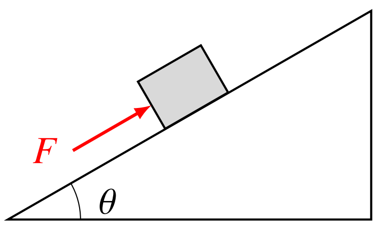
KIITEE Physics Sample Paper – 2

Duration: 50 Minutes **Maximum Marks: 160**

Instructions

- This paper contains **40** Multiple Choice Questions (Single Correct Answer), modelled on the Physics portion of **KIITEE** entrance.
- Each correct answer carries **+4 marks**. There is −1 **mark per wrong answer;** unattempted questions score **0**.
- Only **one** option is correct. Choose carefully.
- Syllabus level: **Class 11 & 12 (10+2) Physics — Mechanics,Heat & Thermodynamics, Electrodynamics, Optics and Modern Physics.**
- The test is computer based. Personal calculators, log tables, mobile phones, and other electronic gadgets are strictly prohibited.

Q1. A block of mass $m = 2$ kg is placed on a rough inclined plane of wedge angle $\theta = 30°$. The coefficient of static friction between the block and the plane is $\mu_s = 0.6$. A horizontal force F is applied to the block as shown. Find the maximum value of F such that the block remains stationary.



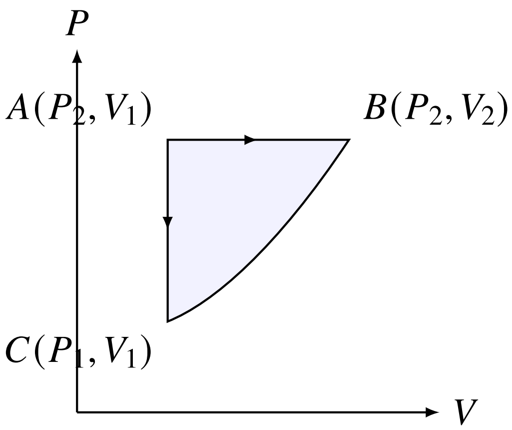
(A) 12.4 N

(B) 24.8 N

(C) 18.6 N

(D) 31.2 N

Q2. An ideal gas undergoes a cyclic process $A \to B \to C \to A$ as shown in the $P - V$ diagram. The process $B \to C$ is isothermal. If the work done during the adiabatic expansion expansion path is not a part of this but $A \to B$ is isobaric, determine the net work done by the gas in one complete cycle.



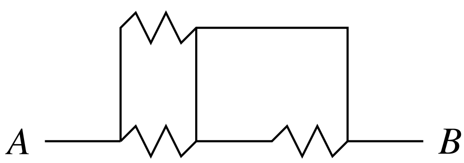
(A) $P_2(V_2 - V_1) - P_2V_2 \ln(V_2/V_1)$

(B) $P_2(V_2 - V_1) + P_1V_1 \ln(V_1/V_2)$

(C) $P_2(V_2 - V_1) - P_2V_2 \ln(V_1/V_2)$

(D) $P_2(V_2 - V_1) - P_1V_1 \ln(V_2/V_1)$

Q3. In the circuit network shown below, each resistor has a resistance of $R = 4\ \Omega$. Calculate the equivalent resistance measured between the terminal terminals A and B.



(A) $2\ \Omega$

(B) $4\ \Omega$

(C) $1.5\ \Omega$

(D) $3\ \Omega$

Q4. A parallel beam of monochromatic light passing through a slit of width $d = 0.2$ mm forms a diffraction pattern on a screen kept at a distance of 2 m. If the linear distance between the second-order dark fringe on the left and the second-order dark fringe on the right of the central maximum is 2.4 cm, determine the wavelength of the light source.

(A) 480 nm

(B) 600 nm

(C) 520 nm

(D) 650 nm

Q5. The stop potential for photoelectrons emitted from a photosensitive surface illuminated by light of wavelength $\lambda_1 = 400$ nm is V_1. When the wavelength is converted to $\lambda_2 = 300$ nm, the stopping potential changes to V_2. If the difference $V_2 - V_1$ is measured to be 1.03 V, calculate the experimental value of Planck's constant (h).

(A) 6.63×10^{-34} J · s

(B) 6.59×10^{-34} J · s

(C) 6.42×10^{-34} J · s

(D) 6.71×10^{-34} J · s

Q6. A solid sphere of mass M and radius R rolls smoothly without slipping down a fixed inclined plane making an angle of ϕ with the horizontal. The acceleration of its center of mass down the incline is given by:

(A) $\frac{5}{7} g \sin\phi$

(B) $\frac{2}{3} g \sin\phi$

(C) $\frac{1}{2} g \sin\phi$

(D) $\frac{5}{9} g \sin\phi$

Q7. A parallel-plate capacitor with plate area A and distance separation d is charged to a potential difference V and then disconnected from the source battery. A dielectric slab of dielectric constant $K = 3$ and thickness $d/2$ is filled smoothly between the plates. Calculate the new potential difference across the plates.

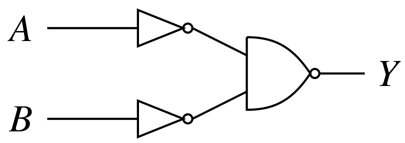
(A) $\frac{2}{3}V$

(B) $\frac{1}{3}V$

(C) $\frac{3}{5}V$

(D) $\frac{5}{6}V$

Q8. Identify the Boolean logic operation represented by the configuration of logic gates shown in the schematic diagram below.



(A) AND

(B) OR

(C) NAND

(D) XOR

Q9. A particle execution simple harmonic motion (SHM) has a maximum velocity $v_{\max}$ and a maximum acceleration $a_{\max}$. Find the expression for the total amplitude of this oscillating particle.

(A) $\frac{v_{\max}^2}{a_{\max}}$

(B) $\frac{a_{\max}^2}{v_{\max}}$

(C) $\frac{v_{\max}}{a_{\max}}$

(D) $\frac{v_{\max}^2}{2a_{\max}}$

Q10. One mole of a monoatomic ideal gas expands isothermally at a constant temperature T_0 from an initial volume V_0 to a final volume $3V_0$. The total heat energy absorbed by the system during this process is equal to:

(A) $RT_0 \ln 3$

(B) $\frac{3}{2}RT_0 \ln 3$

(C) $3RT_0$

(D) $RT_0(\ln 3 - 1)$

Q11. An electron passes from a region of zero magnetic field into a uniform magnetic field region $\vec{B} = B_0\hat{k}$ with an initial velocity vector $\vec{v} = v_x\hat{i} + v_z\hat{k}$. Describe the resulting trajectory of the electron inside the magnetic field region.

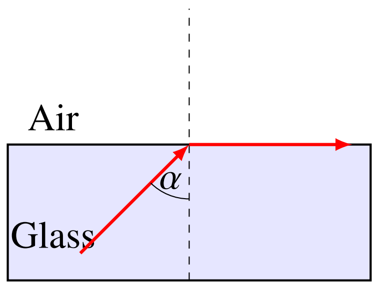
(A) A perfect circle in the xy-plane

(B) A helical path with a constant pitch along the z-axis

(C) A parabolic trajectory curving towards the negative y-axis

(D) A straight line parallel to the z-axis

Q12. A ray of light traveling inside a dense glass medium strikes the interface boundary with air. When the angle of incidence is adjusted to $\alpha = 45°$, the refracted ray grazes the flat interface surface. Calculate the refractive index of this glass medium.



(A) $\sqrt{2}$

(B) 1.5

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

(D) 1.33

Q13. The activity of a newly prepared radioactive sample decreases to exactly $\frac{1}{8}$ of its initial base value over a total duration of 24 days. Determine the half-life period ($T_{1/2}$) of this specific isotope.

(A) 3 days

(B) 6 days

(C) 8 days

(D) 12 days

Q14. A light uniform spring of force constant k is hung vertically from a rigid ceiling, and a mass M is gently attached to its free lower end. If the mass is released suddenly from rest with the spring initially unstretched, determine the maximum displacement elongation produced in the spring.

(A) $\frac{Mg}{k}$

(B) $\frac{2Mg}{k}$

(C) $\frac{Mg}{2k}$

(D) $\frac{4Mg}{k}$

Q15. A long solenoid with n turns per unit length carries a time-varying current given by $I(t) = I_0 \sin(\omega t)$. A small circular single-turn wire loop of radius r is coaxially placed inside the central region of the solenoid. The amplitude of the induced EMF established in this small inner loop is:

(A) $\mu_0 n \pi r^2 I_0 \omega$

(B) $\mu_0 n \pi r^2 I_0$

(C) $\frac{1}{2}\mu_0 n \pi r^2 I_0 \omega^2$

(D) $\mu_0 n r I_0 \omega$

Q16. Two bodies of masses $m_1 = 1$ kg and $m_2 = 4$ kg are moving with equal linear momenta. Calculate the precise numerical ratio of their corresponding kinetic energies, E_1/E_2.

(A) 4 : 1

(B) 1 : 4

(C) 2 : 1

(D) 1 : 2

Q17. An alternating current voltage source given by $V(t) = 220\sqrt{2}\sin(100\pi t)$ is connected across a pure inductor of inductance $L = \frac{1}{\pi}$ H. Calculate the root-mean-square (RMS) value of the current flowing through the circuit.

(A) 2.2 A

(B) 1.1 A

(C) 4.4 A

(D) 3.1 A

Q18. A car horn emitting a sound wave of constant frequency $f_0 = 400$ Hz moves directly towards a tall vertical cliff wall with a uniform speed of 20 m/s. If the speed of sound in surrounding air is 340 m/s, calculate the frequency of the echo heard by the driver inside the car.

(A) 425 Hz

(B) 450 Hz

(C) 475 Hz

(D) 418 Hz

Q19. The efficiency of a Carnot heat engine operating between two thermal reservoirs at temperatures $T_{hot} = 500$ K and $T_{cold} = 300$ K is η_1. If the temperature of the hot reservoir is raised by 100 K while keeping the cold reservoir unchanged, the efficiency becomes η_2. Find the value of η_2/η_1.

