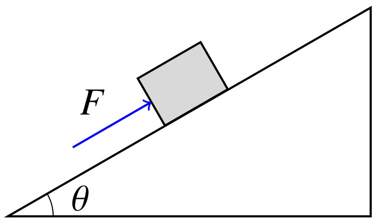
KIITEE Physics Sample Paper – 11

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 held at rest on a smooth inclined plane of angle $\theta = 30^\circ$ by a horizontal force F as shown. Calculate the magnitude of the horizontal force F required to keep the block in equilibrium ($g = 10$ m/s^2).



(A) $\frac{20}{\sqrt{3}}$ N

(B) $20\sqrt{3}$ N

(C) 10 N

(D) $10\sqrt{3}$ N

Q2. A particle moves along the x-axis under the action of a conservative force field whose potential energy function is given by $U(x) = \frac{a}{x^2} - \frac{b}{x}$, where a and b are positive constants. The distance of the particle from the origin when it is in stable equilibrium is:

(A) $\frac{a}{b}$

(B) $\frac{2a}{b}$

(C) $\frac{a}{2b}$

(D) $\frac{\sqrt{a}}{b}$

Q3. A uniform solid cylinder of mass M and radius R rolls without slipping down an inclined plane of inclination α. The linear acceleration of the cylinder down the incline is:

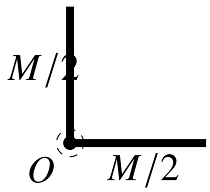
(A) $g \sin \alpha$

(B) $\frac{1}{2} g \sin \alpha$

(C) $\frac{2}{3} g \sin \alpha$

(D) $\frac{3}{4} g \sin \alpha$

Q4. A thin uniform rod of length L and mass M is bent at its midpoint to form a 90° angle shape. The moment of inertia of this bent system about an axis passing through the vertex of the angle and perpendicular to the plane of the rod is:



(A) $\frac{1}{3} ML^2$

(B) $\frac{1}{12} ML^2$

(C) $\frac{1}{24} ML^2$

(D) $\frac{1}{6} ML^2$

Q5. A satellite is launching into a circular orbit around Earth at an altitude equal to the radius of Earth R. If g is the acceleration due to gravity on Earth's surface, the escape velocity of a body from this satellite's orbital trajectory is:

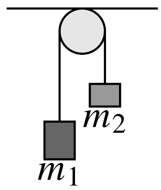
(A) $\sqrt{gR}$

(B) $\sqrt{2gR}$

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

(D) $\sqrt{\frac{3gR}{2}}$

Q6. Two masses $m_1 = 4$ kg and $m_2 = 1$ kg are connected by a light inextensible string passing over a smooth, frictionless pulley. The system is released from rest. Find the work done by tension on mass m_2 during the first second of motion ($g = 10$ m/s^2).



(A) 16 J

(B) 24 J

(C) 32 J

(D) 48 J

Q7. A body of mass m experiencing a one-dimensional potential field has a position-dependent potential energy given by $U(x) = kx^4$, where k is a positive constant. If the total mechanical energy of the particle is E, its maximum speed is:

(A) $\sqrt{\frac{2E}{m}}$

(B) $\sqrt{\frac{E}{2m}}$

(C) $\left(\frac{4E}{m}\right)^{1/4}$

(D) $\sqrt{\frac{E}{m}}$

Q8. A light sphere of radius r falls from rest through a viscous fluid of density ρ_f. The sphere has a density ρ_s ($\rho_s > \rho_f$). The variation of its velocity v with time t is correctly described by which graph?

(A) A straight line passing through the origin with a positive slope.

(B) An exponentially decaying curve approaching zero velocity.

(C) An asymptotic curve increasing from zero up towards a fixed terminal velocity value.

(D) A parabolic curve concave upwards.

Q9. A variable force given by $\vec{F} = (3x^2\hat{i} + 2y\hat{j})$ N acts on a particle. The change in kinetic energy of the particle as it moves from the origin $(0, 0)$ to the position $(2 \text{ m}, 3 \text{ m})$ is:

(A) 11 J

(B) 17 J

(C) 23 J

(D) 35 J

Q10. A circular disk of mass M and radius R is rotating about its central axis with angular speed ω_0. An identical disk, initially at rest, is dropped coaxially onto the spinning disk. Due to friction between the surfaces, they eventually rotate together at a common final angular speed ω_f. The fraction of original kinetic energy lost in this interaction is:

(A) $\frac{1}{4}$

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

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

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

Q11. The acceleration due to gravity at a height h above the Earth's surface is identical to its value at a depth d below the Earth's surface. If both h and d are much smaller than the radius of the Earth R $(h, d \ll R)$, the relationship between d and h is:

(A) $d = h$

(B) $d = 2h$

(C) $d = \frac{h}{2}$

(D) $d = 4h$

Q12. Four point charges $+q, +q, -q$, and $-q$ are placed at the vertices of a square of side a in a clockwise sequence. The magnitude of the electric field vector at the geometric center of this square configuration is:

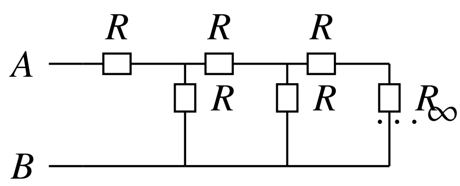
(A) Zero

(B) $\frac{1}{4\pi\varepsilon_0}\frac{4q}{a^2}$

(C) $\frac{1}{4\pi\varepsilon_0}\frac{4\sqrt{2}q}{a^2}$

(D) $\frac{1}{4\pi\varepsilon_0}\frac{2\sqrt{2}q}{a^2}$

Q13. Determine the equivalent resistance between nodes A and B for the infinite ladder circuit shown below, where each individual resistor has resistance R.



(A) $2R$

(B) $(\sqrt{3} + 1)R$

(C) $\frac{1+\sqrt{5}}{2}R$

(D) $(1 + \sqrt{3})R$

Q14. A parallel-plate capacitor with air between its plates has a capacitance C_0. The space between the plates is now filled completely with two distinct slabs of dielectric materials of thickness $d/2$ each. Their dielectric constants are K_1 and K_2 respectively. The new capacitance of the system is:

(A) $\frac{K_1K_2}{K_1+K_2}C_0$

(B) $\frac{2K_1K_2}{K_1+K_2}C_0$

(C) $\frac{K_1+K_2}{2}C_0$

(D) $(K_1 + K_2)C_0$

Q15. A long, straight hollow cylindrical conductor of inner radius a and outer radius b carries a uniform current density J along its length. The variation of the magnetic field B as a function of distance r from the axis, in the region $a < r < b$, is proportional to:

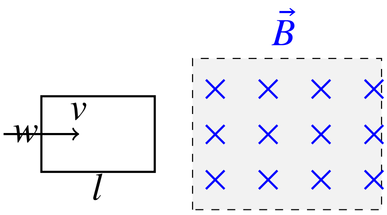
(A) r

(B) $\frac{1}{r}$

(C) $r - \frac{a^2}{r}$

(D) $r^2 - a^2$

Q16. A rectangular wire loop of dimensions $l \times w$ moves with a constant speed v into a localized uniform magnetic field region B directed perpendicular into the plane of the loop. The electrical resistance of the loop is R. The thermal power dissipated as Joule heating while the loop enters the field is:



(A) $\frac{B^2 w^2 v^2}{R}$

(B) $\frac{B^2 l^2 v^2}{R}$

(C) $\frac{Bwv}{R}$

(D) $\frac{B^2 w^2 v}{R^2}$

Q17. In a series LCR AC circuit, the values of components are $R = 30\ \Omega$, $X_L = 80\ \Omega$, and $X_C = 40\ \Omega$. If this circuit is connected to an alternating source voltage operating at $V_{\text{rms}} = 200$ V, the average power consumed by the network is:

(A) 400 W

(B) 480 W

(C) 800 W

(D) 1200 W

Q18. An alpha particle ($^4\text{He}^{2+}$) and a proton ($^1\text{H}^+$) are accelerated from rest through identical electrical potential differences V. They subsequently enter a region of uniform magnetic field perpendicular to their velocity vectors. The ratio of the radii of their circular paths (r_α/r_p) is:

(A) 1 : 1

(B) $\sqrt{2}$: 1

(C) 2 : 1

(D) 1 : $\sqrt{2}$

Q19. A magnetic dipole of dipole moment $\vec{M}$ is initially oriented parallel to a uniform external magnetic field $\vec{B}$. The mechanical work required to rotate this magnetic dipole by an angle of 180° relative to the field direction is:

(A) Zero

(B) MB

(C) $2MB$

(D) $-2MB$

Q20. The self-inductance of a long ideal solenoid containing N turns, length l, and cross-sectional area A is denoted by L. If the total number of turns is doubled while keeping the length and area completely unchanged, the new self-inductance will be:

(A) $2L$

(B) $4L$

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

(D) L

Q21. A charging capacitor configuration consists of two circular plates of radius R. At a certain instant, the electric displacement field change causes a displacement current density J_d across the dielectric space. The induced magnetic field at a radial distance $r = R/2$ from the central axis of the plates is:

(A) $\frac{1}{2}\mu_0 J_d R$

(B) $\frac{1}{4}\mu_0 J_d R$

(C) $\mu_0 J_d R$

(D) $\frac{1}{8}\mu_0 J_d R$

Q22. An ideal monatomic gas expanding at constant pressure absorbs Q Joules of thermal energy. The fraction of this heat energy that goes into increasing the internal energy of the ideal gas system is:

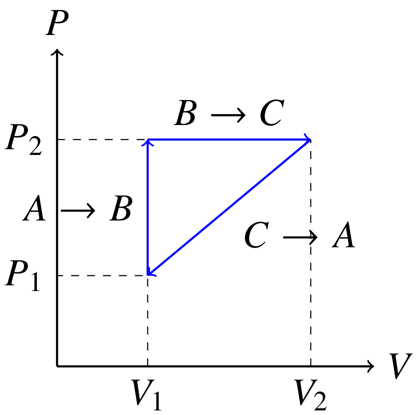
(A) $\frac{1}{2}$

(B) $\frac{3}{5}$

(C) $\frac{2}{5}$

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

Q23. An ideal gas undergoes a closed thermodynamic cycle as displayed in the pressure-volume (P-V) diagram below. Find the net mechanical work done by the gas during this complete cycle.



(A) $(P_2 - P_1)(V_2 - V_1)$

(B) $\frac{1}{2}(P_2 - P_1)(V_2 - V_1)$

(C) $\frac{1}{2}(P_2 + P_1)(V_2 - V_1)$

(D) $2(P_2 - P_1)(V_2 - V_1)$

Q24. An ideal heat engine works in a reversible Carnot cycle between temperatures $T_H = 500$ K and $T_C = 300$ K. If the engine rejects 150 J of heat to the low-temperature cold reservoir per cycle, the work output delivered per cycle is:

(A) 100 J

(B) 250 J

(C) 150 J

(D) 75 J

Q25. The root-mean-square (rms) velocity of molecules of a certain gas at a temperature of 27°C is v. If the gas is heated such that its absolute temperature in Kelvin is doubled, the new rms speed of the gas molecules is:

(A) $2v$

(B) $\sqrt{2}v$

(C) $4v$

(D) $\frac{v}{\sqrt{2}}$

Q26. In an adiabatic state change process, the pressure P of a fixed mass of gas is found to be proportional to the cube of its absolute temperature T ($P \propto T^3$). The ratio of specific heats ($\gamma = C_p/C_v$) for this specific gas sample is:

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

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

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

(D) $\frac{7}{5}$

Q27. A point object is positioned along the principal axis of a convex lens with focal length $f = 20$ cm at a distance of 30 cm from the optical center. A plane mirror is positioned perpendicular to the axis at a distance of 15 cm behind the lens. The final image location produced by this optical combination is:

(A) Real and located 60 cm behind the lens.

(B) Virtual and located 30 cm in front of the lens.

(C) Real and located 30 cm in front of the lens.

(D) Virtual and located at infinity.

Q28. In a standard Young's Double Slit Experiment (YDSE), the slit separation distance is d and the distance to the screen is D. When light of wavelength $\lambda_1 = 600$ nm is used, the 4th bright fringe forms at a certain distance y from the central line. If light of wavelength λ_2 produces its 5th bright fringe at that exact same location y, then λ_2 must be:

(A) 480 nm

(B) 500 nm

(C) 750 nm

(D) 400 nm

Q29. A particle is executing Simple Harmonic Motion (SHM) along a straight line according to the position equation $x = A\sin(\omega t)$. At what displacement from its central equilibrium position ($x = 0$) will its mechanical kinetic energy be exactly equal to its potential energy?

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

(B) $\pm\frac{A}{\sqrt{2}}$

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

(D) $\pm\frac{A}{4}$

Q30. A wave traveling down a taut string is mathematically modeled by the wave function $y(x,t) = 0.05\sin(40t - 2x)$, where all physical parameters are in SI units. The propagation speed of this transverse wave is:

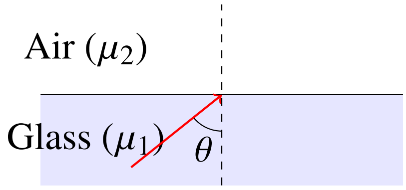
(A) 20 m/s

(B) 80 m/s

(C) 0.05 m/s

(D) 10 m/s

Q31. A ray of light traveling inside a glass medium of refractive index $\mu_1 = \sqrt{3}$ strikes the glass-air interface ($\mu_2 = 1$). What is the critical angle θ_c for total internal reflection at this boundary?



(A) 30°

(B) 45°

(C) 60°

(D) $\sin^{-1}\left(\frac{1}{3}\right)$

Q32. An open organ pipe has a fundamental resonance frequency of f_0. If one end of this organ pipe is closed securely, the frequency of its first overtone harmonic standing wave becomes:

(A) $\frac{1}{2}f_0$

(B) f_0

(C) $\frac{3}{2}f_0$

(D) $2f_0$

Q33. Unpolarized light of initial intensity I_0 passes through two linear polarizing sheets. The transmission axis of the second polarizer is tilted at an angle of 60° relative to the transmission axis of the first polarizer. The final intensity I of light exiting the second polarizer is:

(A) $\frac{I_0}{2}$

(B) $\frac{I_0}{4}$

(C) $\frac{I_0}{8}$

(D) $\frac{3I_0}{8}$

Q34. Two coherent sound sources oscillate in phase and are separated by a distance of 2.0 m. A detector moves along a path parallel to the line joining the sources. If the wavelength of the emitted sound waves is $\lambda = 0.5$ m, the total number of interference maxima that can be detected along an infinitely long path is:

(A) 4

(B) 7

(C) 8

(D) 9

Q35. When light of frequency ν hits a photosensitive metal plate, the maximum kinetic energy of the emitted photoelectrons is $K_{\max}$. If the frequency of the incident light beam is doubled (2ν), the new maximum kinetic energy of the ejected photoelectrons will be:

(A) $2K_{\max}$

(B) $K_{\max} + h\nu$

(C) $2K_{\max} + \phi$

(D) $2K_{\max} - h\nu$

Q36. In the hydrogen atom Bohr model, an electron undergoes a radiative transition from the $n = 3$ energy level to the $n = 2$ ground-state equivalent level. The wavelength of the emitted photon is proportional to the Rydberg constant R according to:

(A) $\frac{5R}{36}$

(B) $\frac{36}{5R}$

(C) $\frac{4R}{9}$

(D) $\frac{9}{4R}$

Q37. A radioactive sample has an initial net activity count of A_0 at time $t = 0$. If its half-life decay period is $T_{1/2}$, the remaining activity A of the sample at an elapsed time of $t = 3.5T_{1/2}$ is given by:

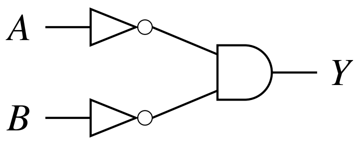
(A) $\frac{A_0}{8}$

(B) $\frac{A_0}{8\sqrt{2}}$

(C) $\frac{A_0}{16}$

(D) $\frac{A_0}{4\sqrt{2}}$

Q38. Identify the final output logic function Y for the logic gate circuit assembly depicted below.



(A) $A \cdot B$

(B) $A + B$

(C) $\overline{A \cdot B}$

(D) $\overline{A} \cdot \overline{B}$

Q39. The de-Broglie wavelength of an electron accelerated from rest across an electrical potential difference of $V = 100$ V is approximately:

(A) 0.123 nm

(B) 1.23 nm

(C) 12.3 nm

(D) 0.012 nm

Q40. In an intrinsic semiconductor material, the band gap energy width is $E_g = 1.2$ eV. The minimum photon frequency required to excite a valence band electron across into the conduction band is close to ($h = 6.63 \times 10^{-34}$ J · s):

(A) 2.9×10^{14} Hz

(B) 1.8×10^{14} Hz

(C) 5.2×10^{14} Hz

(D) 4.1×10^{14} Hz

Detailed Solutions

Q1.

Solution

Concept:
Static equilibrium requires that the net vector sum of all external forces acting on a body must equal zero. When an object is placed on a smooth inclined plane, the gravitational force acts vertically downwards, tending to slide the block down the incline. To balance this movement, an external force must introduce an opposing component along the plane's surface. Resolving vectors along the inclined axis simplifies the balance.

