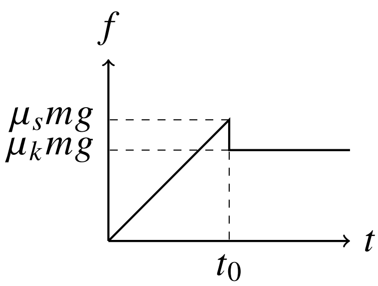
UPCATET Physics Sample Paper-10

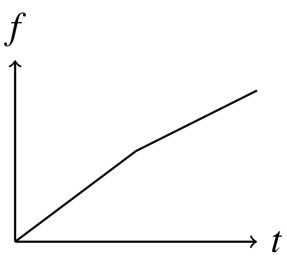
Duration: 45 Minutes **Maximum Marks: 200**

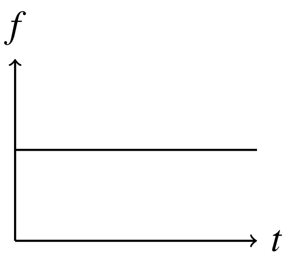
Instructions

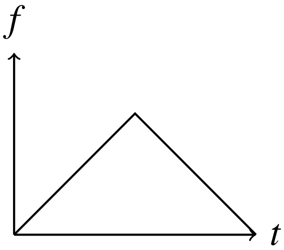
- This paper contains **50** Multiple Choice Questions.
- Each correct answer carries **+4** mark. Incorrect answer: **−1** marks. Only **one** correct option.
- Unattempted questions carry **0** marks.
- Use of mobile phones, smartwatches, or any electronic gadgets is strictly prohibited.

Q1. A block of mass m is placed on a rough horizontal surface. A variable horizontal force $F = kt$ (where k is a positive constant and t is time) is applied to the block. If the coefficient of static friction is μ_s and kinetic friction is μ_k ($\mu_s > \mu_k$), which of the following graphs correctly represents the variation of friction force f with time t?

(A) 

(B) 

(C) 

(D) 

Q2. An alternating current voltage source $v = V_0 \sin(\omega t)$ is connected across a pure inductor of inductance L. The instantaneous power delivered by the source to the inductor varies with a frequency of:

(A) $\frac{\omega}{2\pi}$

(B) $\frac{\omega}{\pi}$

(C) $\frac{\omega}{4\pi}$

(D) Zero

Q3. A monochromatic light wave of wavelength λ traveling in a medium of refractive index n_1 enters another medium of refractive index n_2. If the velocity of light in the first medium is v_1 and in the second medium is v_2, the phase difference between two points separated by a distance x along the path of the wave in the second medium is:

(A) $\frac{2\pi n_2 x}{\lambda}$

(B) $\frac{2\pi n_1 x}{\lambda}$

(C) $\frac{2\pi x}{n_2 \lambda}$

(D) $\frac{2\pi n_2 x}{n_1 \lambda}$

Q4. An ideal gas heat engine operates in a Carnot cycle between temperatures 227°C and 127°C. It absorbs 6×10^4 cal of heat at the higher temperature. The amount of heat converted into useful work is:

(A) 1.2×10^4 cal

(B) 2.4×10^4 cal

(C) 3.6×10^4 cal

(D) 4.8×10^4 cal

Q5. When a hydrogen atom transitions from an excited state with principal quantum number n to the ground state ($n = 1$), the recoil speed of the hydrogen atom (mass M) due to the emission of a photon is approximately given by (where R is Rydberg's constant and h is Planck's constant):

(A) $\frac{hR}{M}\left(1 - \frac{1}{n^2}\right)$

(B) $\frac{hR}{M}\left(\frac{1}{n^2} - 1\right)$

(C) $\frac{M}{hR}\left(1 - \frac{1}{n^2}\right)$

(D) $\frac{hRn^2}{M}$

Q6. Two wires A and B are made of the same material. Wire A has twice the length and half the radius of wire B. If both wires are stretched by the same horizontal force, the ratio of the extension of wire A to that of wire B ($\Delta L_A/\Delta L_B$) is:

(A) 1 : 8

(B) 8 : 1

(C) 1 : 4

(D) 4 : 1

Q7. A particle is projected from the ground with an initial velocity u at an angle θ with the horizontal. The radius of curvature of its trajectory at the highest point of its flight is:

(A) $\frac{u^2 \sin^2 \theta}{g}$

(B) $\frac{u^2 \cos^2 \theta}{g}$

(C) $\frac{u^2}{g}$

(D) $\frac{u^2 \cos^2 \theta}{g \sin \theta}$

Q8. Four identical point charges, each of charge $+q$, are placed at the four corners of a square of side a. The electric potential at the center of the square is:

(A) $\frac{4q}{4\pi\varepsilon_0 a}$

(B) $\frac{2\sqrt{2}q}{\pi\varepsilon_0 a}$

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

(D) Zero

Q9. In a Young's double-slit experiment, the intensity at a point on the screen where the path difference is λ is I_0. If the path difference at another point becomes $\frac{\lambda}{4}$, the intensity at that point will be:

(A) I_0

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

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

(D) $\frac{I_0}{\sqrt{2}}$

Q10. A specific volume of an ideal gas at temperature T and pressure P expands isothermally to double its volume. It is then compressed adiabatically back to its original volume. The final pressure of the gas (where γ is the ratio of specific heats C_p/C_v) is:

(A) $P \cdot 2^{\gamma-1}$

(B) $P \cdot 2^{1-\gamma}$

(C) $P \cdot 2^{\gamma}$

(D) P

Q11. For a common-emitter amplifier configuration using an NPN transistor, what is the phase relationship between the input AC signal voltage and the output AC signal voltage across the collector load resistor?

(A) In phase (0°)

(B) Out of phase (90°)

(C) Out of phase (180°)

(D) Out of phase (270°)

Q12. A uniform solid cylinder of mass M and radius R rolls without slipping down an inclined plane making an angle θ with the horizontal. The linear acceleration of the center of mass of the cylinder is:

(A) $g \sin\theta$

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

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

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

Q13. Three resistors of resistances $2\,\Omega$, $4\,\Omega$, and $6\,\Omega$ are connected in parallel. A total current of 11 A is passed through the combination. The current flowing through the $2\,\Omega$ resistor is:

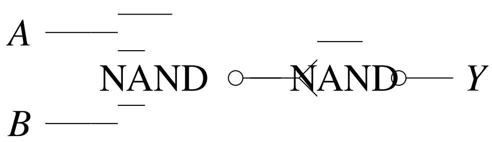
(A) 2 A

(B) 3 A

(C) 6 A

(D) 5 A

Q14. Identify the logic gate represented by the given combination of circuits:



(A) AND Gate

(B) OR Gate

(C) NOT Gate

(D) NAND Gate

Q15. A liquid is flowing through a horizontal non-uniform pipe. At a section where the cross-sectional area is A, the velocity of flow is v and the dynamic pressure is P. At another section where the cross-sectional area is $2A$, the velocity of the liquid will be:

(A) $2v$

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

(C) $4v$

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

Q16. A body of mass m is hauled up a rough inclined plane making an angle θ with the horizontal by a force acting parallel to the incline. If the coefficient of kinetic friction is μ_k and the body moves up a distance d at a constant speed, the total work done against friction is:

(A) $\mu_k mgd \sin\theta$

(B) $\mu_k mgd \cos\theta$

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

(D) $\mu_k mgd$

Q17. The self-inductance of a long solenoid having N total turns, length l, and uniform cross-sectional area A is given by the expression:

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

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

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

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

Q18. An astronomical telescope has an objective lens of focal length 140 cm and an eyepiece of focal length 5.0 cm. What is the magnifying power of the telescope for viewing distant objects in normal adjustment?

(A) 28

(B) 35

(C) 70

(D) 145

Q19. According to the kinetic theory of gases, the root-mean-square (rms) speed of ideal gas molecules at an absolute temperature T is proportional to:

(A) T

(B) T^2

(C) $T^{1/2}$

(D) $T^{-1/2}$

Q20. The work function of a certain photosensitive metal surface is 2.5 eV. If light of photon energy 4.0 eV falls on this surface, the maximum kinetic energy of the emitted photoelectrons will be:

(A) 6.5 eV

(B) 1.5 eV

(C) 2.5 eV

(D) Zero

Q21. A capillary tube of radius r is immersed vertically in a liquid of density ρ and surface tension T. If the angle of contact is zero, the vertical height h to which the liquid rises in the tube is given by:

(A) $\frac{2T}{r\rho g}$

(B) $\frac{T}{2r\rho g}$

(C) $\frac{4T}{r\rho g}$

(D) $\frac{T}{r\rho g}$

Q22. A satellite of mass m is orbiting the Earth at a constant altitude h above the Earth's surface (radius R_E, mass M_E). The total mechanical energy of the satellite is:

(A) $-\frac{GM_Em}{R_E+h}$

(B) $-\frac{GM_Em}{2(R_E+h)}$

(C) $\frac{GM_Em}{2(R_E+h)}$

(D) $-\frac{2GM_Em}{R_E+h}$

Q23. A circular loop of radius R carries a steady current I. The magnetic field strength at the center of the loop is B_1. The magnetic field strength at a point on the axis of the loop at a distance R from the center is B_2. The ratio B_1/B_2 is:

(A) 2

(B) $2\sqrt{2}$

(C) $\sqrt{2}$

(D) 4

Q24. A thin convex lens made of glass (refractive index $n = 1.5$) has a focal length of 20 cm in air. When it is completely immersed in water (refractive index $n = \frac{4}{3}$), its new focal length becomes:

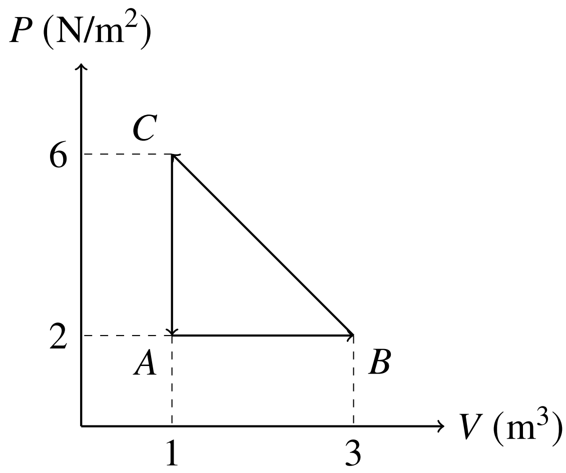
(A) 20 cm

(B) 40 cm

(C) 80 cm

(D) 10 cm

Q25. A sample of gas is taken through the cyclic process shown in the given $P - V$ diagram. What is the total net work done by the gas during one complete cycle $A \rightarrow B \rightarrow C \rightarrow A$?



(A) 8 J

(B) 4 J

(C) −4 J

(D) 2 J

Q26. The half-life of a radioactive isotope is 10 days. What fraction of the original active nuclei sample remains undecayed after a duration of 30 days?