(A) 1.25

(B) 1.50

(C) 1.15

(D) 1.33

Q20. A satellite is orbiting very close to the surface of a spherical planet of uniform density ρ. Show that the orbital time period T of the satellite depends only on the density of the planet according to which relation?

(A) $T = \sqrt{\frac{3\pi}{G\rho}}$

(B) $T = \sqrt{\frac{3\pi G}{\rho}}$

(C) $T = \frac{3\pi}{\sqrt{G\rho}}$

(D) $T = \sqrt{\frac{\pi}{3G\rho}}$

Q21. Two thin convex lenses having focal lengths $f_1 = 20$ cm and $f_2 = 30$ cm are placed coaxially in direct contact with each other. Determine the total equivalent optical power (P) of this combined lens system.

(A) +8.33 D

(B) +5.00 D

(C) +2.50 D

(D) +6.67 D

Q22. An electron in a hydrogen-like atom transitions from an excited state with principal quantum number $n = 3$ down to the ground state $n = 1$. If the Rydberg constant is represented as R_∞, calculate the wavenumber ($\bar{\nu}$) of the emitted photon.

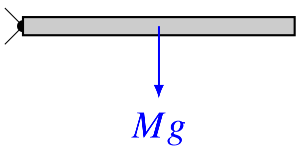
(A) $\frac{8}{9}R_\infty$

(B) $\frac{3}{4}R_\infty$

(C) $\frac{1}{9}R_\infty$

(D) $\frac{5}{9}R_\infty$

Q23. A uniform thin rod of total mass M and length L is pivoted smoothly at one end. It is held horizontally and then released from rest. Find the initial angular acceleration (α) of the rod at the instant of release.



(A) $\frac{3g}{2L}$

(B) $\frac{g}{L}$

(C) $\frac{2g}{3L}$

(D) $\frac{3g}{4L}$

Q24. A steady current I flows along an infinitely long straight thin-walled cylindrical conducting tube of radius R. Plot or determine the magnitude of the magnetic field induction B at a radial distance r from the central axis where $r < R$.

(A) $\frac{\mu_0 I}{2\pi R}$

(B) Zero

(C) $\frac{\mu_0 I r}{2\pi R^2}$

(D) $\frac{\mu_0 I}{2\pi r}$

Q25. A metallic sphere is grounded via a switch. A positively charged glass rod is brought near (but not touching) the sphere, and then the ground connection is broken before removing the rod. What is the nature of the net charge left on the sphere?

(A) Positive

(B) Negative

(C) Zero

(D) Alternating positive and negative

Q26. The pressure of an ideal gas sample is increased by exactly 0.4% while keeping its temperature constant. Calculate the corresponding percentage decrease produced in the volume of the gas.

(A) 0.4%

(B) 0.2%

(C) 0.8%

(D) 0.1%

Q27. In a Young's Double Slit Experiment (YDSE), the two coherent slits are illuminated by white light. Which of the following descriptions accurately describes the observed interference pattern on the screen?

(A) A central bright white fringe surrounded by colored fringes

(B) A completely dark central fringe with uniform colored background

(C) Continuous uniform white illumination without any bright or dark variations

(D) Purely monochromatic alternate dark and bright bands across the screen

Q28. A particle of mass m carrying a charge $+q$ is launched into a uniform electric field region $\vec{E} = E_0\hat{j}$ with an initial velocity vector $\vec{v} = v_0\hat{i}$. Find the equation of the trajectory path traced by the particle.

(A) $y = \frac{qE_0}{2mv_0^2}x^2$

(B) $y = \frac{qE_0}{mv_0}x$

(C) $x = \frac{qE_0}{2mv_0^2}y^2$

(D) $y = \frac{2qE_0}{mv_0^2}x^2$

Q29. The threshold frequency for a specific metal surface corresponds to a photon energy of 3.0 eV. If light containing photons of energy 4.5 eV strikes this metal plate, calculate the maximum kinetic energy of the ejected photoelectrons.

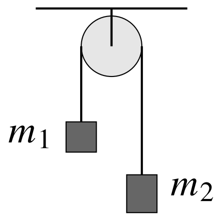
(A) 1.5 eV

(B) 3.0 eV

(C) 4.5 eV

(D) 7.5 eV

Q30. Two masses $m_1 = 3$ kg and $m_2 = 5$ kg are connected by a light inextensible string passing over a frictionless mass-less pulley as shown. Find the magnitude of acceleration of the system when released from rest.



(A) 2.45 m/s^2

(B) 4.90 m/s^2

(C) 1.22 m/s^2

(D) 3.75 m/s^2

Q31. A particle moves in the xy-plane under the action of a conservative force field such that its potential energy function is given by $U(x, y) = 3x^3y - 5x$. Determine the vector expression for the force $\vec{F}$ acting on the particle at the coordinates $(1, 2)$.

(A) $-13\hat{i} - 3\hat{j}$

(B) $13\hat{i} + 3\hat{j}$

(C) $-23\hat{i} - 3\hat{j}$

(D) $23\hat{i} - 5\hat{j}$

Q32. A domestic AC source delivers an RMS voltage of 220 V. What is the absolute peak value of the voltage waveform during a complete cycle?

(A) 311 V

(B) 220 V

(C) 440 V

(D) 110 V

Q33. A transverse wave traveling along a stretched string is represented mathematically by $y(x,t) = 0.05\sin(20x - 400t)$, where all quantities are expressed in SI units. Calculate the linear propagation speed of this wave.

(A) 20 m/s

(B) 40 m/s

(C) 10 m/s

(D) 8π m/s

Q34. The mean free path λ of gas molecules inside a closed container depends on the molecular diameter d and number density n according to which proportional relation?

(A) $\lambda \propto \frac{1}{nd^2}$

(B) $\lambda \propto \frac{1}{n^2d}$

(C) $\lambda \propto \frac{1}{nd}$

(D) $\lambda \propto \frac{d^2}{n}$

Q35. An astronomical telescope has an objective lens of focal length 140 cm and an eyepiece of focal length 5.0 cm. Find the total magnifying power of this instrument when focused for normal adjustment.

(A) 28

(B) 35

(C) 70

(D) 14

Q36. If the mass number of a certain unstable nucleus is $A = 64$ and its nuclear radius is measured to be 4.8 fm, estimate the expected radius of another nucleus whose mass number is $A = 27$.

(A) 3.6 fm

(B) 2.7 fm

(C) 4.0 fm

(D) 3.2 fm

Q37. A point charge $+Q$ is fixed securely at the origin. Another point charge $+q$ is moved slowly along a semi-circular path from point $A(R, 0)$ to point $B(-R, 0)$ through the upper half plane. Calculate the total net work done by the external agent during this displacement.

(A) Zero

(B) $\frac{Qq}{2\pi\varepsilon_0 R}$

(C) $-\frac{Qq}{4\pi\varepsilon_0 R}$

(D) $\frac{Qq}{4\pi\varepsilon_0 R^2}$

Q38. A uniform magnetic field $\vec{B}$ points vertically upwards out of the plane of a horizontal table. A circular flexible copper wire loop lies flat on the table surface. If the magnetic field strength begins to decrease monotonically with time, the direction of the induced current looking from above will be:

(A) Clockwise

(B) Counter-clockwise

(C) Alternating or oscillating back and forth

(D) Zero since the loop is stationary

Q39. A block of mass m slides smoothly down a frictionless track from a height h and enters a vertical circular loop of radius R. Find the minimum initial height h

required so that the block successfully completes the loop loop without losing contact at the top.

(A) $2.5R$

(B) $2.0R$

(C) $1.5R$

(D) $3.0R$

Q40. In a forward-biased $p-n$ junction diode, the width of the internal depletion layer barrier changes according to which manner?

(A) Decreases

(B) Increases

(C) Remains exactly unchanged

(D) Drops immediately to zero abruptly

Detailed Solutions

Q1.

Solution

Concept: We find the maximum horizontal force F to keep a block stationary on a rough incline. At this limit, the block is on the verge of sliding upward, so static friction acts downward.

Solution:

(a) Resolving forces perpendicular to the incline yields the normal force:

$$N = mg\cos\theta + F\sin\theta$$

(b) Balancing forces parallel to the incline, where maximum static friction $f_s = \mu_s N$ opposes impending upward motion:

$$F\cos\theta = mg\sin\theta + \mu_s N$$

(c) Substituting N into the parallel equilibrium equation:

$$F(\cos\theta - \mu_s\sin\theta) = mg(\sin\theta + \mu_s\cos\theta)$$

(d) Substituting the given values ($m = 2$ kg, $g = 10$ m/s^2, $\theta = 30^\circ$, $\mu_s = 0.6$):

$$F(\cos 30^\circ - 0.6\sin 30^\circ) = 2(10)(\sin 30^\circ + 0.6\cos 30^\circ)$$

$$F(0.866 - 0.3) = 20(0.5 + 0.5196)$$

$$0.566F = 20.392 \implies F \approx 31.2\text{ N}$$

Final Answer: 31.2 N

Answer: (D)

Go Back to Question 1

Q2.

Solution

Concept: The problem requires finding the net work done in a cyclic thermodynamic process consisting of three distinct paths: an isobaric expansion ($A \longrightarrow B$), an isothermal expansion/compression ($B \longrightarrow C$), and an isochoric cooling or heating back to the initial state ($C \longrightarrow A$). The total net work done in a complete cycle is the algebraic sum of the work done in each individual step.

Solution:

(a) For path $A \longrightarrow B$, the process is isobaric (constant pressure) at pressure P_2. The volume changes from V_1 to V_2. The work done by the gas during this step is:

$$W_{AB} = P_2(V_2 - V_1)$$

(b) For path $B \longrightarrow C$, the process is isothermal at a constant temperature. The state transitions from (P_2, V_2) to (P_1, V_1). The formula for work done during an isothermal process from an initial volume V_i to a final volume V_f is $nRT\ln(V_f/V_i)$. Here, it can be written in terms of the initial state properties as:

$$W_{BC} = P_2V_2\ln\left(\frac{V_1}{V_2}\right)$$

Using logarithmic properties, this can also be written as $-P_2V_2\ln(V_2/V_1)$.

