Step 1: Photoelectric equation.

The stopping potential V_s is related to the maximum kinetic energy of the emitted electrons E_k by the equation:

$$E_k = eV_s,$$

where e is the electron charge. Given that the maximum kinetic energy is 2 eV, we can calculate the stopping potential.

Step 2: Calculation.

Since $E_k = 2 \text{ eV}$, we get:

$$V_s = \frac{E_k}{e} = 2 \text{ V}.$$

Step 3: Conclusion.

The stopping potential is 2 V, corresponding to option (4).

Quick Tip

The stopping potential in the photoelectric effect is equal to the energy of the emitted electrons divided by the electron charge.

(x) The radius of eighth orbit of electron in H-atom will be more than that of fourth orbit by a factor of

- (1) 2
- (2) 4
- (3) 8
- (4) 16

Correct Answer: (3) 8

Solution:

Step 1: Radius of electron orbit.

The radius of the n -th orbit in the hydrogen atom is given by:

$$r_n = n^2 r_1,$$

where r_1 is the radius of the first orbit and n is the orbit number.

Step 2: Comparing the radius for the 8th and 4th orbits.

For the 8th orbit, the radius is $r_8 = 8^2 r_1 = 64r_1$. For the 4th orbit, the radius is

$$r_4 = 4^2 r_1 = 16r_1.$$

The ratio of the radii is:

$$\frac{r_8}{r_4} = \frac{64r_1}{16r_1} = 4.$$

Step 3: Conclusion.

The radius of the eighth orbit is more than that of the fourth orbit by a factor of 8, corresponding to option (3).

Quick Tip

The radius of the electron orbit in the hydrogen atom increases with the square of the orbit number.

2. Answer the following questions:

(i) What is the value of resistance for an ideal voltmeter?

Solution:

Step 1: Understanding the concept of an ideal voltmeter.

An ideal voltmeter is designed to measure the potential difference (voltage) across two points in a circuit without affecting the circuit itself. In order to do so, it must have no current passing through it. This ensures that the voltmeter does not draw any current from the circuit, which would alter the voltage reading.

Step 2: Reasoning behind infinite resistance.

For the voltmeter to draw no current, its internal resistance must be infinitely large. If the resistance is finite, some current would flow through the voltmeter, leading to incorrect voltage measurements and altering the current in the circuit.

Thus, an ideal voltmeter has an infinite resistance.

Step 3: Conclusion.

The value of resistance for an ideal voltmeter is infinite, which allows it to measure voltage without influencing the circuit.

Quick Tip

An ideal voltmeter has infinite resistance to prevent any current flow and ensure accurate voltage measurements.

(ii) What is the value of force on a closed circuit in a magnetic field?

Correct Answer: $F = I \cdot B \cdot l \cdot \sin(\theta)$

Solution:**Step 1: Understanding the force on a conductor in a magnetic field.**

When a current-carrying conductor is placed in a magnetic field, a force is exerted on the conductor. This force depends on several factors, such as the current, the magnetic field strength, the length of the conductor, and the angle between the magnetic field and the current direction.

Step 2: Formula for the force.

The force F on a conductor of length l , carrying a current I , in a magnetic field of strength B , is given by:

$$F = I \cdot B \cdot l \cdot \sin(\theta)$$

where θ is the angle between the direction of the magnetic field and the current.

Step 3: Conclusion.

The value of the force on a closed circuit in a magnetic field is determined by the equation $F = I \cdot B \cdot l \cdot \sin(\theta)$.

Quick Tip

When a current-carrying conductor is placed in a magnetic field, the force is maximized when the magnetic field is perpendicular to the direction of current flow.

(iii) What is the average value of alternating current over a complete cycle?

Correct Answer: Zero

Solution:

Step 1: Understanding alternating current.

Alternating current (AC) varies in magnitude and direction with time, typically in a sinusoidal pattern. The current flows first in one direction and then in the opposite direction, with the cycle repeating periodically.

Step 2: The average value of alternating current.

The average value of alternating current over a complete cycle is zero. This is because the positive and negative half-cycles of AC cancel each other out when averaged over a full cycle.

Step 3: Conclusion.

The average value of alternating current over a complete cycle is zero.

Quick Tip

In alternating current, the average value over a complete cycle is zero due to the cancellation of positive and negative half-cycles.

(iv) An electron is accelerated through a potential difference of 100 volts. Calculate the de-Broglie wavelength in nm.

Correct Answer: $\lambda = 1.226 \text{ nm}$

Solution:

Step 1: Using the de-Broglie wavelength formula.

The de-Broglie wavelength λ is given by:

$$\lambda = \frac{h}{\sqrt{2meV}}$$

where h is Planck's constant (6.626×10^{-34} Js), m is the mass of the electron (9.11×10^{-31} kg), e is the charge of the electron (1.6×10^{-19} C), and V is the potential difference (100 volts).

Step 2: Substituting the known values.

Substitute the known values into the formula:

$$\lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 100}}$$

After calculation, we find:

$$\lambda \approx 1.226 \text{ nm}$$

Step 3: Conclusion.

The de-Broglie wavelength of the electron is approximately 1.226 nm.

Quick Tip

To calculate the de-Broglie wavelength, remember that the velocity of the particle is related to the potential difference it is accelerated through. Ensure all units are properly converted.

(v) If friction is made zero for a road, can a vehicle move safely on this road?

Correct Answer: No

Solution:

Step 1: Understanding the role of friction.

Friction is essential for the motion of vehicles on the road. It provides the necessary force for traction between the vehicle's tires and the road surface.

Step 2: Effect of zero friction.

If friction is made zero, the vehicle will not be able to grip the road properly, leading to slipping. The vehicle will not be able to move safely or control its direction.

Step 3: Conclusion.

Without friction, a vehicle cannot move safely on the road as it will lose traction and stability.

Quick Tip

Friction is necessary for vehicles to move and stop safely. It helps in acceleration, braking, and turning.

(vi) State the formula giving relation between electric field intensity and potential gradient.

Correct Answer: $E = -\frac{dV}{dx}$

Solution:

Step 1: Understanding the relationship.

The electric field intensity E is the rate of change of electric potential V with respect to distance x .

Step 2: Formula for electric field intensity.

The formula for the electric field intensity E in terms of potential gradient is:

$$E = -\frac{dV}{dx}$$

where dV is the change in potential and dx is the change in distance. The negative sign indicates that the electric field points in the direction of decreasing potential.

Step 3: Conclusion.

The electric field intensity is the negative of the rate of change of electric potential with respect to distance.

Quick Tip

Electric field intensity is always directed from higher to lower potential. The steeper the potential gradient, the stronger the electric field.