(A) $\frac{1}{3}$

(B) $\frac{1}{6}$

(C) $\frac{1}{8}$

(D) $\frac{7}{8}$

Q27. A spherical blackbody of radius R radiates power P at an absolute temperature T. If its radius is halved and the absolute temperature is doubled, the new power radiated by the body will be:

(A) $2P$

(B) $4P$

(C) $8P$

(D) $16P$

Q28. A uniform solid sphere of mass M and radius R is rotating about a tangential axis that is parallel to its diameter. The moment of inertia of the solid sphere about this specific tangential axis is:

(A) $\frac{2}{5}MR^2$

(B) $\frac{7}{5}MR^2$

(C) $\frac{3}{5}MR^2$

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

Q29. A parallel-plate capacitor with air between the plates has a capacitance C. If the separation distance between the plates is cut in half and a dielectric medium of dielectric constant $K = 4$ is completely inserted between the plates, the new capacitance becomes:

(A) $2C$

(B) $4C$

(C) $8C$

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

Q30. In a Fraunhofer single-slit diffraction pattern, the width of the central maximum is found to be twice that of the slit width. If the wavelength of light used is λ

and the slit width is a, the first minimum on either side of the central maximum occurs at an angle θ satisfying:

(A) $\sin\theta = \frac{\lambda}{a}$

(B) $\sin\theta = \frac{2\lambda}{a}$

(C) $\sin\theta = \frac{\lambda}{2a}$

(D) $\sin\theta = \frac{3\lambda}{2a}$

Q31. A particle is executing simple harmonic motion (SHM) along a straight line. At a distance from its mean position equal to half of its maximum amplitude ($x = A/2$), the ratio of its kinetic energy to its potential energy (KE/PE) is:

(A) 1 : 3

(B) 3 : 1

(C) 1 : 1

(D) 4 : 1

Q32. A charge q is positioned at the exact geometric center of a closed regular cube. The total electric flux passing out through any one single face of the six faces of this cube is:

(A) $\frac{q}{\varepsilon_0}$

(B) $\frac{q}{6\varepsilon_0}$

(C) $\frac{q}{4\varepsilon_0}$

(D) Zero

Q33. What is the de Broglie wavelength associated with an electron that has been accelerated from rest through a potential difference of 100 V?

(A) 1.227 Å

(B) 12.27 Å

(C) 0.1227 Å

(D) 122.7 Å

Q34. A metal rod of length L is rotating with a constant angular velocity ω about an axis passing through one of its ends and perpendicular to its length. A uniform magnetic field B exists parallel to the axis of rotation. The induced electromotive force (emf) developed between the two ends of the rod is:

(A) $B\omega L^2$

(B) $\frac{1}{2}B\omega L^2$

(C) $\frac{1}{2}B\omega^2 L$

(D) $2B\omega L^2$

Q35. An unpolarized light beam of intensity I_0 is incident on a pair of ideal polaroid sheets. The orientation angle between the transmission axes of the two polaroids is 60°. The intensity of the light emerging from the second polaroid is:

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

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

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

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

Q36. An ideal gas expands from an initial volume V_1 to a final volume V_2 via three different pathways: path 1 is purely isothermal, path 2 is purely isobaric, and path 3 is purely adiabatic. If W_1, W_2, and W_3 represent the work done by the gas in these respective processes, which relationship holds true?

(A) $W_2 > W_1 > W_3$

(B) $W_3 > W_1 > W_2$

(C) $W_1 > W_2 > W_3$

(D) $W_2 > W_3 > W_1$

Q37. The terminal velocity v of a small spherical ball of radius r falling freely through a viscous liquid column under gravity is related to the radius as:

(A) $v \propto r$

(B) $v \propto r^2$

(C) $v \propto \frac{1}{r}$

(D) $v \propto \frac{1}{r^2}$

Q38. Two point masses m and $4m$ are fixed separated by a distance d. A third point mass M is placed on the line joining them such that the net gravitational force acting on M is exactly zero. The distance of mass M from the mass m is:

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

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

(C) $\frac{d}{4}$

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

Q39. In a potentiometer circuit arrangement, a cell of emf 1.5 V gives a balance point at 30 cm length of the wire. If this cell is replaced by another cell of unknown emf and the balance point shifts to 40 cm, the emf of the second cell is:

(A) 2.0 V

(B) 1.0 V

(C) 2.5 V

(D) 1.75 V

Q40. In the context of semiconductor physics, when a forward bias voltage is applied to a standard P-N junction diode, what happens to the width of the depletion layer region and the barrier potential height?

(A) Depletion width increases, barrier height increases

(B) Depletion width decreases, barrier height decreases

(C) Depletion width increases, barrier height decreases

(D) Depletion width decreases, barrier height increases

Q41. A bullet of mass 10 g traveling horizontally with a speed of 400 m/s strikes a stationary wooden block of mass 990 g and gets embedded inside it. The loss of kinetic energy during this completely inelastic collision process is:

(A) 792 J

(B) 800 J

(C) 79.2 J

(D) 8 J

Q42. A particle with charge q and mass m enters a region of uniform magnetic field B with a velocity v oriented at an angle of 30° relative to the magnetic field direction. The pitch of the helical path traced out by the particle is given by:

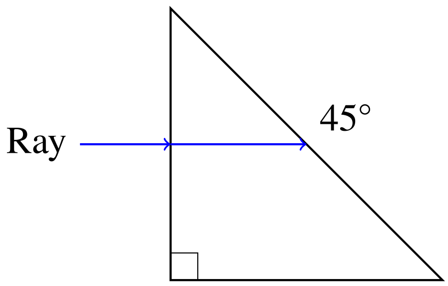
(A) $\frac{2\pi mv}{qB}$

(B) $\frac{\sqrt{3}\pi mv}{qB}$

(C) $\frac{\pi mv}{qB}$

(D) $\frac{2\sqrt{3}\pi mv}{qB}$

Q43. A ray of light is incident normally on one face of a right-angled isosceles prism of refractive index $n = \sqrt{2}$ as shown. What is the total deviation suffered by the ray after exiting the prism?



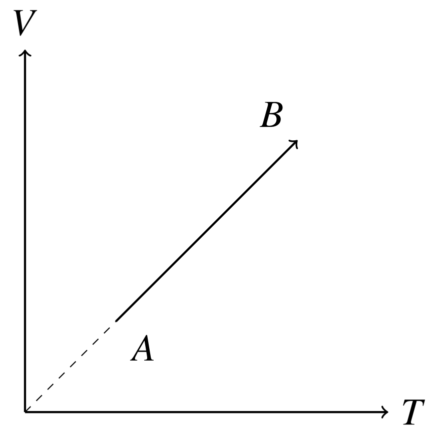
(A) 45°

(B) 90°

(C) 0°

(D) 180°

Q44. A cyclic process performed on an ideal gas is plotted on a $V - T$ (Volume vs Absolute Temperature) coordinate frame as shown in the figure. Which of the following correctly describes the nature of process $A \longrightarrow B$?



(A) Isochoric

(B) Isobaric

(C) Isothermal

(D) Adiabatic

Q45. According to the Bohr model of the hydrogen atom, the velocity of an electron in the n-th permissible stationary orbit is related to the principal quantum number n as:

(A) $v \propto n$

(B) $v \propto \frac{1}{n}$

(C) $v \propto n^2$

(D) $v \propto \frac{1}{n^2}$

Q46. A certain quantity of water at 100°C is converted entirely into steam at 100°C under constant atmospheric pressure conditions. During this physical phase change transition, the internal energy of the system:

(A) Remains constant

(B) Decreases

(C) Increases

(D) First increases then decreases

Q47. A constant torque of 50 N · m applied to a flywheel produces an angular acceleration of 5.0 rad/s^2. The moment of inertia of the flywheel about its axis of rotation is:

(A) 250 kg · m^2

(B) 10 kg · m^2

(C) 0.1 kg · m^2

(D) 50 kg · m^2

Q48. Two long, straight parallel wires separated by a distance r carry currents I_1 and I_2 in opposite directions. The magnetic force per unit length exerted between the two wires is:

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

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

(C) $\frac{\mu_0 I_1 I_2}{4\pi r}$, attractive

(D) $\frac{\mu_0 I_1 I_2}{4\pi r}$, repulsive

Q49. A convex lens of focal length $f_1 = 20$ cm is placed in direct contact coaxially with a concave lens of focal length $f_2 = 10$ cm. The net power of this combined lens system in diopters (D) is:

(A) +5 D

(B) −5 D

(C) +10 D

(D) −10 D

Q50. An electrical circuit contains a pure resistance $R = 30\,\Omega$, an inductive reactance $X_L = 80\,\Omega$, and a capacitive reactance $X_C = 40\,\Omega$ connected in series with an AC power source. The power factor of this series LCR circuit is:

(A) 0.6

(B) 0.8

(C) 1.0

(D) 0.5

Detailed Solutions

Q1.

Solution

Concept:
Friction between a solid body and a rough surface changes phases from static to kinetic based on the applied external force. Static friction is a self-adjusting force that exactly counters the impending motion up to its maximum threshold, known as limiting friction. Once the applied horizontal force exceeds this threshold, the body begins moving, and the friction drops slightly to a constant kinetic friction value.

Solution:

(a) In the initial phase, as time t increases from zero, the applied variable force $F = kt$ increases linearly. As long as F is less than or equal to the maximum static friction, the block remains stationary.

(b) During this stationary phase, the static friction force f must precisely balance the applied force to maintain equilibrium, meaning $f = F = kt$. This yields a linear relationship with a constant positive slope passing through the origin.

(c) The static friction reaches its peak limiting value at a specific critical time t_0, where the maximum friction force is given by $f_{\max} = \mu_s N = \mu_s mg$.

(d) As soon as the time surpasses t_0, the applied force exceeds the limiting static friction, causing the block to break free and begin accelerating across the surface.

(e) Once kinetic sliding begins, the friction force instantly drops to the kinetic friction value, $f_k = \mu_k N = \mu_k mg$. Since $\mu_k < \mu_s$, this value is strictly lower than the peak limiting friction and remains completely constant over time regardless of further velocity changes.

Final Answer: The correct graph shows a linear increase up to $\mu_s mg$, followed by a sudden minor drop to a constant value of $\mu_k mg$.

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept:

When an alternating voltage source is connected across a pure reactive component like an inductor, energy is periodically stored in its magnetic field and subsequently returned to the source. The instantaneous power is defined as the product of the instantaneous voltage and instantaneous current. Analyzing this product using trigonometric identities reveals the frequency at which energy transfer fluctuates.

Solution:

(a) The alternating voltage source across the pure inductor is given by the expression $v = V_0 \sin(\omega t)$, where ω represents the angular frequency of the source.

(b) For a purely inductive circuit, the alternating current lags behind the applied voltage by a phase angle of exactly $\pi/2$ radians (90°). Therefore, the current equation is expressed as $i = I_0 \sin(\omega t - \pi/2) = -I_0 \cos(\omega t)$.

(c) The instantaneous power P delivered to the inductor can be computed by multiplying the instantaneous voltage and current, giving $P = v \cdot i = -V_0 I_0 \sin(\omega t) \cos(\omega t)$.

(d) Applying the double-angle trigonometric identity $2\sin(\theta)\cos(\theta) = \sin(2\theta)$, the expression simplifies directly to $P = -\frac{V_0 I_0}{2} \sin(2\omega t)$.

(e) The resulting mathematical expression shows that the instantaneous power oscillates as a sine wave with a modified angular frequency of $\omega' = 2\omega$. Since the linear frequency is related to angular frequency by $f = \frac{\omega'}{2\pi}$, substituting 2ω yields $f = \frac{2\omega}{2\pi} = \frac{\omega}{\pi}$.