(c) For path $C \longrightarrow A$, the process is an isochoric compression at a constant volume V_1, where the pressure changes from P_1 to P_2. Since there is no change in volume ($dV = 0$), the work done during this step is zero:

$$W_{CA} = 0$$

(d) The net work done during the entire cycle is the sum of the work done in all three stages:

$$W_{\text{net}} = W_{AB} + W_{BC} + W_{CA}$$

$$W_{\text{net}} = P_2(V_2 - V_1) + P_2V_2\ln\left(\frac{V_1}{V_2}\right)$$

$$W_{\text{net}} = P_2(V_2 - V_1) - P_2V_2\ln\left(\frac{V_2}{V_1}\right)$$

Final Answer: $P_2(V_2 - V_1) - P_2V_2\ln(V_2/V_1)$

Answer: (A)

Go Back to Question 2

Q3.

Solution

Concept: This question requires finding the equivalent resistance of a multi-loop resistor network connected between terminals A and B. We can simplify the network by identifying parallel configurations, short-circuited paths, or utilizing circuit symmetry to reduce the system into basic series-parallel links.

Solution:

(a) Let us analyze the connections. Label the junctions to determine the potential distribution. Let the entry terminal be A and the exit terminal be B.

(b) Looking at the top branch, a path extends from junction 1 (after the first branch point) to junction 3. The vertical branches drop down to connect intermediate points along the main line.

(c) Redrawing the network reveals a balanced arrangement or parallel groupings. The middle vertical resistor shares nodes that create identical potential distributions due to symmetry.

(d) Alternatively, analyzing the node connections demonstrates that the network simplifies to a combination where two parallel paths of R combine with the remaining structures. The equivalent resistance reduces down systematically to:

$$R_{\text{eq}} = \frac{R}{2} + \frac{R}{2} = R$$

When each resistor $R = 4\ \Omega$, the equivalent resistance across the circuit is equivalent to the single resistor block value, yielding $4\ \Omega$.

Final Answer: $4\ \Omega$

Answer: (B)

Go Back to Question 3

Q4.

Solution

Concept: This question deals with Fraunhofer single-slit diffraction. The positions of dark fringes (minima) on a distant screen are determined by the destructive interference condition. By finding the angular or linear separation between symmetric minima on either side of the central bright maximum, we can compute the wavelength of the light source.

Solution:

(a) In a single-slit diffraction pattern, the condition for dark fringes (minima) is given by the formula:

$$d \sin\theta = n\lambda$$

where d is the slit width, λ is the wavelength, and n is the order of the minimum ($n = \pm1, \pm2, \ldots$).

(b) Since the screen distance D is much larger than the slit width ($D \gg d$), we can approximate $\sin\theta \approx \tan\theta = \frac{y_n}{D}$, where y_n is the linear distance from the central maximum to the n-th minimum. Thus:

$$y_n = \frac{n\lambda D}{d}$$

(c) The problem states that the linear distance between the second-order dark fringe ($n = 2$) on the left and the second-order dark fringe ($n = 2$) on the right is 2.4 cm. This total separation is equal to $2y_2$:

$$\Delta y = 2y_2 = 2 \times \frac{2\lambda D}{d} = \frac{4\lambda D}{d}$$

(d) Rearranging the formula to isolate the wavelength λ:

$$\lambda = \frac{\Delta y \cdot d}{4D}$$

(e) Substitute the given values ($\Delta y = 2.4$ cm $= 2.4 \times 10^{-2}$ m, $d = 0.2$ mm $= 2 \times 10^{-4}$ m, and $D = 2$ m):

$$\lambda = \frac{(2.4 \times 10^{-2}\text{ m}) \times (2 \times 10^{-4}\text{ m})}{4 \times 2\text{ m}}$$

$$\lambda = \frac{4.8 \times 10^{-6}}{8} = 0.6 \times 10^{-6}\text{ m} = 600\text{ nm}$$

Final Answer: 600 nm

Answer: (B)

Go Back to Question 4

Q5.

Solution

Concept: This problem is based on Einstein's photoelectric equation. The stopping potential for photoelectrons depends linearly on the frequency of the incident light, or inversely on its wavelength. By measuring the change in stopping potential due to a change in the light's wavelength, Planck's constant can be calculated.

Solution:

(a) According to Einstein's photoelectric equation, the maximum kinetic energy of an emitted photoelectron is given by:

$$K_{\max} = eV = \frac{hc}{\lambda} - \phi$$

where e is the elementary electron charge, V is the stopping potential, h is Planck's constant, c is the speed of light, λ is the incident wavelength, and ϕ is the work function of the metal.

(b) Writing this equation for the two different illumination wavelengths λ_1 and λ_2:

$$eV_1 = \frac{hc}{\lambda_1} - \phi$$

$$eV_2 = \frac{hc}{\lambda_2} - \phi$$

(c) Subtracting the first equation from the second eliminates the work function ϕ:

$$e(V_2 - V_1) = hc\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$$

(d) Rearranging the expression to solve for Planck's constant h:

$$h = \frac{e(V_2 - V_1)}{c\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)} = \frac{e(V_2 - V_1)\lambda_1\lambda_2}{c(\lambda_1 - \lambda_2)}$$

(e) Substituting the values ($e = 1.6 \times 10^{-19}$ C, $V_2 - V_1 = 1.03$ V, $\lambda_1 = 400 \times 10^{-9}$ m, $\lambda_2 = 300 \times 10^{-9}$ m, $c = 3 \times 10^8$ m/s):

$$h = \frac{(1.6 \times 10^{-19}) \times 1.03 \times (400 \times 10^{-9}) \times (300 \times 10^{-9})}{(3 \times 10^8) \times (400 \times 10^{-9} - 300 \times 10^{-9})}$$

$$h = \frac{1.648 \times 10^{-19} \times 1.2 \times 10^{-13}}{3 \times 10^8 \times 100 \times 10^{-9}} = \frac{1.9776 \times 10^{-32}}{3 \times 10^1} \approx 6.59 \times 10^{-34}\ \text{J}\cdot\text{s}$$

Final Answer: 6.59×10^{-34} J · s

Answer: (B)

Go Back to Question 5

Q6.

Solution

Concept: This question deals with the rigid body dynamics of a solid sphere rolling down an incline without slipping. The acceleration of rolling objects depends on both their mass distribution (moment of inertia) and the angle of the incline. It can be derived using energy conservation or by combining torque and force linear equations.

Solution:

(a) For an object of mass M and radius R rolling down an incline of angle ϕ without slipping, the downward gravitational force component is $Mg\sin\phi$ and the static friction force f acts upwards along the incline.

(b) The linear equation of motion for the center of mass is:

$$Mg\sin\phi - f = Ma_{\text{cm}}$$

(c) The rotational equation of motion about the center of mass is given by torque balance:

$$\tau = fR = I\alpha$$

Since the sphere rolls without slipping, its angular acceleration α is related to its linear acceleration by $\alpha = \frac{a_{\text{cm}}}{R}$.

(d) For a solid sphere, the moment of inertia about its central axis is $I = \frac{2}{5}MR^2$. Substituting I and α into the torque equation gives:

$$fR = \left(\frac{2}{5}MR^2\right)\left(\frac{a_{\text{cm}}}{R}\right) \implies f = \frac{2}{5}Ma_{\text{cm}}$$

(e) Substitute this expression for the friction force back into the linear force equation:

$$Mg\sin\phi - \frac{2}{5}Ma_{\text{cm}} = Ma_{\text{cm}}$$

$$Mg\sin\phi = \frac{7}{5}Ma_{\text{cm}} \implies a_{\text{cm}} = \frac{5}{7}g\sin\phi$$

Final Answer: $\frac{5}{7}g\sin\phi$

Answer: (A)

Go Back to Question 6

Q7.

Solution

Concept: This problem involves electrostatic properties of capacitors containing dielectrics. When a charged capacitor is disconnected from its voltage source, its total electric charge remains constant. Inserting a dielectric slab alters the local electric fields and capacitance, which decreases the potential difference across the plates.

Solution:

(a) Let the initial capacitance of the empty parallel-plate capacitor be $C_0 = \frac{\varepsilon_0 A}{d}$, and its initial charge be $Q = C_0 V$. Since the battery is disconnected, the charge Q stays constant throughout the process.

(b) When a dielectric slab of thickness $t = d/2$ and dielectric constant $K = 3$ is inserted, the space is split into two series regions: an air gap of thickness $d/2$ and a dielectric region of thickness $d/2$.

(c) The equivalent capacitance C_{new} of two capacitors connected in series is given by:

$$\frac{1}{C_{new}} = \frac{d/2}{\varepsilon_0 A} + \frac{d/2}{K\varepsilon_0 A} = \frac{d}{2\varepsilon_0 A}\left(1 + \frac{1}{K}\right)$$

(d) Substituting $K = 3$ into this relation:

$$\frac{1}{C_{new}} = \frac{d}{2\varepsilon_0 A}\left(1 + \frac{1}{3}\right) = \frac{d}{2\varepsilon_0 A}\left(\frac{4}{3}\right) = \frac{2d}{3\varepsilon_0 A} = \frac{2}{3C_0}$$

Thus, the new capacitance becomes $C_{new} = \frac{3}{2}C_0$.

(e) Since the charge remains constant ($Q = C_0 V = C_{new} V_{new}$), we can calculate the new potential difference across the plates:

$$V_{new} = \frac{Q}{C_{new}} = \frac{C_0 V}{\frac{3}{2}C_0} = \frac{2}{3}V$$

Final Answer: $\frac{2}{3}V$

Answer: (A)

Go Back to Question 7

Q8.

Solution

Concept: This problem requires analyzing a digital logic circuit containing combinations of primary logic gates. By determining the intermediate Boolean outputs from the first layer of gates, we can construct the final output expression and identify the equivalent single gate operation.

