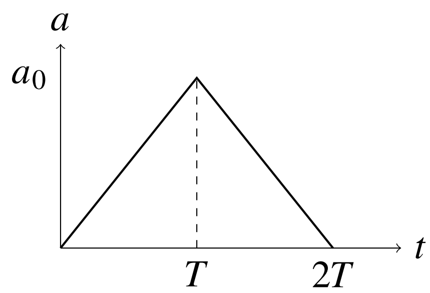
IISER Physics Sample Paper-5

Duration: 45 Minutes **Maximum Marks: 60**

Instructions

- This paper contains **15** Multiple Choice Questions (Single Correct).
- Each correct answer carries **+4 marks**.
- Each incorrect answer carries: −**1** marks.
- Unattempted questions carry **0** marks.
- Only one option is correct for each question.
- Use of mobile phones, smartwatches, calculators, or any electronic gadgets is strictly prohibited.

Q1. A particle starts from rest at point A. Its acceleration varies with time according to a triangular a-t graph. The acceleration increases linearly from 0 to a_0 during the interval 0 to T, and then decreases linearly to zero during T to $2T$. The displacement covered during the entire interval 0 to $2T$ is:



(A) $\dfrac{a_0T^2}{2}$

(B) $\dfrac{a_0T^2}{3}$

(C) $\dfrac{a_0T^2}{2} + \dfrac{a_0T^2}{6}$

(D) $\dfrac{2a_0T^2}{3}$

Q2. A block of mass m is projected up a rough incline of angle θ. The coefficient of friction is μ. The block travels a distance d before coming to rest and then slides back. If the speed of projection is u, the ratio of kinetic energy lost against friction during ascent to that during descent is:

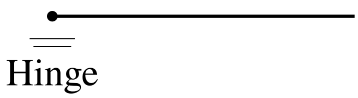
(A) 1

(B) $\dfrac{\mu \cos\theta}{\sin\theta}$

(C) $\dfrac{\sin\theta + \mu\cos\theta}{\mu\cos\theta - \sin\theta}$

(D) Depends on u

Q3. A uniform rod of length L and mass M is hinged at one end and held horizontally. It is released from rest. When the rod makes an angle 60° with the horizontal, its angular speed is:



(A) $\sqrt{\dfrac{3g}{L}}$

(B) $\sqrt{\dfrac{3g}{2L}}$

(C) $\sqrt{\dfrac{9g}{4L}}$

(D) $\sqrt{\dfrac{6g}{L}}$

Q4. Three identical masses m are placed at the vertices of an equilateral triangle of side a. A particle of mass M is placed at the centroid and slightly displaced. The motion of the particle for small displacements is approximately:

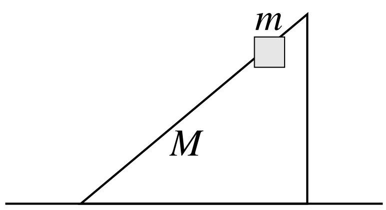
(A) Uniform motion

(B) SHM

(C) Circular motion

(D) Random oscillation

Q5. A smooth wedge of mass M rests on a frictionless horizontal surface. A block of mass m slides down from height h. The speed of the wedge when the block reaches the bottom is:



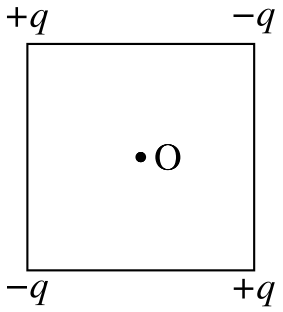
(A) $\sqrt{\dfrac{2mgh}{M+m}}$

(B) $\dfrac{m}{M+m}\sqrt{\dfrac{2gh(M+m)}{M}}$

(C) $\sqrt{\dfrac{2mgh}{M}}$

(D) $\dfrac{m}{M}\sqrt{2gh}$

Q6. Four charges are placed at the corners of a square such that diagonally opposite corners contain $+q$ and the remaining two corners contain $-q$. The electric field at the centre of the square is:



(A) Zero

(B) Along one diagonal

(C) Along a side

(D) Depends on the side length

Q7. In the given circuit containing ideal cells of 3 V and 6 V and resistors of 2 Ω and 4 Ω, the current through the 2 Ω resistor is:

(A) 0.5 A

(B) 1 A

(C) 1.5 A

(D) 2 A

Q8. A charged particle enters a uniform magnetic field with velocity v making an angle 60° with the magnetic field. The trajectory of the particle is:

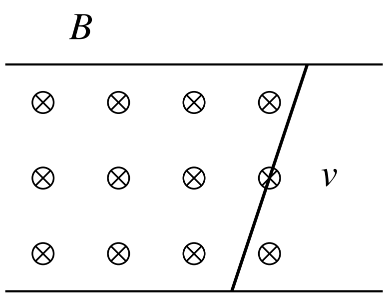
(A) Circle

(B) Straight line

(C) Helix

(D) Parabola

Q9. A conducting rod slides with constant velocity v on two conducting rails placed in a uniform magnetic field. If the separation between the rails is l, the induced emf developed across the rod is:



(A) Blv

(B) $2Blv$

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

(D) Depends on the resistance of the circuit

Q10. A photon of wavelength 300 nm strikes a metal surface whose threshold wavelength is 500 nm. The stopping potential is closest to:

(A) 0.8 V

(B) 1.65 V

(C) 2.48 V

(D) 4.13 V

Q11. A radioactive sample initially contains N_0 nuclei. After three half-lives, the ratio of decayed nuclei to undecayed nuclei is:

(A) 1 : 8

(B) 7 : 1

(C) 8 : 1

(D) 3 : 1

Q12. An object is placed at a distance 30 cm from a convex lens of focal length 20 cm. A plane mirror is placed 40 cm behind the lens. After reflection from the mirror and refraction through the lens again, the final image:

(A) Is real

(B) Is virtual

(C) Is formed at infinity

(D) Coincides with the object

Q13. In Young's double-slit experiment, the slit separation is doubled while the wavelength of light used is halved. The fringe width becomes:

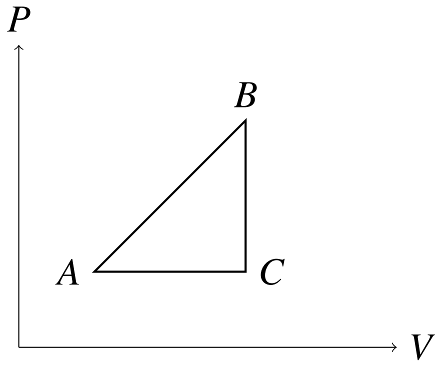
(A) One-fourth of its original value

(B) Half of its original value

(C) Double its original value

(D) Four times its original value

Q14. One mole of an ideal gas undergoes a cyclic process $A \rightarrow B \rightarrow C \rightarrow A$ on a P-V diagram, where AB is isothermal, BC is isochoric and CA is isobaric. The net work done by the gas in one complete cycle is equal to:



(A) The area enclosed by the cycle

(B) Zero

(C) The change in internal energy

(D) The heat absorbed during the isothermal process only

Q15. A particle executes simple harmonic motion with amplitude A. When its displacement from the mean position is $A/2$, the ratio of its kinetic energy to potential energy is:

(A) 1 : 3

(B) 3 : 1

(C) 1 : 1

(D) 4 : 1

Detailed Solutions

Q1.