Final Answer: The instantaneous power fluctuates with a frequency of $\frac{\omega}{\pi}$.

Answer: (B)

Go Back to Question 2

Q3.

Solution

Concept:
When a wave propagates from one optical medium into another, its frequency remains strictly invariant because it is determined solely by the source. However, its velocity and wavelength adapt to the optical density of the medium. The phase difference between two spatial points within a single medium depends directly on the modified wavelength inside that specific medium.
Solution:

(a) Let λ be the wavelength of the monochromatic light wave in free vacuum. When light travels in a medium of refractive index n, its effective wavelength changes to $\lambda_m = \frac{\lambda}{n}$.

(b) The problem states that the light wave enters a second medium characterized by a refractive index of n_2. Therefore, the wavelength of the light wave inside this second medium becomes $\lambda_2 = \frac{\lambda}{n_2}$.

(c) The propagation constant or wave number k_2 in the second medium represents the phase change per unit distance and is defined by the formula $k_2 = \frac{2\pi}{\lambda_2}$.

(d) Substituting the value of the modified wavelength λ_2 into the wave number formula gives the expression $k_2 = \frac{2\pi}{\lambda/n_2} = \frac{2\pi n_2}{\lambda}$.

(e) The phase difference $\Delta\phi$ between two distinct points separated by a path distance x within this second medium is calculated using the relation $\Delta\phi = k_2 \cdot x$. Substituting k_2 yields $\Delta\phi = \frac{2\pi n_2 x}{\lambda}$.

Final Answer: The phase difference between the two points is $\frac{2\pi n_2 x}{\lambda}$.

Answer: (A)

Go Back to Question 3

Q4.

Solution

Concept:

A Carnot engine represents a theoretical thermodynamic cycle that operates at maximum efficiency between two thermal reservoirs. The efficiency depends exclusively on the absolute thermodynamic temperatures of the hot source and the cold sink. This efficiency dictates what fraction of the total heat energy absorbed from the source is successfully converted into net mechanical work.

Solution:

(a) First, convert the given operating temperatures from the Celsius scale to the absolute Kelvin scale. The source temperature is $T_1 = 227°C + 273.15 = 500$ K, and the sink temperature is $T_2 = 127°C + 273.15 = 400$ K.

(b) The thermal efficiency η of a reversible Carnot heat engine is defined by the absolute temperature ratio: $\eta = 1 - \frac{T_2}{T_1}$.

(c) Substituting the absolute Kelvin temperatures into the efficiency equation yields $\eta = 1 - \frac{400}{500} = 1 - 0.8 = 0.2$, which corresponds to an efficiency of 20%.

(d) Efficiency is also fundamentally defined as the ratio of the net useful work output W to the total heat energy absorbed at the high temperature Q_1, expressed as $\eta = \frac{W}{Q_1}$.

(e) Rearranging the equation to solve for the useful mechanical work gives $W = \eta \cdot Q_1$. Substituting the known parameters yields $W = 0.2 \times (6 \times 10^4 \text{ cal}) = 1.2 \times 10^4$ cal.

Final Answer: The amount of heat converted into useful work is 1.2×10^4 cal.

Answer: (A)

Go Back to Question 4

Q5.

Solution

Concept:
When an excited atom transitions to a lower energy state, it emits a single photon to carry away the excess energy. Due to the fundamental law of conservation of linear momentum, the initially stationary atom must experience a backward recoil. The momentum gained by the recoiling atom is precisely equal in magnitude to the momentum carried away by the emitted photon.
Solution:

(a) According to the Rydberg formula for a hydrogen atom, the wavelength λ of the photon emitted during a transition from an excited state n to the ground state $n = 1$ is given by $\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right) = R\left(1 - \frac{1}{n^2}\right)$.

(b) The linear momentum p_{photon} carried by the emitted photon can be determined via the de Broglie relationship, which states that $p_{\text{photon}} = \frac{h}{\lambda}$.

(c) Substituting the expression for $\frac{1}{\lambda}$ from step 1 into the momentum formula gives the photon momentum: $p_{\text{photon}} = hR\left(1 - \frac{1}{n^2}\right)$.

(d) Applying the law of conservation of linear momentum to the system, the magnitude of the atom's recoil momentum must match the photon's momentum: $p_{\text{atom}} = Mv = p_{\text{photon}}$, where M is the mass of the atom and v is its recoil speed.

(e) Rearranging this equation to solve explicitly for the recoil speed v yields $v = \frac{p_{\text{photon}}}{M} = \frac{hR}{M}\left(1 - \frac{1}{n^2}\right)$.

Final Answer: The recoil speed of the hydrogen atom is $\frac{hR}{M}\left(1 - \frac{1}{n^2}\right)$.

Answer: (A)

Go Back to Question 5

Q6.

Solution

Concept:
Hooke's Law states that the elastic elongation of a solid wire under an axial tensile load depends on its dimensions and the inherent stiffness of its material. This material property is quantified by Young's Modulus, which relates tensile stress to tensile strain. Comparing two distinct wires requires setting up a ratio of their geometric parameters.

Solution:

(a) Young's Modulus Y is defined as the ratio of tensile stress to tensile strain: $Y = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$, where F is the force, L is the length, A is the cross-sectional area, and ΔL is the extension.

(b) Rearranging this expression to solve for the extension yields the formula $\Delta L = \frac{FL}{AY} = \frac{FL}{\pi r^2 Y}$, where r represents the radius of the wire.

(c) Since both wires are made of identical material, their Young's Moduli are equal ($Y_A = Y_B$). They are also subjected to the same force F. Thus, extension is proportional to geometry: $\Delta L \propto \frac{L}{r^2}$.

(d) Write the ratio of extensions for wire A and wire B: $\frac{\Delta L_A}{\Delta L_B} = \left(\frac{L_A}{L_B}\right) \times \left(\frac{r_B}{r_A}\right)^2$.

(e) Substitute the given constraints ($L_A = 2L_B$ and $r_A = \frac{1}{2}r_B$) into the ratio: $\frac{\Delta L_A}{\Delta L_B} = (2) \times \left(\frac{1}{1/2}\right)^2 = 2 \times (2)^2 = 2 \times 4 = 8$. This gives a final ratio of $8 : 1$.

Final Answer: The ratio of the extension of wire A to wire B is $8 : 1$.

Answer: (B)

Go Back to Question 6

Q7.

Solution

Concept:
A projectile moving under uniform gravity follows a parabolic trajectory. The radius of curvature at any specific point along a curved path defines the radius of an imaginary circle that best matches the curve at that point. Centripetal acceleration connects this geometric radius to the instantaneous speed and the component of acceleration perpendicular to the direction of motion.

Solution:

(a) When a particle is launched with an initial speed u at an angle θ relative to the horizontal, its velocity vector changes continuously due to gravity, but the horizontal component remains constant: $v_x = u\cos\theta$.

(b) At the highest point of the flight, the vertical component of the velocity becomes exactly zero ($v_y = 0$). Consequently, the total instantaneous velocity of the projectile at this peak is purely horizontal and simplifies to $v = u\cos\theta$.

(c) The only acceleration acting on the projectile throughout its flight is the downward acceleration due to gravity, $a = g$.

(d) At the peak, the downward gravity vector is oriented perfectly perpendicular to the horizontal velocity vector. This means the entire acceleration due to gravity acts as the centripetal acceleration: $a_c = g$.

(e) The formula for centripetal acceleration is $a_c = \frac{v^2}{\rho}$, where ρ represents the radius of curvature. Rearranging for ρ and substituting the values gives $\rho = \frac{v^2}{a_c} = \frac{(u\cos\theta)^2}{g} = \frac{u^2\cos^2\theta}{g}$.

Final Answer: The radius of curvature at the highest point is $\frac{u^2\cos^2\theta}{g}$.

Answer: (B)

Go Back to Question 7

Q8.

Solution

Concept:
Electric potential is a scalar quantity, meaning the total potential at any point in space due to a collection of point charges is simply the algebraic sum of the individual potentials contributed by each charge. The potential depends on the magnitude of the charge and its direct spatial distance from the point of interest.
Solution:

(a) Consider a square of side length a. The center of the square is located at the intersection of its two diagonals. The length of a full diagonal of this square can be found using the Pythagorean theorem, which gives $d = \sqrt{a^2 + a^2} = a\sqrt{2}$.

(b) The distance r from any of the four corners to the exact geometric center is equal to half the length of a full diagonal: $r = \frac{d}{2} = \frac{a\sqrt{2}}{2} = \frac{a}{\sqrt{2}}$.

(c) The electrostatic potential V_i created by a single point charge $+q$ at a distance r is given by the standard formula: $V_i = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$.

(d) Since all four point charges are identical ($+q$) and located at equal distances r from the center, each charge contributes an identical scalar potential value.

(e) The total electric potential V at the center is the sum of these four contributions: $V = 4 \times V_i = 4 \times \left(\frac{1}{4\pi\varepsilon_0}\frac{q}{a/\sqrt{2}}\right) = \frac{4\sqrt{2}q}{4\pi\varepsilon_0 a} = \frac{2\sqrt{2}q}{\pi\varepsilon_0 a}$.

Final Answer: The total electric potential at the center of the square is $\frac{2\sqrt{2}q}{\pi\varepsilon_0 a}$.

Answer: (B)

Go Back to Question 8

Q9.

Solution

Concept:
In a Young's Double Slit Experiment, coherent light waves overlap on a screen to form an interference pattern. The resultant intensity at any point depends on the phase difference between the interacting waves. This phase difference is directly proportional to the physical path difference traveled by the waves from each slit.

Solution:

(a) The phase difference ϕ is mathematically related to the path difference Δx by the expression: $\phi = \frac{2\pi}{\lambda}\Delta x$, where λ is the wavelength of the monochromatic light.

(b) For the first point, the path difference is given as $\Delta x_1 = \lambda$. Substituting this into the formula yields a phase difference of $\phi_1 = \frac{2\pi}{\lambda}(\lambda) = 2\pi$ radians.

(c) The formula for the resultant intensity of two interfering waves of equal intensity is $I = I_{\max}\cos^2\left(\frac{\phi}{2}\right)$. For $\phi_1 = 2\pi$, $I_1 = I_{\max}\cos^2(\pi) = I_{\max} = I_0$. Thus, the maximum intensity is I_0.

(d) For the second point, the path difference changes to $\Delta x_2 = \frac{\lambda}{4}$. The corresponding phase difference is calculated as $\phi_2 = \frac{2\pi}{\lambda}\left(\frac{\lambda}{4}\right) = \frac{\pi}{2}$ radians (90°).

(e) Substitute this new phase difference ϕ_2 into the intensity formula: $I_2 = I_0\cos^2\left(\frac{\pi/2}{2}\right) = I_0\cos^2\left(\frac{\pi}{4}\right)$. Since $\cos\left(\frac{\pi}{4}\right) = \frac{1}{\sqrt{2}}$, squaring it gives $I_2 = I_0\left(\frac{1}{2}\right) = \frac{I_0}{2}$.

Final Answer: The intensity at the point with a path difference of $\frac{\lambda}{4}$ is $\frac{I_0}{2}$.

Answer: (B)

Go Back to Question 9

Q10.