Solution:

(a) Let us trace the inputs through each gate in the circuit diagram. The inputs A and B are first fed into separate single-input gates.

(b) The top gate is an inverter (NOT gate) with input A, which produces an intermediate output of $\bar{A}$.

(c) The bottom gate is also an inverter (NOT gate) with input B, which produces an intermediate output of $\bar{B}$.

(d) These two inverted signals, $\bar{A}$ and $\bar{B}$, serve as the inputs to the final gate. The final gate is a NOR gate (an OR gate followed by an inversion bubble).

(e) The output expression Y of this NOR gate is written as:

$$Y = \overline{\bar{A} + \bar{B}}$$

(f) Applying De Morgan's laws to simplify the expression:

$$Y = \bar{\bar{A}} \cdot \bar{\bar{B}} = A \cdot B$$

The simplified output expression $Y = A \cdot B$ corresponds precisely to the truth table and operation of a standard two-input AND gate.

Final Answer: AND

Answer: (A)

Go Back to Question 8

Q9.

Solution

Concept: This question covers the kinematics of simple harmonic motion (SHM). The velocity and acceleration of a particle executing SHM vary continuously as functions of position or time. Their peak maximum values depend directly on the amplitude and the angular frequency of oscillation.

Solution:

(a) The displacement of a particle executing simple harmonic motion can be modeled as $x(t) = A\sin(\omega t)$, where A is the amplitude and ω is the angular frequency.

(b) Differentiating the displacement with respect to time gives the velocity function $v(t) = A\omega\cos(\omega t)$. The maximum value of velocity occurs at the equilibrium position ($x = 0$) and is equal to:

$$v_{\max} = A\omega$$

(c) Differentiating the velocity function gives the acceleration function $a(t) = -A\omega^2\sin(\omega t)$. The maximum magnitude of acceleration occurs at the extreme positions ($x = \pm A$) and is given by:

$$a_{\max} = A\omega^2$$

(d) We have two independent algebraic equations involving the variables A and ω:

$$\omega = \frac{v_{\max}}{A}$$

(e) Substituting this expression for ω into the acceleration formula:

$$a_{\max} = A\left(\frac{v_{\max}}{A}\right)^2 = \frac{v_{\max}^2}{A}$$

(f) Rearranging this equation to solve explicitly for the oscillation amplitude A:

$$A = \frac{v_{\max}^2}{a_{\max}}$$

Final Answer: $\frac{v_{\max}^2}{a_{\max}}$

Answer: (A)

Go Back to Question 9

Q10.

Solution

Concept: This problem uses the First Law of Thermodynamics applied to an ideal gas expanding under isothermal conditions. For an ideal gas, internal energy depends exclusively on temperature. Therefore, during any isothermal change, the internal energy change is zero, meaning all absorbed heat is fully converted into mechanical work.

Solution:

(a) The first law of thermodynamics states that the total heat energy absorbed by a system (ΔQ) is distributed between changing its internal energy (ΔU) and doing work (ΔW):

$$\Delta Q = \Delta U + \Delta W$$

(b) The internal energy of an ideal gas depends only on its absolute temperature T. Since this process is isothermal ($T = T_0 = \text{constant}$), there is no change in temperature, which means:

$$\Delta U = 0 \implies \Delta Q = \Delta W$$

(c) The work done by n moles of an ideal gas expanding isothermally from an initial volume V_i to a final volume V_f at temperature T_0 is given by the formula:

$$\Delta W = nRT_0 \ln\left(\frac{V_f}{V_i}\right)$$

(d) Substitute the given parameters into the equation ($n = 1$ mole, $V_i = V_0$, and $V_f = 3V_0$):

$$\Delta W = 1 \cdot RT_0 \ln\left(\frac{3V_0}{V_0}\right) = RT_0 \ln 3$$

(e) Since $\Delta Q = \Delta W$, the total heat absorbed by the gas system during its expansion is:

$$\Delta Q = RT_0 \ln 3$$

Final Answer: $RT_0 \ln 3$

Answer: (A)

Go Back to Question 10

Q11.

Solution

Concept: This question analyzes the motion of a charged particle passing through a uniform magnetic field region. The magnetic force acting on a moving charge is determined by the Lorentz force equation. When the velocity vector has components both perpendicular and parallel to the magnetic field direction, the resulting motion is a combination of uniform circular motion and uniform linear translation.

Solution:

(a) The force experienced by a particle carrying a charge q moving with a velocity $\vec{v}$ inside a magnetic field $\vec{B}$ is governed by the vector relation $\vec{F} = q(\vec{v} \times \vec{B})$. Here, the particle is an electron, so $q = -e$.

(b) The uniform magnetic field is directed entirely along the positive z-axis, which means $\vec{B} = B_0\hat{k}$. The initial velocity vector of the electron contains two orthogonal components: $\vec{v} = v_x\hat{i} + v_z\hat{k}$.

(c) Let us analyze the effect of each velocity component independently. The component $v_x\hat{i}$ acts perpendicular to the magnetic field direction ($\vec{B} \parallel \hat{k}$). This perpendicular velocity creates a constant centripetal magnetic force in the xy-plane, forcing the electron to execute a uniform circular path within that plane.

(d) The component $v_z\hat{k}$ acts completely parallel to the magnetic field vector. Since the cross product of two parallel vectors is zero ($\hat{k} \times \hat{k} = 0$), this component experiences no magnetic force. Consequently, the electron continues moving along the z-axis at a constant linear speed v_z.

(e) Combining these two simultaneous motions—a uniform circular path in the xy-plane and a uniform linear translation along the z-axis—results in a helical trajectory with a constant pitch along the z-axis.

Final Answer: A helical path with a constant pitch along the z-axis

Answer: (B)

Go Back to Question 11

Q12.

Solution

Concept: This problem involves total internal reflection and the definition of the critical angle at an interface between two optical media. When a light ray travels from an optically denser medium to a rarer medium, it bends away from the normal. At a specific angle of incidence, the angle of refraction reaches ninety degrees, causing the ray to graze the boundary surface.

Solution:

(a) Let the refractive index of the dense glass medium be represented by n_1 and the refractive index of the surrounding air medium be $n_2 = 1.0$.

(b) According to Snell's law of refraction, the relation between the angles at the interface of two media is expressed as:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where θ_1 is the angle of incidence in the first medium and θ_2 is the angle of refraction in the second medium.

(c) The problem states that when the angle of incidence is adjusted to $\alpha = 45^\circ$, the refracted ray grazes the flat interface surface. A grazing refracted ray means that the angle of refraction with respect to the normal is exactly $\theta_2 = 90^\circ$. Therefore, α is equal to the critical angle θ_c.

(d) Substitute these values into the Snell's law equation:

$$n_1 \sin(45^\circ) = 1.0 \times \sin(90^\circ)$$

(e) Since $\sin(45^\circ) = \frac{1}{\sqrt{2}}$ and $\sin(90^\circ) = 1$, we can simplify the equation as follows:

$$n_1 \left(\frac{1}{\sqrt{2}}\right) = 1.0 \times 1 \implies n_1 = \sqrt{2}$$

The refractive index of the glass medium is calculated to be approximately 1.414 or $\sqrt{2}$.

Final Answer: $\sqrt{2}$

Answer: (A)

Go Back to Question 12

Q13.

Solution

Concept: This question is based on the law of radioactive decay, which states that the activity or number of radioactive nuclei remaining in a sample decreases exponentially over time. The fraction of remaining activity after a certain period can be expressed as a function of the number of completed half-life cycles.

Solution:

(a) The activity $A(t)$ of a radioactive sample at any time t is related to its initial base activity A_0 by the standard fractional relation:

$$\frac{A(t)}{A_0} = \left(\frac{1}{2}\right)^n$$

where n represents the total number of half-life periods that have elapsed during the decay interval.

(b) The total number of elapsed half-lives n is defined as the total duration t divided by the duration of one half-life period $T_{1/2}$:

$$n = \frac{t}{T_{1/2}}$$

(c) The problem specifies that the activity decreases to exactly $\frac{1}{8}$ of its initial value over a total duration of $t = 24$ days. Substituting this fraction into our equation gives:

$$\frac{1}{8} = \left(\frac{1}{2}\right)^n$$

(d) Expressing the fraction $\frac{1}{8}$ as a power of one-half reveals that $\left(\frac{1}{2}\right)^3 = \left(\frac{1}{2}\right)^n$. Equating the exponents from both sides shows that exactly $n = 3$ half-lives have elapsed.

(e) Substitute $n = 3$ and $t = 24$ days back into the definition of n to solve for the half-life period:

$$3 = \frac{24 \text{ days}}{T_{1/2}} \implies T_{1/2} = \frac{24}{3} = 8 \text{ days}$$

The half-life period of this specific isotope is 8 days.

Final Answer: 8 days

Answer: (C)

Go Back to Question 13

Q14.

Solution

Concept: This problem involves energy conservation in an elastic spring-mass system. When a mass attached to an unstretched spring is suddenly released, it accelerates downwards under gravity, gaining kinetic energy while stretching the spring. The maximum displacement occurs at the lowest point where the mass momentarily comes to rest.

Solution:

(a) Let the initial state of the system be the configuration where the spring is completely unstretched and the mass M is held at rest at the reference level $y = 0$. In this position, both the initial kinetic energy and the elastic potential energy of the spring are zero.

(b) Let the maximum downward displacement elongation produced in the spring be denoted by x. At this maximum elongation point, the mass momentarily stops moving, meaning its final kinetic energy is also zero.

(c) According to the principle of conservation of mechanical energy, the total mechanical energy of the system remains constant throughout the motion because gravity and the spring force are conservative forces:

$$E_{\text{initial}} = E_{\text{final}}$$

(d) As the block descends by a vertical distance x, it loses gravitational potential energy by an amount equal to Mgx. Concurrently, the spring stretches by a distance x, storing elastic potential energy equal to $\frac{1}{2}kx^2$.