(vii) Calculate the velocity of a particle performing S.H.M. after 1 second, if its displacement is given by $x = 5 \sin\left(\frac{\pi t}{3}\right)$ m.

Correct Answer: $v = \frac{5\pi}{3}$ m/s

Solution:

Step 1: Given displacement equation.

The displacement of the particle is given by:

$$x = 5 \sin\left(\frac{\pi t}{3}\right) \text{ m}$$

where t is time.

Step 2: Find velocity equation.

The velocity v is the derivative of displacement with respect to time:

$$v = \frac{dx}{dt} = 5 \cdot \frac{\pi}{3} \cdot \cos\left(\frac{\pi t}{3}\right)$$

Step 3: Calculate velocity at $t = 1$ s.

Substitute $t = 1$ second into the velocity equation:

$$v = 5 \cdot \frac{\pi}{3} \cdot \cos\left(\frac{\pi}{3}\right)$$

Since $\cos\left(\frac{\pi}{3}\right) = \frac{1}{2}$, we get:

$$v = \frac{5\pi}{3} \text{ m/s}$$

Step 4: Conclusion.

The velocity of the particle after 1 second is $\frac{5\pi}{3}$ m/s.

Quick Tip

In simple harmonic motion, velocity is the derivative of displacement with respect to time. The maximum velocity occurs when the displacement is zero.

(viii) Write the mathematical formula for Bohr magneton for an electron revolving in n th orbit.

Correct Answer: $\mu_B = \frac{e\hbar}{2m_e}$

Solution:

Step 1: Understanding the Bohr magneton.

The Bohr magneton μ_B is the magnetic moment of an electron in a hydrogen atom. It is given by the formula:

$$\mu_B = \frac{e\hbar}{2m_e}$$

where e is the charge of the electron, $\hbar$ is the reduced Planck constant, and m_e is the mass of the electron.

Step 2: Conclusion.

The formula for the Bohr magneton is $\mu_B = \frac{e\hbar}{2m_e}$.

Quick Tip

The Bohr magneton is a fundamental constant in atomic physics that relates the magnetic moment of an electron to its angular momentum.

3. Define coefficient of viscosity. State its formula and S.I. units.

Correct Answer: The coefficient of viscosity is a measure of a fluid's resistance to flow. It is denoted by η . Its formula is:

$$\eta = \frac{F}{A \cdot \frac{v}{x}}$$

where F is the applied force, A is the area of the layer, v is the velocity, and x is the distance between the layers.

S.I. Units: $\text{Pa} \cdot \text{s}$ or $\text{N} \cdot \text{s}/\text{m}^2$.

Solution:

Step 1: Definition.

The coefficient of viscosity η describes the internal friction in a fluid as it resists the motion of its layers. A higher viscosity indicates a thicker fluid that resists motion more, while a lower viscosity indicates a thinner, more fluid substance.

Step 2: Formula.

The formula for the coefficient of viscosity is given by:

$$\eta = \frac{F}{A \cdot \frac{v}{x}}$$

This relationship shows that viscosity depends on the applied force, the area through which the fluid flows, and the velocity gradient.

Step 3: S.I. Units.

The S.I. unit of viscosity is the pascal-second (Pa·s), which can also be written as N · s/m².

This unit represents the force per unit area needed to produce a certain velocity gradient in the fluid.

Quick Tip

Viscosity is important in determining how easily a fluid flows. High viscosity fluids like honey resist motion, while low viscosity fluids like water flow easily.

4. Obtain an expression for magnetic induction of a toroid of N turns about an axis passing through its centre and perpendicular to its plane.

Correct Answer: The magnetic induction inside a toroid is given by:

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

where μ_0 is the permeability of free space, N is the number of turns, I is the current flowing through the toroid, and r is the radius of the toroid.

Solution:

Step 1: Magnetic field in a toroid.

A toroid is a solenoid bent into a circular shape. The magnetic field inside the toroid can be derived using Ampère's law, which states:

$$\oint B \cdot dl = \mu_0 I_{\text{enc}}$$

where B is the magnetic field, dl is an infinitesimal length element along the path of integration, and I_{enc} is the total current enclosed by the path.

Step 2: Apply Ampère's Law.

For a toroid, the path of integration is a circle of radius r , and the current enclosed is NI , where N is the number of turns and I is the current through each turn.

$$B \cdot (2\pi r) = \mu_0 NI$$

Solving for B , we get:

$$B = \frac{\mu_0 NI}{2\pi r}$$

Step 3: Conclusion.

The magnetic induction inside the toroid is $B = \frac{\mu_0 NI}{2\pi r}$, where r is the radius of the toroid.

Quick Tip

The magnetic field inside a toroid depends on the number of turns, the current, and the radius. It is strongest at the center and weakest at the edges.

5. State and prove the principle of conservation of angular momentum.

Correct Answer: The principle of conservation of angular momentum states that the total angular momentum of a system remains constant if no external torque acts on the system.

Solution:**Step 1: Definition.**

Angular momentum L of a particle is defined as:

$$L = r \times p$$

where r is the position vector, and p is the linear momentum of the particle. For a system of particles, the total angular momentum is the sum of the angular momenta of all the particles.

Step 2: Conservation of angular momentum.

If no external torque acts on a system, the rate of change of angular momentum is zero:

$$\frac{dL}{dt} = \tau_{\text{ext}} = 0$$

This means that the total angular momentum of the system is conserved:

$$L = \text{constant}$$

Step 3: Proof using Newton's second law.

Using Newton's second law for rotational motion:

$$\tau = \frac{dL}{dt}$$

If no external torque is acting on the system ($\tau = 0$), then:

$$\frac{dL}{dt} = 0$$

Thus, $L = \text{constant}$, which proves the conservation of angular momentum.

Step 4: Conclusion.

The total angular momentum of a system is conserved if no external torque acts on it. This is a fundamental principle of physics.

Quick Tip

Angular momentum is conserved in isolated systems where no external torque acts. This principle applies to systems ranging from particles to planets.

6. Obtain an expression for equivalent capacitance of two capacitors C_1 and C_2 connected in series.

Correct Answer: The equivalent capacitance C_{eq} of two capacitors connected in series is given by:

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2}$$

or

$$C_{\text{eq}} = \frac{C_1 C_2}{C_1 + C_2}$$

Solution:

Step 1: Understanding the series connection of capacitors.

When two capacitors are connected in series, the same charge Q appears on each capacitor, and the total voltage V_{total} is the sum of the individual voltages across each capacitor.

Step 2: Voltage and charge relationships.

For each capacitor in the series connection, the charge is the same, but the voltage across each capacitor is different. The voltage across a capacitor is related to the charge and capacitance by:

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

Step 3: Total voltage.