Solution

Concept:
This thermodynamic process consists of two consecutive stages: an isothermal expansion followed by an adiabatic compression. Isothermal steps occur at a constant temperature, governed by Boyle's Law. Adiabatic steps involve no heat exchange with the surroundings, meaning the pressure and volume follow a power-law relationship dictated by the heat capacity ratio.

Solution:

(a) The ideal gas starts at an initial state with pressure $P_1 = P$ and volume $V_1 = V$. It undergoes an isothermal expansion until its volume doubles, so the intermediate volume becomes $V_2 = 2V$.

(b) For an isothermal process involving an ideal gas, the temperature remains constant, which implies $P_1V_1 = P_2V_2$. Substituting the values gives $P \cdot V = P_2 \cdot (2V)$, which simplifies to an intermediate pressure of $P_2 = \frac{P}{2}$.

(c) Next, the gas is compressed adiabatically from its intermediate state back to its original volume, so the final volume is $V_3 = V_1 = V$.

(d) The governing equation for a reversible adiabatic process is $P_2V_2^\gamma = P_3V_3^\gamma$, where γ is the adiabatic index (C_p/C_v).

(e) Rearranging the equation to solve for the final pressure P_3 gives: $P_3 = P_2\left(\frac{V_2}{V_3}\right)^\gamma = \left(\frac{P}{2}\right)\left(\frac{2V}{V}\right)^\gamma = \frac{P}{2} \cdot 2^\gamma = P \cdot 2^{\gamma-1}$.

Final Answer: The final pressure of the gas after the two processes is $P \cdot 2^{\gamma-1}$.

Answer: (A)

Go Back to Question 10

Q11.

Solution

Concept:

In a common-emitter electronic amplifier configuration using an NPN bipolar junction transistor, the output signal voltage is extracted across a load resistor connected to the collector terminal. The configuration fundamentally exhibits a phase-reversing property between the alternating current input base signal and the resulting alternating current output collector signal, which is a structural characteristic of the common-emitter design.

Solution:

(a) When the input AC signal voltage experiences its positive half-cycle, it increases the forward bias voltage across the base-emitter junction of the NPN transistor.

(b) This enhanced forward bias directly causes a significant increase in the base current, which subsequently results in a much larger increase in the collector current due to the transistor's current gain.

(c) The output voltage at the collector terminal is determined by subtracting the voltage drop across the collector load resistor from the constant supply voltage, mathematically represented as $V_{\text{out}} = V_{CC} - I_C R_C$.

(d) Because the collector current I_C increases during this positive input phase, the voltage drop $I_C R_C$ across the load resistor increases accordingly, which forces the output potential V_{out} to drop significantly below its quiescent value.

(e) Conversely, a negative input signal cycle reduces the base-emitter bias, lowering the collector current and causing the output voltage to rise toward the supply voltage, establishing a precise phase shift of 180° between input and output.

Final Answer: Out of phase (180°)

Answer: (C)

Go Back to Question 11

Q12.

Solution

Concept:
When a rigid body rolls down an inclined plane without slipping, its mechanical behavior is governed by a combination of translational motion of its center of mass and rotational motion about that center. The gravitational force accelerating the body down the slope must overcome both translational inertia and rotational inertia, with the latter determined by the body's specific geometry and mass distribution.

Solution:

(a) For any uniform rigid body rolling down an incline of angle θ without slipping, the general expression for linear acceleration a is given by the formula $a = \frac{g\sin\theta}{1+\frac{I}{MR^2}}$, where I represents the moment of inertia.

(b) A uniform solid cylinder of mass M and radius R possesses a geometric distribution of mass that yields a rotational moment of inertia about its central longitudinal axis equal to $I = \frac{1}{2}MR^2$.

(c) Substituting this specific moment of inertia value into the general acceleration formula simplifies the denominator term to $1 + \frac{\frac{1}{2}MR^2}{MR^2}$, which directly reduces to $1 + \frac{1}{2} = \frac{3}{2}$.

(d) Now, substituting this simplified denominator back into the main expression yields the final linear acceleration equation: $a = \frac{g\sin\theta}{3/2}$.

(e) Inverting the fraction in the denominator gives $a = \frac{2}{3}g\sin\theta$, demonstrating that the acceleration is a constant fraction of the standard frictionless acceleration and is independent of both the cylinder's total mass and its outer radius.

Final Answer: $\frac{2}{3}g\sin\theta$

Answer: (B)

Go Back to Question 12

Q13.

Solution

Concept:
When resistors are connected together in a parallel circuit configuration, the electric potential difference across each individual component remains identical. The total incoming current entering the parallel junction splits among the available parallel branches in an inverse proportion to each branch's specific resistance value, as dictated by Ohm's Law and Kirchhoff's Current Law.

Solution:

(a) Let the three parallel resistors be denoted as $R_1 = 2\,\Omega$, $R_2 = 4\,\Omega$, and $R_3 = 6\,\Omega$, with a total current of $I = 11$ A passing through the combined parallel network.

(b) The equivalent resistance R_p of the three parallel branches can be calculated using the reciprocal formula: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6}$.

(c) Finding a common denominator of 12 for the fractions gives $\frac{1}{R_p} = \frac{6+3+2}{12} = \frac{11}{12}\,\Omega^{-1}$, which means the total equivalent resistance of the network is $R_p = \frac{12}{11}\,\Omega$.
4. The total potential difference V across the parallel combination can be determined by applying Ohm's L

(d) Because the voltage is uniform across all parallel branches, the specific current I_1 flowing through the $2\,\Omega$ resistor is found by dividing this common voltage by its resistance: $I_1 = \frac{V}{R_1} = \frac{12\text{ V}}{2\,\Omega} = 6$ A.

Final Answer: 6 A

Answer: (C)

Go Back to Question 13

Q14.

Solution

Concept:
Complex digital logic systems can be constructed by combining multiple universal logic gates, such as NAND gates. By analyzing the boolean algebraic output expression at each consecutive stage of a combination circuit for all possible binary input states, the overall logical behavior can be simplified to reveal the equivalent fundamental logic gate.

Solution:

(a) The given digital circuit diagram shows two distinct stages of logic gates. The first stage consists of a standard two-input NAND gate receiving the primary binary inputs labeled A and B.

(b) The boolean algebraic output expression emerging from this first stage NAND gate is given by the expression $Y_1 = \overline{A \cdot B}$, which represents the inverted conjunction of inputs A and B.

(c) This intermediate output signal Y_1 is then routed directly to the second stage, where it is split and connected to both input terminals of a second NAND gate.

(d) When the inputs of a standard NAND gate are tied together to receive the same single logic signal, the gate functions as a simple digital inverter or NOT gate.

(e) Therefore, the final output Y of the second gate is the logical inversion of its intermediate input, giving $Y = \overline{Y_1} = \overline{\overline{A \cdot B}}$. According to the boolean law of double negation, the two bars cancel out, yielding $Y = A \cdot B$, which is the exact logical operation of an AND gate.

Final Answer: AND Gate

Answer: (A)

Go Back to Question 14

Q15.

Solution

Concept:

The fluid dynamic behavior of an ideal, incompressible, and non-viscous fluid undergoing steady streamline flow through a horizontal enclosed conduit is governed by the principle of conservation of mass. This principle dictates that the total mass flow rate must remain perfectly constant at every sequential cross-section along the fluid's path, a relationship known as the continuity equation.

Solution:

(a) The equation of continuity for steady fluid flow state asserts that the product of the cross-sectional area of the pipe and the local flow velocity of the fluid remains constant throughout the channel, expressed as $A_1 v_1 = A_2 v_2$.

(b) From the parameters provided in the problem statement, the initial section of the horizontal pipe has a cross-sectional area of $A_1 = A$ and an initial fluid velocity of $v_1 = v$.

(c) At the second downstream section of the non-uniform pipe, the cross-sectional area expands to a value of $A_2 = 2A$, while the new fluid flow velocity at this section is denoted as v_2.

(d) Substituting these specific values directly into the continuity equation yields the relationship: $A \cdot v = (2A) \cdot v_2$.

(e) To solve for the unknown velocity v_2, the common area term A can be mathematically canceled from both sides of the equation, leaving $v = 2v_2$, which rearranges to reveal that the final fluid velocity is $v_2 = \frac{v}{2}$.

Final Answer: $\frac{v}{2}$

Answer: (B)

Go Back to Question 15

Q16.

Solution

Concept:
When a solid body is dragged across a rough surface, a dissipative frictional force acts opposing the direction of relative motion. The work done against this kinetic friction represents energy transformed into thermal energy. This work depends on the magnitude of the friction force and the total displacement, with the force itself determined by the normal reaction.

Solution:

(a) Consider a body of mass m placed on an inclined plane that makes a steady angle θ with the horizontal direction. The weight of the body acts vertically downward with a magnitude of mg.

(b) Resolving this gravitational weight vector into components parallel and perpendicular to the inclined plane yields a perpendicular force component pushing into the surface equal to $mg\cos\theta$.

(c) Since there is no acceleration perpendicular to the inclined surface, the normal reaction force N exerted by the rough plane on the body must perfectly balance this component, giving $N = mg\cos\theta$.

(d) The magnitude of the kinetic friction force f_k opposing the body's upward movement along the incline is determined by the formula $f_k = \mu_k N$, which becomes $f_k = \mu_k mg\cos\theta$.

(e) The total work done W against this dissipative friction force as the body moves a distance d up the plane is calculated using the mechanical work formula $W = f_k \cdot d$, substituting f_k gives $W = \mu_k mgd\cos\theta$.

Final Answer: $\mu_k mgd\cos\theta$

Answer: (B)

Go Back to Question 16

Q17.

Solution

Concept:
Self-inductance is a geometric property of an electrical conductor that quantifies its ability to induce an electromotive force within itself due to a changing magnetic flux produced by a varying current. For a long air-core solenoid, this value depends on total structural dimensions, such as total turns, length, cross-sectional area, and core permeability.

Solution:

(a) When an electric current I flows through a long solenoid of length l having a total number of turns N, the internal magnetic field B generated inside its core is uniform and given by $B = \mu_0 nI = \mu_0 \left(\frac{N}{l}\right) I$.

(b) The magnetic flux Φ_s passing through a single turn of this solenoid is equal to the product of the uniform internal magnetic field and the cross-sectional area A, which yields $\Phi_s = B \cdot A = \frac{\mu_0 NIA}{l}$.

(c) The total magnetic flux linkage Φ_{total} linked across all N turns of the solenoid is found by multiplying the single-turn flux by the total number of turns: $\Phi_{total} = N \cdot \Phi_s = \frac{\mu_0 N^2 IA}{l}$.

(d) By fundamental definition, the self-inductance L of any inductor relates its total magnetic flux linkage to the current flowing through it via the proportional relationship $\Phi_{total} = L \cdot I$.

(e) Equating these expressions allows the current term I to be canceled from both sides, yielding the definitive structural formula for self-inductance: $L = \frac{\mu_0 N^2 A}{l}$.

Final Answer: $\frac{\mu_0 N^2 A}{l}$

Answer: (A)

Go Back to Question 17

Q18.

Solution

Concept:
An astronomical refracting telescope consists of two primary converging optical components: a large objective lens and a smaller eyepiece. When configured in normal adjustment, the telescope is focused to view objects located at infinity, which means the final image is formed at infinity, allowing the observer's eye to remain fully relaxed.