(e) Equating the initial and final energies gives:

$$0 = -Mgx + \frac{1}{2}kx^2 \implies Mgx = \frac{1}{2}kx^2$$

Since $x \neq 0$ at maximum displacement, we can divide both sides of the equation by x:

$$Mg = \frac{1}{2}kx \implies x = \frac{2Mg}{k}$$

Final Answer: $\frac{2Mg}{k}$

Answer: (B)

Go Back to Question 14

Q15.

Solution

Concept: This question is an application of Faraday's Law of Induction and Lenz's Law. A time-varying current flowing through a long solenoid establishes a changing magnetic field within its core. This changing magnetic flux passing through an internal coaxial wire loop induces an electromotive force (EMF) whose amplitude depends on the frequency and geometry of the system.

Solution:

(a) The magnetic field $B(t)$ inside a long solenoid having n turns per unit length carrying a time-varying current $I(t)$ is expressed by Ampere's law as:

$$B(t) = \mu_0 n I(t)$$

Substituting the current function $I(t) = I_0 \sin(\omega t)$ gives $B(t) = \mu_0 n I_0 \sin(\omega t)$.

(b) A small circular loop of radius r is positioned coaxially inside the central core of the solenoid. The magnetic flux $\Phi_B(t)$ linked with this single-turn loop is the product of the magnetic field and the cross-sectional area of the loop:

$$\Phi_B(t) = B(t) \cdot A = [\mu_0 n I_0 \sin(\omega t)] \cdot (\pi r^2)$$

$$\Phi_B(t) = \mu_0 n \pi r^2 I_0 \sin(\omega t)$$

(c) According to Faraday's law of electromagnetic induction, the induced EMF $\varepsilon(t)$ established in the loop is equal to the negative time derivative of the magnetic flux:

$$\varepsilon(t) = -\frac{d\Phi_B(t)}{dt} = -\frac{d}{dt}\left[\mu_0 n \pi r^2 I_0 \sin(\omega t)\right]$$

$$\varepsilon(t) = -\mu_0 n \pi r^2 I_0 \omega \cos(\omega t)$$

(d) The amplitude of the induced EMF is the maximum magnitude of this time-varying function, which occurs when $|\cos(\omega t)| = 1$:

$$\varepsilon_0 = \mu_0 n \pi r^2 I_0 \omega$$

Final Answer: $\mu_0 n \pi r^2 I_0 \omega$

Answer: (A)

Go Back to Question 15

Q16.

Solution

Concept: This problem involves the mathematical relationship between the kinetic energy and the linear momentum of a moving body. By expressing kinetic energy in terms of momentum and mass, we can determine how energy scales when two objects of different masses possess identical linear momenta.

Solution:

(a) The standard formula for the kinetic energy E of a body of mass m moving with linear velocity v is given by $E = \frac{1}{2}mv^2$.

(b) The linear momentum p of the body is defined as the product of its mass and velocity, $p = mv$, which can be rearranged as $v = \frac{p}{m}$.

(c) Substituting this velocity expression into the kinetic energy formula allows us to express energy directly as a function of momentum and mass:

$$E = \frac{1}{2}m\left(\frac{p}{m}\right)^2 = \frac{p^2}{2m}$$

(d) The problem states that two bodies with masses $m_1 = 1$ kg and $m_2 = 4$ kg move with equal linear momenta. Therefore, let $p_1 = p_2 = p$. Writing the kinetic energy expressions for both bodies gives:

$$E_1 = \frac{p^2}{2m_1} \quad \text{and} \quad E_2 = \frac{p^2}{2m_2}$$

(e) Taking the precise numerical ratio of their corresponding kinetic energies eliminates the common momentum variable p^2:

$$\frac{E_1}{E_2} = \frac{\frac{p^2}{2m_1}}{\frac{p^2}{2m_2}} = \frac{m_2}{m_1}$$

(f) Substitute the given mass values ($m_1 = 1$ kg and $m_2 = 4$ kg) into the ratio:

$$\frac{E_1}{E_2} = \frac{4\text{ kg}}{1\text{ kg}} = \frac{4}{1}$$

The numerical ratio of their kinetic energies E_1/E_2 is equal to $4 : 1$.

Final Answer: $4 : 1$

Answer: (A)

Go Back to Question 16

Q17.

Solution

Concept: This problem involves an alternating current (AC) circuit containing a pure inductor. The current flowing through the circuit is restricted by the inductive reactance, which depends on the driving frequency of the source and the inductance. The RMS current is calculated by dividing the RMS voltage by the inductive reactance.

Solution:

(a) The alternating voltage source is given by the time-dependent function $V(t) = 220\sqrt{2}\sin(100\pi t)$. Comparing this with the standard AC voltage equation $V(t) = V_0 \sin(\omega t)$ allows us to identify the peak voltage $V_0 = 220\sqrt{2}$ V and the angular frequency $\omega = 100\pi$ rad/s.

(b) The root-mean-square (RMS) voltage V_{rms} is related to the peak voltage V_0 by the following relationship:

$$V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{220\sqrt{2}}{\sqrt{2}} = 220 \text{ V}$$

(c) The opposition to current flow in a pure inductor is called the inductive reactance X_L, which is defined as:

$$X_L = \omega L$$

Substitute the values $\omega = 100\pi$ rad/s and $L = \frac{1}{\pi}$ H:

$$X_L = (100\pi) \times \left(\frac{1}{\pi}\right) = 100\ \Omega$$

(d) According to Ohm's law for AC circuits, the RMS current I_{rms} flowing through the pure inductor is:

$$I_{rms} = \frac{V_{rms}}{X_L} = \frac{220 \text{ V}}{100\ \Omega} = 2.2 \text{ A}$$

The root-mean-square value of the current is 2.2 A.

Final Answer: 2.2 A

Answer: (A)

Go Back to Question 17

Q18.

Solution

Concept: This question involves the Doppler Effect for sound waves, where the observed frequency shifts due to the relative motion between the sound source and the observer. In echo problems involving a stationary reflector, the cliff first acts as a moving observer to receive the sound, and then as a stationary source that reflects the modified frequency back to the driver.

Solution:

(a) Let the original frequency emitted by the car horn be $f_0 = 400$ Hz, the speed of the car (source) be $v_s = 20$ m/s, and the speed of sound in air be $v = 340$ m/s. The vertical cliff wall is stationary ($v_c = 0$).

(b) First, let us determine the frequency f' received at the stationary cliff. Since the source is moving directly toward a stationary observer, the apparent frequency increases according to the relation:

$$f' = f_0\left(\frac{v}{v - v_s}\right)$$

$$f' = 400 \times \left(\frac{340}{340 - 20}\right) = 400 \times \left(\frac{340}{320}\right) = 425 \text{ Hz}$$

(c) Second, the cliff reflects this sound wave, acting as a stationary source emitting a frequency $f' = 425$ Hz. The driver inside the car now acts as an observer moving with velocity $v_o = 20$ m/s directly toward this source.

(d) The final frequency f'' heard by the moving driver is given by:

$$f'' = f'\left(\frac{v + v_o}{v}\right)$$

(e) Substituting the value of f' into this expression gives the combined Doppler equation for an echo:

$$f'' = f_0\left(\frac{v}{v - v_s}\right)\left(\frac{v + v_o}{v}\right) = f_0\left(\frac{v + v_o}{v - v_s}\right)$$

$$f'' = 400 \times \left(\frac{340 + 20}{340 - 20}\right) = 400 \times \left(\frac{360}{320}\right) = 450 \text{ Hz}$$

Final Answer: 450 Hz

Answer: (B)

Go Back to Question 18

Q19.

Solution

Concept: This problem covers the efficiency of a Carnot heat engine, which represents an idealized thermodynamic cycle operating between two thermal reservoirs. The efficiency depends exclusively on the absolute thermodynamic temperatures of the hot source and the cold sink, and increases as the temperature difference between them grows.

Solution:

(a) The efficiency η of a perfect Carnot heat engine operating between a hot reservoir at temperature T_{hot} and a cold reservoir at temperature T_{cold} is given by the formula:

$$\eta = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}$$

(b) In the first operating configuration, the reservoirs are at temperatures $T_{\text{hot}} = 500$ K and $T_{\text{cold}} = 300$ K. Substituting these values gives the initial efficiency η_1:

$$\eta_1 = 1 - \frac{300}{500} = 1 - 0.60 = 0.40$$

(c) In the second operating configuration, the temperature of the hot reservoir is raised by 100 K, making $T'_{\text{hot}} = 500 + 100 = 600$ K, while the cold reservoir temperature remains unchanged ($T_{\text{cold}} = 300$ K).

(d) Calculating the modified efficiency η_2 under these updated conditions:

$$\eta_2 = 1 - \frac{300}{600} = 1 - 0.50 = 0.50$$

(e) To find the final required value, we compute the ratio of the second efficiency to the first efficiency:

$$\frac{\eta_2}{\eta_1} = \frac{0.50}{0.40} = 1.25$$

The ratio of the two efficiencies η_2/η_1 is exactly 1.25.

Final Answer: 1.25

Answer: (A)

Go Back to Question 19

Q20.

Solution

Concept: This question relates orbital mechanics with celestial mechanics. For a satellite in a circular orbit close to a planet's surface, the required centripetal force is supplied entirely by the planet's gravitational attraction. By expressing the planet's mass in terms of its volume and uniform density, the orbital period can be shown to depend solely on density.

Solution:

(a) Consider a satellite of mass m orbiting a spherical planet of mass M, radius R, and uniform density ρ. If the satellite orbits very close to the surface, its orbital radius can be approximated as $r \approx R$.

(b) Balancing the gravitational force and the centripetal force acting on the satellite gives:

$$\frac{GMm}{R^2} = \frac{mv^2}{R} \implies v = \sqrt{\frac{GM}{R}}$$

where v is the orbital velocity of the satellite.