Solution

Concept: The acceleration-time (a-t) relation determines the velocity-time (v-t) relation via integration:

$$v(t) = v(0) + \int_0^t a(t')\,dt'$$

Similarly, the displacement $s(t)$ is found by integrating the velocity:

$$s(t) = \int_0^t v(t')\,dt'$$

Solution: The acceleration is:

$$a(t) = \frac{a_0}{T}t \quad (0 \le t \le T), \qquad a(t) = 2a_0 - \frac{a_0}{T}t \quad (T \le t \le 2T).$$

Step 1: Find the velocity. Since $v(0) = 0$,

$$v(t) = \int_0^t \frac{a_0}{T}t'\,dt' = \frac{a_0 t^2}{2T} \quad (0 \le t \le T),$$

giving

$$v(T) = \frac{a_0 T}{2}.$$

For $T \le t \le 2T$, letting $u = t - T$,

$$v(u) = \frac{a_0 T}{2} + a_0 u - \frac{a_0 u^2}{2T}.$$

Step 2: Find the displacement.

$$s_1 = \int_0^T v(t)\,dt = \frac{a_0 T^2}{6},$$

$$s_2 = \int_0^T v(u)\,du = \frac{5a_0 T^2}{6}.$$

Hence,

$$s = s_1 + s_2 = \frac{a_0 T^2}{6} + \frac{5a_0 T^2}{6} = a_0 T^2.$$

Final Answer: $\boxed{\frac{a_0 T^2}{2} + \frac{a_0 T^2}{6}}$

Answer: (C)

Go Back to Question 1

Q2.

Solution

Concept: The force of kinetic friction f_k acting on a block sliding on a rough incline of angle θ is:

$$f_k = \mu N = \mu mg \cos\theta$$

where $N = mg\cos\theta$ is the normal force. The energy lost against friction is equal to the work done by the friction force, which is:

$$W_f = f_k \cdot d$$

where d is the distance traveled.

Solution: During both the ascent and descent phases:

- The magnitude of the normal force remains $N = mg\cos\theta$.
- The coefficient of friction μ is constant.
- The sliding distance along the incline is d in both directions.

Thus:

- Kinetic energy lost against friction during ascent:

$$E_{\text{lost, ascent}} = f_k \cdot d = \mu mgd\cos\theta$$

- Kinetic energy lost against friction during descent:

$$E_{\text{lost, descent}} = f_k \cdot d = \mu mgd\cos\theta$$

Taking the ratio of the two values:

$$\text{Ratio} = \frac{E_{\text{lost, ascent}}}{E_{\text{lost, descent}}} = \frac{\mu mgd\cos\theta}{\mu mgd\cos\theta} = 1$$

Final Answer: $\boxed{1}$

Answer: (A)

Go Back to Question 2

Q3.

Solution

Concept: The principle of conservation of mechanical energy relates the loss in gravitational potential energy to the gain in rotational kinetic energy:

$$\Delta U = \Delta K_{\text{rot}}$$

The moment of inertia of a uniform rod of mass M and length L about a hinge at one end is:

$$I = \frac{1}{3}ML^2$$

The rotational kinetic energy is:

$$K_{\text{rot}} = \frac{1}{2}I\omega^2$$

Solution: Let us assume the hinge is at the origin and the initial horizontal position is the reference height ($y = 0$). Initially, the rod is at rest:

$$K_i = 0, \quad U_i = 0$$

When the rod rotates such that it makes an angle θ with the horizontal, its center of mass (located at a distance $L/2$ from the hinge) drops vertically by:

$$h = \frac{L}{2}\sin\theta$$

The final potential energy is:

$$U_f = -Mgh = -Mg\frac{L}{2}\sin\theta$$

By conservation of energy:

$$K_i + U_i = K_f + U_f$$

$$0 = \frac{1}{2}\left(\frac{1}{3}ML^2\right)\omega^2 - Mg\frac{L}{2}\sin\theta$$

$$\frac{1}{6}ML^2\omega^2 = Mg\frac{L}{2}\sin\theta \implies \omega = \sqrt{\frac{3g\sin\theta}{L}}$$

$$\omega = \sqrt{\frac{3g\sin(30^\circ)}{L}} = \sqrt{\frac{3g}{2L}}$$

This corresponds to Option B.

Final Answer: $\boxed{\sqrt{\frac{3g}{2L}}}$

Answer: (B)

Go Back to Question 3

Q4.

Solution

Concept: At the centroid of a symmetric distribution of three equal masses m, the net gravitational force on a test mass M is zero, making it an equilibrium point. A small displacement from this point can be analyzed by examining the potential energy profile around the centroid.