Solution:

(a) In a standard astronomical telescope configuration adjusted for normal viewing conditions, the parallel light rays from a distant object converge to form an intermediate image exactly at the focal point of the objective lens.

(b) For the final image to be projected to infinity for relaxed viewing, this intermediate image must also lie exactly at the focal point of the second lens, which is the eyepiece. Thus, the total barrel length equals $f_o + f_e$.

(c) The angular magnifying power m of a refracting telescope operating under normal adjustment is defined as the ratio of the focal length of the objective lens to the focal length of the eyepiece lens.

(d) The mathematical formula representing this magnifying ratio is given by $m = \frac{f_o}{f_e}$. From the parameters provided, the objective focal length $f_o = 140$ cm and the eyepiece focal length $f_e = 5.0$ cm.

(e) Substituting these values into the ratio yields $m = \frac{140\text{ cm}}{5.0\text{ cm}} = 28$. This dimensionless value signifies that the angular size of the object viewed through the telescope appears 28 times larger than when seen with the naked eye.

Final Answer: 28

Answer: (A)

Go Back to Question 18

Q19.

Solution

Concept:
The kinetic theory of gases models a macroscopic gas as a collection of microscopic point-like molecules undergoing continuous random motion. The absolute thermodynamic temperature of the gas serves as a direct macroscopic measure of the average translational kinetic energy of these constituent molecules, establishing a link between temperature and molecular speed.
Solution:

(a) According to the fundamental kinetic theory of gases, the pressure exerted by an ideal gas can be related to molecular parameters, leading to the formulation of the average translational kinetic energy of a molecule as $K_{avg} = \frac{3}{2}k_B T$.

(b) This average translational kinetic energy can also be expressed in terms of the molecular mass m and the root-mean-square speed v_{rms} of the gas molecules using the relation $K_{avg} = \frac{1}{2}mv_{rms}^2$.

(c) Equating these two expressions for kinetic energy gives $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_B T$, which simplifies by canceling the common factor of one-half to $mv_{rms}^2 = 3k_B T$.

(d) Solving explicitly for the root-mean-square speed yields the standard Maxwell-Boltzmann expression: $v_{rms} = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3RT}{M}}$, where M is the molar mass.

(e) Because the parameters 3, R, and M are completely constant for a specific gas sample, this mathematical formula reveals that the root-mean-square speed is directly proportional to the square root of the absolute temperature, meaning $v_{rms} \propto T^{1/2}$.

Final Answer: $T^{1/2}$

Answer: (C)

Go Back to Question 19

Q20.

Solution

Concept:
The photoelectric effect describes the emission of electrons from a metal surface when illuminated by light of sufficiently high frequency. This phenomenon is governed by Einstein's photoelectric equation, which applies the principle of conservation of energy to a single quantum interaction between an incident photon and a bound conduction electron.

Solution:

(a) Einstein's photoelectric equation states that the total energy E carried by an incident photon is split into two parts: a minimum energy required to liberate the electron from the metal surface, and the remaining kinetic energy.

(b) The minimum energy needed to free an electron from the metal surface is a material property known as the work function, denoted by ϕ_0. Any excess photon energy is converted into the maximum kinetic energy K_{max} of the electron.

(c) The conservation of energy equation is written as: $E = \phi_0 + K_{max}$, where E is the incident photon energy and ϕ_0 is the work function.

(d) Rearranging this linear equation to solve for the maximum kinetic energy of the escaping photoelectrons gives the relation: $K_{max} = E - \phi_0$.

(e) From the values given in the problem, the incident photon energy $E = 4.0$ eV and the metal's work function $\phi_0 = 2.5$ eV. Substituting these into the formula yields $K_{max} = 4.0\text{ eV} - 2.5\text{ eV} = 1.5\text{ eV}$.

Final Answer: 1.5 eV

Answer: (B)

Go Back to Question 20

Q21.

Solution

Concept:
When a clean, narrow-bore cylindrical capillary tube is lowered vertically into a pool of wetting liquid, the liquid spontaneously rises against gravity inside the channel. This capillary action occurs because the adhesive forces pulling the liquid molecules toward the tube wall exceed the cohesive forces holding the liquid molecules together, which distorts the surface into a curved meniscus.

Solution:

(a) The upward force supporting the lifted liquid column is generated by the vertical component of surface tension acting along the inner circumference boundary of the tube, expressed mathematically as $F_{\text{up}} = 2\pi r T \cos\theta$.

(b) For a wetting liquid that exhibits a zero angle of contact ($\theta = 0°$), the cosine term becomes unity, meaning the net upward mechanical surface tension force simplifies directly to $F_{\text{up}} = 2\pi r T$.

(c) This upward pulling force is perfectly counterbalanced by the downward gravitational weight of the elevated liquid column inside the tube, which has a cylindrical volume equal to $\pi r^2 h$.

(d) The total gravitational weight of this lifted fluid column is calculated by multiplying its volume by the liquid density and the acceleration due to gravity, yielding $W = \pi r^2 h \rho g$.

(e) Equating the upward force to the downward weight gives $2\pi r T = \pi r^2 h \rho g$. Canceling the common factors of π and r from both sides allows us to isolate the vertical height, revealing the expression $h = \frac{2T}{r\rho g}$.

Final Answer: $\frac{2T}{r\rho g}$

Answer: (A)

Go Back to Question 21

Q22.

Solution

Concept:
The total mechanical energy of a satellite orbiting a massive central body is a combination of its gravitational potential energy and its translational kinetic energy. Because the gravitational force acts as a stable attractive centripetal force holding the satellite in its path, these two energy forms are fundamentally linked by a precise mathematical proportion.

Solution:

(a) Let a satellite of mass m travel in a stable circular orbit at an altitude h above the Earth's surface. The total radial distance from the center of the Earth to the satellite is $r = R_E + h$.

(b) The gravitational potential energy U of the satellite-Earth system arises from its configuration in the field and is given by the negative attractive expression $U = -\frac{GM_E m}{R_E+h}$.

(c) To maintain a stable circular path, the gravitational attraction must supply the necessary centripetal acceleration, which gives $\frac{GM_E m}{(R_E+h)^2} = \frac{mv^2}{R_E+h}$, simplifying to $mv^2 = \frac{GM_E m}{R_E+h}$.

(d) The kinetic energy K of the orbiting satellite is given by $K = \frac{1}{2}mv^2$. Substituting the orbital velocity relation into this kinetic energy equation yields $K = \frac{GM_E m}{2(R_E+h)}$.

(e) The total mechanical energy E is the sum of these kinetic and potential components: $E = K + U = \frac{GM_E m}{2(R_E+h)} - \frac{GM_E m}{R_E+h}$, which simplifies to the negative bound value $E = -\frac{GM_E m}{2(R_E+h)}$.

Final Answer: $-\frac{GM_E m}{2(R_E+h)}$

Answer: (B)

Go Back to Question 22

Q23.

Solution

Concept:
The magnetic field produced by a steady electric current passing through a circular loop of wire can be calculated at any position using the Biot-Savart law. The field strength reaches its absolute maximum at the geometric center of the loop and decreases continuously as an observer moves outward along the central axis away from the loop's plane.

Solution:

(a) The general formula for the magnetic field strength B at a distance x along the axis from the center of a circular current-carrying loop of radius R is expressed as $B = \frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}}$.

(b) To find the magnetic field strength B_1 at the exact geometric center of the loop, we evaluate this general expression at $x = 0$, which yields the standard equation $B_1 = \frac{\mu_0 I R^2}{2(R^2)^{3/2}} = \frac{\mu_0 I}{2R}$.

(c) To find the magnetic field strength B_2 at an axial point located at a distance equal to the loop's radius, we substitute $x = R$ into the general formula, giving $B_2 = \frac{\mu_0 I R^2}{2(R^2+R^2)^{3/2}}$.

(d) Evaluating the denominator for B_2 gives $2(2R^2)^{3/2} = 2 \cdot 2^{3/2} \cdot R^3 = 4\sqrt{2}R^3$. Substituting this back into the formula simplifies the axial field expression to $B_2 = \frac{\mu_0 I R^2}{4\sqrt{2}R^3} = \frac{\mu_0 I}{4\sqrt{2}R}$.

(e) Taking the ratio of the central magnetic field to the axial magnetic field gives $\frac{B_1}{B_2} = \left(\frac{\mu_0 I}{2R}\right) / \left(\frac{\mu_0 I}{4\sqrt{2}R}\right) = \frac{4\sqrt{2}}{2}$, which simplifies directly to $2\sqrt{2}$.

Final Answer: $2\sqrt{2}$

Answer: (B)

Go Back to Question 23

Q24.

Solution

Concept:
The focal length of a thin spherical glass lens depends on both the curvature of its refractive surfaces and the relative refractive index of the glass with respect to the surrounding medium. When a lens is submerged in a liquid medium instead of air, this relative refractive index decreases, which reduces the light-bending capability of the lens.

Solution:

(a) The lens-maker's formula describes the focal length f_a of a lens surrounded by air as $\frac{1}{f_a} = (n_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$, where $n_g = 1.5$ is the refractive index of the glass.

(b) Substituting the glass refractive index into the air equation yields $\frac{1}{20} = (1.5 - 1) \cdot K = 0.5 \cdot K$, which implies that the constant geometric curvature factor $K = \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ equals $\frac{1}{10}$.

(c) When the lens is fully immersed in a water medium of refractive index $n_w = \frac{4}{3}$, the modified lens-maker's equation becomes $\frac{1}{f_w} = \left(\frac{n_g}{n_w} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.

(d) Evaluating the relative index term gives $\frac{1.5}{4/3} - 1 = \frac{3/2}{4/3} - 1 = \frac{9}{8} - 1 = \frac{1}{8}$. Substituting this value and the curvature factor K into the formula gives $\frac{1}{f_w} = \frac{1}{8} \times \frac{1}{10}$.

(e) This calculation simplifies directly to $\frac{1}{f_w} = \frac{1}{80}$, which demonstrates that the new focal length of the glass lens when completely immersed under water expands to a value of $f_w = 80$ cm.

Final Answer: 80 cm

Answer: (C)

Go Back to Question 24

Q25.

Solution

Concept:
In thermodynamics, the total work done by an ideal gas system during a cyclic process plotted on a pressure-volume diagram corresponds to the geometric area enclosed by the path. The algebraic sign of this net work depends on the direction of the cycle, with a clockwise loop representing positive work done by the gas.

Solution:

(a) The given pressure-volume diagram displays a closed triangular cyclic path traced in a clockwise sequence $A \to B \to C \to A$. A clockwise cycle implies that expansion occurs at higher pressures than compression, yielding a positive net work output.

(b) The total net work done W during this single complete thermodynamic cycle is equivalent to the geometric area enclosed within the boundaries of the right-angled triangle ABC on the coordinate grid.

(c) The mathematical formula for calculating the area of a right-angled triangle is given by the standard geometric relation $\text{Area} = \frac{1}{2} \times \text{base} \times \text{height}$.

(d) Identifying the dimensions from the plot axes, the horizontal base line segment AB extends along the volume axis from $V = 1\ \text{m}^3$ to $V = 3\ \text{m}^3$, giving a base length of $\Delta V = 3 - 1 = 2\ \text{m}^3$.