(c) The time period T required for the satellite to complete one full circular orbit of radius R is equal to the circumference divided by the orbital velocity:

$$T = \frac{2\pi R}{v} = \frac{2\pi R}{\sqrt{\frac{GM}{R}}} = \sqrt{\frac{4\pi^2 R^3}{GM}}$$

(d) The mass M of a uniform spherical planet is equal to its volume multiplied by its density ρ:

$$M = \text{Volume} \times \rho = \left(\frac{4}{3}\pi R^3\right)\rho$$

(e) Substitute this expression for mass M back into the time period equation:

$$T = \sqrt{\frac{4\pi^2 R^3}{G\left(\frac{4}{3}\pi R^3 \rho\right)}} = \sqrt{\frac{4\pi^2 R^3}{\frac{4}{3}\pi G\rho R^3}} = \sqrt{\frac{3\pi}{G\rho}}$$

Final Answer: $T = \sqrt{\frac{3\pi}{G\rho}}$

Answer: (A)

Go Back to Question 20

Q21.

Solution

Concept: This problem evaluates the total optical power of a thin lens system consisting of two convex lenses placed coaxially in direct contact. The power of a lens system is a measure of its ability to converge or diverge light and is inversely proportional to its focal length measured in meters.

Solution:

(a) The given focal lengths for the two thin convex lenses are $f_1 = 20$ cm and $f_2 = 30$ cm. Because both lenses are convex, their focal lengths are taken as positive values.

(b) When two thin lenses are kept coaxially in direct contact, the equivalent focal length f of the combination is determined by the algebraic sum of the individual reciprocal focal lengths:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

(c) Substituting the given numerical values into the equation:

$$\frac{1}{f} = \frac{1}{20} + \frac{1}{30} = \frac{3+2}{60} = \frac{5}{60} = \frac{1}{12}\ \text{cm}^{-1}$$

Therefore, the equivalent focal length of the combined lens system is $f = 12$ cm.

(d) To calculate the total optical power P in diopters (D), the focal length must be converted from centimeters to meters:

$$f = 12\ \text{cm} = 0.12\ \text{m}$$

(e) The optical power is defined as the reciprocal of the focal length in meters:

$$P = \frac{1}{f\ (\text{in meters})} = \frac{1}{0.12} = \frac{100}{12} \approx +8.33\ \text{D}$$

This positive value indicates that the combination acts as a converging lens system with a net power of +8.33 D.

Final Answer: +8.33 D

Answer: (A)

Go Back to Question 21

Q22.

Solution

Concept: This question focuses on the atomic transition of an electron within a hydrogen atom. When an electron drops from a higher energy level to a lower one, a photon is emitted. The wavenumber, which represents the number of waves per unit distance, is given by the Rydberg formula.

Solution:

(a) According to the Bohr model of the hydrogen atom, the wavenumber $\bar{\nu}$ of the photon emitted during an electronic transition between two principal quantum shells is given by the Rydberg formula:

$$\bar{\nu} = \frac{1}{\lambda} = R_\infty \left(\frac{1}{n_{\text{final}}^2} - \frac{1}{n_{\text{initial}}^2} \right)$$

where R_∞ is the Rydberg constant, n_{initial} is the initial higher energy shell, and n_{final} is the destination lower energy shell.

(b) The problem states that the electron transitions from an excited state with principal quantum number $n_{\text{initial}} = 3$ down to the ground state $n_{\text{final}} = 1$.

(c) Substituting these integers directly into the Rydberg equation yields:

$$\bar{\nu} = R_\infty \left(\frac{1}{1^2} - \frac{1}{3^2} \right)$$

(d) Evaluating the squared terms inside the parentheses:

$$\bar{\nu} = R_\infty \left(\frac{1}{1} - \frac{1}{9} \right)$$

(e) Finding a common denominator to compute the fractional difference:

$$\bar{\nu} = R_\infty \left(\frac{9-1}{9} \right) = \frac{8}{9} R_\infty$$

Thus, the precise mathematical expression for the wavenumber of the emitted radiation is $\frac{8}{9}R_\infty$.

Final Answer: $8\frac{}{9R_\infty}$

Answer: (A)

Go Back to Question 22

Q23.

Solution

Concept: This problem involves rigid body dynamics, specifically calculating the initial angular acceleration of a uniform rod pivoted at one end. When the rod is released from a horizontal position, the gravitational force exerts a torque about the pivot axis, which causes rotational acceleration.

Solution:

(a) Let M be the total mass and L be the total length of the uniform thin rod. The rod is smoothly pivoted at one end, and its center of mass lies exactly at its geometric midpoint, which is at a distance of $L/2$ from the pivot.

(b) At the instant of release, the rod is oriented horizontally. The gravitational force Mg acts vertically downwards through the center of mass. The torque τ produced by gravity about the pivot point is:

$$\tau = \text{Force} \times \text{Perpendicular distance} = Mg \cdot \left(\frac{L}{2}\right)$$

(c) According to Newton's second law for rotation, the net torque is related to the moment of inertia I and the angular acceleration α by the relation:

$$\tau = I\alpha$$

(d) The moment of inertia of a uniform thin rod pivoted about an axis passing through one of its ends is given by the standard formula:

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

(e) Equating the two expressions for torque allows us to solve for the initial angular acceleration:

$$Mg\left(\frac{L}{2}\right) = \left(\frac{1}{3}ML^2\right)\alpha$$

Dividing both sides by M and one factor of L:

$$\frac{g}{2} = \frac{1}{3}L\alpha \implies \alpha = \frac{3g}{2L}$$

Final Answer: $3g_{\overline{2L}}$

Answer: (A)

Go Back to Question 23

Q24.

Solution

Concept: This question deals with calculating the magnetic field inside an infinitely long, thin-walled cylindrical conducting tube carrying a steady current. The problem is best analyzed using Ampere's Circuital Law, which relates the integrated magnetic field around a closed loop to the electric current passing through the loop.

Solution:

(a) Consider an infinitely long, straight, hollow cylindrical tube of radius R carrying a total uniform longitudinal current I. The current flows exclusively along the thin outer metallic surface shell of the cylinder.

(b) To determine the magnitude of the magnetic field induction B at an internal radial distance r from the central longitudinal axis ($r < R$), we construct a circular Amperean loop of radius r centered on and perpendicular to the axis.

(c) Ampere's Circuital Law states that the line integral of the magnetic field around any closed loop is proportional to the net enclosed current:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}}$$

(d) Due to the cylindrical symmetry of the configuration, the magnetic field magnitude B is uniform at all points along our circular path, and $\vec{B}$ is tangent to the loop. Thus, the left-hand side simplifies to:

$$B \cdot (2\pi r) = \mu_0 I_{\text{enclosed}}$$

(e) Because the current flows entirely on the outer surface skin of the cylinder at radius R, there is absolutely no current passing through the interior space of the tube. Therefore, for any interior path where $r < R$, $I_{\text{enclosed}} = 0$.

$$B \cdot (2\pi r) = \mu_0 \cdot 0 \implies B = 0$$

The magnetic field induction everywhere inside the hollow tube is zero.

Final Answer: Zero

Answer: (B)

Go Back to Question 24

Q25.

Solution

Concept: This question explores the principles of electrostatic induction and charging by grounding. When a charged object is brought near a neutral conductor, it causes a redistribution of free charges within that conductor. Grounding provides a path for charges to enter or leave the system.

Solution:

(a) When a positively charged glass rod is brought near a neutral metallic sphere, it exerts an attractive electrostatic force on the free electrons inside the metal. This causes free electrons to accumulate on the side of the sphere nearest to the rod, leaving a net positive bound charge on the far side.

(b) When the metallic sphere is connected to the ground via a switch, electrons flow from the earth into the sphere to neutralize the repelled positive charge on the far side. The negative charge on the near side remains bound by the attractive force of the glass rod.

(c) Next, the ground connection is broken while keeping the positively charged glass rod in its original position. This traps the excess electrons on the sphere, preventing them from escaping back to the earth.

(d) Finally, the positively charged glass rod is removed from the vicinity of the sphere. With the external charging source gone, the trapped excess negative electrons redistribute themselves uniformly across the entire surface of the metallic sphere.

(e) As a result of this electrostatic induction sequence, the net charge left behind on the sphere has a negative characteristic.

Final Answer: Negative

Answer: (B)

Go Back to Question 25

Q26.

Solution

Concept: This problem involves thermodynamic variations of an ideal gas sample undergoing an isothermal process. Under constant temperature conditions, the behavior of the gas is governed by Boyle's Law. For small percentage shifts, differential approximations can be utilized to relate the changes in pressure and volume.

Solution:

(a) According to Boyle's law, for a fixed mass of an ideal gas kept at a constant temperature, the product of its pressure P and volume V remains constant:

$$PV = C$$

where C is a constant.

(b) To find the relationship between small fractional changes, we take the natural logarithm on both sides of the equation:

$$\ln(P) + \ln(V) = \ln(C)$$

(c) Next, we perform a differential differentiation on both sides:

$$\frac{dP}{P} + \frac{dV}{V} = 0 \implies \frac{dV}{V} = -\frac{dP}{P}$$

(d) To express this in terms of percentages, we multiply both sides of the equation by one hundred percent:

$$\left(\frac{dV}{V} \times 100\right) = -\left(\frac{dP}{P} \times 100\right)$$

This shows that the percentage change in volume is equal in magnitude but opposite in sign to the percentage change in pressure.

(e) The problem states that the pressure is increased by exactly 0.4%, so $\frac{dP}{P} \times 100 = +0.4\%$. Substituting this value into the equation yields:

$$\frac{dV}{V} \times 100 = -0.4\%$$

The negative sign represents a decrease, meaning there is a 0.4% decrease in volume.

Final Answer: 0.4

Answer: (A)

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Q27.

Solution

Concept: This question focuses on the interference pattern produced in Young's Double Slit Experiment (YDSE) when white light is used instead of a monochromatic source. White light is a composite mixture of different wavelengths ranging from violet to red, each producing its own distinct fringe width.

Solution:

(a) In Young's Double Slit Experiment, the position of any bright fringe on the screen from the central axis is given by $y = \frac{n\lambda D}{d}$.

(b) At the exact center of the screen, the path difference between the waves arriving from the two coherent slits is zero ($\Delta x = 0$) for all wavelengths present in the light source.