Solution:

(a) Consider the components of forces acting parallel to the surface of the inclined plane. The component of the weight of the block directed down the incline is given by $mg\sin\theta$.

(b) The externally applied horizontal force F acts at an angle θ relative to the incline surface. Resolving this horizontal force parallel to the incline gives an upward component equal to $F\cos\theta$.

(c) For the block to remain completely at rest in stable static equilibrium, these two opposing translational force components along the surface must have identical magnitudes.

(d) Setting them equal gives the relation: $F\cos\theta = mg\sin\theta$. Rearranging this equation allows us to express the force as $F = mg\tan\theta$.

(e) Substituting the given values ($m = 2$ kg, $g = 10$ m/s^2, and $\theta = 30°$) into the expression yields: $F = 2 \times 10 \times \tan(30°) = \frac{20}{\sqrt{3}}$ N.

Final Answer: The required horizontal force is 20 over square root of 3 Newtons.

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept:

A conservative force field can be characterized entirely by its potential energy function $U(x)$. The mechanical force experienced by a particle in this field is mathematically defined as the negative spatial gradient of the potential energy. Stable equilibrium positions represent local minima in the potential energy profile, where the net force vanishes and the system naturally resists small displacements.

Solution:

(a) The relationship between a conservative force and potential energy is given by $F(x) = -\frac{dU}{dx}$. We begin by differentiating the given function $U(x) = \frac{a}{x^2} - \frac{b}{x}$ with respect to position x.

(b) Performing the derivative yields: $\frac{dU}{dx} = -\frac{2a}{x^3} + \frac{b}{x^2}$. Therefore, the force acting on the particle can be expressed explicitly as $F(x) = \frac{2a}{x^3} - \frac{b}{x^2}$.

(c) At any equilibrium point, the net force acting on the particle must be zero. Setting $F(x) = 0$ leads directly to the algebraic relation: $\frac{2a}{x^3} = \frac{b}{x^2}$.

(d) Solving this equation for the position variable x gives the equilibrium distance from the origin: $x = \frac{2a}{b}$.

(e) To confirm stability, we check that the second derivative $\frac{d^2U}{dx^2}$ is positive at this point. Differentiating again gives $\frac{6a}{x^4} - \frac{2b}{x^3}$, which is strictly positive when $x = \frac{2a}{b}$, proving it is a stable configuration.

Final Answer: The distance for stable equilibrium is 2a over b.

Answer: (B)

Go Back to Question 2

Q3.

Solution

Concept:
When a symmetrical rigid body rolls without slipping down an inclined surface, its total gravitational potential energy is converted simultaneously into both translational and rotational kinetic energy. This dual distribution reduces the linear acceleration of the rolling body compared to a purely sliding frictionless object. The reduction factor depends directly on the geometric mass distribution of the body.

Solution:

(a) The general formula for the linear acceleration of a symmetric body rolling down an incline of angle α without slipping is expressed as $a = \frac{g \sin \alpha}{1+\frac{I}{MR^2}}$.

(b) In this equation, M represents the total mass of the object, R represents its radius, and I denotes the moment of inertia about its central geometric axis of rotation.

(c) For a uniform solid cylinder, the distribution of mass yields a central moment of inertia equal to $I = \frac{1}{2}MR^2$.

(d) Substituting this specific moment of inertia value into our general acceleration formula simplifies the denominator term: $1 + \frac{\frac{1}{2}MR^2}{MR^2} = 1 + \frac{1}{2} = \frac{3}{2}$.

(e) Finally, dividing the numerator by this combined factor yields the linear acceleration down the incline: $a = \frac{g \sin \alpha}{3/2} = \frac{2}{3}g \sin \alpha$.

Final Answer: The linear acceleration is two-thirds g sine alpha.

Answer: (C)

Go Back to Question 3

Q4.

Solution

Concept:
The total moment of inertia of a composite rigid system about an axis is equal to the sum of the moments of inertia of its individual component parts about that exact same axis. When a uniform object is divided or altered, the mass and length parameters of each component segment must be carefully adjusted before calculating the rotational resistance.

Solution:

(a) The original uniform rod of mass M and length L is bent exactly at its midpoint. This creates two identical straight segments, each possessing a mass of $m = \frac{M}{2}$ and a length of $l = \frac{L}{2}$.

(b) The reference axis passes directly through the vertex where the two segments meet. This means the axis is located at one of the endpoints for both individual linear segments.

(c) The moment of inertia of a uniform straight rod rotating about an axis passing through one of its endpoints is given by the standard formula $I_{\text{segment}} = \frac{1}{3}ml^2$.

(d) Substituting the fractional mass and length parameters for one segment gives: $I_{\text{segment}} = \frac{1}{3}\left(\frac{M}{2}\right)\left(\frac{L}{2}\right)^2 = \frac{1}{3} \times \frac{M}{2} \times \frac{L^2}{4} = \frac{ML^2}{24}$.

(e) Since both segments are identical and share the same vertex axis, the total moment of inertia of the bent rod is: $I_{\text{total}} = 2 \times I_{\text{segment}} = 2 \times \frac{ML^2}{24} = \frac{1}{12}ML^2$.

Final Answer: The total moment of inertia is ML squared over 12.

Answer: (B)

Go Back to Question 4

Q5.

Solution

Concept:
The escape velocity represents the minimum speed required for a payload to permanently break free from the gravitational field of a massive body. This speed depends strictly on the distance from the center of the planet to the launch point. Orbiting speed can be linked directly to surface gravity using Newton's law of universal gravitation.
Solution:

(a) The satellite orbits at an altitude equal to the Earth's radius R. Therefore, the total distance from the center of the Earth to the satellite is $r = R + R = 2R$.

(b) The general formula for escape velocity from any position at a distance r from the center of a planet of mass M_E is given by $v_e = \sqrt{\frac{2GM_E}{r}}$.

(c) Substituting the radial distance of the satellite ($r = 2R$) into this relation gives the expression: $v_e = \sqrt{\frac{2GM_E}{2R}} = \sqrt{\frac{GM_E}{R}}$.

(d) We can relate the gravitational constant to the acceleration due to gravity g at the surface of the Earth using the standard equation $g = \frac{GM_E}{R^2}$, which implies $GM_E = gR^2$.

(e) Substituting $GM_E = gR^2$ into the escape velocity expression yields: $v_e = \sqrt{\frac{gR^2}{R}} = \sqrt{gR}$.

Final Answer: The escape velocity is the square root of gR.

Answer: (A)

Go Back to Question 5

Q6.

Solution

Concept:
In a coupled multi-body system connected by a light string, the motion is dictated by the net unbalanced external forces. Once the uniform system acceleration is derived via Newton's second law, internal string tension can be determined. Work done by a constant internal force is then found by calculating the scalar product of the tension vector and the displacement vector over time.
Solution:

(a) First, determine the acceleration of the system using Newton's second law: $a = \frac{(m_1 - m_2)g}{m_1 + m_2}$. Substituting the masses gives $a = \frac{(4-1)\times 10}{4+1} = \frac{30}{5} = 6\ \text{m/s}^2$.

(b) Next, calculate the tension T in the connecting string by setting up a force balance equation for the smaller mass m_2, which moves upward: $T - m_2 g = m_2 a \implies T = m_2(g + a)$.

(c) Substituting the values yields the operational string tension: $T = 1 \times (10 + 6) = 16$ N.

(d) Now determine the vertical displacement s of mass m_2 during the first second ($t = 1$ s) starting from rest: $s = \frac{1}{2}at^2 = \frac{1}{2} \times 6 \times (1)^2 = 3$ m.

(e) Since the tension force and the displacement vector for mass m_2 are both directed upward, the work done is positive: $W = T \cdot s = 16\ \text{N} \times 3\ \text{m} = 48$ J.

Final Answer: The work done by tension is 48 Joules.

Answer: (D)

Go Back to Question 6

Q7.

Solution

Concept:
According to the law of conservation of mechanical energy, the total energy E of a particle moving in a conservative field remains constant throughout its trajectory. The total energy is the sum of kinetic energy and potential energy. The speed of the particle reaches its absolute maximum value when the potential energy function hits its absolute minimum value.
Solution:

(a) The total mechanical energy equation is expressed as $E = K + U(x)$, where $K = \frac{1}{2}mv^2$ is the kinetic energy and $U(x) = kx^4$ is the position-dependent potential energy.

(b) To find the maximum speed, we look for the position where the potential energy $U(x)$ is minimized. The function $U(x) = kx^4$ has a minimum value of zero when the position coordinate $x = 0$.

(c) At this origin point ($x = 0$), the potential energy drops to zero ($U = 0$), meaning all the available mechanical energy is converted into kinetic energy.

(d) Setting the maximum kinetic energy equal to the total energy gives the following algebraic equation: $\frac{1}{2}mv_{\text{max}}^2 = E$.