(e) The vertical height segment AC extends along the pressure axis from $P = 2\ \text{N/m}^2$ to $P = 6\ \text{N/m}^2$, giving a height of $\Delta P = 6 - 2 = 4\ \text{N/m}^2$. Substituting these values yields $W = \frac{1}{2} \times 2 \times 4 = 4\ \text{J}$.

Final Answer: 4 J

Answer: (B)

Go Back to Question 25

Q26.

Solution

Concept:

Radioactive decay is a stochastic quantum process governed by a statistical exponential law, stating that the rate of disintegration is proportional to the number of active nuclei present. The half-life is the constant duration required for exactly one-half of any initial population of unstable radioactive nuclei to decay.

Solution:

(a) According to the standard law of radioactive decay, the remaining fraction of active, undecayed nuclei left in a sample after an elapsed time t can be modeled using the discrete equation $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$.

(b) In this exponential relationship, the variable n represents the total number of elapsed half-life periods, calculated by dividing the total time by the material's half-life: $n = \frac{t}{T_{1/2}}$.

(c) From the parameters specified in the problem statement, the half-life of the radioactive isotope is $T_{1/2} = 10$ days and the total elapsed duration is $t = 30$ days.

(d) Calculating the number of half-life cycles completed during this interval gives $n = \frac{30\text{ days}}{10\text{ days}} = 3$. This means the sample undergoes exactly three successive halving events.

(e) Substituting this value into the fraction equation gives $\frac{N}{N_0} = \left(\frac{1}{2}\right)^3 = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$. Thus, a fraction of $\frac{1}{8}$ of the original active nuclei remains undecayed.

Final Answer: $\frac{1}{8}$

Answer: (C)

Go Back to Question 26

Q27.

Solution

Concept:
The total thermal energy radiated per unit time by an ideal blackbody is governed by Stefan-Boltzmann's law. This law states that the total radiant power output is directly proportional to both the exposed surface area of the body and the fourth power of its absolute thermodynamic temperature.

Solution:

(a) Stefan-Boltzmann's law states that the radiant power P emitted by a spherical blackbody of radius R at temperature T is given by $P = \sigma \cdot A \cdot T^4$, where σ is Stefan's constant.

(b) The total exposed surface area A of a perfect sphere is calculated from its radius using the geometric equation $A = 4\pi R^2$. Substituting this into the power law yields $P = \sigma(4\pi R^2)T^4 = 4\pi\sigma R^2 T^4$.

(c) This formula shows that the total power output scales with the parameters according to the proportional relationship $P \propto R^2 T^4$. Let the initial state be described by $P_1 = kR^2T^4$.

(d) According to the modified parameters, the new radius is halved ($R' = \frac{R}{2}$) and the absolute temperature is doubled ($T' = 2T$). We substitute these updated terms into the proportion.

(e) The new power P_2 is calculated as $P_2 \propto \left(\frac{R}{2}\right)^2 (2T)^4 = \frac{R^2}{4} \cdot 16T^4 = 4R^2T^4$. Comparing this result to the initial expression shows that the new power output is exactly $4P$.

Final Answer: $4P$

Answer: (B)

Go Back to Question 27

Q28.

Solution

Concept:
The moment of inertia of a rigid body quantifies its rotational inertia and depends on its mass distribution relative to a chosen axis. If the moment of inertia about an axis passing through the center of mass is known, the parallel-axis theorem can calculate the moment of inertia about any parallel axis.

Solution:

(a) The parallel-axis theorem states that the moment of inertia I of a body about any arbitrary axis is equal to its moment of inertia about a parallel axis passing through its center of mass plus a shift term, written as $I = I_{\text{cm}} + Md^2$.

(b) In this equation, M represents the total mass of the object and d represents the perpendicular separation distance between the central axis and the new parallel axis of rotation.

(c) For a uniform solid sphere of mass M and radius R, standard geometric integration shows that its moment of inertia about a central axis passing directly through its diameter is $I_{\text{cm}} = \frac{2}{5}MR^2$.

(d) The problem specifies that the new axis of rotation is a tangential line running along the outer surface of the sphere, parallel to the diameter. The distance from the center to this surface tangent is exactly $d = R$.

(e) Substituting these parameters into the parallel-axis formula gives $I = \frac{2}{5}MR^2 + M(R)^2$. Combining these terms using a common denominator yields $I = \frac{2+5}{5}MR^2 = \frac{7}{5}MR^2$.

Final Answer: $\frac{7}{5}MR^2$

Answer: (B)

Go Back to Question 28

Q29.

Solution

Concept:
The electrical capacitance of a parallel-plate capacitor measures its ability to store charge per unit potential difference. This value is determined entirely by geometric parameters, such as the area of the plates and their separation distance, along with the permittivity of the dielectric material filling the gap.
Solution:

(a) The initial capacitance C of a parallel-plate capacitor with plate area A and separation distance d filled with air is given by the standard formula $C = \frac{\varepsilon_0 A}{d}$.

(b) According to the modifications described, the separation distance between the plates is reduced to half of its initial value, which means the new plate gap distance can be written as $d' = \frac{d}{2}$.

(c) Concurrently, an insulating material with a dielectric constant of $K = 4$ is inserted, replacing the air and increasing the baseline permittivity of the intervening space by a factor of four.

(d) The formula for the modified capacitance C' incorporating both changes is written as $C' = \frac{K\varepsilon_0 A}{d'} = \frac{4 \cdot \varepsilon_0 A}{(d/2)}$.

(e) Simplifying this algebraic fraction by moving the factor of two from the denominator up to the numerator yields $C' = 2 \times 4 \times \frac{\varepsilon_0 A}{d} = 8\left(\frac{\varepsilon_0 A}{d}\right)$, which means the new capacitance is $8C$.

Final Answer: $8C$

Answer: (C)

Go Back to Question 29

Q30.

Solution

Concept:
Fraunhofer single-slit diffraction occurs when a coherent, monochromatic light wave passes through a narrow rectangular aperture, producing an interference pattern on a distant screen. This pattern features a wide, intense central maximum flanked by a series of alternating symmetrical minima and weaker secondary maxima.

Solution:

(a) In a single-slit diffraction configuration, the angular positions θ where destructive interference occurs—resulting in dark fringes or minima—are governed by the slit width equation $a \sin\theta = m\lambda$.

(b) In this expression, the integer parameter m denotes the order of the minimum, λ represents the wavelength of the light source, and a is the physical width of the open slit.

(c) The first diffraction minimum on either side of the bright central maximum corresponds to the first order of destructive interference, which is evaluated by setting the integer $m = 1$.

(d) Substituting $m = 1$ directly into the single-slit condition gives the relationship $a \sin\theta = 1 \cdot \lambda$, which simplifies to $a \sin\theta = \lambda$.

(e) Isolating the trigonometric term by dividing both sides of the equation by the slit width parameter a reveals that the angular position of the first minimum satisfies the condition $\sin\theta = \frac{\lambda}{a}$.

Final Answer: $\sin\theta = \frac{\lambda}{a}$

Answer: (A)

Go Back to Question 30

Q31.

Solution

Concept:
A particle executing linear simple harmonic motion possesses a constant total mechanical energy that dynamically alternates between kinetic energy and potential energy. The potential energy depends on the instantaneous displacement of the particle from its stable equilibrium position, while the kinetic energy depends on its instantaneous velocity.

Solution:

(a) The potential energy of a particle undergoing simple harmonic motion at any given displacement x from the mean position is given by the foundational mechanical formula $\text{PE} = \frac{1}{2}m\omega^2x^2$.

(b) The kinetic energy of the same particle at that specific position is determined by subtracting its localized potential energy from its total constant mechanical energy, expressed as $\text{KE} = \frac{1}{2}m\omega^2(A^2 - x^2)$.

(c) The problem states that the particle is located at an instantaneous displacement equal to exactly half of its maximum oscillation amplitude, which is written mathematically as $x = \frac{A}{2}$.

(d) Substituting this displacement value into the potential energy equation yields $\text{PE} = \frac{1}{2}m\omega^2\left(\frac{A}{2}\right)^2 = \frac{1}{2}m\omega^2\left(\frac{A^2}{4}\right)$, which represents a quarter of the total system energy.

(e) Substituting the same displacement value into the kinetic energy equation yields $\text{KE} = \frac{1}{2}m\omega^2\left(A^2 - \frac{A^2}{4}\right) = \frac{1}{2}m\omega^2\left(\frac{3A^2}{4}\right)$. Taking the ratio of kinetic energy to potential energy gives $\frac{\text{KE}}{\text{PE}} = \frac{3/4}{1/4} = 3$.

Final Answer: 3 : 1

Answer: (B)

Go Back to Question 31

Q32.

Solution

Concept:
Gauss's law relates the total net electric flux exiting any closed three-dimensional boundary surface directly to the net electrostatic charge enclosed within that surface. When a system exhibits high geometric symmetry, the total flux is distributed equally across all identical structural sub-surfaces that compose the entire boundary.

Solution:

(a) According to the fundamental statement of Gauss's law, the total outward electric flux passing through any complete closed surface is equal to the enclosed net electric charge divided by the permittivity of free space, written as $\Phi_{\text{total}} = \frac{q}{\varepsilon_0}$.

(b) A regular geometric cube forms a symmetric closed Gaussian surface that completely surrounds any point charge positioned inside its volume. In this specific configuration, the charge $+q$ is located at the exact geometric center of the cube.

(c) Because the point charge is situated precisely at the center, it maintains an identical spatial orientation and equal perpendicular distance with respect to all the surrounding boundaries of the object.

(d) A regular cube is composed of exactly six identical, flat, square planar faces. Due to the perfect geometric symmetry of the charge placement, the total electric flux must be distributed equally among these six outer boundaries.

(e) Therefore, the localized electric flux passing out through any one single face of the cube is found by dividing the total flux by six, giving the symmetric expression $\Phi_{\text{face}} = \frac{\Phi_{\text{total}}}{6} = \frac{q}{6\varepsilon_0}$.

Final Answer: $\frac{q}{6\varepsilon_0}$

Answer: (B)

Go Back to Question 32

Q33.

Solution

Concept:

The de Broglie hypothesis attributes wave-particle duality to matter, stating that any moving particle has an associated matter wavelength that depends inversely on its momentum. For a charged particle accelerated from rest, this momentum can be expressed directly as a function of the electrical potential difference applied to it.

Solution:

(a) The de Broglie wavelength associated with any moving particle is given by $\lambda = \frac{h}{p}$, where h is Planck's constant and p represents the magnitude of the particle's translational momentum vector.

(b) When an electron of mass m and charge e is accelerated from rest through a potential difference V, it gains a kinetic energy equal to $K = eV$, which relates to its momentum by the equation $p = \sqrt{2mK} = \sqrt{2meV}$.

(c) Substituting this momentum expression into the wavelength formula yields the specific equation for an accelerated electron: $\lambda = \frac{h}{\sqrt{2meV}}$.

(d) Inserting the known fundamental constants for the electron mass, electron charge, and Planck's constant simplifies this analytical relation to a practical numerical formula given by $\lambda = \frac{12.27}{\sqrt{V}}$ Å.

(e) The problem specifies an accelerating potential difference of $V = 100$ V. Substituting this numerical value into the simplified formula yields $\lambda = \frac{12.27}{\sqrt{100}} = \frac{12.27}{10} = 1.227$ Å.