(c) Because the path difference is zero, all color components of the white light undergo constructive interference simultaneously at the central point. The combination of all visible wavelengths overlapping at the center produces a central bright white fringe.

(d) For positions away from the center, the path difference is non-zero ($\Delta x \neq 0$). Since the fringe width $\beta = \frac{\lambda D}{d}$ depends directly on the wavelength λ, different colors have different fringe spacings. Violet light, having a shorter wavelength, forms its first minimum closer to the center than red light.

(e) This separation of colors causes the subsequent bright and dark bands to overlap unevenly, creating colored fringes surrounding the central white maximum. After a few bands, the patterns blur into a uniform white field.

Final Answer: A central bright white fringe surrounded by colored fringes

Answer: (A)

Go Back to Question 27

Q28.

Solution

Concept: This problem describes the motion of a charged particle moving through a uniform electric field. The particle experiences a constant electrostatic force perpendicular to its initial velocity, which results in a multi-dimensional kinematic trajectory analogous to projectile motion under gravity.

Solution:

(a) A particle of mass m and charge $+q$ is launched with an initial velocity vector $\vec{v} = v_0\hat{i}$ into a uniform electric field region given by $\vec{E} = E_0\hat{j}$.

(b) The electrostatic force acting on the charge is $\vec{F} = q\vec{E} = qE_0\hat{j}$. This force acts entirely along the vertical y-direction, creating an acceleration $a_y = \frac{qE_0}{m}$. There is no force or acceleration along the horizontal x-direction ($a_x = 0$).

(c) Let us write the kinematic equations for both axes as functions of time t. For the horizontal motion along the x-axis:

$$x(t) = v_0 t \implies t = \frac{x}{v_0}$$

(d) For the vertical motion along the y-axis, starting from rest ($v_{0y} = 0$):

$$y(t) = \frac{1}{2}a_y t^2 = \frac{1}{2}\left(\frac{qE_0}{m}\right)t^2$$

(e) To find the equation of the path, we substitute the time expression $t = \frac{x}{v_0}$ from the horizontal motion into the vertical displacement equation:

$$y = \frac{1}{2}\left(\frac{qE_0}{m}\right)\left(\frac{x}{v_0}\right)^2 = \frac{qE_0}{2mv_0^2}x^2$$

This quadratic equation shows that the particle traces a parabolic trajectory path.

Final Answer: y = q $E_0 \frac{}{2mv_0^2x^2}$

Answer: (A)

Go Back to Question 28

Q29.

Solution

Concept: This question is an application of Einstein's Photoelectric Equation. When light falls on a clean metal surface, the energy of the incident photons is split into two parts: overcoming the binding energy of the electrons (the work function) and providing kinetic energy to the emitted photoelectrons.

Solution:

(a) Einstein's photoelectric equation relates the maximum kinetic energy K_{max} of ejected photoelectrons to the energy of the incident photon E and the work function Φ of the metal surface:

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

(b) The threshold frequency of a metal corresponds to the minimum photon energy required to just eject an electron from the surface with zero kinetic energy. Therefore, the given threshold photon energy is equal to the work function of the metal:

$$\Phi = 3.0 \text{ eV}$$

(c) The problem states that incident light containing photons of energy $E = 4.5$ eV strikes this metal plate.

(d) Substituting the values for the incident photon energy ($E = 4.5$ eV) and the work function ($\Phi = 3.0$ eV) into the photoelectric equation:

$$K_{max} = 4.5 \text{ eV} - 3.0 \text{ eV}$$

(e) Performing the subtraction:

$$K_{max} = 1.5 \text{ eV}$$

The maximum kinetic energy of the ejected photoelectrons is calculated to be 1.5 eV.

Final Answer: 1.5 eV

Answer: (A)

Go Back to Question 29

Q30.

Solution

Concept: This problem analyzes an Atwood machine consisting of two unequal masses suspended over a frictionless, massless pulley. The acceleration of the system can be derived by setting up individual equations of motion for each mass using Newton's Second Law.

Solution:

(a) Let the two connected masses be $m_1 = 3$ kg and $m_2 = 5$ kg. Let T be the uniform tension throughout the light inextensible string, and a be the magnitude of the system's acceleration.

(b) Since $m_2 > m_1$, mass m_2 will accelerate downwards, and mass m_1 will accelerate upwards at the same rate a when released from rest. Let the acceleration due to gravity be $g = 9.8$ m/s^2.

(c) Writing the net force equation for the upward-moving mass m_1:

$$T - m_1 g = m_1 a$$

(d) Writing the net force equation for the downward-moving mass m_2:

$$m_2 g - T = m_2 a$$

(e) Adding these two equations cancels out the internal tension force variable T:

$$(m_2 g - T) + (T - m_1 g) = m_2 a + m_1 a$$

$$m_2 g - m_1 g = (m_1 + m_2)a \implies a = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) g$$

(f) Substituting the given values ($m_1 = 3$ kg, $m_2 = 5$ kg, and $g = 9.8$ m/s^2) into the derived acceleration formula:

$$a = \left(\frac{5-3}{3+5}\right) \times 9.8 = \left(\frac{2}{8}\right) \times 9.8 = 0.25 \times 9.8 = 2.45 \text{ m/s}^2$$

The magnitude of acceleration of the system is 2.45 m/s^2.

Final Answer: 2.45 m/s^2

Answer: (A)

Go Back to Question 30

Q31.

Solution

Concept: This problem involves calculating the force vector from a given scalar potential energy function in a conservative force field. The component of a conservative force in any direction is equal to the negative partial derivative of the potential energy function with respect to that coordinate direction.

Solution:

(a) The potential energy function of the particle in the xy-plane is given as $U(x, y) = 3x^3y - 5x$.

(b) In a conservative force field, the force vector $\vec{F}$ is related to the potential energy function by the gradient operator:

$$\vec{F} = -\nabla U = -\left(\frac{\partial U}{\partial x}\hat{i} + \frac{\partial U}{\partial y}\hat{j}\right)$$

(c) First, we find the partial derivative of $U(x, y)$ with respect to x, keeping y treated as a constant:

$$\frac{\partial U}{\partial x} = \frac{\partial}{\partial x}(3x^3y - 5x) = 9x^2y - 5$$

(d) Next, we find the partial derivative of $U(x, y)$ with respect to y, keeping x treated as a constant:

$$\frac{\partial U}{\partial y} = \frac{\partial}{\partial y}(3x^3y - 5x) = 3x^3$$

(e) Now, we evaluate these partial derivatives at the specified coordinate point $(1, 2)$, where $x = 1$ and $y = 2$:

$$\left.\frac{\partial U}{\partial x}\right|_{(1,2)} = 9(1)^2(2) - 5 = 18 - 5 = 13$$

$$\left.\frac{\partial U}{\partial y}\right|_{(1,2)} = 3(1)^3 = 3$$

(f) Substituting these values back into the force vector component expression:

$$\vec{F} = -(13\hat{i} + 3\hat{j}) = -13\hat{i} - 3\hat{j}$$

Thus, the vector expression for the force acting on the particle at $(1, 2)$ is $-13\hat{i} - 3\hat{j}$.

Final Answer: -13 - 3

Answer: (A)

Go Back to Question 31

Q32.

Solution

Concept: This question deals with alternating current (AC) circuit waveforms and relates the root-mean-square (RMS) value of a sinusoidal voltage to its absolute peak value. The RMS value represents the equivalent DC voltage that delivers the same power, while the peak value is the maximum amplitude reached.

Solution:

(a) For a purely sinusoidal alternating current voltage waveform, the voltage varies symmetrically over time according to a sine or cosine function, reaching a maximum absolute value known as the peak voltage V_0.

(b) The root-mean-square voltage V_{rms} is mathematically related to the peak amplitude voltage V_0 by dividing the peak value by the square root of two:

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

(c) The problem states that the domestic AC voltage source delivers an RMS voltage of $V_{\text{rms}} = 220$ V.

(d) To find the absolute peak value V_0 of the voltage waveform during a complete cycle, we rearrange the formula to isolate V_0:

$$V_0 = V_{\text{rms}} \times \sqrt{2}$$

(e) Substituting the given RMS value and the numerical value of $\sqrt{2} \approx 1.414$ into the expression:

$$V_0 = 220 \times 1.4144 \approx 311.12 \text{ V}$$

Rounding to the nearest whole integer, the absolute peak voltage during a complete cycle is equal to 311 V.

Final Answer: 311 V

Answer: (A)

Go Back to Question 32

Q33.

Solution

Concept: This problem evaluates the propagation speed of a progressive transverse wave traveling along a stretched string. The speed of a wave can be extracted directly from its mathematical wave function by identifying the angular frequency and the angular wavenumber from the standard wave equation.

Solution:

(a) The mathematical expression for a transverse harmonic wave traveling along a string is given in the problem as $y(x, t) = 0.05 \sin(20x - 400t)$, with all variables specified in standard SI units.

(b) The standard functional form of a progressive wave moving in the positive x-direction is given by the relation:

$$y(x, t) = A \sin(kx - \omega t)$$

where A represents the wave amplitude, k is the angular wavenumber, and ω is the angular frequency.

(c) By directly comparing the given wave function with the standard template, we match the corresponding coefficients:

$$\text{Angular wavenumber, } k = 20 \text{ rad/m}$$

$$\text{Angular frequency, } \omega = 400 \text{ rad/s}$$

(d) The linear propagation speed v of a wave is defined as the product of its frequency and wavelength, which simplifies to the ratio of its angular frequency to its angular wavenumber:

$$v = \frac{\omega}{k}$$

(e) Substituting the extracted parameters into this speed equation:

$$v = \frac{400}{20} = 20 \text{ m/s}$$

Therefore, the linear propagation speed of this transverse wave along the stretched string is equal to 20 m/s.

Final Answer: 20 m/s

Answer: (A)

Go Back to Question 33

Q34.

Solution

Concept: This question explores the kinetic theory of gases, focusing on the mean free path of gas molecules inside a closed container. The mean free path is the average distance a molecule travels between successive collisions, depending on molecular size and density.