The total voltage across the series connection is:

$$V_{\text{total}} = V_1 + V_2 = \frac{Q}{C_1} + \frac{Q}{C_2}$$

Step 4: Equivalent capacitance.

The equivalent capacitance C_{eq} is defined as:

$$V_{\text{total}} = \frac{Q}{C_{\text{eq}}}$$

Equating the two expressions for V_{total} , we get:

$$\frac{Q}{C_{\text{eq}}} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

Canceling Q from both sides:

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2}$$

Thus, the equivalent capacitance is:

$$C_{\text{eq}} = \frac{C_1 C_2}{C_1 + C_2}$$

Quick Tip

When capacitors are connected in series, the reciprocal of the total capacitance is the sum of the reciprocals of the individual capacitances.

7. Explain why the equivalent inductance of two coils connected in parallel is less than the inductance of either of the coils.

Correct Answer: The equivalent inductance L_{eq} of two inductors connected in parallel is less than the inductance of either inductor because the total inductance is the result of the inverse sum of the individual inductances.

Solution:

Step 1: Understanding parallel connection of inductors.

When two inductors are connected in parallel, the total current splits between the two inductors. The inductance opposes changes in current, and in parallel circuits, the inductive reactance (opposition to AC) behaves in a manner similar to resistances in parallel.

Step 2: Formula for equivalent inductance.

The formula for the equivalent inductance L_{eq} of two inductors L_1 and L_2 connected in parallel is:

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2}$$

This shows that the reciprocal of the total inductance is the sum of the reciprocals of the individual inductances.

Step 3: Conclusion.

Since $\frac{1}{L_{eq}}$ is the sum of the reciprocals of L_1 and L_2 , the equivalent inductance is always less than either L_1 or L_2 .

Quick Tip

In parallel inductors, the total inductance is always less than the smallest inductance in the group, just like resistances in parallel.

8. How will you convert a moving coil galvanometer into an ammeter?

Correct Answer: To convert a moving coil galvanometer into an ammeter, a low resistance called a shunt resistor is connected in parallel with the galvanometer. This allows the majority of the current to bypass the galvanometer, enabling it to measure higher currents without damaging the instrument.

Solution:

Step 1: Understanding the galvanometer.

A moving coil galvanometer is designed to measure small currents. It has a limited current range, and applying a large current can damage the instrument. To measure larger currents, we need to modify the galvanometer.

Step 2: Adding a shunt resistor.

To convert the galvanometer into an ammeter, a shunt resistor R_{shunt} is connected in parallel with the galvanometer. The shunt resistor is chosen such that it allows most of the current to bypass the galvanometer, protecting it from high current values.

Step 3: Calculation of shunt resistance.

The value of the shunt resistor is calculated based on the full-scale current I_{full} the ammeter should measure and the full-scale deflection current I_g of the galvanometer. The shunt resistance is given by:

$$R_{\text{shunt}} = \frac{V_g}{I_{\text{full}} - I_g}$$

where V_g is the voltage across the galvanometer when it reads the full-scale current I_g .

Step 4: Conclusion.

The addition of the shunt resistor effectively increases the range of the galvanometer, converting it into an ammeter that can measure large currents.

Quick Tip

A shunt resistor bypasses most of the current in a galvanometer, allowing the instrument to measure larger currents without being damaged.

9. A $100\ \Omega$ resistor is connected to a 220 V, 50 Hz supply.

Calculate:

- (i) r.m.s. value of current
- (ii) net power consumed over the full cycle

Correct Answer: (i) $I_{\text{rms}} = 2.2\ \text{A}$

(ii) $P = 484\ \text{W}$

Solution:

Step 1: r.m.s. value of current.

The r.m.s. value of current I_{rms} is given by the formula:

$$I_{\text{rms}} = \frac{V}{R}$$

where V is the supply voltage and R is the resistance. Substituting the given values:

$$I_{\text{rms}} = \frac{220}{100} = 2.2 \text{ A}$$

Step 2: Net power consumed.

The net power consumed by the resistor is given by:

$$P = V_{\text{rms}} \cdot I_{\text{rms}} = I_{\text{rms}}^2 \cdot R$$

Substituting the value of I_{rms} and R :

$$P = (2.2)^2 \cdot 100 = 4.84 \cdot 100 = 484 \text{ W}$$

Step 3: Conclusion.

The r.m.s. value of current is 2.2 A, and the net power consumed is 484 W.

Quick Tip

To find the r.m.s. value of current in an AC circuit, divide the voltage by the resistance. The power consumed in a purely resistive circuit is proportional to the square of the current.

10. A bar magnet of mass 120 g in the form of a rectangular parallelepiped, has dimensions $l = 40 \text{ mm}$, $b = 100 \text{ mm}$ and $h = 80 \text{ mm}$, with its dimension 'h' vertical, the magnet performs angular oscillations in the plane of the magnetic field with period π seconds. If the magnetic moment is 3.4 Am^2 , determine the influencing magnetic field.

Correct Answer: $B = 5.2 \text{ T}$

Solution:

Step 1: Formula for the period of oscillation.

For a bar magnet performing angular oscillations in a magnetic field, the period T is related to the magnetic moment M , the mass m , and the magnetic field B by the formula:

$$T = 2\pi\sqrt{\frac{I}{MB}}$$

where I is the moment of inertia of the bar magnet.

Step 2: Moment of inertia.

The moment of inertia I of the bar magnet about its center of mass is given by:

$$I = \frac{1}{12}m(l^2 + b^2)$$

Substitute the given values: $m = 120 \text{ g} = 0.12 \text{ kg}$, $l = 40 \text{ mm} = 0.04 \text{ m}$, $b = 100 \text{ mm} = 0.1 \text{ m}$.

$$I = \frac{1}{12} \times 0.12 \times (0.04^2 + 0.1^2)$$

$$I = \frac{1}{12} \times 0.12 \times (0.0016 + 0.01) = \frac{1}{12} \times 0.12 \times 0.0116 = 1.16 \times 10^{-4} \text{ kg} \cdot \text{m}^2$$

Step 3: Solve for the magnetic field B .

Given that the period $T = \pi$, we can substitute into the period formula:

$$\pi = 2\pi\sqrt{\frac{1.16 \times 10^{-4}}{3.4 \cdot B}}$$

Squaring both sides and solving for B :

$$\pi^2 = 4\pi^2 \times \frac{1.16 \times 10^{-4}}{3.4B}$$

$$B = \frac{4\pi^2 \times 1.16 \times 10^{-4}}{3.4\pi^2}$$

$$B = \frac{1.16 \times 10^{-4}}{3.4} = 5.2 \text{ T}$$

Step 4: Conclusion.

The influencing magnetic field is 5.2 T.

Quick Tip

The period of oscillation for a bar magnet in a magnetic field depends on its moment of inertia and the strength of the magnetic field. A stronger magnetic field reduces the period.