Final Answer: 1.227 Å

Answer: (A)

Go Back to Question 33

Q34.

Solution

Concept:

When a straight conductor moves through a magnetic field, the free mobile charges inside experience a magnetic Lorentz force that drives them along the length of the conductor. This redistribution of charge generates a motional electromotive force between the ends of the rod, which can be evaluated by integrating localized differential emf elements.

Solution:

(a) Consider a straight metal rod of total length L rotating with a constant angular velocity ω about a fixed perpendicular axis passing through one end. The rod moves through a uniform magnetic field B oriented parallel to the rotation axis.

(b) Take a small differential element of length dx located along the rod at a radial distance x from the pivot point. The instantaneous linear speed of this localized element is given by the rotational relation $v = \omega x$.

(c) The infinitesimal motional electromotive force $d\varepsilon$ induced across this small differential segment is perpendicular to the motion and field lines, satisfying the standard equation $d\varepsilon = B \cdot v \cdot dx = B(\omega x)dx$.

(d) To determine the total integrated electromotive force developed between the two endpoints of the rod, we integrate this differential expression over the full span of the conductor from $x = 0$ to $x = L$.

(e) Performing the definite integration yields $\varepsilon = \int_0^L B\omega x\,dx = B\omega\left[\frac{x^2}{2}\right]_0^L$. Evaluating this at the integration boundaries gives the final standard expression $\varepsilon = \frac{1}{2}B\omega L^2$.

Final Answer: $\frac{1}{2}B\omega L^2$

Answer: (B)

Go Back to Question 34

Q35.

Solution

Concept:

Malus's law describes the intensity variation of a polarized light beam passing through an ideal polarizing filter. It states that the transmitted intensity depends directly on the square of the cosine of the angle between the polarization direction of the incident light and the transmission axis of the analyzer.

Solution:

(a) The incident light beam is initially completely unpolarized and has a total intensity of I_0. When this unpolarized light passes through the first ideal polaroid sheet, it becomes linearly polarized along the orientation of its axis.

(b) An unpolarized beam contains light waves with electric field vectors oscillating randomly in all transverse directions. Passing through an initial ideal polarizer reduces its intensity by exactly half, giving $I_1 = \frac{I_0}{2}$.

(c) This linearly polarized light beam of intensity I_1 then encounters a second polaroid sheet whose transmission axis is inclined at an angle of $\theta = 60^\circ$ relative to the polarization direction of the incident wave.

(d) According to Malus's law, the final emerging intensity I_2 after passing through this second polarizing filter is given by the mathematical relation $I_2 = I_1 \cos^2 \theta$.

(e) Substituting the value of I_1 and the given angle into the equation yields $I_2 = \left(\frac{I_0}{2}\right) \cos^2(60^\circ)$. Since $\cos(60^\circ) = \frac{1}{2}$, squaring it gives $\frac{1}{4}$. Thus, the final intensity is $I_2 = \frac{I_0}{2} \times \frac{1}{4} = \frac{I_0}{8}$.

Final Answer: $\frac{I_0}{8}$

Answer: (C)

Go Back to Question 35

Q36.

Solution

Concept:
The total mechanical work performed by an expanding ideal gas system corresponds to the integral of pressure with respect to volume, which matches the geometric area under the process curve on a $P - V$ coordinate grid. For a fixed volumetric expansion, the work done depends on how pressure changes along each thermodynamic pathway.

Solution:

(a) Consider three different thermodynamic pathways starting from an identical initial state (P_1, V_1) and expanding to the same final volume V_2. On a standard pressure-volume plot, these processes trace distinct curves.

(b) In a purely isobaric expansion (path 2), the system pressure remains constant at its maximum initial value throughout the volume change. This constant pressure level forms a rectangular area under the path, yielding the greatest possible work output: W_2.

(c) In a purely isothermal expansion (path 1), the pressure decreases hyperbolically as volume increases because temperature is held constant. The curve drops, but remains higher than the adiabatic curve due to continuous heat absorption.

(d) In a purely adiabatic expansion (path 3), the gas does work entirely at the expense of its own internal thermal energy without heat exchange, causing temperature to drop. Consequently, the pressure falls sharply, tracing the steepest curve.

(e) Comparing the geometric areas under these curves shows that the isobaric path encloses the most area, followed by the isothermal path, while the adiabatic path encloses the least. This establishes the strict inequality $W_2 > W_1 > W_3$.

Final Answer: $W_2 > W_1 > W_3$

Answer: (A)

Go Back to Question 36

Q37.

Solution

Concept:
A solid spherical object falling freely through a column of viscous fluid experiences a downward gravitational force, an upward buoyant force, and an opposing upward viscous drag force. As the object accelerates, the velocity-dependent drag force increases until the net force acting on the sphere becomes zero, leading to a constant terminal velocity.

Solution:

(a) According to Stokes's law, the magnitude of the resistive viscous drag force acting on a smooth spherical particle of radius r moving through a fluid with dynamic viscosity η at velocity v is given by $F_d = 6\pi\eta rv$.

(b) The downward force driving the motion is the net weight of the sphere, which is the actual gravitational weight minus the upward buoyant force: $F_{\text{net\_weight}} = \frac{4}{3}\pi r^3\rho g - \frac{4}{3}\pi r^3\sigma g = \frac{4}{3}\pi r^3(\rho - \sigma)g$.

(c) In this equation, the parameter ρ represents the mass density of the falling solid sphere, while the parameter σ represents the localized mass density of the surrounding liquid medium.

(d) Dynamic mechanical equilibrium is reached when the upward viscous drag force perfectly balances this net downward weight, which is written mathematically as $6\pi\eta rv = \frac{4}{3}\pi r^3(\rho - \sigma)g$.

(e) Solving this equilibrium equation for the velocity isolates the constant terminal velocity, yielding $v = \frac{2}{9}\frac{r^2(\rho-\sigma)g}{\eta}$. This explicit analytical expression demonstrates that the terminal velocity scales as $v \propto r^2$.

Final Answer: $v \propto r^2$

Answer: (B)

Go Back to Question 37

Q38.

Solution

Concept:

Newton's law of universal gravitation states that the attractive gravitational force acting between two isolated point masses is directly proportional to the product of their masses and inversely proportional to the square of the distance separating their centers. At a zero-force equilibrium point, the opposing gravitational pull from each mass must balance exactly.

Solution:

(a) Let two point masses, m and $4m$, be fixed at a separation distance d. A third mass M is placed on the line connecting them at a distance x from the smaller mass m.

(b) Because the total distance separating the two main masses is d, the distance from the third mass M to the larger mass $4m$ along the connecting line is equal to the remaining segment, expressed as $d - x$.

(c) The attractive gravitational force exerted on M by the mass m pulls it toward the origin and is given by $F_1 = \frac{GmM}{x^2}$. The force exerted by the mass $4m$ pulls it in the opposite direction and is given by $F_2 = \frac{G(4m)M}{(d-x)^2}$.

(d) For the net gravitational force acting on the mass M to be zero, these two opposing forces must have equal magnitudes: $\frac{GmM}{x^2} = \frac{G(4m)M}{(d-x)^2}$.

(e) Canceling the common factors G, m, and M simplifies the equation to $\frac{1}{x^2} = \frac{4}{(d-x)^2}$. Taking the positive square root of both sides gives $\frac{1}{x} = \frac{2}{d-x}$, which cross-multiplies to $d - x = 2x$, solving directly to $x = \frac{d}{3}$.

Final Answer: $\frac{d}{3}$

Answer: (B)

Go Back to Question 38

Q39.

Solution

Concept:

A potentiometer is a high-precision instrument used to measure an unknown electromotive force without drawing any current from the source at the balance condition. It operates on the principle that the potential drop across a uniform slide-wire is directly proportional to the length of the wire segment when a constant current flows through it.

Solution:

(a) Let ϕ represent the potential gradient of the potentiometer wire, which is the uniform voltage drop per unit length of the slide-wire. The emf E of a balanced cell is given by the linear relation $E = \phi \cdot l$.

(b) For the first cell tested, the known electromotive force is $E_1 = 1.5$ V, and the circuit achieves a null balance point at a wire length of $l_1 = 30$ cm. This gives the equation $1.5 = \phi \cdot 30$.

(c) When this first cell is replaced by a second cell of unknown electromotive force E_2, the potential gradient ϕ along the wire remains unchanged, and the new balance point shifts to a length of $l_2 = 40$ cm, giving $E_2 = \phi \cdot 40$.

(d) To eliminate the unknown potential gradient variable ϕ, we divide the second balance equation by the first equation, creating the direct proportion $\frac{E_2}{E_1} = \frac{l_2}{l_1}$.

(e) Substituting the known values into this ratio gives $\frac{E_2}{1.5} = \frac{40}{30} = \frac{4}{3}$. Isolating the unknown electromotive force gives $E_2 = 1.5 \times \frac{4}{3} = \frac{6.0}{3} = 2.0$ V.

Final Answer: 2.0 V

Answer: (A)

Go Back to Question 39

Q40.

Solution

Concept:
A standard P-N junction diode features a localized depletion region at the boundary interface where mobile charge carriers have recombined, leaving behind a fixed space-charge layout that establishes an internal barrier potential. Applying an external bias voltage alters the electric field across this junction, modifying its physical width and energy height.

Solution:

(a) In an unbiased P-N junction, diffusion of majority carriers creates a depletion layer containing fixed positive donor ions on the N-side and fixed negative acceptor ions on the P-side, generating an internal barrier potential directed from N to P.

(b) When a forward bias is applied, the positive terminal of the external voltage source is connected to the P-type semiconductor material and the negative terminal is connected to the N-type material. [Image of forward biased P-N junction diode]

(c) This forward bias creates an external electric field directed from the P-side to the N-side, which opposes the built-in internal electric field of the depletion region.

(d) The opposing external field reduces the net field at the interface, lowering the potential energy barrier. This lower barrier allows majority charge carriers to diffuse across the junction more easily.

(e) Concurrently, the external forward voltage pushes majority carriers into the depletion zone, neutralizing some of the fixed space charge. This compression forces the physical width of the depletion layer to decrease.

Final Answer: Depletion width decreases, barrier height decreases

Answer: (B)

Go Back to Question 40

Q41.

Solution

Concept:
A completely inelastic collision occurs when two colliding bodies stick together after the impact and move with a common final velocity. While the total linear momentum of the system remains conserved throughout the process due to the absence of external forces, the total mechanical kinetic energy is not conserved and undergoes a maximum loss.

Solution:

(a) Let $m = 10$ g $= 0.01$ kg be the mass of the bullet moving with an initial velocity $u = 400$ m/s, and let $M = 990$ g $= 0.99$ kg be the mass of the stationary block.

(b) According to the law of conservation of linear momentum, the total momentum before the collision equals the total momentum after the collision: $mu + M(0) = (m + M)v$, where v is the common final velocity.

(c) Substituting the values gives $0.01 \times 400 = (0.01 + 0.99)v$, which simplifies to $4 = 1 \times v$. Thus, the common velocity of the embedded system is $v = 4$ m/s.

(d) The initial kinetic energy of the system is residing entirely within the moving bullet, calculated as $K_i = \frac{1}{2}mu^2 = \frac{1}{2} \times 0.01 \times (400)^2 = 0.005 \times 160000 = 800$ J.

