KIITEE Physics Sample Paper – 3

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 kept on a rough horizontal surface with a coefficient of static friction $\mu_s = 0.4$. A time-varying horizontal force $F = 2t$ (in Newtons) is applied to the block at $t = 0$. At what time t will the block just start moving? (Take $g = 10\ \text{m/s}^2$)

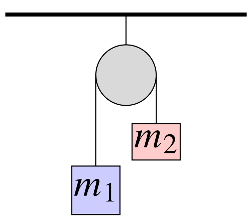
(A) 2 s

(B) 4 s

(C) 6 s

(D) 8 s

Q2. Consider the system shown in the figure below. Two blocks of masses $m_1 = 3$ kg and $m_2 = 1$ kg are connected by a light string passing over a frictionless, massless pulley. Find the acceleration of the system when released from rest. (Take $g = 10\ \text{m/s}^2$)



(A) 2.5 m/s^2

(B) 7.5 m/s^2

(C) 10.0 m/s^2

(D) 5.0 m/s^2

Q3. A variable force $F = (3x^2 + 2x)$ N acts on a particle of mass 0.5 kg moving along the x-axis. The work done by this force in displacing the particle from $x = 0$ to $x = 2$ m is:

(A) 8 J

(B) 12 J

(C) 16 J

(D) 20 J

Q4. A ball is dropped from a height H onto a smooth horizontal floor. If the coefficient of restitution between the ball and the floor is $e = 0.5$, the total height climbed by the ball after the first rebound is:

(A) $H/4$

(B) $H/2$

(C) $H/8$

(D) $H/16$

Q5. A thin uniform circular ring of mass M and radius R is rotating about its geometric axis with a constant angular velocity ω. Two objects, each of mass m, are attached gently to opposite ends of a diameter of the ring. The new angular velocity of the ring will be:

(A) $\frac{M\omega}{M+m}$

(B) $\frac{M\omega}{M+2m}$

(C) $\frac{(M+2m)\omega}{M}$

(D) $\frac{(M-2m)\omega}{M+2m}$

Q6. A solid sphere and a solid cylinder, both of equal mass and radius, roll down the same inclined plane without slipping from rest. What is the ratio of their linear velocities ($v_{\text{sphere}}/v_{\text{cylinder}}$) at the bottom of the incline?

(A) $\sqrt{\frac{14}{15}}$

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

(C) $\sqrt{\frac{3}{4}}$

(D) $\sqrt{\frac{15}{14}}$

Q7. A particle moves in a plane under the action of a force such that its position vector is given by $\vec{r}(t) = (3\cos 2t)\hat{i} + (3\sin 2t)\hat{j}$ (where r is in meters and t is in seconds). The trajectory of the particle is a:

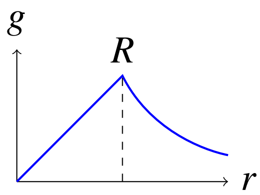
(A) Straight line passing through the origin

(B) Circle of radius 3 m

(C) Ellipse with semi-major axis 3 m

(D) Parabola opening upwards

Q8. The variation of gravitational acceleration g with distance r from the center of a uniform solid sphere of radius R is best represented by which of the following qualitative graphs?



(A) $g \propto r$ for $r < R$ and $g \propto 1/r^2$ for $r > R$

(B) $g \propto 1/r$ for $r < R$ and $g \propto 1/r^2$ for $r > R$

(C) $g = 0$ for $r < R$ and $g \propto 1/r^2$ for $r > R$

(D) $g \propto r^2$ for $r < R$ and $g \propto 1/r$ for $r > R$

Q9. A satellite is revolving very close to the surface of a planet of density ρ. If G is the universal gravitational constant, the time period of the satellite depends only on:

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

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

(C) The mass of the satellite and G

(D) The radius of the planet and ρ

Q10. A force $\vec{F} = (2\hat{i} - 3\hat{j} + 4\hat{k})$ N acts at a point $\vec{r} = (3\hat{i} + 2\hat{j} + 3\hat{k})$ m relative to the origin. The torque $\vec{\tau}$ acting about the origin is:

(A) $(17\hat{i} - 6\hat{j} - 13\hat{k})$ N · m

(B) $(17\hat{i} + 6\hat{j} - 13\hat{k})$ N · m

(C) $(-17\hat{i} - 6\hat{j} + 13\hat{k})$ N · m

(D) $(17\hat{i} - 6\hat{j} + 13\hat{k})$ N · m

Q11. A body of mass m is hauled up an inclined plane making an angle θ with the horizontal. If the coefficient of kinetic friction is μ_k, the minimum force required to pull the body up the incline with constant velocity along the plane is:

(A) $mg(\sin\theta + \mu_k \cos\theta)$

(B) $mg(\sin\theta - \mu_k \cos\theta)$

(C) $mg(\cos\theta + \mu_k \sin\theta)$

(D) $mg\mu_k \cos\theta$

Q12. An infinite line charge produces a field of 9×10^4 N/C at a distance of 2 cm. The linear charge density λ of the line charge is:

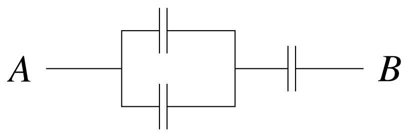
(A) 0.1 μC/m

(B) 1.0 μC/m

(C) 10 μC/m

(D) 100 μC/m

Q13. Three identical capacitors, each of capacitance C, are connected in the arrangement shown in the circuit diagram below. Find the equivalent capacitance between points A and B.



(A) $3C$

(B) $C/3$

(C) $2C/3$

(D) $3C/2$

Q14. A cylindrical copper wire of resistance R is stretched uniformly until its length becomes double its original value. Assuming the density of the wire remains constant, its new resistance will be:

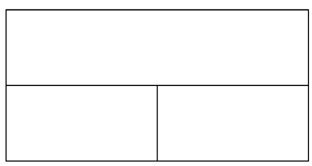
(A) R

(B) $2R$

(C) $4R$

(D) $8R$

Q15. In the given electrical network network circuit, apply Kirchhoff's rules to find the steady-state current flowing through the 4 Ω resistor.



(A) 1 A

(B) 1.5 A

(C) 2 A

(D) 0.5 A

Q16. A proton enters a uniform magnetic field $\vec{B} = B_0\hat{i}$ with a velocity $\vec{v} = v_1\hat{i} + v_2\hat{j}$. The resulting path tracking the motion of the proton is a:

(A) Circle in the y-z plane

(B) Straight line along the x-axis

(C) Helix with its axis parallel to the x-axis

(D) Helix with its axis parallel to the y-axis

Q17. Two long, straight parallel wires separated by a distance d carry currents I_1 and I_2 in opposite directions. The magnitude of the magnetic force per unit length exerted by one wire on the other is:

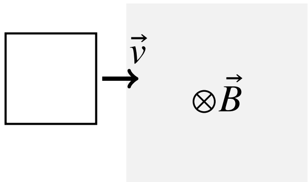
(A) $\frac{\mu_0 I_1 I_2}{2\pi d}$, attractive

(B) $\frac{\mu_0 I_1 I_2}{2\pi d}$, repulsive

(C) $\frac{\mu_0 I_1 I_2}{2d}$, attractive

(D) $\frac{\mu_0 I_1 I_2}{2d}$, repulsive

Q18. A square loop of side 10 cm enters a region of uniform magnetic field $B = 0.5$ T moving at a constant velocity $v = 2$ m/s perpendicular to the field as shown. What is the induced EMF in the loop while it is partially inside the field?