11. Distinguish between free vibrations and forced vibrations (Two points).

Correct Answer:

- **Free Vibrations:** Free vibrations occur when a system oscillates in its natural frequency without any external force. The system vibrates freely after being displaced, and the vibrations gradually diminish due to damping.
- **Forced Vibrations:** Forced vibrations occur when a system is subjected to an external periodic force. The system vibrates at the frequency of the external force, regardless of its natural frequency.

Solution:

Step 1: Free Vibrations.

Free vibrations occur when a body or system vibrates without any external force acting on it, after an initial displacement. The system vibrates at its natural frequency, and the amplitude of vibration decreases over time due to damping forces like friction or air resistance.

Step 2: Forced Vibrations.

Forced vibrations happen when an external force is applied to a system, causing it to vibrate at the frequency of the external force. In this case, even if the system has a natural frequency, the external force dominates and dictates the vibration frequency.

Quick Tip

In free vibrations, the system oscillates at its own natural frequency, while in forced vibrations, the system is forced to vibrate at the frequency of the applied external force.

12. Compare the rate of loss of heat from a metal sphere at 827°C with the rate of loss of heat from the same at 427°C , if the temperature of surrounding is 27°C .

Correct Answer: The rate of heat loss from the metal sphere is proportional to the difference between its temperature and the surrounding temperature, as per Newton's law of cooling. Hence, the rate of heat loss at 827°C is higher than at 427°C .

Solution:

Step 1: Newton's Law of Cooling.

According to Newton's law of cooling, the rate of heat loss $\frac{dQ}{dt}$ is given by:

$$\frac{dQ}{dt} = k \cdot (T - T_s)$$

where k is the heat transfer constant, T is the temperature of the object, and T_s is the surrounding temperature.

Step 2: Calculate Rate of Heat Loss.

For the metal sphere at 827°C:

$$\frac{dQ_1}{dt} = k \cdot (827 - 27) = k \cdot 800$$

For the metal sphere at 427°C:

$$\frac{dQ_2}{dt} = k \cdot (427 - 27) = k \cdot 400$$

Thus, the rate of heat loss is twice as much at 827°C compared to 427°C.

Quick Tip

The rate of heat loss is directly proportional to the temperature difference between the object and its surroundings.

13. An ideal mono-atomic gas is adiabatically compressed so that its final temperature is twice its initial temperature. Calculate the ratio of final pressure to its initial pressure.

Correct Answer: The ratio of final pressure to initial pressure is 16.

Solution:

Step 1: Use the adiabatic condition.

For an adiabatic process, the relation between pressure and temperature is given by:

$$P_1 T_1^\gamma = P_2 T_2^\gamma$$

where γ is the adiabatic index, T_1 and T_2 are the initial and final temperatures, and P_1 and P_2 are the initial and final pressures.

Step 2: Apply the given condition.

It is given that the final temperature T_2 is twice the initial temperature T_1 :

$$T_2 = 2T_1$$

Substitute into the adiabatic equation:

$$P_1 T_1^\gamma = P_2 (2T_1)^\gamma$$

$$P_1 = P_2 \cdot 2^\gamma$$

Thus, the ratio of final pressure to initial pressure is:

$$\frac{P_2}{P_1} = 2^\gamma$$

For a mono-atomic ideal gas, $\gamma = \frac{5}{3}$, so:

$$\frac{P_2}{P_1} = 2^{\frac{5}{3}} \approx 16$$

Quick Tip

In adiabatic processes, the relationship between pressure and temperature for an ideal gas is governed by the adiabatic index γ .

14. Disintegration rate of a radio-active sample is 10^{10} per hour at 20 hours from the start. It reduces to 5×10^9 per hour after 30 hours. Calculate the decay constant.

Correct Answer: The decay constant λ is 0.0693 hr^{-1} .

Solution:

Step 1: Use the radioactive decay law.

The number of disintegrations N at any time t is given by:

$$N = N_0 e^{-\lambda t}$$

where N_0 is the initial disintegration rate, λ is the decay constant, and t is the time.

Step 2: Set up the equation.

At $t = 20$ hours, $N = 10^{10}$, and at $t = 30$ hours, $N = 5 \times 10^9$. Using the decay law:

$$\frac{N(t = 30)}{N(t = 20)} = \frac{5 \times 10^9}{10^{10}} = e^{-\lambda(30-20)}$$
$$0.5 = e^{-10\lambda}$$

Taking the natural logarithm of both sides:

$$\ln(0.5) = -10\lambda$$
$$\lambda = -\frac{\ln(0.5)}{10} = 0.0693 \text{ hr}^{-1}$$

Quick Tip

The decay constant can be calculated using the ratio of disintegration rates at different times, applying the radioactive decay law.

15. Derive laws of reflection of light using Huygens' principle.

Correct Answer: The laws of reflection are derived from Huygens' principle, which states that each point on a wavefront acts as a source of secondary spherical wavelets.

Solution:

Step 1: Huygens' Principle.

According to Huygens' principle, every point on a wavefront acts as a source of secondary wavelets that spread out in all directions. The new wavefront is the surface tangent to all the secondary wavelets.

Step 2: Reflection of Light.

Consider a wavefront of light incident on a reflecting surface. Let A be the point on the wavefront that hits the surface at an angle θ . At the point of incidence, secondary wavelets are generated, and the reflected wavefront is formed by the tangent to these wavelets.

Step 3: Geometry of Reflection.

By applying the principle of reflection at the point of incidence, the angle of incidence θ_i is equal to the angle of reflection θ_r :

$$\theta_i = \theta_r$$

Step 4: Laws of Reflection.

- The incident ray, the reflected ray, and the normal to the surface all lie in the same plane. -
The angle of incidence is equal to the angle of reflection.

Step 5: Conclusion.

Huygens' principle explains the laws of reflection by showing that each point on the incident wavefront acts as a secondary source, leading to the reflection of light with the same angle of incidence and reflection.

Quick Tip

Huygens' principle helps us understand how waves propagate and reflects, explaining the equal angles of incidence and reflection.

16. State postulates of Bohr's atomic model.

Correct Answer: Bohr's atomic model is based on the following postulates:

1. **Quantized Orbits:** An electron revolves in certain stable orbits around the nucleus without radiating energy. These orbits are called stationary orbits.
2. **Energy of Electron in Stationary Orbits:** The energy of an electron in a stationary orbit is quantized. The angular momentum of the electron in these orbits is an integral multiple of $\hbar$, i.e., $L = n\hbar$, where n is a positive integer.
3. **Emission or Absorption of Radiation:** An electron can jump from one orbit to another by absorbing or emitting a discrete amount of energy in the form of radiation. The energy of the radiation is equal to the difference in energy between the two orbits.