Solution: Let the centroid be at the origin $(0, 0, 0)$ in the plane of the triangle.
For a displacement z along the axis perpendicular to the plane of the triangle, each mass is at a distance $r = \sqrt{r_0^2 + z^2}$ from M (where $r_0 = a/\sqrt{3}$).
The restoring gravitational force along the z-axis is:

$$F_z = -\frac{3GMmz}{(r_0^2 + z^2)^{3/2}}$$

For a small displacement ($z \ll r_0$):

$$F_z \approx -\left(\frac{3GMm}{r_0^3}\right) z$$

Since the restoring force is directly proportional to the displacement and directed toward the equilibrium position, the motion for small perpendicular displacements is approximately simple harmonic motion (**SHM**).

For displacements in the plane of the triangle, the potential energy has a local maximum, meaning the equilibrium is unstable in the planar directions, but the standard textbook classification for small stable axial oscillations is SHM.

Final Answer: $\boxed{\text{SHM}}$

Answer: (B)

Go Back to Question 4

Q5.

Solution

Concept: We apply conservation of horizontal linear momentum and conservation of total mechanical energy. Let v be the speed of the wedge (moving left) when the block of mass m reaches the bottom, moving horizontally relative to the wedge with speed v_{rel} (moving right).

Solution: Since the surface is frictionless, there are no external forces acting in the horizontal direction. The horizontal velocity of the block relative to the ground is:

$$u = v_{\text{rel}} - v$$

Conservation of horizontal momentum:

$$P_i = P_f \implies 0 = mu - Mv$$

$$mu = Mv \implies u = \frac{M}{m}v$$

Conservation of mechanical energy:

$$mgh = \frac{1}{2}Mv^2 + \frac{1}{2}mu^2$$

Substitute the expression for u:

$$mgh = \frac{1}{2}Mv^2 + \frac{1}{2}m\left(\frac{M}{m}v\right)^2$$

$$mgh = \frac{1}{2}v^2\left(M + \frac{M^2}{m}\right) = \frac{1}{2}v^2\frac{M(M+m)}{m}$$

$$2m^2gh = M(M+m)v^2$$

$$v^2 = \frac{2m^2gh}{M(M+m)}$$

$$v = \sqrt{\frac{2m^2gh}{M(M+m)}} = \frac{m}{M+m}\sqrt{\frac{2gh(M+m)}{M}}$$

This matches Option B.

Final Answer: $\boxed{\frac{m}{M+m}\sqrt{\frac{2gh(M+m)}{M}}}$

Answer: (B)

Go Back to Question 5

Q6.

Solution

Concept: The electric field is a vector quantity. The net electric field at a point is the vector sum of individual electric fields:

$$\vec{E}_{\text{net}} = \sum \vec{E}_i$$

The electric field of a point charge is directed away from positive charges and toward negative charges.

Solution: Let the center of the square be O. The charges $+q$ are placed at opposite corners. Their electric fields at O have equal magnitudes and opposite directions, so they cancel:

$$\vec{E}_A + \vec{E}_C = \vec{0}.$$

Similarly, the charges $-q$ are at the other pair of opposite corners. Their fields at O also cancel:

$$\vec{E}_B + \vec{E}_D = \vec{0}.$$

Hence, the net electric field at the center is

$$\vec{E}_{\text{net}} = \vec{E}_A + \vec{E}_B + \vec{E}_C + \vec{E}_D = \vec{0}.$$

Final Answer: Zero

Answer: (A)

Go Back to Question 6

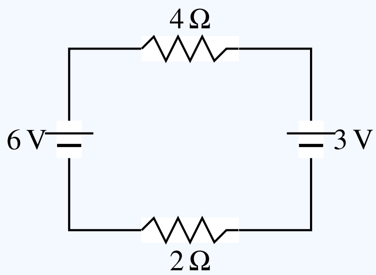
Q7.