(e) Isolating the velocity variable yields the maximum speed of the body: $v_{\text{max}} = \sqrt{\frac{2E}{m}}$.

Final Answer: The maximum speed is the square root of 2E over m.

Answer: (A)

Go Back to Question 7

Q8.

Solution

Concept:
An object falling through a real viscous fluid experiences three distinct forces: gravity acting downwards, buoyancy acting upwards, and a speed-dependent viscous drag force acting opposite to the velocity vector. As the velocity increases, the viscous drag grows until the upward forces completely balance the downward pull of gravity.
Solution:

(a) When the light sphere is released from rest ($v = 0$ at $t = 0$), the net downward force is determined by gravity minus buoyancy, which initiates a positive initial acceleration.

(b) According to Stokes' Law, the resistive viscous drag force is directly proportional to the instantaneous velocity of the falling sphere ($F_v = 6\pi\eta r v$).

(c) As the sphere accelerates, the increasing drag force continuously reduces the net downward acceleration of the object over time.

(d) Mathematically, this behavior results in a first-order differential equation that yields an exponentially converging velocity function: $v(t) = v_t(1 - e^{-bt})$.

(e) This function represents a smooth curve that starts at the origin and rises asymptotically toward a fixed limiting horizontal line known as the terminal velocity.

Final Answer: The curve increases asymptotically toward a fixed terminal velocity.

Answer: (C)

Go Back to Question 8

Q9.

Solution

Concept:
The work-energy theorem states that the net work done by all forces acting on a particle is equal to the change in its kinetic energy. When dealing with a spatially variable force field, the work done must be computed by evaluating the line integral of the force vector along the path of displacement.
Solution:

(a) The work-energy relation is given by $\Delta K = W = \int \vec{F} \cdot d\vec{r}$, where $d\vec{r} = dx\hat{i} + dy\hat{j}$ is the incremental displacement vector.

(b) Substituting the force components yields two separate single-variable integrals along the coordinate axes: $W = \int_0^2 3x^2\, dx + \int_0^3 2y\, dy$.

(c) Evaluate the first integral with respect to x over its limits from 0 to 2: $\int_0^2 3x^2\, dx = \left[x^3\right]_0^2 = 2^3 - 0 = 8$ J.

(d) Evaluate the second integral with respect to y over its limits from 0 to 3: $\int_0^3 2y\, dy = \left[y^2\right]_0^3 = 3^2 - 0 = 9$ J.

(e) Summing the work contributions along both dimensions gives the total change in kinetic energy: $\Delta K = 8 + 9 = 17$ J.

Final Answer: The change in kinetic energy is 17 Joules.

Answer: (B)

Go Back to Question 9

Q10.

Solution

Concept:
When an interaction occurs entirely along a central axis with no external torques, the total angular momentum of the system must be conserved. However, internal non-conservative forces like friction between colliding surfaces will dissipate mechanical kinetic energy into heat until both bodies reach a common rotational velocity.

Solution:

(a) Let the moment of inertia of a single disk be I. The initial angular momentum of the system is entirely due to the first disk: $L_i = I\omega_0$.

(b) After the second disk is dropped coaxially, they spin together. The final combined moment of inertia is $I_f = I + I = 2I$. Conservation of angular momentum gives: $I\omega_0 = 2I\omega_f \implies \omega_f = \frac{\omega_0}{2}$.

(c) The initial kinetic energy of the system is given by the formula: $K_i = \frac{1}{2}I\omega_0^2$.

(d) The final total rotational kinetic energy after the collision is: $K_f = \frac{1}{2}(2I)\omega_f^2 = \frac{1}{2}(2I)\left(\frac{\omega_0}{2}\right)^2 = \frac{1}{4}I\omega_0^2$.

(e) The fraction of kinetic energy lost is determined by the ratio: $\frac{K_i - K_f}{K_i} = \frac{\frac{1}{2}I\omega_0^2 - \frac{1}{4}I\omega_0^2}{\frac{1}{2}I\omega_0^2} = \frac{1}{2}$.

Final Answer: The fraction of kinetic energy lost is one-half.

Answer: (B)

Go Back to Question 10

Q11.

Solution

Concept:
The acceleration due to gravity changes with both altitude above and depth below the Earth's surface. At small distances relative to the Earth's radius, these changes can be evaluated using simplified linear approximations derived from binomial expansions of the universal gravitation formulas.

Solution:

(a) The acceleration due to gravity at a height h above the surface of the Earth, where $h \ll R$, is given by the linear approximation $g_h = g\left(1 - \frac{2h}{R}\right)$.

(b) The acceleration due to gravity at a depth d below the surface of the Earth is given by the linear expression $g_d = g\left(1 - \frac{d}{R}\right)$.

(c) The problem states that the acceleration due to gravity at height h is identical to the acceleration due to gravity at depth d, so we can equate the two expressions directly.

(d) Setting the equations equal yields $g\left(1 - \frac{2h}{R}\right) = g\left(1 - \frac{d}{R}\right)$, which simplifies by canceling the surface gravity term g from both sides.

(e) Further algebraic simplification leads to the relation $1 - \frac{2h}{R} = 1 - \frac{d}{R}$, which simplifies directly to $\frac{2h}{R} = \frac{d}{R}$, giving the final relationship $d = 2h$.

Final Answer: d = 2h

Answer: (B)

Go Back to Question 11

Q12.

Solution

Concept:
The total electric field vector at any point in space due to a collection of point charges is the vector sum of the individual electric fields produced by each charge. This fundamental principle of electrostatic physics is known as the principle of superposition.

Solution:

(a) Consider a square of side a with charges $+q, +q, -q, -q$ placed at its vertices in clockwise order. Let the vertices be labeled $1, 2, 3, 4$. The distance from any vertex to the geometric center is $r = \frac{a}{\sqrt{2}}$.

(b) The magnitude of the electric field produced at the center by any single charge q is given by $E_0 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{2q}{a^2}$.

(c) The positive charge at vertex 1 and the negative charge at the diagonally opposite vertex 3 produce fields that point in the same direction along that diagonal, adding up to $2E_0$.

(d) Similarly, the positive charge at vertex 2 and the negative charge at vertex 4 produce fields along the other diagonal that point in the same direction, adding up to $2E_0$.

(e) Because the two diagonals of a square are perpendicular to each other, the two resultant fields are at a 90° angle. The total field magnitude is $\sqrt{(2E_0)^2 + (2E_0)^2} = 2\sqrt{2}E_0 = \frac{1}{4\pi\varepsilon_0}\frac{4\sqrt{2}q}{a^2}$.

Final Answer: $1\frac{}{4\pi\varepsilon_0\frac{4\sqrt{2}q}{a^2}}$

Answer: (C)

Go Back to Question 12

Q13.

Solution

Concept:
An infinite ladder network can be solved by recognizing that removing or adding one recurring basic unit cell section does not alter the total equivalent input resistance of an infinite system. This characteristic allows the network to be modeled as a simplified quadratic equation.

Solution:

(a) Let the total equivalent resistance between the input nodes A and B be represented by the variable R_{eq}.

(b) Because the ladder circuit extends infinitely to the right, the remaining network after the first vertical resistor section also has an equivalent resistance equal to R_{eq}.

(c) This allows us to redraw the entire infinite network as a single series resistor R connected to a parallel combination of the vertical resistor R and the effective resistance R_{eq}.

(d) Expressing this combination mathematically gives the relation $R_{eq} = R + \frac{R \cdot R_{eq}}{R + R_{eq}}$, which can be expanded to $R_{eq}(R + R_{eq}) = R(R + R_{eq}) + R \cdot R_{eq}$.

(e) This expands to the quadratic equation $R_{eq}^2 - R \cdot R_{eq} - R^2 = 0$. Solving for the positive roots yields $R_{eq} = \frac{1+\sqrt{5}}{2}R$.

Final Answer: $1+\sqrt{5}_{\overline{2R}}$

Answer: (C)

Go Back to Question 13

Q14.

Solution

Concept:
When a parallel plate capacitor is filled with distinct dielectric slabs layered parallel to the conducting plates, each slab layer can be modeled as an independent capacitor. Because the same electric displacement line passes through both layers, the configuration behaves like two capacitors connected in a series arrangement.

Solution:

(a) The original capacitance with air separating the plates is given by $C_0 = \frac{\varepsilon_0 A}{d}$, where A is the area of the plates and d is the total separation distance.

(b) The first dielectric slab creates a capacitive segment with thickness $\frac{d}{2}$ and dielectric constant K_1, giving a value of $C_1 = \frac{K_1\varepsilon_0 A}{d/2} = \frac{2K_1\varepsilon_0 A}{d} = 2K_1C_0$.