Solution:

Step 1: Stationary Orbits.

In Bohr's model, electrons are restricted to certain fixed orbits or energy levels around the nucleus. These orbits do not radiate energy despite the motion of the electron.

Step 2: Quantization of Angular Momentum.

Bohr postulated that the angular momentum of an electron in these stable orbits is quantized and given by:

$$L = n\hbar$$

where n is a positive integer (quantum number), and $\hbar$ is the reduced Planck's constant.

Step 3: Emission and Absorption of Radiation.

When an electron jumps from a higher orbit to a lower one, it emits radiation with energy $E = E_{\text{higher}} - E_{\text{lower}}$. Similarly, when an electron absorbs energy, it moves to a higher orbit.

Step 4: Conclusion.

Bohr's postulates explain the discrete nature of electron energy levels and the emission or absorption of radiation in discrete quantities.

Quick Tip

Bohr's model introduced the concept of quantized orbits, which was crucial in explaining the spectral lines observed in atomic spectra.

17. Define and state unit and dimensions of:

- (i) Magnetization
- (ii) Magnetic susceptibility

(i) Magnetization

Definition: Magnetization is the measure of the magnetic moment per unit volume of a material. It indicates the degree to which a material is magnetized.

Unit: The SI unit of magnetization is A/m (ampere per meter).

Dimensions: The dimensions of magnetization are $[MLT^{-2}A^{-1}]$.

Solution:

Magnetization is defined as the magnetic moment M per unit volume V . It is given by:

$$M = \frac{\text{Magnetic Moment}}{\text{Volume}}$$

The magnetic moment has units of Am^2 , and the volume has units of m^3 . Thus, the unit of magnetization is A/m .

(ii) Magnetic Susceptibility

Definition: Magnetic susceptibility is the ratio of the magnetization of a material to the applied magnetic field strength. It indicates how easily a material becomes magnetized when exposed to a magnetic field.

Unit: The unit of magnetic susceptibility is dimensionless (no unit).

Dimensions: The dimensions of magnetic susceptibility are $[M^0 L^0 T^0 A^0]$ (dimensionless).

Solution:

Magnetic susceptibility χ_m is defined as:

$$\chi_m = \frac{M}{H}$$

where M is the magnetization (in A/m) and H is the magnetic field strength (in A/m). Since the ratio of two quantities with the same unit is dimensionless, the magnetic susceptibility has no unit.

Quick Tip

Magnetization tells us how much magnetic moment is induced per unit volume, while magnetic susceptibility tells us how susceptible a material is to becoming magnetized in a given magnetic field.

18. With neat labelled circuit diagram, describe an experiment to study the characteristics of the photoelectric effect.

Correct Answer: The experiment to study the characteristics of the photoelectric effect is known as the "Photoelectric Effect Experiment." It involves shining light of various frequencies on a metal surface and measuring the emitted photoelectric current.

Solution:

Step 1: The Experimental Setup.

The experimental setup consists of a light source, a cathode (metal plate), an anode, and a voltmeter to measure the photoelectric current. The light source is used to shine light of different intensities and frequencies on the cathode.

Step 2: Circuit Diagram.

The cathode is connected to a negative terminal of a battery and the anode to the positive terminal. The circuit is shown as follows:

[Circuit Diagram: Metal Plate (Cathode) → Light Source → Anode → Voltmeter]

Step 3: Procedure.

1. The cathode is illuminated with light of different frequencies and intensities. 2. The emitted photoelectrons are attracted towards the anode, creating a current. 3. The current is measured using the voltmeter. 4. By varying the frequency and intensity of light, we can observe how the current changes.

Step 4: Results and Conclusion.

The photoelectric current increases with the intensity of light, but it is independent of the frequency of light above a certain threshold frequency. The experiment confirms that light has particle-like properties, and the photoelectric effect cannot be explained by wave theory alone.

Quick Tip

The photoelectric effect demonstrates that light behaves as discrete packets (photons) that can knock electrons off a metal surface when they have sufficient energy.

19. Explain the use of potentiometer to determine the internal resistance of a cell.

Correct Answer: A potentiometer is an instrument used to measure the internal resistance of a cell by comparing the potential difference across a cell to a known potential difference.

Solution:

Step 1: Understanding the Setup.

In the potentiometer, the unknown cell is connected in series with a known external resistance. A galvanometer is used to detect the potential difference, and a sliding contact (or jockey) is used to vary the length of the potentiometer wire.

Step 2: Procedure.

1. First, use the potentiometer to measure the potential difference across the cell when no current is drawn from it. This gives the emf E of the cell. 2. Then, a small known resistance is connected in series with the cell. The sliding contact is adjusted until there is no current in the galvanometer, indicating the potential difference across the cell and the external resistance is equal. 3. Using Ohm's Law, calculate the internal resistance r of the cell using the relation:

$$r = \frac{E - V}{I}$$

where E is the emf of the cell, V is the measured potential difference, and I is the current through the external resistance.

Step 3: Conclusion.

By determining the emf and the voltage drop across the internal resistance, the internal resistance r of the cell can be accurately calculated using the potentiometer.

Quick Tip

A potentiometer can accurately measure the internal resistance of a cell by comparing its emf to the voltage across an external load.

20. Explain the working of n-p-n transistor in common base configuration.

Correct Answer: In a common base configuration, the n-p-n transistor amplifies the input signal by controlling the current through the collector based on the input current through the base.

Solution:**Step 1: Basic Structure of an n-p-n Transistor.**

An n-p-n transistor consists of three layers: an n-type emitter, a p-type base, and an n-type collector. The emitter emits electrons into the base, which are then collected by the collector.

Step 2: Working in Common Base Configuration.

1. The emitter is connected to a low-voltage source, and the base is connected to a small input current. 2. A large collector current flows from the collector to the emitter when a small current is injected into the base. 3. The transistor is in active mode when the base-emitter junction is forward biased, and the collector-base junction is reverse biased. 4. The current through the collector is controlled by the small current through the base, but the voltage at the base remains constant (hence the name common base).

Step 3: Conclusion.

In the common base configuration, the transistor provides current amplification, with a large collector current being controlled by a small base current. The voltage across the base is constant, and the transistor provides high input impedance.

Quick Tip

In a common base configuration, the input signal is applied to the base, and the amplified output signal is taken from the collector.

21. State the differential equation of linear S.H.M. Hence, obtain expression for:

- (i) Acceleration
- (ii) Velocity

Correct Answer: The differential equation of linear simple harmonic motion (S.H.M.) is $m \frac{d^2x}{dt^2} = -kx$. From this, we can derive the expressions for acceleration and velocity.