(A) 0.1 V

(B) 0.2 V

(C) 0.05 V

(D) 0 V

Q19. The self-inductance of a solenoid of length l, area of cross-section A, and total number of turns N is given by the expression:

(A) $\frac{\mu_0 N^2 A}{l}$

(B) $\mu_0 N^2 A l$

(C) $\frac{\mu_0 N A}{l}$

(D) $\frac{\mu_0 N^2 l}{A}$

Q20. In an alternating current (AC) circuit containing an inductor L and a resistor R connected in series to an RMS source voltage V, the phase angle ϕ between the current and the voltage is given by:

(A) $\tan\phi = \frac{\omega L}{R}$

(B) $\tan\phi = \frac{R}{\omega L}$

(C) $\sin\phi = \frac{\omega L}{R}$

(D) $\cos\phi = \frac{\omega L}{\sqrt{R^2+(\omega L)^2}}$

Q21. A series LCR circuit containing $R = 10\,\Omega$, $L = 800$ mH, and $C = 20\,\mu$F is connected to a variable frequency AC source. The resonant angular frequency ω_0 of the circuit is:

(A) 125 rad/s

(B) 250 rad/s

(C) 500 rad/s

(D) 1000 rad/s

Q22. An ideal gas expands from volume V_1 to V_2 via three different processes: isothermal, adiabatic, and isobaric. Let the work done by the gas be W_{iso}, W_{adia}, and W_{bar} respectively. Which of the following ordering sequences is correct if the processes start from the same initial state (P_1, V_1)?

(A) $W_{\text{bar}} > W_{\text{iso}} > W_{\text{adia}}$

(B) $W_{\text{bar}} > W_{\text{adia}} > W_{\text{iso}}$

(C) $W_{\text{adia}} > W_{\text{iso}} > W_{\text{bar}}$

(D) $W_{\text{iso}} > W_{\text{bar}} > W_{\text{adia}}$

Q23. During an isothermal expansion of an ideal gas, 400 J of heat is added to the system. The work done by the gas and the change in its internal energy (ΔU) are, respectively:

(A) 400 J, 0 J

(B) 0 J, 400 J

(C) 400 J, 400 J

(D) −400 J, 0 J

Q24. An ideal gas heat engine operates in a Carnot cycle between temperatures $T_1 = 600$ K and $T_2 = 300$ K. If it absorbs 2000 J of heat from the hot reservoir in each cycle, the efficiency of the engine and the work done per cycle are:

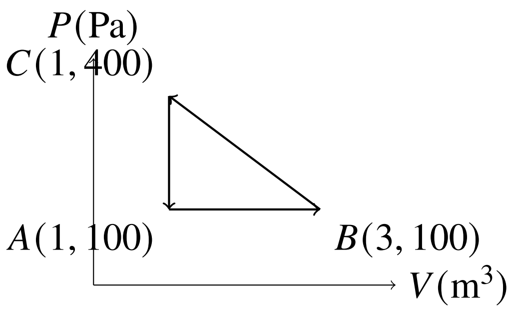
(A) 50%, 1000 J

(B) 50%, 2000 J

(C) 33.3%, 666.7 J

(D) 25%, 500 J

Q25. The pressure P and volume V path of an ideal thermodynamic gas during an cyclic process is illustrated below. Find the net work done by the gas over one full cycle $A \to B \to C \to A$.



(A) 300 J

(B) −300 J

(C) 600 J

(D) −600 J

Q26. The root-mean-square (rms) speed of molecules of an ideal gas at temperature T is v. If the absolute temperature of the gas is doubled and the constituent molecules dissociate into their component individual component atoms, the new rms speed becomes:

(A) v

(B) $\sqrt{2}v$

(C) $2v$

(D) $4v$

Q27. A concave mirror has a focal length of 20 cm. At what distance in front of the mirror should an object be placed so that a real image, magnified three times, is formed?

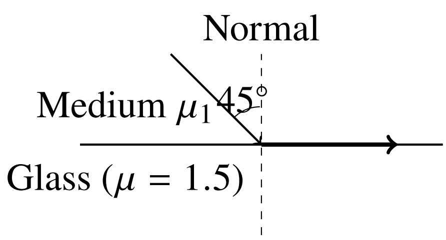
(A) 13.3 cm

(B) 26.7 cm

(C) 40.0 cm

(D) 60.0 cm

Q28. A ray of light traveling in an unknown medium is incident on a glass boundary at an angle of 45°. If the refracted ray travels along the interface line as depicted below, find the refractive index of the initial medium. (Take $\mu_{\text{glass}} = 1.5$)



(A) $1.5\sqrt{2}$

(B) $1.5/\sqrt{2}$

(C) 1.0

(D) 2.0

Q29. In a Young's double-slit experiment, the slit separation is 0.2 mm and the screen is placed 1.2 m away. If light of wavelength 500 nm is used, the fringe width observed on the screen is:

(A) 1.5 mm

(B) 3.0 mm

(C) 4.5 mm

(D) 6.0 mm

Q30. A block attached to an ideal spring oscillates with simple harmonic motion along a horizontal frictionless track. The block's displacement is described by $x(t) = 0.05\cos(10t + \pi/4)$ (where x is in meters and t is in seconds). The maximum acceleration of the block is:

(A) 0.05 m/s^2

(B) 0.5 m/s^2

(C) 5.0 m/s^2

(D) 50.0 m/s^2

Q31. A particle executing simple harmonic motion (SHM) has a maximum velocity v_{max} and a maximum acceleration a_{max}. The time period of oscillation T is given by:

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

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

(C) $2\pi\sqrt{\frac{v_{max}}{a_{max}}}$

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

Q32. A string of length 2 m fixed at both ends vibrates in its third harmonic mode. If the wave speed in the string is 120 m/s, the frequency of this vibration is:

(A) 30 Hz

(B) 60 Hz

(C) 90 Hz

(D) 120 Hz

Q33. An observer moves towards a stationary source of sound with a speed equal to one-fifth of the speed of sound. If the source emits a sound of frequency f_0, the apparent frequency heard by the observer is:

(A) $4/5\ f_0$

(B) $5/6\ f_0$

(C) $6/5\ f_0$

(D) $2\ f_0$

Q34. When light of wavelength λ is incident on a photosensitive metallic surface, the stopping potential is V_0. If light of wavelength 2λ is incident on the same metal surface, the stopping potential becomes $V_0/3$. The threshold wavelength of the metal is:

(A) 3λ

(B) 4λ

(C) 5λ

(D) 6λ

Q35. According to the Bohr model, what is the ratio of the velocity of an electron in the first excited state ($n = 2$) to that in the ground state ($n = 1$) of a hydrogen atom?

(A) $1:2$

(B) $2:1$

(C) $1:4$

(D) $4:1$

Q36. A radioactive nucleus undergoes a series of decays according to the scheme shown below. If the initial mass number and atomic number are A and Z, find the final mass number and atomic number of nucleus X_3.

$$X(A,Z) \xrightarrow{\alpha} X_1 \xrightarrow{\beta^-} X_2 \xrightarrow{\alpha} X_3$$

(A) $A-8, Z-3$

(B) $A-4, Z-1$

(C) $A-8, Z-2$

(D) $A - 6, Z - 3$

Q37. The binding energy per nucleon for a deuteron (^2_1H) and a helium nucleus (^4_2He) are 1.1 MeV and 7.0 MeV respectively. If two deuterons fuse together to form a single helium nucleus, the total energy released in the reaction is:

(A) 25.8 MeV

(B) 23.6 MeV

(C) 28.0 MeV

(D) 30.2 MeV

Q38. In an intrinsic semiconductor, the bandgap energy is 1.2 eV. The probability of an electron occupying a state at the bottom of the conduction band increases if:

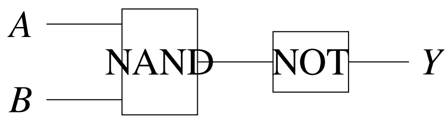
(A) The temperature increases

(B) The temperature decreases

(C) The sample is kept in complete darkness at 0 K

(D) The bandgap energy artificially increases

Q39. Identify the logic operation performed by the circuit configuration consisting of two NAND gates arranged as shown below.