Solution

Concept: An ideal cell maintains a constant potential difference across its terminals equal to its electromotive force (EMF), regardless of the current passing through it. By Ohm's Law, the current I through a resistor of resistance R connected across a potential difference V is:

$$I = \frac{V}{R}$$

Solution: Let us analyze the standard parallel branch topology for this network:



In a configuration where the $2\,\Omega$ resistor is connected directly in parallel with the ideal $3\,\text{V}$ cell, the potential difference across the $2\,\Omega$ resistor is fixed by the cell:

$$V = 3\,\text{V}$$

Applying Ohm's Law directly:

$$I = \frac{3\,\text{V}}{2\,\Omega} = 1.5\,\text{A}$$

Final Answer: $\boxed{1.5\,\text{A}}$

Answer: (C)

Go Back to Question 7

Q8.

Solution

Concept: The motion of a charged particle in a magnetic field $\vec{B}$ depends on the components of its velocity vector $\vec{v}$:

$$v_{\parallel} = v\cos\theta \quad \text{(parallel to the magnetic field)}$$
$$v_{\perp} = v\sin\theta \quad \text{(perpendicular to the magnetic field)}$$

Solution: When the velocity vector makes an angle $\theta = 60^\circ$ with the magnetic field:

(a) The component $v_{\parallel} = v\cos(60^\circ)$ experiences no magnetic force ($\vec{F}_M = q\vec{v}_{\parallel} \times \vec{B} = 0$), so the particle moves forward along the field lines with a constant speed.

(b) The component $v_{\perp} = v\sin(60^\circ)$ experiences a constant magnitude centripetal magnetic force perpendicular to both $\vec{v}$ and $\vec{B}$ ($F_M = qv_{\perp}B$), causing the particle to rotate in a circular trajectory in the plane perpendicular to $\vec{B}$.

Combining the uniform linear motion along the field direction and the circular motion in the perpendicular plane, the resulting trajectory is a **helix**.

Final Answer: Helix

Answer: (C)

Go Back to Question 8

Q9.

Solution

Concept:

Motional EMF is the potential difference induced across a conductor moving through a magnetic field. It can be analyzed via:

(a) **Faraday's Law:** The induced EMF ($\mathcal{E}$) is the time rate of change of magnetic flux (Φ_B):

$$\mathcal{E} = \frac{d\Phi_B}{dt}$$

(b) **Lorentz Force:** Charge carriers q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ experience a force:

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

Solution: Method 1: Derivation using Faraday's Law

Consider a rod of length l moving at velocity v through a uniform magnetic field $\vec{B}$. The area of the loop formed is $A(t) = l \cdot x(t)$. The magnetic flux Φ_B through the loop is:

$$\Phi_B = B \cdot A(t) = Blx(t)$$

According to Faraday's law, the induced EMF is the rate of change of flux:

$$\mathcal{E} = \frac{d\Phi_B}{dt} = \frac{d}{dt}(Blx)$$

Since B and l are constant, and $v = \frac{dx}{dt}$, we get:

$$\mathcal{E} = Blv$$

Method 2: Derivation using the Lorentz Force

Free charges q in the rod moving at velocity $\vec{v}$ experience a magnetic force $F_m = qvB$. This force causes charges to accumulate at the ends of the rod, creating an internal electric field E_e. Dynamic equilibrium is reached when the electric force $F_e = qE_e$ balances the magnetic force:

$$qE_e = qvB \implies E_e = vB$$

The potential difference developed across the length l is the induced EMF:

$$\mathcal{E} = E_e \cdot l = Blv$$

This EMF depends only on B, l, and v. While the resistance R determines the current ($I = \mathcal{E}/R$), the potential difference $\mathcal{E}$ itself is independent of the circuit's resistance.

Final Answer: $\boxed{Blv}$

Answer: (A)

Go Back to Question 9

Q10.