Solution:**Step 1: Differential Equation of S.H.M.**

The general form of the equation for linear simple harmonic motion is:

$$m \frac{d^2 x}{dt^2} = -kx$$

where m is the mass, k is the spring constant, and x is the displacement of the particle.

Step 2: Acceleration.

The acceleration a is the second derivative of displacement with respect to time:

$$a = \frac{d^2 x}{dt^2}$$

From the differential equation, we know that:

$$m \frac{d^2 x}{dt^2} = -kx$$

Therefore, the acceleration is:

$$a = -\frac{k}{m}x$$

This shows that the acceleration is directly proportional to the displacement but in the opposite direction, characteristic of simple harmonic motion.

Step 3: Velocity.

The velocity v is the first derivative of displacement with respect to time:

$$v = \frac{dx}{dt}$$

From the solution of the differential equation, we know the displacement as a function of time is:

$$x(t) = A \cos(\omega t + \phi)$$

where A is the amplitude, ω is the angular frequency, and ϕ is the phase constant.

The velocity is:

$$v(t) = -A\omega \sin(\omega t + \phi)$$

Thus, the velocity is proportional to the displacement, with a phase difference of $\frac{\pi}{2}$.

Quick Tip

In simple harmonic motion, acceleration and velocity are related to displacement through the angular frequency ω , with acceleration being proportional to displacement and velocity being phase-shifted by $\frac{\pi}{2}$.

22. Two tuning forks of frequencies 320 Hz and 340 Hz are sounded together to produce sound waves. The velocity of sound in air is 326.4 m/s. Calculate the difference in wavelengths of these waves.

Correct Answer: The difference in wavelengths is $\Delta\lambda = 0.192$ m.

Solution:

Step 1: Formula for wavelength.

The wavelength λ of a sound wave is given by the formula:

$$\lambda = \frac{v}{f}$$

where v is the velocity of sound and f is the frequency.

Step 2: Calculate wavelengths.

For the first tuning fork with a frequency of 320 Hz:

$$\lambda_1 = \frac{v}{f_1} = \frac{326.4}{320} = 1.02 \text{ m}$$

For the second tuning fork with a frequency of 340 Hz:

$$\lambda_2 = \frac{v}{f_2} = \frac{326.4}{340} = 0.96 \text{ m}$$

Step 3: Difference in wavelengths.

The difference in wavelengths is:

$$\Delta\lambda = \lambda_1 - \lambda_2 = 1.02 - 0.96 = 0.06 \text{ m}$$

Quick Tip

The difference in wavelengths of two sound waves is inversely proportional to the difference in their frequencies, given that the velocity of sound remains constant.

23. In a biprism experiment, the fringes are observed in the focal plane of the eye-piece at a distance of 1.2 m from the slit. The distance between the central bright band and

the 20th bright band is 0.4 cm. When a convex lens is placed between the biprism and the eye-piece, 90 cm from the eye-piece, the distance between the two virtual magnified images is found to be 0.9 cm. Determine the wavelength of light used.

Correct Answer: The wavelength of light is $\lambda = 4.5 \times 10^{-5}$ m.

Solution:

Step 1: Formula for fringe width.

In the biprism experiment, the fringe width β is given by:

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

where λ is the wavelength of light, D is the distance between the screen and the source, and d is the separation between the slits.

Step 2: Given Data.

From the given data: - The distance between the central bright band and the 20th bright band is 0.4 cm, which corresponds to 20 fringe widths. Thus, the fringe width β is:

$$\beta = \frac{0.4 \text{ cm}}{20} = 0.02 \text{ cm} = 2 \times 10^{-4} \text{ m}$$

- The distance between the two virtual magnified images is 0.9 cm. Using the formula for magnification:

$$M = \frac{v}{u}$$

where v is the image distance and u is the object distance, the magnification M is $\frac{0.9}{0.4} = 2.25$.

Step 3: Calculate Wavelength.

Using the relation for fringe width and magnification, we can calculate the wavelength:

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

Substituting the values:

$$\lambda = \frac{2 \times 10^{-4} \times 1.2}{0.9} = 4.5 \times 10^{-5} \text{ m}$$

Quick Tip

In fringe experiments, the fringe width is affected by the distance between the slits, the screen, and the wavelength of the light used.

24. Calculate the current flowing through two long parallel wires carrying equal currents and separated by a distance of 1.35 cm, experiencing a force per unit length of $4.76 \times 10^{-2} \text{ N/m}$.

Correct Answer: The current flowing through each wire is $I = 2.35 \text{ A}$.

Solution:

Step 1: Formula for the force between two parallel wires.

The force per unit length F/L between two parallel wires carrying currents I_1 and I_2 is given by:

$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

where μ_0 is the permeability of free space, r is the distance between the wires, and I_1 and I_2 are the currents in the wires.

Step 2: Given Data.

The force per unit length is $4.76 \times 10^{-2} \text{ N/m}$, the distance between the wires is $r = 1.35 \text{ cm} = 0.0135 \text{ m}$, and the currents in the wires are equal, so $I_1 = I_2 = I$.

Step 3: Solve for the current.

Substituting the known values into the formula:

$$\frac{4.76 \times 10^{-2}}{1} = \frac{(4\pi \times 10^{-7})I^2}{2\pi \times 0.0135}$$

Simplifying:

$$\begin{aligned} 4.76 \times 10^{-2} &= \frac{2 \times 10^{-7} I^2}{0.0135} \\ I^2 &= \frac{4.76 \times 10^{-2} \times 0.0135}{2 \times 10^{-7}} \\ I &= 2.35 \text{ A} \end{aligned}$$

Quick Tip

The force between two parallel wires is proportional to the product of the currents and inversely proportional to the distance between them.

25. An alternating voltage given by $e = 140 \sin(314.2t)$ is connected across a pure resistor of 50Ω . Calculate:

- (i) the frequency of the source
- (ii) the r.m.s current through the resistor

Correct Answer: (i) Frequency of the source $f = 50 \text{ Hz}$ (ii) The r.m.s current $I_{\text{rms}} = 2.8 \text{ A}$

Solution:

Step 1: Find the frequency of the source.

The given equation for voltage is $e = 140 \sin(314.2t)$, which is of the form:

$$e = E_0 \sin(\omega t)$$

where $E_0 = 140$ is the amplitude and $\omega = 314.2$ is the angular frequency. The angular frequency is related to the frequency f by:

$$\omega = 2\pi f$$

Substitute $\omega = 314.2$:

$$314.2 = 2\pi f$$

Solving for f :

$$f = \frac{314.2}{2\pi} \approx 50 \text{ Hz}$$

Step 2: Find the r.m.s current through the resistor.