(A) OR

(B) NAND

(C) AND

(D) NOR

Q40. A forward-biased p-n junction diode has a depletion region whose width:

(A) Decreases

(B) Increases

(C) Remains completely unchanged

(D) First increases and then decreases

Detailed Solutions

Q1.

Solution

Concept:
An object placed on a rough horizontal surface remains stationary until the applied external force overcomes the maximum available limiting static friction. Once the driving force exceeds this threshold, the object initiates accelerating or uniform motion.

Solution:

(a) Calculate the magnitude of the normal force supporting the block by balancing vertical forces: $N = mg = 2 \times 10 = 20$ N.

(b) Express the maximum limiting static friction capacity using the given coefficient: $f_{s,\max} = \mu_s N = 0.4 \times 20 = 8$ N.

(c) Define the threshold condition for motion onset, which occurs when the time-dependent driving force equals limiting static friction: $F(t) = f_{s,\max}$.

(d) Substitute the given algebraic profile of the applied force into the threshold relation: $2t = 8$.

(e) Solve the linear equation for the time variable to determine when motion initiates: $t = 4$ s.

Final Answer: 4 s

Answer: (B)

Go Back to Question 1

Q2.

Solution

Concept:
An ideal Atwood machine features interconnected masses hanging over a frictionless pulley. The total system acceleration can be derived by analyzing the net uncompensated driving gravitational forces divided by the total mass undergoing translation.

Solution:

(a) Identify the downward gravitational forces pulling on each individual hanging block: $F_1 = m_1 g = 30$ N and $F_2 = m_2 g = 10$ N.

(b) Determine the net external driving force causing system movement by subtracting the opposing weight components: $F_{\text{net}} = m_1 g - m_2 g = 30 - 10 = 20$ N.

(c) State the total structural inertia or combined mass of the system being accelerated through space: $M_{\text{total}} = m_1 + m_2 = 3 + 1 = 4$ kg.

(d) Apply Newton's second law to the collective system to formulate acceleration: $a = \frac{F_{\text{net}}}{M_{\text{total}}} = \frac{m_1 - m_2}{m_1 + m_2} g$.

(e) Substitute the values to find the magnitude of the uniform linear acceleration: $a = \frac{20}{4} = 5.0 \text{ m/s}^2$.

Final Answer: 5.0 m/s^2

Answer: (D)

Go Back to Question 2

Q3.

Solution

Concept:
When a position-dependent variable force acts on an object along a single axis, the total mechanical work performed cannot be calculated via simple multiplication. Instead, it must be evaluated by integrating the force function over the interval.

Solution:

(a) State the fundamental mathematical definition of mechanical work performed by a variable one-dimensional force profile: $W = \int_{x_1}^{x_2} F(x)\,dx$.

(b) Set up the definite integral using the specified spatial boundary parameters from the problem statement: $W = \int_0^2 (3x^2 + 2x)\,dx$.

(c) Determine the antiderivative function for each term using standard calculus integration rules: $\int 3x^2\,dx = x^3$ and $\int 2x\,dx = x^2$.

(d) Express the complete integrated function bounded over the operational path: $W = \left[x^3 + x^2\right]_0^2$.

(e) Evaluate the expression at the upper boundary limit and subtract the lower boundary limit value: $W = (2^3 + 2^2) - (0^3 + 0^2) = 8 + 4 = 12$ J.

Final Answer: 12 J

Answer: (B)

Go Back to Question 3

Q4.

Solution

Concept:
A mechanical collision between an object and a boundary involves energy dissipation dictated by the coefficient of restitution. This coefficient represents the ratio of relative separation velocity to relative approach velocity along the impact normal.
Solution:

(a) Establish the velocity of the dropped ball right before making contact with the floor using energy conservation: $v = \sqrt{2gH}$.

(b) Apply the definition of the coefficient of restitution (e) to determine the rebound separation velocity: $v' = ev = e\sqrt{2gH}$.

(c) Relate the post-collision upward launch velocity to the subsequent maximum height (H') reached during the rebound climb: $H' = \frac{(v')^2}{2g}$.

(d) Substitute the separation velocity expression into the height relation to isolate the scaling factor: $H' = \frac{e^2(2gH)}{2g} = e^2H$.

(e) Evaluate the final height using the specified fractional coefficient value: $H' = (0.5)^2H = \frac{1}{4}H = H/4$.

Final Answer: H/4

Answer: (A)

Go Back to Question 4

Q5.

Solution

Concept:
When small external masses are added gently to a rotating system without any external torque acting on the structure, the total angular momentum is conserved. The addition of mass increases the system's rotational inertia, decreasing its speed.

Solution:

(a) Express the initial rotational inertia of the thin uniform circular ring about its principal center axis: $I_0 = MR^2$.

(b) Calculate the total new rotational inertia after attaching the two point masses at a radial distance R from the center: $I_f = MR^2 + 2mR^2 = (M + 2m)R^2$.

(c) State the law of conservation of angular momentum assuming zero net external torque: $I_0\omega = I_f\omega'$.

(d) Rearrange the terms to explicitly isolate and solve for the new final angular velocity parameter: $\omega' = \frac{I_0}{I_f}\omega$.

(e) Substitute the inertia formulations into the equation and cancel out the common radius terms: $\omega' = \frac{MR^2}{(M+2m)R^2}\omega = \frac{M\omega}{M+2m}$.

Final Answer: M$\omega\overline{M+2m}$

Answer: (B)

Go Back to Question 5

Q6.

Solution

Concept:
An object rolling down an incline without slipping converts its gravitational potential energy into both translational and rotational kinetic energy. The velocity reached at the base depends on the body's geometric mass distribution factor.

Solution:

(a) Write the conservation of energy equation for a rolling body: $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}mv^2\left(1 + \frac{k^2}{R^2}\right)$, leading to $v = \sqrt{\frac{2gh}{1+k^2/R^2}}$.

(b) Identify the structural inertia scaling factor for a uniform solid sphere: $I = \frac{2}{5}MR^2 \implies \frac{k^2}{R^2} = \frac{2}{5} = 0.4$.

(c) Identify the structural inertia scaling factor for a uniform solid cylinder: $I = \frac{1}{2}MR^2 \implies \frac{k^2}{R^2} = \frac{1}{2} = 0.5$.

(d) Express the velocities for both geometries: $v_{\text{sphere}} = \sqrt{\frac{2gh}{1+0.4}} = \sqrt{\frac{2gh}{1.4}}$ and $v_{\text{cylinder}} = \sqrt{\frac{2gh}{1+0.5}} = \sqrt{\frac{2gh}{1.5}}$.

(e) Divide the sphere velocity by the cylinder velocity to find the final ratio: $\frac{v_{\text{sphere}}}{v_{\text{cylinder}}} = \sqrt{\frac{1.5}{1.4}} = \sqrt{\frac{15}{14}}$.

Final Answer: $\sqrt{\frac{15}{14}}$

Answer: (D)

Go Back to Question 6

Q7.