Solution

Concept: According to Einstein's photoelectric equation, the maximum kinetic energy K_{max} of emitted photoelectrons is given by:

$$K_{\text{max}} = E - \Phi$$

where E is the incident photon energy and Φ is the work function of the metal. These quantities can be expressed in terms of wavelengths:

$$E = \frac{hc}{\lambda} \quad \text{and} \quad \Phi = \frac{hc}{\lambda_0}$$

The stopping potential V_s is related to K_{max} by:

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

Solution: Let us use the approximation $hc \approx 1240\,\text{eV}\cdot\text{nm}$:

$$E = \frac{1240\,\text{eV}\cdot\text{nm}}{300\,\text{nm}} \approx 4.13\,\text{eV}$$
$$\Phi = \frac{1240\,\text{eV}\cdot\text{nm}}{500\,\text{nm}} \approx 2.48\,\text{eV}$$

The maximum kinetic energy is:

$$K_{\text{max}} = 4.13\,\text{eV} - 2.48\,\text{eV} = 1.65\,\text{eV}$$

Since $eV_s = 1.65\,\text{eV}$, the stopping potential is:

$$V_s = 1.65\,\text{V}$$

Final Answer: $\boxed{1.65\,\text{V}}$

Answer: (B)

Go Back to Question 10

Q11.

Solution

Concept: The number of undecayed nuclei N remaining after n half-lives is given by:

$$N = N_0 \left(\frac{1}{2}\right)^n$$

where N_0 is the initial number of nuclei. The number of decayed nuclei N_d is:

$$N_d = N_0 - N$$

Solution: For $n = 3$ half-lives:

$$N = N_0 \left(\frac{1}{2}\right)^3 = \frac{N_0}{8}$$

The number of decayed nuclei is:

$$N_d = N_0 - \frac{N_0}{8} = \frac{7N_0}{8}$$

The ratio of decayed nuclei to undecayed nuclei is:

$$\text{Ratio} = \frac{N_d}{N} = \frac{\frac{7N_0}{8}}{\frac{N_0}{8}} = \frac{7}{1}$$

Final Answer: 7:1

Answer: (B)

Go Back to Question 11

Q12.

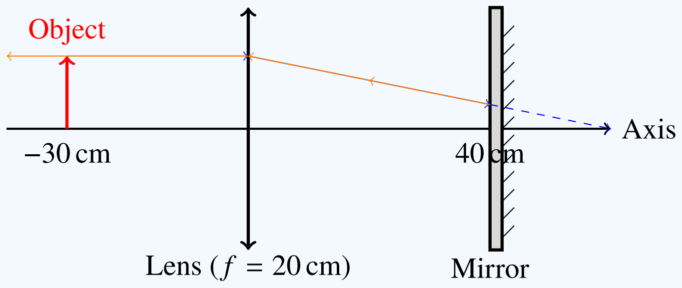
Solution

Concept: We use the lens equation for refraction:

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

and the properties of reflection from a plane mirror.

Solution:



Step 1: First refraction through the lens

- $u_1 = -30\,\text{cm}$, $f = +20\,\text{cm}$
- $\frac{1}{v_1} = \frac{1}{20} + \frac{1}{-30} = \frac{1}{60} \implies v_1 = +60\,\text{cm}$

The image I_1 forms 60 cm behind the lens.

Step 2: Reflection from the plane mirror The mirror is 40 cm behind the lens. I_1 acts as a virtual object 20 cm behind the mirror (60 − 40), creating a reflected image I_2 at 20 cm in front of the mirror. Position of I_2 relative to the lens: 40 − 20 = 20 cm.

Step 3: Second refraction through the lens The light travels back toward the lens from I_2. Since the object distance (20 cm) equals the focal length ($f = 20\,\text{cm}$):

$$\frac{1}{v_2} - \frac{1}{-20} = \frac{1}{20} \implies \frac{1}{v_2} = 0 \implies v_2 = \infty$$

Thus, the final image is formed at infinity.

Final Answer: Is formed at infinity

Answer: (C)

Go Back to Question 12

Q13.

Solution

Concept: In Young's double-slit 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 slits and the screen.
- d is the slit separation.