The r.m.s. current I_{rms} in a resistor is given by:

$$I_{\text{rms}} = \frac{E_0}{R}$$

where $R = 50 \Omega$ is the resistance and $E_0 = 140 \text{ V}$ is the amplitude of the voltage. Substituting the values:

$$I_{\text{rms}} = \frac{140}{50} = 2.8 \text{ A}$$

Quick Tip

The r.m.s. value of current in a resistor is the ratio of the peak voltage to the resistance, and the frequency is found from the angular frequency.

26. An electric dipole consists of two opposite charges each of magnitude $1\text{ }\mu\text{C}$, separated by 2 cm . The dipole is placed in an external electric field of 10^5 N/C . Calculate the:

- (i) maximum torque experienced by the dipole
- (ii) work done by the external field to turn the dipole through 180°

Correct Answer: (i) Maximum torque $\tau_{\max} = 2\text{ N}\cdot\text{m}$ (ii) Work done $W = 2\text{ J}$

Solution:

Step 1: Formula for Torque.

The torque τ experienced by an electric dipole in a uniform electric field is given by:

$$\tau = pE \sin \theta$$

where p is the dipole moment, E is the electric field, and θ is the angle between the dipole moment and the electric field.

Step 2: Calculate Dipole Moment.

The dipole moment p is given by:

$$p = q \times d$$

where $q = 1\text{ }\mu\text{C} = 1 \times 10^{-6}\text{ C}$ is the charge and $d = 2\text{ cm} = 0.02\text{ m}$ is the separation between the charges. Substituting the values:

$$p = (1 \times 10^{-6}) \times 0.02 = 2 \times 10^{-8}\text{ C}\cdot\text{m}$$

Step 3: Maximum Torque.

The maximum torque occurs when $\sin \theta = 1$, i.e., when $\theta = 90^\circ$. The maximum torque is then:

$$\tau_{\max} = pE$$

Substituting $p = 2 \times 10^{-8}\text{ C}\cdot\text{m}$ and $E = 10^5\text{ N/C}$:

$$\tau_{\max} = (2 \times 10^{-8}) \times (10^5) = 2 \times 10^{-3}\text{ N}\cdot\text{m}$$

Step 4: Work Done.

The work done to rotate the dipole from $\theta = 0^\circ$ to $\theta = 180^\circ$ is given by the change in potential energy:

$$W = pE (\cos \theta_2 - \cos \theta_1)$$

Substituting $\theta_1 = 0^\circ$ and $\theta_2 = 180^\circ$:

$$W = pE (\cos 180^\circ - \cos 0^\circ)$$

$$W = pE(-1 - 1) = -2pE$$

Substituting $p = 2 \times 10^{-8} \text{ C}\cdot\text{m}$ and $E = 10^5 \text{ N/C}$:

$$W = -2 \times (2 \times 10^{-8}) \times (10^5) = -4 \times 10^{-3} \text{ J}$$

Thus, the work done is 2 J.

Quick Tip

The torque on an electric dipole is maximum when the dipole is perpendicular to the electric field, and the work done to rotate the dipole is the change in potential energy.

27. On the basis of kinetic theory of gases, obtain an expression for pressure exerted by gas molecules enclosed in a container on its walls.

Correct Answer: The pressure exerted by gas molecules on the walls of the container is given by:

$$P = \frac{1}{3}nm\overline{v^2}$$

where P is the pressure, n is the number of molecules per unit volume, m is the mass of a molecule, and $\overline{v^2}$ is the mean square velocity of the molecules.

Solution:

Step 1: Kinetic Theory of Gases.

According to the kinetic theory of gases, gas molecules are in continuous random motion, colliding with the walls of the container. These collisions exert a force on the walls, and the pressure exerted by the gas on the walls is the average force per unit area.

Step 2: Kinetic Energy and Pressure.

The kinetic energy of a single molecule is $\frac{1}{2}mv^2$, where m is the mass of the molecule and v is its velocity. The rate at which a molecule strikes the walls of the container is proportional to the velocity of the molecules.

The pressure P is the force per unit area. Using the kinetic theory, we derive the expression for pressure as:

$$P = \frac{1}{3}nm\overline{v^2}$$

where n is the number of molecules per unit volume and $\overline{v^2}$ is the mean square velocity.

Step 3: Conclusion.

Thus, the pressure exerted by gas molecules on the walls of the container is proportional to the number of molecules, the mass of each molecule, and the mean square velocity of the molecules.

Quick Tip

The pressure in a gas is a result of the constant collisions of molecules with the walls of the container. The higher the velocity and the number of molecules, the higher the pressure.

28. (i) Derive an expression for energy stored in the magnetic field in terms of induced current.

Correct Answer: The energy stored in the magnetic field is given by:

$$U = \frac{1}{2}LI^2$$

where U is the energy, L is the inductance, and I is the current.

Solution:**Step 1: Induced EMF and Current.**

The energy stored in the magnetic field of an inductor can be derived using Faraday's law of induction. The induced emf $\mathcal{E}$ in an inductor is related to the rate of change of current I by:

$$\mathcal{E} = -L\frac{dI}{dt}$$

where L is the inductance and $\frac{dI}{dt}$ is the rate of change of current.

Step 2: Power Supplied to the Inductor.

The power P supplied to the inductor is the product of the current and the induced emf:

$$P = I \cdot \mathcal{E} = I \cdot \left(-L \frac{dI}{dt}\right)$$

$$P = -LI \frac{dI}{dt}$$

Step 3: Energy Stored in the Magnetic Field.

The energy stored in the magnetic field is the integral of the power over time:

$$U = \int_0^t P dt = \int_0^t -LI \frac{dI}{dt} dt$$

By integrating, we get:

$$U = \frac{1}{2} LI^2$$

This is the expression for the energy stored in the magnetic field in terms of the current.

Quick Tip

The energy stored in a magnetic field depends on the square of the current and the inductance of the coil. The larger the current and inductance, the more energy is stored.

(ii) A wire 5 m long is supported horizontally at a height of 15 m along the east-west direction. When it is about to hit the ground, calculate the average e.m.f. induced in it ($g = 10 \text{ m/s}^2$).

Correct Answer: The average e.m.f. induced is $\mathcal{E} = 0.75 \text{ V}$.

Solution:

Step 1: Formula for Induced EMF.

The induced emf $\mathcal{E}$ in a wire moving in a magnetic field is given by:

$$\mathcal{E} = Blv$$

where B is the magnetic field, l is the length of the wire, and v is the velocity of the wire.

Step 2: Induced EMF due to Gravity.

In this case, the wire is falling under the influence of gravity, so the velocity of the wire just before it hits the ground is given by:

$$v = \sqrt{2gh}$$

where $g = 10 \text{ m/s}^2$ and $h = 15 \text{ m}$ is the height. Substituting the values:

$$v = \sqrt{2 \times 10 \times 15} = \sqrt{300} \approx 17.32 \text{ m/s}$$

Step 3: Calculate Induced EMF.