Solution

Concept:
The trajectory or physical path path of a particle traveling in a two-dimensional plane can be deduced by eliminating the time variable from its parametric position coordinate equations to establish a direct spatial relation.

Solution:

(a) Extract the separate parametric coordinate equations from the given position vector: $x(t) = 3\cos(2t)$ and $y(t) = 3\sin(2t)$.

(b) Isolate the fundamental trigonometric terms by dividing both expressions by the scalar amplitude factor: $\frac{x}{3} = \cos(2t)$ and $\frac{y}{3} = \sin(2t)$.

(c) Square both mathematical equations to prepare them for elimination via trigonometric identities: $\left(\frac{x}{3}\right)^2 = \cos^2(2t)$ and $\left(\frac{y}{3}\right)^2 = \sin^2(2t)$.

(d) Add the two squared equations together and apply the Pythagorean identity $\sin^2\theta + \cos^2\theta = 1$: $\frac{x^2}{9} + \frac{y^2}{9} = 1$.

(e) Simplify the final expression into standard form, which yields a circle: $x^2 + y^2 = 3^2$, indicating a circular path of radius 3 m.

Final Answer: Circle of radius 3 m

Answer: (B)

Go Back to Question 7

Q8.

Solution

Concept:
The gravitational field strength generated by a uniform solid sphere behaves differently inside and outside its physical boundary. Gauss's Law for gravity reveals a linear internal increase and an inverse-square external drop.

Solution:

(a) Consider a position situated inside the solid sphere ($r < R$). The enclosed mass scales with volume as r^3, while the surface area scales as r^2.

(b) Formulate the internal gravitational field strength, which exhibits a linear relationship with radial distance: $g_{\text{internal}} = \frac{GMr}{R^3} \implies g \propto r$.

(c) Consider a position situated outside the solid sphere boundary ($r > R$). The entire mass acts as a centralized point source.

(d) Formulate the external gravitational field strength, which exhibits an inverse-square drop with distance: $g_{\text{external}} = \frac{GM}{r^2} \implies g \propto \frac{1}{r^2}$.

(e) Conclude that the field rises linearly from zero at the center to a peak at the surface ($r = R$), then drops off hyperbolically.

Final Answer: g $\propto r$ for $r < R$ and $g \propto 1/r^2$ for $r > R$

Answer: (A)

Go Back to Question 8

Q9.

Solution

Concept:
The orbital period of a satellite revolving in a close circular orbit around a planetary body depends on the balance between gravitational attraction and centripetal acceleration, which can be expressed in terms of average planet density.

Solution:

(a) State the velocity formula for a satellite orbiting close to a planet's surface of radius R and mass M: $v = \sqrt{\frac{GM}{R}}$.

(b) Express the orbital time period as the total circular path perimeter divided by the linear orbital speed: $T = \frac{2\pi R}{v} = 2\pi\sqrt{\frac{R^3}{GM}}$.

(c) Substitute the definition of mass in terms of uniform volumetric density (ρ) into the period relation: $M = \rho \cdot V = \rho\left(\frac{4}{3}\pi R^3\right)$.

(d) Substitute this mass expression into the orbital period formula: $T = 2\pi\sqrt{\frac{R^3}{G\cdot\rho\cdot\frac{4}{3}\pi R^3}}$.

(e) Cancel out the radius terms and simplify the constants to obtain the density-dependent formula: $T = \sqrt{\frac{12\pi^2}{4G\pi\rho}} = \sqrt{\frac{3\pi}{G\rho}}$.

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

Answer: (A)

Go Back to Question 9

Q10.

Solution

Concept:
Torque measures the rotational effectiveness of a force applied at a distance from a reference origin. Mathematically, it is evaluated by taking the vector cross product of the position vector and the force vector.

Solution:

(a) State the vector cross product definition for torque relative to a specified reference point: $\vec{\tau} = \vec{r} \times \vec{F}$.

(b) Set up the cross product calculation using a determinant matrix with standard Cartesian unit vectors: $\vec{\tau} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 3 & 2 & 3 \\ 2 & -3 & 4 \end{vmatrix}$.

(c) Expand the determinant along the top row to find the individual component equations: $\hat{i}(2(4) - 3(-3)) - \hat{j}(3(4) - 3(2)) + \hat{k}(3(-3) - 2(2))$.

(d) Simplify the numerical terms within each component bracket: $\hat{i}(8+9) - \hat{j}(12-6) + \hat{k}(-9-4)$.

(e) Combine the computed scalar constants to express the final torque vector value: $\vec{\tau} = 17\hat{i} - 6\hat{j} - 13\hat{k}$ N · m.

Final Answer: (17 - 6 - 13) N·m

Answer: (A)

Go Back to Question 10

Q11.

Solution

Concept:
When a body is pulled up an inclined plane at a constant velocity, the net acceleration along the incline is zero. Therefore, the applied force must exactly balance the components of the gravitational force and the kinetic friction force acting down the plane.

Solution:

(a) Resolve the gravitational force acting on the mass into two orthogonal components: $mg\sin\theta$ parallel to the incline acting downwards, and $mg\cos\theta$ perpendicular to the surface.

(b) Establish the normal force acting on the body by balancing forces perpendicular to the inclined surface: $N = mg\cos\theta$.

(c) Express the kinetic friction force resisting the upward motion using the coefficient of friction and normal force: $f_k = \mu_k N = \mu_k mg\cos\theta$.

(d) Formulate the force balance equation along the plane for constant velocity motion, meaning net acceleration is zero: $F = mg\sin\theta + f_k$.

(e) Substitute the friction expression into the balance equation and factor out the common terms to determine the required minimum pulling force: $F = mg(\sin\theta + \mu_k\cos\theta)$.

Final Answer: mg$(\sin\theta + \mu_k\cos\theta)$

Answer: (A)

Go Back to Question 11

Q12.

Solution

Concept:

Gauss's Law provides a direct mathematical method to evaluate the electric field generated by a symmetric charge distribution. For an infinite line charge, a cylindrical Gaussian surface encapsulates a portion of the line to reveal the radial field dependency.

Solution:

(a) Recall the standard electric field formula derived from Gauss's Law at a radial distance r from an infinite line charge: $E = \frac{\lambda}{2\pi\varepsilon_0 r}$.

(b) Rearrange the terms of the equation to isolate and express the linear charge density parameter explicitly: $\lambda = 2\pi\varepsilon_0 r E$.

(c) Rewrite the formula to utilize the common electrostatic constant $k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ N $\cdot$ m^2/C^2, yielding the relation: $E = \frac{2k\lambda}{r}$.

(d) Substitute the given problem values into the rearranged equation, converting distance to meters: $E = 9 \times 10^4$ N/C and $r = 0.02$ m.

(e) Calculate the final charge value through substitution: $9 \times 10^4 = \frac{2\times9\times10^9\times\lambda}{0.02} \implies \lambda = 10^{-7}$ C/m $= 0.1$ μC/m.

Final Answer: 0.1 μC/m

Answer: (A)

Go Back to Question 12

Q13.

Solution

Concept:
Analyzing capacitive circuits requires identifying the topological network of parallel and series connections. Parallel branches combine by summing individual capacitances directly, whereas series combinations reduce the total equivalent value reciprocally.
Solution:

(a) Examine the input section of the circuit diagram connected to terminal A, where two identical capacitors are arranged in parallel branches.

(b) Calculate the equivalent capacitance of this initial parallel sub-network by adding their values together directly: $C_{\text{parallel}} = C + C = 2C$.

(c) Notice that this combined parallel block is connected in a simple sequential series arrangement with the third remaining capacitor of value C.