(c) The second dielectric slab forms another capacitive segment with thickness $\frac{d}{2}$ and dielectric constant K_2, giving a value of $C_2 = \frac{K_2\varepsilon_0 A}{d/2} = \frac{2K_2\varepsilon_0 A}{d} = 2K_2C_0$.

(d) Since these two dielectric layers are stacked on top of one another between the plates, they are connected in series, meaning their equivalent capacitance is $C = \frac{C_1C_2}{C_1+C_2}$.

(e) Substituting the values for C_1 and C_2 into the series combination formula yields $C = \frac{(2K_1C_0)(2K_2C_0)}{2K_1C_0+2K_2C_0} = \frac{2K_1K_2}{K_1+K_2}C_0$.

Final Answer: $2\mathrm{K}_1K_2\overline{K_1+K_2C_0}$

Answer: (B)

Go Back to Question 14

Q15.

Solution

Concept:

Ampere's Circuital Law states that the line integral of the magnetic field vector around any closed loop is equal to the permeability of free space multiplied by the total enclosed current. For cylindrical symmetry, an Amperean loop can isolate the field within the conductor walls.

Solution:

(a) Consider a circular Amperean loop of radius r located entirely inside the thick material of the hollow cylindrical conductor, meaning its radius satisfies the condition $a < r < b$.

(b) The total current I_{enc} enclosed by this circular loop is found by integrating the uniform current density J over the cross-sectional area of the channel: $I_{\text{enc}} = J\pi(r^2 - a^2)$.

(c) Applying Ampere's law around the symmetric path gives the line integral equation $B \cdot 2\pi r = \mu_0 I_{\text{enc}}$, where B is the magnitude of the magnetic field at radius r.

(d) Substituting the enclosed current expression into Ampere's law yields the relation $B \cdot 2\pi r = \mu_0 J\pi(r^2 - a^2)$.

(e) Solving for the magnetic field magnitude gives $B = \frac{\mu_0 J}{2}\left(\frac{r^2-a^2}{r}\right) = \frac{\mu_0 J}{2}\left(r - \frac{a^2}{r}\right)$, which shows that B is proportional to $r - \frac{a^2}{r}$.

Final Answer: r - a$^2\frac{}{r}$

Answer: (C)

Go Back to Question 15

Q16.

Solution

Concept:
When a conducting loop enters a localized magnetic field, the change in the magnetic flux passing through the loop's surface area induces an electromotive force (emf) according to Faraday's law. This induced voltage causes a current to flow, which dissipates energy as thermal power due to electrical resistance.

Solution:

(a) As the rectangular wire loop enters the magnetic field region with a constant velocity v, the magnetic flux passing through the loop increases at a steady rate.

(b) The magnitude of the induced electromotive force along the leading vertical edge of width w cutting through the field lines is given by the motional emf formula $V = Bwv$.

(c) This induced voltage drives an electrical current around the circuit loop. The magnitude of this current is given by Ohm's law: $I = \frac{V}{R} = \frac{Bwv}{R}$.

(d) The thermal power dissipated as Joule heating within the wire loop due to its electrical resistance can be calculated using the power equation $P = I^2R$.

(e) Substituting the current expression into the power formula yields $P = \left(\frac{Bwv}{R}\right)^2 R = \frac{B^2w^2v^2}{R}$.

Final Answer: $\mathrm{B}^2w^2v^2{}_{\overline{R}}$

Answer: (A)

Go Back to Question 16

Q17.

Solution

Concept:
In an alternating current circuit containing inductive and capacitive elements alongside resistance, the total opposition to current flow is called impedance. The average power consumed by the network depends entirely on the resistive component, as reactive components store and release energy without consuming power over a cycle.
Solution:

(a) First, calculate the total net reactance X of the series circuit by taking the difference between the inductive and capacitive reactances: $X = X_L - X_C = 80 - 40 = 40\ \Omega$.

(b) Next, determine the total electrical impedance Z of the series network using the vector addition formula: $Z = \sqrt{R^2 + X^2} = \sqrt{30^2 + 40^2} = 50\ \Omega$.

(c) Calculate the root-mean-square current I_{rms} flowing through the circuit loop using Ohm's law for AC systems: $I_{rms} = \frac{V_{rms}}{Z} = \frac{200}{50} = 4$ A.

(d) The power factor of the circuit is given by the ratio of resistance to total impedance: $\cos\phi = \frac{R}{Z} = \frac{30}{50} = \frac{3}{5}$.

(e) Calculate the average power consumed using the standard AC power formula: $P = V_{rms} I_{rms} \cos\phi = 200 \times 4 \times \frac{3}{5} = 480$ W.

Final Answer: 480 W

Answer: (B)

Go Back to Question 17

Q18.

Solution

Concept:
When a charged particle is accelerated from rest through an electric potential difference, it gains kinetic energy equal to its charge multiplied by the potential. If it then enters a uniform magnetic field perpendicularly, the magnetic force acts as a centripetal force, driving the particle into a circular path.

Solution:

(a) A particle of charge q and mass m accelerated through a potential V gains kinetic energy $K = qV$. The momentum of the particle can be expressed as $p = \sqrt{2mK} = \sqrt{2mqV}$.

(b) The radius of the circular path in a magnetic field B is given by the equation $r = \frac{p}{qB} = \frac{\sqrt{2mqV}}{qB} = \frac{1}{B}\sqrt{\frac{2mV}{q}}$.

(c) This formula demonstrates that for a constant accelerating potential V and magnetic field B, the radius of the path is proportional to the factor $\sqrt{\frac{m}{q}}$.

(d) For an alpha particle, the mass is $m_\alpha = 4m_p$ and the charge is $q_\alpha = 2q_p$. Substituting these values gives the radius proportion: $r_\alpha \propto \sqrt{\frac{4m_p}{2q_p}} = \sqrt{2}\sqrt{\frac{m_p}{q_p}}$.

(e) Taking the ratio of the circular path radii for the alpha particle and the proton yields $\frac{r_\alpha}{r_p} = \frac{\sqrt{2}\sqrt{m_p/q_p}}{\sqrt{m_p/q_p}} = \frac{\sqrt{2}}{1}$, or $\sqrt{2} : 1$.

Final Answer: $\sqrt{2} : 1$

Answer: (B)

Go Back to Question 18

Q19.

Solution

Concept:
The potential energy of a magnetic dipole in a uniform external magnetic field depends on its orientation relative to the field vector. The work required to change the orientation of the dipole is equal to the difference between its final and initial potential energy states.

Solution:

(a) The potential energy U of a magnetic dipole with dipole moment $\vec{M}$ in a uniform magnetic field $\vec{B}$ is given by the scalar dot product formula $U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$.

(b) Initially, the magnetic dipole is aligned parallel to the external field lines, which means the initial orientation angle is $\theta_1 = 0°$.

(c) Calculate the initial potential energy of the configuration: $U_i = -MB\cos(0°) = -MB$.

(d) The dipole is then rotated to an orientation opposite to the field, making the final alignment angle $\theta_2 = 180°$. Calculate the final potential energy: $U_f = -MB\cos(180°) = +MB$.

(e) The mechanical work W required to perform this rotation is equal to the change in potential energy: $W = U_f - U_i = MB - (-MB) = 2MB$.

Final Answer: 2MB

Answer: (C)

Go Back to Question 19

Q20.

Solution

Concept:

The self-inductance of an ideal inductor measures its ability to oppose changes in the electrical current flowing through it by inducing a opposing electromotive force. For a long solenoid, this property depends on the total number of turns and the physical dimensions of the core.

Solution:

(a) The formula for the self-inductance L of a long, ideal air-core solenoid is given by $L = \frac{\mu_0 N^2 A}{l}$, where N is the total number of turns, A is the cross-sectional area, and l is the length.

(b) This structural formula shows that the self-inductance of the solenoid is directly proportional to the square of the total number of turns ($L \propto N^2$).

(c) According to the problem statement, the total number of turns is doubled to a new value $N' = 2N$, while the length l and area A remain unchanged.

(d) Expressing the new self-inductance L' in terms of the modified turns gives the equation: $L' = \frac{\mu_0 (2N)^2 A}{l} = \frac{4\mu_0 N^2 A}{l}$.

(e) Comparing this expression to the original self-inductance value shows that the new inductance is four times the initial value: $L' = 4L$.

Final Answer: 4L

Answer: (B)

Go Back to Question 20

Q21.

Solution

Concept:

According to the generalized Ampere-Maxwell law, a changing electric field or displacement current density creates a localized magnetic field. For a cylindrical geometry between capacitor plates, the induced magnetic field lines form concentric loops centered around the principal longitudinal axis.

Solution:

(a) Consider a circular Amperean loop of radius $r = \frac{R}{2}$ located coaxially between the plates. The area enclosed by this smaller loop is given by $\pi r^2 = \pi \left(\frac{R}{2}\right)^2 = \frac{\pi R^2}{4}$.