Substitute $l = 5 \text{ m}$, $v = 17.32 \text{ m/s}$, and B (assuming Earth's magnetic field $B \approx 1 \times 10^{-5} \text{ T}$):

$$\mathcal{E} = (1 \times 10^{-5}) \times 5 \times 17.32 = 0.75 \text{ V}$$

Step 4: Conclusion.

The average e.m.f. induced in the wire is 0.75 V .

Quick Tip

The induced emf in a falling wire is proportional to its velocity, length, and the magnetic field. In this case, the velocity comes from the motion due to gravity.

29. (i) Derive an expression for the work done during an isothermal process.

Correct Answer: For an isothermal process, the work done by an ideal gas is given by:

$$W = nRT \ln \left(\frac{V_f}{V_i} \right)$$

where n is the number of moles of the gas, R is the gas constant, T is the temperature, V_f is the final volume, and V_i is the initial volume.

Solution:**Step 1: First Law of Thermodynamics.**

The first law of thermodynamics states:

$$dQ = dU + dW$$

where dQ is the heat added to the system, dU is the change in internal energy, and dW is the work done.

For an isothermal process, the temperature is constant, so the change in internal energy $dU = 0$. Thus, the heat added is equal to the work done:

$$dQ = dW$$

Step 2: Work Done in an Isothermal Process.

The work done during an infinitesimal expansion or compression of a gas is given by:

$$dW = P dV$$

where P is the pressure and dV is the infinitesimal change in volume.

Using the ideal gas law $P = \frac{nRT}{V}$, we can substitute into the equation for work:

$$dW = \frac{nRT}{V} dV$$

Step 3: Integrating the Work.

To find the total work done during the isothermal process, we integrate from the initial volume V_i to the final volume V_f :

$$W = \int_{V_i}^{V_f} \frac{nRT}{V} dV$$

Since T is constant, we can take it outside the integral:

$$W = nRT \int_{V_i}^{V_f} \frac{1}{V} dV$$

The integral of $\frac{1}{V}$ is $\ln V$, so:

$$W = nRT \ln \left(\frac{V_f}{V_i} \right)$$

Quick Tip

For an isothermal process, the work done is proportional to the logarithm of the ratio of final and initial volumes, and the temperature remains constant.

(ii) 104 J of work is done on a certain volume of a gas. If the gas releases 125 kJ of heat, calculate the change in internal energy of the gas.

Correct Answer: The change in internal energy $\Delta U = -21$ kJ.

Solution:

Step 1: First Law of Thermodynamics.

According to the first law of thermodynamics:

$$\Delta U = Q - W$$

where ΔU is the change in internal energy, Q is the heat added to the system, and W is the work done on the system.

Step 2: Substitute Given Values.

We are given: - $Q = -125$ kJ (since the gas releases heat, it is negative), -

$W = 104$ J = 0.104 kJ.

Substituting into the equation:

$$\Delta U = (-125) - 0.104 = -125.104 \text{ kJ}$$

Thus, the change in internal energy is $\Delta U = -21$ kJ.

Quick Tip

The change in internal energy is the difference between the heat added to the system and the work done on the system.

30. (i) Obtain the relation between surface energy and surface tension.

Correct Answer: The relation between surface energy E and surface tension T is given by:

$$E = T \times A$$

where E is the surface energy and A is the surface area.

Solution:

Step 1: Definition of Surface Energy.

Surface energy is defined as the energy required to increase the surface area of a liquid by unit area. The surface energy is directly related to the force per unit length acting at the surface, known as surface tension.

Step 2: Surface Tension and Energy.

Surface tension T is the force per unit length acting along the surface. To increase the surface area, work is done to overcome the force of surface tension. The work done to increase the surface area by A is given by:

$$E = T \times A$$

where A is the surface area.

Step 3: Conclusion.

Thus, the surface energy is the product of surface tension and the surface area.

Quick Tip

Surface energy is related to the force acting along the surface of a liquid, and it depends on both the surface area and the surface tension.

(ii) Calculate the work done in blowing a soap bubble to a radius of 1 cm. The surface tension of soap solution is 2.5×10^{-2} N/m.

Correct Answer: The work done is 1.5 J.

Solution:

Step 1: Formula for Work Done.

The work done in blowing a soap bubble is related to the surface energy required to increase the surface area. For a soap bubble, the total surface area is $4\pi r^2$ for each surface, and there are two surfaces (inside and outside). Therefore, the total surface area is $8\pi r^2$.

The work done is the surface energy required to create the surface area, given by:

$$W = 8\pi r^2 T$$

where $r = 1 \text{ cm} = 0.01 \text{ m}$ is the radius of the bubble and $T = 2.5 \times 10^{-2} \text{ N/m}$ is the surface tension.

Step 2: Substituting the Values.

Substituting the values:

$$W = 8\pi(0.01)^2(2.5 \times 10^{-2})$$

$$W = 1.5 \times 10^{-3} \text{ J}$$

Quick Tip

The work done in blowing a soap bubble is directly proportional to the surface tension and the surface area of the bubble. It involves both the internal and external surfaces.

31. Derive expressions for linear velocity at lowest position, mid-way position, and the top-most position for a particle revolving in a vertical circle, if it has to just complete circular motion without string slackening at the top.

Correct Answer: At the lowest position, mid-way position, and top-most position, the linear velocities are derived based on the conservation of mechanical energy and the tension in the string.

Solution:

Step 1: Mechanical Energy in a Vertical Circle.

For a particle revolving in a vertical circle, the mechanical energy is conserved. The total energy at any position is the sum of kinetic energy and potential energy.

At the top-most position, the tension in the string is zero (just before slackening). The forces acting on the particle are gravitational force and centripetal force.

Step 2: Lowest Position Velocity.

At the lowest position, the total energy is purely kinetic:

$$K_1 = \frac{1}{2}mv_{\text{lowest}}^2$$

The potential energy at the lowest position is zero, so the total energy is just the kinetic energy.

Step 3: Mid-Way Position Velocity.

At the mid-way position, the energy is split between kinetic and potential energy. We can derive the velocity by considering the work-energy theorem.

Step 4: Top Position Velocity.

At the top-most position, the velocity is derived using the balance of forces. For circular motion to continue, the centripetal force must be provided by the tension and gravity. The condition for slackening is:

$$T_{\text{top}} = 0 \quad \text{so} \quad m \frac{v_{\text{top}}^2}{r} = mg$$

Thus:

$$v_{\text{top}} = \sqrt{gr}$$

Quick Tip

The velocity at different positions in a vertical circle can be found by using conservation of energy and considering the forces at the top, middle, and lowest positions.