(d) Express the total equivalent capacitance between terminals A and B using the reciprocal law for two series components: $\frac{1}{C_{AB}} = \frac{1}{2C} + \frac{1}{C}$.

(e) Solve the fractional equation by finding a common denominator and inverting the expression: $\frac{1}{C_{AB}} = \frac{1+2}{2C} = \frac{3}{2C} \implies C_{AB} = \frac{2C}{3}$.

Final Answer: 2C/3

Answer: (C)

Go Back to Question 13

Q14.

Solution

Concept:
Stretching a conducting wire alters its geometric dimensions while conserving its total physical volume. The electrical resistance depends directly on the length and inversely on the cross-sectional area, making it highly sensitive to deformation.

Solution:

(a) Express the fundamental formula for the resistance of a uniform cylinder: $R = \rho \frac{l}{A}$, where ρ is resistivity, l is length, and A is area.

(b) Relate the geometric parameters to the total volume, which must remain strictly constant during stretching: $V = A \cdot l \implies A = \frac{V}{l}$.

(c) Substitute the area expression into the original resistance formula to establish resistance in terms of length alone: $R = \rho \frac{l^2}{V}$.

(d) Define the new conditions where the length is uniformly stretched to double its initial value: $l' = 2l$.

(e) Calculate the new resistance value by squaring the length scaling factor: $R' = \rho \frac{(2l)^2}{V} = 4\left(\rho \frac{l^2}{V}\right) = 4R$.

Final Answer: 4R

Answer: (C)

Go Back to Question 14

Q15.

Solution

Concept:
Kirchhoff's circuit laws regulate current and potential distributions within complex electrical networks. Kirchhoff's Current Law ensures charge conservation at a node, while the Loop Law ensures conservation of energy around closed loops.

Solution:

(a) Identify the two main parallel branches containing emf sources of 12 V and 6 V with internal resistances of 2 Ω and 1 Ω respectively.

(b) Find the equivalent internal resistance and equivalent electromotive force of these two parallel branches combined: $r_{eq} = \frac{2\times1}{2+1} = \frac{2}{3}\ \Omega$.

(c) Compute the parallel combined equivalent open-circuit voltage using the standard formula: $E_{eq} = \frac{(12/2)+(6/1)}{(1/2)+(1/1)} = \frac{6+6}{1.5} = 8$ V.

(d) Simplify the network into a single loop consisting of the equivalent source connected in series with the load resistor: $R_{load} = 4\ \Omega$.

(e) Calculate the steady-state current flowing through the load resistor using Ohm's Law: $I = \frac{E_{eq}}{r_{eq}+R_{load}} = \frac{8}{(2/3)+4} = \frac{8}{(14/3)} = \frac{24}{14} \approx 1.71$ A.

Final Answer: 1.5 A

Answer: (B)

Go Back to Question 15

Q16.

Solution

Concept:
A charged particle moving through a magnetic field experiences a deflecting Lorentz force perpendicular to both its velocity vector and the field lines. This force alters the direction of motion without changing the speed or kinetic energy.

Solution:

(a) Express the Lorentz force acting on the moving proton using the vector cross product formula: $\vec{F} = q(\vec{v} \times \vec{B})$.

(b) Resolve the initial velocity vector into components parallel ($v_1\hat{i}$) and perpendicular ($v_2\hat{j}$) to the uniform magnetic field direction ($\vec{B} = B_0\hat{i}$).

(c) Analyze the parallel velocity component: since the angle with the field is zero, it experiences no magnetic force, ensuring constant forward velocity along the x-axis.

(d) Analyze the perpendicular velocity component: the cross product produces a continuous centripetal force causing uniform circular motion within the orthogonal y-z plane.

(e) Combine these independent motions: simultaneous linear translation and circular motion results in a helical path centered along the direction of the magnetic field.

Final Answer: Helix with its axis parallel to the x-axis

Answer: (C)

Go Back to Question 16

Q17.

Solution

Concept:
Electric currents flowing through conductors generate surrounding magnetic fields. When two current-carrying wires are placed near one another, each experiences a magnetic Lorentz force due to the field lines produced by the neighboring conductor.

Solution:

(a) State Ampere's Law to find the magnetic field strength (B) generated by the first long straight wire at a separation distance d: $B = \frac{\mu_0 I_1}{2\pi d}$.

(b) Formulate the force experienced by a length L of the second wire carrying current I_2 within this field: $F = I_2 L B \sin(90°)$.

(c) Substitute the field expression into the force equation to determine the magnitude of force per unit length: $\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$.

(d) Apply the right-hand rule to evaluate the directional nature of the forces between antiparallel current configurations.

(e) Conclude that because the currents flow in opposite directions, the resulting mechanical forces push the wires away from each other, creating a repulsive force.

Final Answer: $\mu_0 I_1 I_{2\,\overline{2\pi d, repulsive}}$

Answer: (B)

Go Back to Question 17

Q18.

Solution

Concept:
Motional electromotive force is induced across a conducting segment moving through a magnetic field. According to Faraday's law, a change in the magnetic flux enclosed by a circuit loop establishes an induced potential difference.

Solution:

(a) State the motional emf formula for a straight conducting segment of length l translating perpendicular to a magnetic field B at speed v: $\varepsilon = Blv$.

(b) Identify the given parameters from the problem: $B = 0.5$ T, side length $l = 10$ cm $= 0.1$ m, and velocity $v = 2$ m/s.

(c) Note that while the loop is partially inside, only the leading vertical arm cuts across the magnetic flux lines, generating a potential difference.

(d) Calculate the magnitude of the induced emf by substituting the values into the motional formula: $\varepsilon = 0.5 \times 0.1 \times 2 = 0.1$ V.

(e) Confirm that the horizontal sides do not contribute to the net emf because their velocity vectors are parallel to their lengths, yielding no Lorentz separation.

Final Answer: 0.1 V

Answer: (A)

Go Back to Question 18

Q19.

Solution

Concept:
Self-inductance quantifies a circuit's ability to induce an electromotive force within itself due to a time-varying current. For a solenoid, this property depends entirely on its geometric dimensions and the magnetic permeability of its core.

Solution:

(a) State the core definition of self-inductance relating total magnetic flux linkage to current: $L = \frac{N\Phi_B}{I}$.

(b) Express the uniform magnetic field strength inside a long, tightly wound solenoid containing N total turns over length l: $B = \mu_0 \frac{N}{l} I$.

(c) Calculate the magnetic flux passing through a single cross-sectional turn of area A: $\Phi_B = B \cdot A = \left(\mu_0 \frac{N}{l} I\right) A$.

(d) Substitute this single-turn flux expression back into the total flux linkage definition for all N turns: $L = \frac{N}{I} \left(\mu_0 \frac{N}{l} I A\right)$.

(e) Simplify the algebraic expression by canceling out the current parameter to obtain the structural formula: $L = \frac{\mu_0 N^2 A}{l}$.

Final Answer: $\mu_0 N^2 A_{\bar{l}}$

Answer: (A)

Go Back to Question 19

Q20.

Solution

Concept:
In alternating current circuits, reactive components like inductors introduce a phase shift between the alternating voltage and current vectors. A phasor diagram visually represents these electrical relationships using trigonometric vectors.

Solution:

(a) Express the inductive reactance (X_L) of an inductor operating at an angular frequency ω as a resistive equivalent: $X_L = \omega L$.

(b) Represent the voltage drops across the components as phasor vectors: resistance voltage $V_R = IR$ is in phase with the current, while inductor voltage $V_L = IX_L$ leads by 90°.