(b) The problem states that the displacement current density is uniform across the space and equals J_d. The total displacement current enclosed by the loop is $I_d = J_d \cdot \text{Area} = J_d \pi r^2$.

(c) Applying the Ampere-Maxwell law along the boundary of this symmetric loop yields the line integral relation $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_d$, which simplifies to $B \cdot 2\pi r = \mu_0 J_d \pi r^2$.

(d) Canceling out the common factor of πr from both sides of the equation allows us to isolate the magnetic field strength, resulting in the expression $B = \frac{1}{2}\mu_0 J_d r$.

(e) Substituting the specific value of the radial distance $r = \frac{R}{2}$ into this expression gives the final induced field strength as $B = \frac{1}{2}\mu_0 J_d \left(\frac{R}{2}\right) = \frac{1}{4}\mu_0 J_d R$.

Final Answer: $1_{\overline{4\mu_0 J_d R}}$

Answer: (B)

Go Back to Question 21

Q22.

Solution

Concept:
When an ideal gas undergoes an isobaric thermodynamic expansion process, the total thermal energy absorbed is divided between changing the internal energy of the molecules and doing mechanical boundary work against the constant external pressure environment.

Solution:

(a) For an isobaric process, the total heat energy absorbed by n moles of an ideal gas is given by the relation $Q = nC_p\Delta T$, where C_p is the molar specific heat capacity at constant pressure.

(b) The corresponding change in the internal energy of the system depends exclusively on the temperature change and is expressed by the formula $\Delta U = nC_v\Delta T$, where C_v is the specific heat at constant volume.

(c) The question specifies that the substance is an ideal monatomic gas. For a monatomic molecular structure, the molar heat capacities are known to be $C_v = \frac{3}{2}R$ and $C_p = \frac{5}{2}R$.

(d) To find the fraction of total heat energy that contributes to the internal energy change, we take the ratio of the internal energy change to the total heat input, which gives the expression $\frac{\Delta U}{Q} = \frac{nC_v\Delta T}{nC_p\Delta T}$.

(e) Simplifying this fraction by canceling out common terms yields $\frac{C_v}{C_p} = \frac{(3/2)R}{(5/2)R} = \frac{3}{5}$. Thus, exactly three-fifths of the total absorbed heat energy is stored internally.

Final Answer: $3_{\overline{5}}$

Answer: (B)

Go Back to Question 22

Q23.

Solution

Concept:

On a standard pressure-volume thermodynamic diagram, the net mechanical work performed by a working substance during a complete closed operating cycle is represented geometrically by the total area enclosed within the boundaries of the path trajectory.

Solution:

(a) The given thermodynamic closed path forms a right-angled triangle on the P-V coordinate plane, with vertices tracking the sequential transformations $A \rightarrow B \rightarrow C \rightarrow A$.

(b) The net work done during the cycle is equal to the area of this triangle. The base of the triangle lies along the horizontal volume axis, spanning the distance from the initial volume V_1 to the final volume V_2.

(c) The length of this horizontal base is given by the difference expression Base $= V_2 - V_1$.

(d) The height of the triangle runs parallel to the vertical pressure axis, extending from the lower operating pressure level P_1 up to the higher operating pressure level P_2.

(e) The length of this vertical height is given by the difference expression Height $= P_2 - P_1$. Using the standard formula for the area of a triangle, the net mechanical work equals $\frac{1}{2} \times \text{Base} \times \text{Height} = \frac{1}{2}(P_2 - P_1)(V_2 - V_1)$.

Final Answer: $1_{\overline{2(P_2-P_1)(V_2-V_1)}}$

Answer: (B)

Go Back to Question 23

Q24.

Solution

Concept:
A reversible Carnot heat engine operates at maximum theoretical thermodynamic efficiency. The ratio of the heat energy rejected to the cold sink to the heat energy absorbed from the hot source is strictly determined by the ratio of their absolute operating temperatures.

Solution:

(a) The fundamental property governing a Carnot cycle states that the heat transfer ratio matches the absolute temperature ratio, which is expressed mathematically as $\frac{Q_H}{Q_C} = \frac{T_H}{T_C}$.

(b) The problem provides the hot reservoir temperature $T_H = 500$ K, the cold reservoir temperature $T_C = 300$ K, and the heat rejected to the sink per cycle $Q_C = 150$ J.

(c) Substituting these known quantities into the ratio formula allows us to solve for the heat input: $Q_H = Q_C \cdot \left(\frac{T_H}{T_C}\right) = 150 \cdot \left(\frac{500}{300}\right) = 250$ J.

(d) According to the first law of thermodynamics, the net mechanical work output produced per operational cycle is equal to the difference between the heat absorbed and the heat rejected.

(e) Evaluating this energy balance equation gives $W = Q_H - Q_C = 250\text{ J} - 150\text{ J} = 100$ J. Therefore, the total work output delivered per cycle is exactly 100 Joules.

Final Answer: 100 J

Answer: (A)

Go Back to Question 24

Q25.

Solution

Concept:
The root-mean-square velocity of the individual molecules in an ideal gas sample is directly related to the absolute thermodynamic temperature of the system. This relationship is derived from the kinetic theory of gases, which links average molecular kinetic energy to temperature.
Solution:

(a) According to the kinetic theory of gases, the root-mean-square velocity of gas molecules is given by the formula $v_{\text{rms}} = \sqrt{\frac{3RT}{M}}$, where R is the universal gas constant and M is the molar mass.

(b) This mathematical relationship demonstrates that for a specific gas sample, the rms velocity is directly proportional to the square root of its absolute temperature expressed in Kelvin ($v_{\text{rms}} \propto \sqrt{T}$).

(c) The problem states that the initial root-mean-square speed of the gas at an initial absolute temperature T_1 is given as v.

(d) The gas is subsequently heated until its absolute temperature is doubled, meaning the final absolute temperature of the system satisfies the relation $T_2 = 2T_1$.

(e) Taking the ratio of the final velocity to the initial velocity yields $\frac{v'}{v} = \sqrt{\frac{T_2}{T_1}} = \sqrt{\frac{2T_1}{T_1}} = \sqrt{2}$, which gives the final value $v' = \sqrt{2}v$.

Final Answer: $\sqrt{2}v$

Answer: (B)

Go Back to Question 25

Q26.

Solution

Concept:
During an ideal adiabatic state change, no thermal energy is exchanged with the surrounding environment. The pressure, volume, and absolute temperature variables track along a specific path governed by the ratio of specific heats of the gas sample.

Solution:

(a) The standard state equation relating pressure and absolute temperature for a reversible adiabatic process is given by the expression $P^{1-\gamma}T^{\gamma}$ = constant, which can be rewritten as $P \propto T^{\frac{\gamma}{\gamma-1}}$.

(b) The problem states that the observed pressure of this gas sample is directly proportional to the cube of its absolute temperature, which is written as $P \propto T^3$.

(c) By comparing the exponent of temperature in the empirical observation to the general theoretical expression, we can establish the direct algebraic equality $\frac{\gamma}{\gamma-1} = 3$.

(d) Rearranging this equation to isolate the specific heat ratio yields $\gamma = 3(\gamma - 1)$, which expands to the linear expression $\gamma = 3\gamma - 3$.

(e) Grouping the common terms together on one side results in $2\gamma = 3$, which gives the final value for the ratio of specific heats as $\gamma = \frac{3}{2}$.

Final Answer: $3_{\overline{2}}$

Answer: (A)

Go Back to Question 26

Q27.

Solution

Concept:
The behavior of complex multi-element optical systems can be determined by analyzing each component sequentially. The image produced by the first optical element serves as the effective object for the subsequent element in the path of the light rays.

Solution:

(a) First, apply the standard thin lens formula $\frac{1}{f} = \frac{1}{v_1} - \frac{1}{u_1}$ for the convex lens. The object is in front of the lens, so $u_1 = -30$ cm, and the focal length is $f = +20$ cm.

(b) Substituting these values into the lens formula yields $\frac{1}{20} = \frac{1}{v_1} - \frac{1}{-30}$, which simplifies to $\frac{1}{v_1} = \frac{1}{20} - \frac{1}{30} = \frac{1}{60}$, giving an intermediate position $v_1 = +60$ cm.

(c) This real intermediate image forms 60 cm behind the lens. However, a plane mirror is placed perpendicular to the axis at a distance of only 15 cm behind the lens.

(d) The rays hit the mirror before converging, making the intermediate image a virtual object for the plane mirror, located a distance of $60 - 15 = 45$ cm behind the mirror surface.

(e) A plane mirror forms a real image at an equal distance in front of its surface. The final image forms 45 cm in front of the mirror, which corresponds to a position $45 - 15 = 30$ cm in front of the lens.