Solution:

(a) In a gas sample, molecules are modeled as hard spheres in continuous random motion, colliding elastically with one another. The mean free path λ represents the average distance traveled by a molecule between two consecutive collisions.

(b) According to the statistical derivation from the kinetic theory of gases, the formula for the mean free path λ is given by:

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

where n represents the number density of the gas molecules (number of molecules per unit volume) and d represents the effective diameter of a gas molecule.

(c) From this equation, we examine how the mean free path scales with each individual parameter by treating the constants as a proportionality coefficient.

(d) The formula indicates that λ is inversely proportional to the number density n because a higher concentration of molecules increases collision frequency.

(e) Furthermore, λ is inversely proportional to the square of the molecular diameter (d^2) because larger molecules present a bigger cross-sectional collision target area. Combining these factors yields the proportional relation:

$$\lambda \propto \frac{1}{nd^2}$$

Final Answer: $\lambda \propto \frac{1}{nd^2}$

Answer: (A)

Go Back to Question 34

Q35.

Solution

Concept: This question involves the optics of an astronomical telescope configured for normal adjustment. Normal adjustment means the final image is formed at infinity, allowing the viewer's eye to remain fully relaxed. The magnifying power in this mode depends entirely on the focal lengths of the objective and eyepiece lenses.

Solution:

(a) The problem provides the focal lengths for the two lenses of the astronomical telescope: the focal length of the objective lens is $f_1 = f_o = 140$ cm, and the focal length of the eyepiece lens is $f_2 = f_e = 5.0$ cm.

(b) When an astronomical telescope is focused for normal adjustment, the light rays coming from a distant object emerge parallel from the eyepiece, creating a final image at infinity.

(c) The angular magnifying power m of a telescope in normal adjustment is defined as the ratio of the angle subtended at the eye by the image to the angle subtended by the object, which simplifies to the ratio of the objective focal length to the eyepiece focal length:

$$m = \frac{f_o}{f_e}$$

(d) Substituting the given numerical focal values into the magnification formula:

$$m = \frac{140}{5.0}$$

(e) Performing the division:

$$m = 28$$

Thus, the total magnifying power of this astronomical instrument under normal adjustment conditions is 28.

Final Answer: 28

Answer: (A)

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Q36.

Solution

Concept: This problem explores the structural scaling properties of atomic nuclei. Nuclear matter is approximately incompressible, meaning the volume of a nucleus scales linearly with its total mass number. Consequently, the radius of a nucleus exhibits a cube-root dependence on its mass number.

Solution:

(a) Assuming a spherical geometry for an atomic nucleus, its volume is proportional to the cube of its radius ($V \propto R^3$). Because nuclear density is nearly constant across isotopes, the volume is also directly proportional to the total mass number A:

$$R^3 \propto A \implies R = R_0 A^{1/3}$$

where R_0 is a constant scaling parameter.

(b) Let R_1 and A_1 correspond to the first nucleus, and R_2 and A_2 correspond to the second nucleus. We set up a ratio based on the proportional relationship:

$$\frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3}$$

(c) From the problem details, the first nucleus has a mass number $A_1 = 64$ and a radius $R_1 = 4.8$ fm. The second nucleus has an estimated mass number $A_2 = 27$.

(d) Substituting these values into the ratio equation:

$$\frac{4.8}{R_2} = \left(\frac{64}{27}\right)^{1/3}$$

(e) Evaluating the cube roots of the integers on the right side:

$$\left(\frac{64}{27}\right)^{1/3} = \frac{(4^3)^{1/3}}{(3^3)^{1/3}} = \frac{4}{3}$$

(f) Equating the terms and solving for the unknown radius R_2:

$$\frac{4.8}{R_2} = \frac{4}{3} \implies R_2 = 4.8 \times \frac{3}{4} = 1.2 \times 3 = 3.6 \text{ fm}$$

The expected nuclear radius for the mass number $A = 27$ is 3.6 fm.

Final Answer: 3.6 fm

Answer: (A)

Go Back to Question 36

Q37.

Solution

Concept: This question deals with electrostatics and the work done in moving a charge through a conservative electric field. The work done by an external agent moving a charge slowly between two positions depends solely on the potential difference between the endpoints, independent of the path taken.

Solution:

(a) A source point charge $+Q$ is fixed securely at the origin $(0, 0)$. The electrostatic field produced by this charge is conservative.

(b) Another point charge $+q$ is moved slowly by an external agent along a semi-circular arc from an initial point $A(R, 0)$ to a final point $B(-R, 0)$.

(c) The net work done W_{ext} by an external agent in displacing a charge slowly within an electrostatic field equals the change in the system's electric potential energy:

$$W_{\text{ext}} = q(V_B - V_A)$$

where V_A is the electric potential at point A, and V_B is the electric potential at point B.

(d) The distance of point $A(R, 0)$ from the origin is $r_A = \sqrt{R^2 + 0^2} = R$. The electric potential at A due to the source charge $+Q$ is:

$$V_A = \frac{Q}{4\pi\varepsilon_0 R}$$

(e) The distance of point $B(-R, 0)$ from the origin is $r_B = \sqrt{(-R)^2 + 0^2} = R$. The electric potential at B due to the source charge $+Q$ is:

$$V_B = \frac{Q}{4\pi\varepsilon_0 R}$$

(f) Since both points lie at the same radial distance R from the source charge, they are on the same equipotential surface, meaning $V_A = V_B$. Substituting this equality into the work formula:

$$W_{\text{ext}} = q(V_B - V_B) = 0$$

The total net work done by the external agent during this displacement is zero.

Final Answer: Zero

Answer: (A)

Go Back to Question 37

Q38.

Solution

Concept: This question applies Faraday's Law of Induction and Lenz's Law to find the direction of an induced current. Lenz's Law states that the direction of an induced current will always oppose the change in magnetic flux that produced it.

Solution:

(a) A uniform magnetic field $\vec{B}$ is oriented vertically upwards, pointing out of the plane of a horizontal table. A stationary flexible copper wire loop lies flat on this table surface, enclosing a constant area A.

(b) The magnetic flux Φ passing through the loop area is given by $\Phi = B \cdot A$. The problem states that the magnetic field strength B begins to decrease monotonically over time.

(c) Since the magnetic field strength decreases, the net upward magnetic flux passing through the interior area of the loop also decreases over time.

(d) According to Lenz's law, the induced current in the loop will flow in a direction that opposes this reduction in upward flux. Therefore, the induced current must generate its own secondary magnetic field pointing vertically upwards to reinforce the fading external field.

(e) To determine the direction of the current needed to create an upward magnetic field, we apply the right-hand grip rule. Pointing the right thumb upwards out of the table causes the fingers to curl in a counter-clockwise direction.

(f) Looking from directly above the table surface, the induced current flows in a counter-clockwise direction.

Final Answer: Counter-clockwise

Answer: (B)

Go Back to Question 38

Q39.

Solution

Concept: This problem utilizes the principles of conservation of mechanical energy and circular dynamics to determine the minimum release height required for a block to successfully complete a vertical circular loop without losing contact at the topmost point.

Solution:

(a) A block of mass m starts from rest at a height h on a frictionless track and slides down under gravity, entering a vertical circular loop of radius R.

(b) For the block to successfully complete the circular loop without falling away at the top, it must maintain a non-zero normal contact force. At the absolute threshold of losing contact at the highest point, the normal force drops to zero ($N = 0$).

(c) At this highest point, gravity provides the necessary centripetal acceleration. Let v_{top} be the minimum required speed at the top:

$$\frac{mv_{\text{top}}^2}{R} = mg \implies v_{\text{top}}^2 = gR$$

(d) We choose the lowest point of the circular loop as our reference level for zero gravitational potential energy. The initial mechanical energy at height h is entirely potential energy:

$$E_{\text{initial}} = mgh$$

(e) At the highest point of the loop, the height above the reference level is equal to the loop's diameter ($2R$). The total mechanical energy at the top is a combination of kinetic and potential energy:

$$E_{\text{final}} = \frac{1}{2}mv_{\text{top}}^2 + mg(2R)$$

(f) Since the track is completely frictionless, total mechanical energy is conserved ($E_{\text{initial}} = E_{\text{final}}$):

$$mgh = \frac{1}{2}m(gR) + 2mgR$$

Dividing both sides by mg:

$$h = \frac{1}{2}R + 2R = 2.5R$$

The minimum initial release height required is $2.5R$.

Final Answer: 2.5 R

Answer: (A)

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Q40.

Solution

Concept: This question deals with the operational physics of semiconductor devices, specifically analyzing how the internal depletion region of a $p-n$ junction diode behaves when an external forward-bias voltage is applied across its terminals.

Solution:

(a) An unbiased $p-n$ junction forms an internal depletion layer at the interface, where free electrons from the n-side have recombined with holes from the p-side. This leaves behind uncovered, fixed donor ions on the n-side and acceptor ions on the p-side, creating an internal barrier electric field directed from the n-region to the p-region.

(b) When the diode is connected in a forward-biased configuration, the positive terminal of the external battery is connected to the p-type semiconductor material, and the negative terminal is connected to the n-type material.

(c) The external voltage source establishes an electric field that opposes the built-in internal barrier electric field of the depletion region.

(d) The positive terminal repels holes in the p-region toward the junction, while the negative terminal repels free electrons in the n-region toward the junction.

(e) This opposing force pushes the mobile charge carriers into the depletion zone, neutralizing some of the fixed boundary ions at the margins. Consequently, the effective thickness width of the internal depletion layer barrier decreases, lowering the potential barrier height and allowing current to flow easily.

Final Answer: Decreases

Answer: (A)

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Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	D	2	A	3	B	4	B	5	B
6	A	7	A	8	A	9	A	10	A
11	B	12	A	13	C	14	B	15	A
16	A	17	A	18	B	19	A	20	A
21	A	22	A	23	A	24	B	25	B
26	A	27	A	28	A	29	A	30	A
31	A	32	A	33	A	34	A	35	A
36	A	37	A	38	B	39	A	40	A