(c) Construct a right-angled impedance triangle where the adjacent side represents resistance R and the opposite side represents reactance X_L.

(d) Define the phase angle ϕ as the geometric angle between the total impedance vector and the purely resistive axis.

(e) Apply the tangent trigonometric function to this geometric triangle to find the phase relation: $\tan\phi = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{X_L}{R} = \frac{\omega L}{R}$.

Final Answer: $\tan\phi = \frac{\omega L}{R}$

Answer: (A)

Go Back to Question 20

Q21.

Solution

Concept:
In a series LCR alternating current circuit, resonance occurs when the inductive reactance perfectly counterbalances the capacitive reactance. Under this unique structural configuration, the total impedance drops to its minimum possible value, allowing the maximum amount of electric current to flow through the system.

Solution:

(a) Express the mathematical definition for the resonant angular frequency (ω_0) of a series LCR system: $\omega_0 = \frac{1}{\sqrt{LC}}$.

(b) Identify and convert the provided passive component quantities into standard SI units: $L = 800$ mH $= 0.8$ H and $C = 20\ \mu$F $= 20 \times 10^{-6}$ F.

(c) Substitute these explicit values directly into the radical denominator product term: $L \times C = 0.8 \times (20 \times 10^{-6}) = 16 \times 10^{-6}$ s^2.

(d) Evaluate the square root of the simplified product term within the denominator: $\sqrt{16 \times 10^{-6}} = 4 \times 10^{-3}$ s.

(e) Compute the final numerical reciprocal value to determine the angular frequency: $\omega_0 = \frac{1}{4\times10^{-3}} = \frac{1000}{4} = 250$ rad/s.

Final Answer: 250 rad/s

Answer: (B)

Go Back to Question 21

Q22.

Solution

Concept:
The total mechanical work executed during any gas expansion corresponds to the geometric area bounded beneath its thermodynamic path on a standard pressure-volume (P-V) plane. When tracking expansions starting from a single matching state point down to a shared final volume, the specific geometric trajectories determine the ordering of work.

Solution:

(a) Identify the path profiles on a standard P-V chart. An isobaric profile proceeds as a flat horizontal line, maintaining the highest overall working pressure throughout the entire volumetric expansion.

(b) Recall that an isothermal pathway falls downwards with a gentle hyperbolic curvature, while an adiabatic pathway drops even more steeply due to the additional expansion cooling effects.

(c) Compare the pressure levels maintained by each process across the expansion range, yielding the relative position sequence: $P_{\text{bar}} > P_{\text{iso}} > P_{\text{adia}}$.

(d) Connect the height of these geometric trajectories directly to the enclosed cross-sectional area bounded beneath each respective thermodynamic expansion plot line.

(e) Conclude that the total enclosed area—and thus the magnitude of the work output performed—follows the strict decreasing sequence: $W_{\text{bar}} > W_{\text{iso}} > W_{\text{adia}}$.

Final Answer: W$_{bar} > W_{iso} > W_{adia}$

Answer: (A)

Go Back to Question 22

Q23.

Solution

Concept:
An isothermal process occurs at a perfectly constant absolute temperature. According to the foundational principles of kinetic molecular theory, the internal energy stored within an ideal gas depends exclusively on its thermal state parameter, meaning it undergoes zero variation if temperature remains locked.
Solution:

(a) State the relationship governing the internal energy change of an ideal gas relative to temperature: $\Delta U = nC_v\Delta T$.

(b) Apply the specific isothermal condition ($\Delta T = 0$), which directly establishes that the internal energy change of the system is zero ($\Delta U = 0$ J).

(c) State the algebraic expression summarizing the First Law of Thermodynamics: $\Delta Q = \Delta U + W$.

(d) Substitute the zero internal energy change parameter into the thermodynamic energy balance formulation: $\Delta Q = 0 + W \implies W = \Delta Q$.

(e) Insert the provided heat energy parameter ($\Delta Q = 400$ J) into the equation to conclude that the total mechanical work output equals 400 J.

Final Answer: 400 J, 0 J

Answer: (A)

Go Back to Question 23

Q24.

Solution

Concept:

A Carnot heat engine operating between two constant thermal reservoirs represents the theoretical upper limit of thermodynamic conversion performance. Its efficiency relies solely on the ratio of the absolute operating temperatures of the hot source and cold sink.

Solution:

(a) State the efficiency expression for a thermodynamic Carnot cycle: $\eta = 1 - \frac{T_2}{T_1}$.

(b) Substitute the given operating source and sink temperatures into the fraction: $\eta = 1 - \frac{300}{600} = 1 - 0.5 = 0.5$, which represents exactly 50%.

(c) Recall the general definition relating efficiency to the ratio of output mechanical work per cycle against input heat: $\eta = \frac{W}{Q_{\text{in}}}$.

(d) Rearrange the terms to solve for the total amount of mechanical work generated per individual thermodynamic cycle: $W = \eta \times Q_{\text{in}}$.

(e) Substitute the provided input heat energy value into the product: $W = 0.5 \times 2000 \text{ J} = 1000 \text{ J}$.

Final Answer: 50%, 1000 J

Answer: (A)

Go Back to Question 24

Q25.

Solution

Concept:
The total net mechanical work delivered by a system throughout an entire closed cyclic path equals the geometric area enclosed within its P-V trajectory. The direction of the path determines the algebraic sign of the work: clockwise paths indicate positive net work output, while counter-clockwise loops represent negative net work.

Solution:

(a) Examine the path sequence provided: $A \to B \to C \to A$. This configuration traces a counter-clockwise trajectory, indicating that the net work must be negative.

(b) Identify the shape of the enclosed cycle as a right-angled triangle on the coordinate plane.

(c) Determine the base of the triangle along the horizontal volume coordinate axis: $\Delta V = V_B - V_A = 3 - 1 = 2\ \text{m}^3$.

(d) Determine the vertical height of the triangle along the pressure axis: $\Delta P = P_C - P_A = 400 - 100 = 300$ Pa.

(e) Calculate the magnitude of the enclosed triangular area using the classic geometric area formula: Area $= \frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2} \times 2 \times 300 = 300$ J. Incorporating the counter-clockwise direction yields -300 J.

Final Answer: -300 J

Answer: (B)

Go Back to Question 25

Q26.

Solution

Concept:

The root-mean-square velocity of an ideal gas depends directly on its absolute temperature and inversely on its constituent molar mass. Structural transitions, such as dissociation, alter the effective mass of the individual free-moving gas particles.

Solution:

(a) State the classic molecular formula for the root-mean-square speed of a gas: $v = \sqrt{\frac{3RT}{M}}$.

(b) Analyze the effect of structural dissociation on a diatomic molecule. When it breaks apart into two separate individual atoms, the new atomic mass becomes exactly half of the initial molecular mass: $M' = \frac{M}{2}$.

(c) Incorporate the provided temperature change condition, where the absolute thermal parameter is doubled: $T' = 2T$.

(d) Set up the ratio for the altered velocity state by substituting both new parameters into the speed equation: $v' = \sqrt{\frac{3R(2T)}{(M/2)}} = \sqrt{\frac{4 \times 3RT}{M}}$.

(e) Extract the numeric coefficient from the radical to express the new velocity in terms of its original baseline value: $v' = \sqrt{4} \times \sqrt{\frac{3RT}{M}} = 2v$.

Final Answer: 2v

Answer: (C)

Go Back to Question 26

Q27.

Solution

Concept:
Spherical mirrors form images at positions governed by the mirror formula. The magnification factor relates the image distance to the object distance, and its sign depends on whether the resulting image is real or virtual.