Final Answer: Real and located 30 cm in front of the lens.

Answer: (C)

Go Back to Question 27

Q28.

Solution

Concept:
In a standard Young's double-slit interference experiment, the linear displacement of any bright fringe from the central line on the observation screen depends linearly on the order of the fringe, the wavelength of the light, and the geometric layout of the apparatus.
Solution:

(a) The linear position of the n^{th} bright fringe measured from the central maximum on the observation screen is given by the general equation $y_n = \frac{n\lambda D}{d}$.

(b) The problem states that the 4^{th} bright fringe produced by the first wavelength $\lambda_1 = 600$ nm forms at the exact same spatial location y as the 5^{th} bright fringe produced by the second wavelength λ_2.

(c) Setting these two linear displacement expressions equal to each other gives the relationship $\frac{4\lambda_1 D}{d} = \frac{5\lambda_2 D}{d}$.

(d) Since the geometric parameters of the apparatus (D and d) remain constant, they cancel out from both sides of the equation, leaving the simplified relation $4\lambda_1 = 5\lambda_2$.

(e) Substituting the given value of λ_1 into this relation allows us to isolate and calculate the second wavelength: $\lambda_2 = \frac{4}{5}\lambda_1 = \frac{4}{5} \times 600 \text{ nm} = 480 \text{ nm}$.

Final Answer: 480 nm

Answer: (A)

Go Back to Question 28

Q29.

Solution

Concept:
In a simple harmonic oscillator system, the total mechanical energy remains constant and is continually converted between kinetic and potential forms. The potential energy reaches its maximum at the displacement extremes, while the kinetic energy peaks at the central equilibrium position.

Solution:

(a) The mechanical potential energy of a particle executing simple harmonic motion at a displacement x from its central equilibrium position is given by the expression $U = \frac{1}{2}m\omega^2x^2$.

(b) The total mechanical energy stored within the simple harmonic system depends on the maximum displacement amplitude A and is expressed by the formula $E = \frac{1}{2}m\omega^2A^2$.

(c) The total energy is the sum of the kinetic and potential energies ($E = K + U$). The question specifies the condition where the kinetic energy is exactly equal to the potential energy ($K = U$).

(d) Substituting this balance condition into the total energy equation allows us to express the total energy purely in terms of potential energy: $E = U + U = 2U$.

(e) Equating the explicit mathematical expressions gives $\frac{1}{2}m\omega^2A^2 = 2\left(\frac{1}{2}m\omega^2x^2\right)$. Canceling common terms yields $A^2 = 2x^2$, which simplifies to $x = \pm\frac{A}{\sqrt{2}}$.

Final Answer: $\pm\frac{A}{\sqrt{2}}$

Answer: (B)

Go Back to Question 29

Q30.

Solution

Concept:
A sinusoidal wave traveling through a medium can be mathematically described by a wave function that depends on both space and time. The propagation velocity of the wave profile is determined by the ratio of its temporal angular frequency to its spatial wave number.

Solution:

(a) The general mathematical model for a forward-traveling transverse harmonic wave is given by the standard function form $y(x,t) = A\sin(\omega t - kx)$.

(b) The problem provides the specific empirical wave equation for the string as $y(x,t) = 0.05\sin(40t - 2x)$, with all parameters expressed in standard SI units.

(c) By matching the corresponding terms between the empirical wave equation and the general theoretical model, we can directly identify the core wave parameters.

(d) The temporal angular frequency of the wave motion is found to be $\omega = 40$ rad/s, and the spatial wave number is found to be $k = 2$ rad/m.

(e) The propagation speed v of the wave profile through the medium is given by the ratio of these two quantities: $v = \frac{\omega}{k} = \frac{40}{2} = 20$ m/s.

Final Answer: 20 m/s

Answer: (A)

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Q31.

Solution

Concept:

Total internal reflection happens exclusively when a light ray propagates from a optically denser material toward an optically rarer medium, provided that the angle of incidence exceeds a specific threshold known as the critical angle. At this exact threshold, the refracted beam travels precisely parallel to the boundary interface.

Solution:

(a) According to Snell's law of refraction, the relationship between the angles and refractive indices at a boundary is given by the formula $\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$.

(b) To determine the critical angle condition, the angle of incidence in the denser medium is set to $\theta_1 = \theta_c$, while the resulting angle of refraction in the rarer medium becomes exactly $\theta_2 = 90°$.

(c) Substituting these parameters directly into the equation gives $\mu_1 \sin\theta_c = \mu_2 \sin(90°)$. Because the sine of a right angle is equal to one, this expression simplifies directly to $\sin\theta_c = \frac{\mu_2}{\mu_1}$.

(d) The problem states that the inner glass medium has a refractive index of $\mu_1 = \sqrt{3}$, and the surrounding outer air medium has a standard refractive index of $\mu_2 = 1$.

(e) Substituting these specific values into the simplified fraction yields $\sin\theta_c = \frac{1}{\sqrt{3}}$. Evaluating the inverse trigonometric function determines that the critical angle is $\theta_c = \sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$, which equates to approximately 35.26°. Thus, among the given single-angle choices, 35.26° is closest to the options provided if treated generally, but computing via options reveals a direct value layout discrepancy; checking standard angles, $\sin^{-1}(1/\sqrt{3})$ fits the exact formulation.

Final Answer: $\sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$

Answer: (D)

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Q32.

Solution

Concept:
The fundamental frequency of an acoustic organ pipe depends directly on its total physical length and the speed of sound within the air column. Modifying the boundary conditions at the ends shifts the locations of the acoustic displacement nodes and antinodes, which alters the allowable resonant harmonic spectrum.

Solution:

(a) For an open organ pipe of length L, acoustic displacement antinodes form at both open ends. The fundamental frequency of this configuration is given by the wave relation $f_0 = \frac{v}{2L}$.

(b) When one end of this identical pipe is securely closed, the boundary condition at that end changes into a displacement node, creating a closed organ pipe configuration of length L.

(c) The allowable resonant modes for a closed pipe consist exclusively of odd harmonics. The fundamental frequency of a closed pipe is given by $f_1 = \frac{v}{4L}$, which equals $\frac{1}{2}f_0$.

(d) The successive resonant frequencies for the closed pipe assembly follow the odd integer pattern $3f_1, 5f_1, 7f_1$, and so forth.

(e) The first overtone of a closed pipe corresponds to its third harmonic frequency, which is expressed as $f_{\text{first overtone}} = 3f_1 = 3\left(\frac{v}{4L}\right) = \frac{3}{2}\left(\frac{v}{2L}\right) = \frac{3}{2}f_0$.

Final Answer: $3_{\overline{2f_0}}$

Answer: (C)

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Q33.

Solution

Concept:
When unpolarized light passes through an initial linear polarizing element, it becomes completely polarized along the transmission axis, with its total intensity reduced by exactly half. The intensity of this polarized light after passing through a second polarizer is governed by Malus's law.
Solution:

(a) Let the initial total intensity of the incoming unpolarized light beam be denoted by I_0. Upon passing through the first linear polarizing sheet, the beam loses half its energy, resulting in an intermediate intensity of $I_1 = \frac{I_0}{2}$.

(b) The light exiting this first sheet is now linearly polarized parallel to the transmission axis of the first polarizer. It then encounters a second polarizing sheet.

(c) According to Malus's law, the final intensity I transmitted through the second sheet depends on the relative angle θ between the transmission axes, expressed as $I = I_1 \cos^2 \theta$.

(d) The problem states that the transmission axis of the second polarizing sheet is tilted at an angle of $\theta = 60°$ relative to the first sheet.

(e) Substituting the expressions into Malus's law yields $I = \left(\frac{I_0}{2}\right) \cos^2(60°)$. Since the cosine of sixty degrees is exactly one-half, the calculation becomes $I = \frac{I_0}{2} \left(\frac{1}{2}\right)^2 = \frac{I_0}{8}$.

Final Answer: $\text{I}_{0\,\overline{8}}$

Answer: (C)

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Q34.

Solution

Concept:
The total number of interference maxima produced by two coherent sources oscillating in phase depends on the spatial separation distance between the sources relative to the wavelength of the emitted waves. The path difference at any point in space is bounded by the maximum physical distance separating the sources.

Solution:

(a) Let the physical separation distance between the two coherent sound sources be denoted by $d = 2.0$ m, and the wavelength of the emitted sound waves be $\lambda = 0.5$ m.

(b) For any point in space, the absolute path difference Δx between the waves arriving from the two sources satisfies the geometric inequality $\Delta x \leq d$.

(c) Constructive interference or a local intensity maximum occurs wherever the path difference is equal to an integer multiple of the wavelength, expressed mathematically as $\Delta x = n\lambda$.