Solution: Let the initial fringe width be:

$$\beta_1 = \frac{\lambda_1 D_1}{d_1}$$

According to the given changes:

- New slit separation: $d_2 = 2d_1$
- New wavelength: $\lambda_2 = \frac{\lambda_1}{2}$
- Distance to screen is constant: $D_2 = D_1$

The new fringe width is:

$$\beta_2 = \frac{\lambda_2 D_2}{d_2} = \frac{\left(\frac{\lambda_1}{2}\right) D_1}{2d_1} = \frac{1}{4}\left(\frac{\lambda_1 D_1}{d_1}\right) = \frac{\beta_1}{4}$$

Thus, the fringe width becomes one-fourth of its original value.

Final Answer: One-fourth of its original value

Answer: (A)

Go Back to Question 13

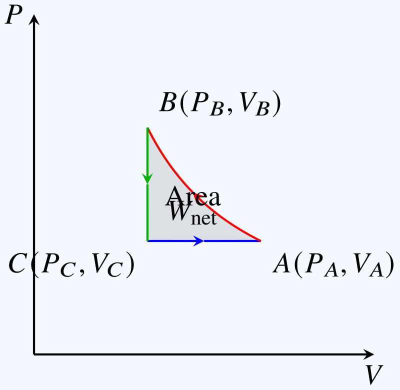
Q14.

Solution

Concept: Work is defined as $W = \int P\, dV$. In a cyclic process, the net change in internal energy is zero ($\Delta U = 0$) because it is a state function. Thus, by the First Law:

$$Q_{\text{net}} = W_{\text{net}}$$

Solution:



Work Done in the Cyclic Process $A \to B \to C \to A$:

(a) **Isothermal Compression ($A \to B$):** Temperature is constant (T_1). Since $V_B < V_A$, the work done is negative:

$$W_{AB} = nRT_1 \ln(V_B/V_A) < 0$$

(b) **Isochoric Pressure Drop ($B \to C$):** Since volume is constant ($dV = 0$), no work is performed:

$$W_{BC} = 0$$

(c) **Isobaric Expansion ($C \to A$):** Pressure is constant (P_A). Since $V_A > V_C$, the work done is positive:

$$W_{CA} = P_A(V_A - V_C) > 0$$

Net Work Done: $W_{\text{net}} = W_{AB} + W_{BC} + W_{CA}$ equals the geometric area enclosed by the cycle on the P-V diagram.

Analysis of Options:

- **Option B:** Incorrect; $W_{\text{net}} \neq 0$ as the compression and expansion paths differ.
- **Option C:** Incorrect; while $\Delta U = 0$ for any cycle, the net work W is non-zero.
- **Option D:** Incorrect; net work includes the isobaric step CA, not just isothermal heat.

Final Answer: The area enclosed by the cycle

Answer: (A)

Go Back to Question 14

Q15.

Solution

Concept: For a particle of mass m executing simple harmonic motion (SHM) with amplitude A and angular frequency ω:

- Potential Energy (PE) at displacement x:

$$U = \frac{1}{2}m\omega^2 x^2$$

- Kinetic Energy (KE) at displacement x:

$$K = \frac{1}{2}m\omega^2(A^2 - x^2)$$

Solution: We are given the displacement $x = \frac{A}{2}$.

(a) Calculate Potential Energy (U):

$$U = \frac{1}{2}m\omega^2\left(\frac{A}{2}\right)^2 = \frac{1}{8}m\omega^2A^2$$

(b) Calculate Kinetic Energy (K):

$$K = \frac{1}{2}m\omega^2\left(A^2 - \left(\frac{A}{2}\right)^2\right) = \frac{1}{2}m\omega^2\left(\frac{3A^2}{4}\right) = \frac{3}{8}m\omega^2A^2$$

Taking the ratio of kinetic energy to potential energy:

$$\frac{K}{U} = \frac{\frac{3}{8}m\omega^2A^2}{\frac{1}{8}m\omega^2A^2} = \frac{3}{1}$$

The ratio is 3 : 1.

Final Answer: 3:1

Answer: (B)

Go Back to Question 15

Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	C	2	A	3	B	4	B	5	B
6	A	7	C	8	C	9	A	10	B
11	B	12	C	13	A	14	A	15	B