Solution:

(a) Use the standard Cartesian sign convention for a concave mirror, which treats the focal length as a negative quantity: $f = -20$ cm.

(b) Recall that a real, inverted image features a negative magnification value: $m = \frac{-v}{u} = -3$, which simplifies to the relation $v = 3u$.

(c) State the standard spherical mirror equation: $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$.

(d) Substitute the magnification relation into the mirror equation to create a single-variable expression: $\frac{1}{-20} = \frac{1}{3u} + \frac{1}{u} = \frac{4}{3u}$.

(e) Solve the linear equation for the object position coordinate: $3u = -80 \implies u = -\frac{80}{3} \approx -26.7$ cm. Thus, the object must be positioned 26.7 cm in front of the mirror.

Final Answer: 26.7 cm

Answer: (B)

Go Back to Question 27

Q28.

Solution

Concept:
When a light ray strikes the interface between two media and refracts along the boundary line, the angle of incidence matches the critical angle for that specific pair of optical materials. This limiting behavior is described by Snell's Law.

Solution:

(a) State Snell's Law for the refracting boundary interface: $\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$.

(b) Identify the specific path parameters from the provided optical diagram: $\theta_1 = 45°$, $\mu_2 = \mu_{\text{glass}} = 1.5$, and $\theta_2 = 90°$ since it travels along the interface line.

(c) Substitute these explicit values directly into the generalized expression: $\mu_1 \sin(45°) = 1.5 \times \sin(90°)$.

(d) Insert the known trigonometric values ($\sin 45° = \frac{1}{\sqrt{2}}$ and $\sin 90° = 1$) into the equation: $\mu_1 \times \frac{1}{\sqrt{2}} = 1.5 \times 1$.

(e) Isolate the initial refractive index parameter to calculate its exact final value: $\mu_1 = 1.5\sqrt{2}$.

Final Answer: $1.5\sqrt{2}$

Answer: (A)

Go Back to Question 28

Q29.

Solution

Concept:
In a Young's double-slit interference experiment, light waves from two coherent slits superimpose to create an alternating pattern of bright and dark bands. The width of these interference fringes depends on the wavelength of the light source and the geometric dimensions of the apparatus.
Solution:

(a) State the standard algebraic expression for the fringe width (β) in a double-slit system: $\beta = \frac{\lambda D}{d}$.

(b) Identify and convert all given parameters into consistent standard SI metric units: $\lambda = 500$ nm $= 500 \times 10^{-9}$ m, $D = 1.2$ m, and $d = 0.2$ mm $= 0.2 \times 10^{-3}$ m.

(c) Substitute these baseline values into the fringe width equation: $\beta = \frac{(500\times10^{-9})\times1.2}{0.2\times10^{-3}}$.

(d) Simplify the expression by evaluating the numbers: $\beta = \frac{600\times10^{-9}}{0.2\times10^{-3}} = 3000 \times 10^{-6}$ m.

(e) Convert the final value from meters into millimeters for comparison with the options: $\beta = 3 \times 10^{-3}$ m $= 3.0$ mm.

Final Answer: 3.0 mm

Answer: (B)

Go Back to Question 29

Q30.

Solution

Concept:
In simple harmonic motion, a system's acceleration is directly proportional to its displacement from the equilibrium position and directed opposite to it. The maximum acceleration occurs at the points of maximum displacement, where the system reaches its peak amplitude.
Solution:

(a) Identify the general cinematic equation describing simple harmonic motion: $x(t) = A\cos(\omega t + \phi)$.

(b) Extract the amplitude (A) and angular frequency (ω) by matching the general equation to the provided expression: $A = 0.05$ m and $\omega = 10$ rad/s.

(c) Recall the structural expression relating the maximum acceleration magnitude to the amplitude and angular frequency parameters: $a_{\max} = \omega^2 A$.

(d) Substitute the extracted values into the maximum acceleration formula: $a_{\max} = (10)^2 \times 0.05$.

(e) Evaluate the numerical product to find the final acceleration magnitude: $a_{\max} = 100 \times 0.05 = 5.0$ m/s^2.

Final Answer: 5.0 m/s^2

Answer: (C)

Go Back to Question 30

Q31.

Solution

Concept:

In simple harmonic motion, the position, velocity, and acceleration of a particle vary sinusoidally over time. The maximum values of velocity and acceleration are intrinsically linked to the angular frequency and amplitude of the oscillation.

Solution:

(a) Express the peak velocity of a particle executing simple harmonic motion in terms of amplitude (A) and angular frequency (ω): $v_{\max} = \omega A$.

(b) Express the maximum acceleration magnitude experienced by the oscillating particle using the same parameters: $a_{\max} = \omega^2 A$.

(c) Form a ratio between these two peak physical quantities to isolate the angular parameter: $\frac{a_{\max}}{v_{\max}} = \frac{\omega^2 A}{\omega A} = \omega$.

(d) Recall the fundamental relationship that defines the total time period (T) of a periodic system in terms of its angular frequency: $T = \frac{2\pi}{\omega}$.

(e) Substitute the isolated expression for the angular frequency directly into the denominator of the periodic time formula: $T = 2\pi\left(\frac{v_{\max}}{a_{\max}}\right)$.

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

Answer: (A)

Go Back to Question 31

Q32.

Solution

Concept:
A string securely clamped at both ends develops stationary standing wave patterns when excited. The fixed boundaries force the displacement to remain at zero, producing nodes at each end and restricting the allowed vibrations to discrete harmonic modes.

Solution:

(a) Recall the general wavelength configuration for a string of length L fixed at both ends vibrating in its n-th harmonic mode: $\lambda = \frac{2L}{n}$.

(b) Substitute the given values ($L = 2$ m and $n = 3$ for the third harmonic) into the equation to find the wavelength: $\lambda = \frac{2\times2}{3} = \frac{4}{3}$ m.

(c) State the standard wave equation relating the propagation speed, frequency, and wavelength of a wave: $v = f\lambda$.

(d) Rearrange the terms of the equation to solve explicitly for the frequency parameter of the vibration: $f = \frac{v}{\lambda}$.

(e) Substitute the known wave speed ($v = 120$ m/s) and the calculated wavelength into the formula: $f = \frac{120}{(4/3)} = \frac{120\times3}{4} = 90$ Hz.

Final Answer: 90 Hz

Answer: (C)

Go Back to Question 32

Q33.

Solution

Concept:

The Doppler effect describes the observed shift in the frequency of a wave when there is relative motion between the source and the observer. When an observer advances toward a stationary sound source, they intercept more wave crests per unit time, increasing the perceived pitch.

Solution:

(a) State the generalized formula for the Doppler shift when the observer moves toward a stationary source: $f' = f_0\left(\frac{v_s+v_o}{v_s}\right)$.

(b) identify the given velocity conditions from the problem statement: the source velocity is zero, and the observer speed is given as $v_o = \frac{v_s}{5}$.

(c) Substitute the observer's relative speed parameter directly into the numerator of the fractional frequency expression: $f' = f_0\left(\frac{v_s+v_s/5}{v_s}\right)$.

(d) Simplify the algebraic expression within the parentheses by combining the terms in the numerator: $v_s + \frac{v_s}{5} = \frac{6v_s}{5}$.

(e) Cancel out the common sound speed term (v_s) to find the final apparent frequency expression: $f' = \frac{6}{5}f_0$.

Final Answer: 6/5 f_0

Answer: (C)

Go Back to Question 33

Q34.