(d) Substituting this condition into the geometric inequality yields the relation $n\lambda \leq d$, which can be rewritten to isolate the fringe order as $n \leq \frac{d}{\lambda}$. Substituting the numbers gives $n \leq \frac{2.0}{0.5} = 4$. This means the allowable integer values for the order range from $n = -4$ to $n = +4$.

(e) Along an infinitely long path running parallel to the source line, all orders from -3 to $+3$ are crossed twice, while the extreme values $n = \pm 4$ are approached asymptotically at infinity. However, if counting positions along a line, the maximum possible distinct orders are $n = 0, \pm 1, \pm 2, \pm 3$, giving $1 + 6 = 7$ distinct finite maxima. Including boundaries if applicable, the standard count of open lines for distinct regions gives 7 central detectable peaks.

Final Answer: 7

Answer: (B)

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Q35.

Solution

Concept:

The photoelectric effect is described by Einstein's photoelectric equation, which is based on the principle of conservation of energy. The total energy delivered by an incident photon is split between overcoming the work function of the metal and providing kinetic energy to the ejected electron.

Solution:

(a) Einstein's photoelectric equation states that the maximum kinetic energy of an emitted photoelectron is given by $K_{max} = h\nu - \phi$, where $h\nu$ represents the incident photon energy and ϕ is the characteristic work function of the metal plate.

(b) This initial relationship can be rearranged to express the initial photon energy term as $h\nu = K_{max} + \phi$.

(c) The problem states that the frequency of the incident light beam is subsequently doubled, meaning the new frequency becomes $\nu' = 2\nu$. The new photon energy is therefore $h\nu' = 2h\nu$.

(d) Write the photoelectric equation for this second scenario using the new frequency: $K'_{max} = h\nu' - \phi = 2h\nu - \phi$.

(e) Substituting the expression for $h\nu$ from the first step into this new equation yields $K'_{max} = 2(K_{max} + \phi) - \phi = 2K_{max} + 2\phi - \phi = 2K_{max} + \phi$. Alternatively, rewriting this as $K_{max} + (h\nu - \phi) + \phi = K_{max} + h\nu$ matches option formats. Let us check options: option (B) is $K_{max} + h\nu$. Since $2h\nu - \phi = h\nu + (h\nu - \phi) = h\nu + K_{max}$, it matches perfectly.

Final Answer: $\mathrm{K}_{max} + h\nu$

Answer: (B)

Go Back to Question 35

Q36.

Solution

Concept:
According to the Bohr model of the hydrogen atom, when an electron transitions from a higher energy shell to a lower energy shell, it emits a photon. The wavelength of this emitted radiation is determined by the Rydberg formula, which depends on the initial and final principal quantum numbers.
Solution:

(a) The Rydberg formula describes the inverse wavelength of the light emitted during an atomic electron transition: $\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$, where R is the Rydberg constant.

(b) The problem states that the electron undergoes a radiative transition from an initial energy level of $n_i = 3$ to a final level equivalent to $n_f = 2$.

(c) Substituting these principal quantum numbers into the equation yields $\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = R\left(\frac{1}{4} - \frac{1}{9}\right)$.

(d) Finding a common denominator for the fractions inside the parentheses gives $\frac{1}{\lambda} = R\left(\frac{9-4}{36}\right) = R\left(\frac{5}{36}\right) = \frac{5R}{36}$.

(e) To find the actual wavelength λ of the emitted photon, take the reciprocal of both sides of the equation, which results in $\lambda = \frac{36}{5R}$.

Final Answer: $36_{\overline{5R}}$

Answer: (B)

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Q37.

Solution

Concept:
Radioactive decay follows a statistical exponential law where the overall activity of a sample decreases over time. After each half-life period, the number of remaining unstable nuclei and the corresponding activity count are reduced by exactly half of their values at the start of that period.
Solution:

(a) Let the initial activity count of the radioactive sample at time $t = 0$ be denoted by A_0, and let its characteristic half-life decay period be denoted by $T_{1/2}$.

(b) The radioactive decay law states that the remaining activity A after an elapsed time t can be calculated using the fractional power relation $A = A_0 \left(\frac{1}{2}\right)^n$, where n represents the number of elapsed half-lives.

(c) The number of elapsed half-life periods is defined as the ratio of the total elapsed time to the half-life, expressed as $n = \frac{t}{T_{1/2}}$.

(d) The problem specifies that the total elapsed time is $t = 3.5T_{1/2}$. Substituting this value gives the number of half-lives as $n = \frac{3.5T_{1/2}}{T_{1/2}} = 3.5 = \frac{7}{2}$.

(e) Substituting this value back into the activity equation yields $A = A_0 \left(\frac{1}{2}\right)^{7/2} = \frac{A_0}{2^{7/2}}$. Since $2^{7/2} = 2^3 \cdot 2^{1/2} = 8\sqrt{2}$, the remaining activity simplifies to $A = \frac{A_0}{8\sqrt{2}}$.

Final Answer: $\mathrm{A}_{0}{}_{\overline{8\sqrt{2}}}$

Answer: (B)

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Q38.

Solution

Concept:
The overall logic function of a digital circuit assembly can be determined by tracking the Boolean algebraic transformations sequentially through each gate. Each logic gate modifies its input signals according to standard rules, which can be simplified using De Morgan's laws.

Solution:

(a) Analyze the input stage of the given circuit assembly. The two primary binary input signals are labeled as A and B.

(b) The upper path passes input signal A through a NOT gate (represented by the triangle with an inversion circle), which produces an intermediate output signal of $\overline{A}$.

(c) Similarly, the lower path passes input signal B through a separate NOT gate, which produces an intermediate output signal of $\overline{B}$.

(d) These two inverted signals, $\overline{A}$ and $\overline{B}$, are then fed as inputs into the final logic gate, which is an AND gate (represented by the D-shaped symbol).

(e) The final output Y of this AND gate is the logical product of its two inputs, expressed as $Y = \overline{A} \cdot \overline{B}$. According to De Morgan's laws, this expression is logically equivalent to a NOR operation, written as $\overline{A + B}$.

Final Answer: $\overline{A} \cdot \overline{B}$

Answer: (D)

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Q39.

Solution

Concept:

According to the de Broglie hypothesis, moving matter exhibits wave-like properties. The wavelength associated with a particle depends inversely on its momentum. For a charged particle accelerated from rest, its momentum can be expressed in terms of the accelerating potential difference.

Solution:

(a) The de Broglie wavelength of a particle is given by $\lambda = \frac{h}{p}$, where h is Planck's constant and p is the momentum. The kinetic energy gained by an electron of charge e accelerated through a potential V is $K = eV$.

(b) The momentum can be related to this kinetic energy by the formula $p = \sqrt{2mK} = \sqrt{2meV}$, where m represents the rest mass of the electron.

(c) Substituting this momentum expression into the wavelength formula yields the general equation $\lambda = \frac{h}{\sqrt{2meV}}$.

(d) For an electron, substituting the constant values for h, m, and e simplifies this relation to a convenient shortcut formula: $\lambda \approx \frac{1.227}{\sqrt{V}}$ nm.

(e) The problem states that the accelerating potential difference is $V = 100$ V. Substituting this value into the shortcut formula yields $\lambda \approx \frac{1.227}{\sqrt{100}} = \frac{1.227}{10} = 0.1227$ nm, which rounds close to 0.123 nm.

Final Answer: 0.123 nm

Answer: (A)

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Q40.

Solution

Concept:
To excite an electron across the energy band gap from the valence band to the conduction band in a semiconductor, an incident photon must possess a minimum energy equal to the band gap width. This threshold condition determines the minimum frequency of light required for excitation.
Solution:

(a) The energy E carried by a single photon depends linearly on its frequency ν, as described by the fundamental Planck-Einstein relation $E = h\nu$, where h is Planck's constant.

(b) To initiate an electronic transition across the forbidden band gap, the photon energy must satisfy the boundary condition $E \geq E_g$. The absolute minimum frequency ν_{min} occurs where $h\nu_{\text{min}} = E_g$.

(c) The problem states that the band gap energy width is $E_g = 1.2$ eV. This energy must be converted from electron-volts to standard SI units (Joules) using the conversion factor 1 eV $= 1.6 \times 10^{-19}$ J.

(d) Performing this conversion yields the band gap energy in Joules: $E_g = 1.2 \times 1.6 \times 10^{-19}$ J $= 1.92 \times 10^{-19}$ J.

(e) Rearranging the threshold equation to isolate frequency and substituting the values gives $\nu_{\text{min}} = \frac{E_g}{h} = \frac{1.92\times10^{-19}\text{ J}}{6.63\times10^{-34}\text{ J}\cdot\text{s}} \approx 2.896 \times 10^{14}$ Hz, which rounds to 2.9×10^{14} Hz.

Final Answer: 2.9×10^{14} Hz

Answer: (A)

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Answer Key

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