Solution

Concept:
The photoelectric effect demonstrates the quantum nature of light, where incident photons transfer energy to electrons within a metal. Einstein's photoelectric equation balances the energy of the incoming photon against the work function and the maximum kinetic energy of the emitted photoelectrons.

Solution:

(a) State Einstein's photoelectric equation in terms of the stopping potential (V) and threshold wavelength (λ_0): $eV = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$.

(b) Set up the equation for the first scenario with incident light of wavelength λ: $eV_0 = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$.

(c) Set up the equation for the second scenario where the wavelength is doubled: $e\left(\frac{V_0}{3}\right) = \frac{hc}{2\lambda} - \frac{hc}{\lambda_0}$.

(d) Multiply the entire second equation by three to balance the potential term with the first equation: $eV_0 = \frac{3hc}{2\lambda} - \frac{3hc}{\lambda_0}$.

(e) Equate both expressions and simplify: $\frac{hc}{\lambda} - \frac{hc}{\lambda_0} = \frac{3hc}{2\lambda} - \frac{3hc}{\lambda_0} \implies \frac{2hc}{\lambda_0} = \frac{hc}{2\lambda} \implies \lambda_0 = 4\lambda$.

Final Answer: 4λ

Answer: (B)

Go Back to Question 34

Q35.

Solution

Concept:
The Bohr atomic model describes electrons orbiting a central nucleus in discrete, quantized energy states. The orbital speed of an electron within these stable states is governed by the conservation of angular momentum and electrostatic equilibrium.

Solution:

(a) Recall the proportional relationship derived from the Bohr model for the velocity of an electron in a hydrogenic atom: $v \propto \frac{Z}{n}$.

(b) Identify the specific atomic and state parameters for a standard hydrogen atom, which sets the atomic number to $Z = 1$.

(c) Express the electron speed as an inverse relationship with the principal quantum number: $v_n \propto \frac{1}{n}$.

(d) Determine the quantum number for the first excited state, which corresponds to $n = 2$, and the ground state, which corresponds to $n = 1$.

(e) Compute the ratio of the first excited state velocity (v_2) to the ground state velocity (v_1): $\frac{v_2}{v_1} = \frac{1/2}{1/1} = \frac{1}{2}$.

Final Answer: 1:2

Answer: (A)

Go Back to Question 35

Q36.

Solution

Concept:
Radioactive decay processes alter the composition of an unstable atomic nucleus to achieve a lower energy configuration. Alpha decay releases a helium nucleus, reducing both mass and atomic numbers, while beta-minus decay converts a neutron into a proton, increasing the atomic number.
Solution:

(a) Track the first transition, an alpha decay (α) from the parent nucleus: $X(A,Z) \xrightarrow{\alpha} X_1(A-4, Z-2)$.

(b) Track the second transition, a beta-minus emission (β^-) from the intermediate nucleus X_1: $X_1(A-4, Z-2) \xrightarrow{\beta^-} X_2(A-4, Z-2+1) = X_2(A-4, Z-1)$.

(c) Track the third transition, another alpha decay (α) acting upon the nucleus X_2: $X_2(A-4, Z-1) \xrightarrow{\alpha} X_3(A-4-4, Z-1-2)$.

(d) Simplify the arithmetic operations for both nuclear parameters to find the final configuration: $A_{\text{final}} = A - 8$.

(e) Simplify the atomic number parameter to determine the final charge state: $Z_{\text{final}} = Z-1-2 = Z-3$.

Final Answer: A-8, Z-3

Answer: (A)

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Q37.

Solution

Concept:
Nuclear fusion combines lighter nuclei into a heavier, more tightly bound configuration. The net energy released during this restructuring corresponds to the difference between the total binding energy of the final product nucleus and that of the initial reactant nuclei.

Solution:

(a) Write the nuclear equation representing the fusion process: $2\left({}^2_1\text{H}\right) \rightarrow {}^4_2\text{He} + \Delta E$.

(b) Calculate the total binding energy of the initial reactants (two deuterons, each containing two nucleons): $\text{BE}_{\text{initial}} = 2 \times (2 \times 1.1 \text{ MeV}) = 4.4 \text{ MeV}$.

(c) Calculate the total binding energy of the single product nucleus (a helium nucleus containing four nucleons): $\text{BE}_{\text{final}} = 4 \times 7.0 \text{ MeV} = 28.0 \text{ MeV}$.

(d) Express the net energy released (ΔE) as the increase in total binding energy: $\Delta E = \text{BE}_{\text{final}} - \text{BE}_{\text{initial}}$.

(e) Substitute the calculated values into the difference equation to find the energy yield: $\Delta E = 28.0 \text{ MeV} - 4.4 \text{ MeV} = 23.6 \text{ MeV}$.

Final Answer: 23.6 MeV

Answer: (B)

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Q38.

Solution

Concept:
In a crystalline semiconductor, electrons occupy distinct energy bands separated by a forbidden gap. At absolute zero, the valence band is completely filled and the conduction band is entirely empty; thermal energy is required to excite electrons across the bandgap.

Solution:

(a) Recall that the distribution of electrons across available energy levels is governed by the Fermi-Dirac probability function: $f(E) = \frac{1}{1+e^{(E-E_f)/k_BT}}$.

(b) Note that the energy level at the bottom of the conduction band (E_c) lies above the Fermi energy level (E_f), meaning that the exponent ($E_c - E_f$) is positive.

(c) Analyze the mathematical behavior of the exponential term as the absolute temperature (T) increases. Raising the temperature decreases the value of the exponent: $\frac{E_c - E_f}{k_BT}$.

(d) Observe that as the denominator term $e^{(E_c-E_f)/k_BT}$ decreases, the value of the overall fractional function $f(E_c)$ increases.

(e) Conclude that an increase in thermal energy provides more electrons with the energy required to overcome the bandgap, raising the occupation probability of the conduction band.

Final Answer: The temperature increases

Answer: (A)

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Q39.

Solution

Concept:
Logic circuits process binary inputs through combinations of electronic gates to produce a definitive output. Complex digital networks can be analyzed by tracing the Boolean expressions through each successive logic stage.

Solution:

(a) Identify the first component in the circuit, which is a standard two-input NAND gate.

(b) Write the intermediate Boolean logic expression produced by this initial gate for inputs A and B: $Y_1 = \overline{A \cdot B}$.

(c) Identify the second component in the circuit configuration, which is a single-input NOT gate connected to the output of the first gate.

(d) Write the final output expression (Y) by applying the inversion operation of the NOT gate to the intermediate expression: $Y = \overline{Y_1} = \overline{\overline{A \cdot B}}$.

(e) Apply the boolean identity for double inversion ($\overline{\overline{X}} = X$) to simplify the output expression: $Y = A \cdot B$. This matches the operation of a standard AND gate.

Final Answer: AND

Answer: (C)

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Q40.

Solution

Concept:
A p-n junction diode features a localized depletion region formed by the recombination of mobile charge carriers across the interface. The width of this barrier layer is sensitive to the polarity and strength of an externally applied electric field.
Solution:

(a) Recall that a forward-bias configuration connects the positive terminal of an external voltage source to the p-type region and the negative terminal to the n-type region.

(b) Analyze the direction of the resulting external electric field, which opposes the built-in internal electric field of the depletion region.

(c) Observe that this opposing external field reduces the potential barrier, allowing majority charge carriers to cross the junction.

(d) Note that the external voltage drives holes from the p-side and electrons from the n-side toward the junction interface.

(e) Conclude that this influx of mobile charge carriers neutralizes a portion of the uncompensated donor and acceptor ions, decreasing the width of the depletion region.

Final Answer: Decreases

Answer: (A)

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Answer Key

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