(e) The final kinetic energy of the combined system moving together is $K_f = \frac{1}{2}(m + M)v^2 = \frac{1}{2} \times 1 \times (4)^2 = 8$ J. The mechanical energy lost during this inelastic impact is $\Delta K = K_i - K_f = 800 - 8 = 792$ J.

Final Answer: 792 J

Answer: (A)

Go Back to Question 41

Q42.

Solution

Concept:

When a charged particle enters a uniform magnetic field at an oblique angle, its velocity vector splits into two independent components. The component parallel to the field drives uniform straight-line motion, while the component perpendicular to the field drives uniform circular motion, combining to form a helical trajectory.

Solution:

(a) A particle of charge q and mass m enters a magnetic field B at an angle $\theta = 30°$. The velocity component parallel to the field lines is $v_{\parallel} = v\cos(30°)$, and the component perpendicular to the field lines is $v_{\perp} = v\sin(30°)$.

(b) The perpendicular velocity component is responsible for keeping the particle in a circular path, where the magnetic force provides the centripetal acceleration. This yields a time period for one full revolution given by $T = \frac{2\pi m}{qB}$.

(c) The pitch of the helix is defined as the forward linear distance traveled by the charged particle along the direction of the magnetic field vector during the exact time span of one complete circular revolution.

(d) Therefore, the formula for calculating the pitch of this helical path is expressed as $P = v_{\parallel} \times T = v\cos(30°) \times \left(\frac{2\pi m}{qB}\right)$.

(e) Substituting the value of $\cos(30°) = \frac{\sqrt{3}}{2}$ into this expression gives $P = v\left(\frac{\sqrt{3}}{2}\right)\left(\frac{2\pi m}{qB}\right) = \frac{\sqrt{3}\pi m v}{qB}$.

Final Answer: $\frac{\sqrt{3}\pi m v}{qB}$

Answer: (B)

Go Back to Question 42

Q43.

Solution

Concept:
When a light ray strikes an optical boundary normally, it passes through into the medium without any angular deviation. However, if it subsequently strikes another interface at an angle of incidence that exceeds the critical angle for that pair of media, it undergoes total internal reflection instead of refraction.

Solution:

(a) The incident light ray enters the first face of the right-angled isosceles prism normally, meaning its angle of incidence at the entrance boundary is $0°$, allowing it to pass straight through without deviation.

(b) The ray travels inside the glass medium and strikes the hypotenuse face of the prism. From the geometry of a right-angled isosceles triangle ($45°$-$90°$-$45°$), the angle of incidence at this second face is exactly $i = 45°$.

(c) The critical angle θ_c for the prism-air boundary is determined using Snell's law: $\sin(\theta_c) = \frac{1}{n} = \frac{1}{\sqrt{2}}$, which gives a critical angle value of exactly $\theta_c = 45°$.

(d) Since the actual angle of incidence ($i = 45°$) does not exceed the critical angle ($\theta_c = 45°$), the light ray emerges along the surface of the interface, refracting at an angle of $90°$ relative to the normal.

(e) Using Snell's law at the exit face: $n \sin(45°) = 1 \sin(r)$, which gives $\sqrt{2} \times \frac{1}{\sqrt{2}} = \sin(r) = 1$, confirming $r = 90°$. The net angular deviation from its original horizontal path is $\delta = r - i = 90° - 45° = 45°$.

Final Answer: $45°$

Answer: (A)

Go Back to Question 43

Q44.

Solution

Concept:
According to the ideal gas law, the state parameters of a gas sample are related by $PV = nRT$. When analyzing a thermodynamic process plotted on a volume-temperature $(V - T)$ coordinate frame, the structural nature of the path can be deduced directly from the mathematical properties of its slope.

Solution:

(a) The ideal gas equation can be rearranged to express volume as a function of temperature: $V = \left(\frac{nR}{P}\right)T$. On a $V - T$ graph, this represents a straight line passing through the origin, provided the pressure remains constant.

(b) The given diagram displays process $A \to B$ as a straight line pointing directly toward the coordinate origin, indicated by the extension of the dashed line back to $(0, 0)$.

(c) The mathematical slope of any straight line moving through the origin on a $V - T$ coordinate plot is constant and can be written as $\frac{V}{T} = \text{constant}$.

(d) Comparing this graph behavior with our rearranged ideal gas equation demonstrates that the parameter group $\left(\frac{nR}{P}\right)$ must be a constant value along this entire path.

(e) Since the number of moles n and the universal gas constant R are inherently fixed quantities for a closed sample, the pressure P must remain constant. A constant pressure process is defined as an isobaric process.

Final Answer: Isobaric

Answer: (B)

Go Back to Question 44

Q45.

Solution

Concept:

The Bohr model of the hydrogen atom postulates that an electron rotates around a dense nucleus in specific stable circular orbits where its angular momentum is quantized as an integral multiple of $\frac{h}{2\pi}$. This condition limits the allowed orbital radii and corresponding velocities to discrete values.

Solution:

(a) According to Bohr's quantization postulate for an electron of mass m moving with speed v in a stable circular orbit of radius r, the angular momentum is given by $mvr = \frac{nh}{2\pi}$, where n is the principal quantum number.

(b) The electrostatic Coulomb force between the positive nucleus of charge Ze and the electron provides the necessary centripetal force: $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$, which simplifies to $mv^2 r = \frac{Ze^2}{4\pi\varepsilon_0}$.

(c) To isolate the orbital velocity vector magnitude, we can divide the centripetal force equation by the angular momentum quantization equation: $\frac{mv^2 r}{mvr} = \left(\frac{Ze^2}{4\pi\varepsilon_0}\right) / \left(\frac{nh}{2\pi}\right)$.

(d) Simplifying this algebraic fraction cancels out the mass and orbital radius variables, leaving the explicit velocity equation: $v = \frac{Ze^2}{2\varepsilon_0 nh}$.

(e) For a specific hydrogen atom, the atomic number is fixed at $Z = 1$. Since e, ε_0, and h are fundamental constants, the relation reduces to $v \propto \frac{1}{n}$, meaning velocity is inversely proportional to the principal quantum number.

Final Answer: $v \propto \frac{1}{n}$

Answer: (B)

Go Back to Question 45

Q46.

Solution

Concept:
According to the first law of thermodynamics, any net heat energy added to a thermodynamic system is split between performing external mechanical work against the surroundings and changing the internal energy of the system. During a constant-temperature phase transition, energy changes relate strictly to changes in molecular configurations.

Solution:

(a) When a quantity of liquid water at 100°C transforms completely into gaseous steam at 100°C, the system absorbs a specific amount of heat known as the latent heat of vaporization ($Q = mL$).

(b) This physical phase change occurs under constant temperature conditions, meaning the average translational kinetic energy of the molecules remains constant throughout the vaporization process.

(c) However, the first law of thermodynamics states that $\Delta U = Q - W$, where ΔU is the change in internal energy, Q is the added heat, and W is the work performed by the expanding system.

(d) As liquid transitions to gas, it undergoes a massive volumetric expansion, doing positive mechanical work ($W = P\Delta V$) against the constant atmospheric pressure.

(e) The absorbed latent heat is much larger than the work done during expansion ($Q > W$). This excess energy goes into breaking the attractive intermolecular forces holding the water molecules together, which increases the potential energy component of the system and causes the internal energy to increase.

Final Answer: Increases

Answer: (C)

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Q47.

Solution

Concept:
Newton's second law for rotational motion states that the net external torque applied to a rigid body about a fixed axis of rotation is directly proportional to the resulting angular acceleration. The constant of proportionality is the moment of inertia, which measures the body's rotational inertia about that axis.

Solution:

(a) The fundamental equation connecting torque, moment of inertia, and angular acceleration for a rigid body rotating around a fixed axis is given by the rotational analogue formula $\tau = I\alpha$.

(b) In this equation, the parameter τ represents the applied external torque measured in Newton-meters, I represents the moment of inertia measured in $kg \cdot m^2$, and α represents the angular acceleration in rad/s^2.

(c) The problem provides the numerical value for the constant torque acting on the flywheel as $\tau = 50\ N \cdot m$ and the resulting angular acceleration as $\alpha = 5.0\ rad/s^2$.

(d) To solve for the unknown moment of inertia of the flywheel, we rearrange the primary rotational formula to isolate the inertia variable: $I = \frac{\tau}{\alpha}$.

(e) Substituting the given values into this rearranged expression yields $I = \frac{50}{5.0} = 10\ kg \cdot m^2$. This value represents the mass distribution of the flywheel relative to its central axis of rotation.

Final Answer: $10\ kg \cdot m^2$

Answer: (B)

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Q48.

Solution

Concept:
A current-carrying conductor generates a surrounding magnetic field whose geometry is governed by Ampere's law. When a second current-carrying wire is placed inside this magnetic field, it experiences a magnetic Lorentz force whose direction can be determined using the right-hand rule.
Solution:

(a) Consider two long, straight parallel wires separated by a distance r carrying currents I_1 and I_2. The first wire carries current I_1 and produces a circular magnetic field around itself. At the location of the second wire, the field magnitude is $B_1 = \frac{\mu_0 I_1}{2\pi r}$.

(b) The second wire carries a current I_2 through this magnetic field B_1. The magnetic force acting on a segment of length l of the second wire is given by the Lorentz relation $F = I_2 \cdot l \cdot B_1$.

(c) Substituting the field expression into the force equation gives $F = I_2 l \left(\frac{\mu_0 I_1}{2\pi r}\right)$. Dividing by length isolates the force per unit length: $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$.

(d) The directional nature of this force depends on the relative directions of the currents. According to the right-hand rule, parallel currents flowing in the same direction exert an attractive force on each other.

(e) Conversely, when the currents flow in opposite directions (antiparallel), the magnetic forces push the conductors away from one another. Therefore, the force per unit length is repulsive.

Final Answer: $\frac{\mu_0 I_1 I_2}{2\pi r}$, repulsive

Answer: (B)

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Q49.

Solution

Concept:
The optical power of a lens measures its ability to converge or diverge incident light rays and is defined as the reciprocal of its focal length in meters. When multiple thin lenses are placed in direct contact coaxially, the total net power of the combined system is equal to the algebraic sum of the individual powers.

Solution:

(a) The focal length of the first lens, which is a convex (converging) lens, is positive according to standard Cartesian sign convention: $f_1 = +20 \text{ cm} = +0.2 \text{ m}$.

(b) The focal length of the second lens, which is a concave (diverging) lens, is negative according to the same sign convention: $f_2 = -10 \text{ cm} = -0.1 \text{ m}$.

(c) The power of an individual lens in diopters (D) is calculated using $P = \frac{1}{f(\text{m})}$. Calculating the powers gives $P_1 = \frac{1}{+0.2} = +5 \text{ D}$ and $P_2 = \frac{1}{-0.1} = -10 \text{ D}$.

(d) For a combination of thin lenses placed in direct contact, the net optical power equation is the simple algebraic sum: $P_{net} = P_1 + P_2$.

(e) Substituting the individual power values into the summation expression yields $P_{net} = (+5 \text{ D}) + (-10 \text{ D}) = -5 \text{ D}$. The negative sign indicates that the combined lens system behaves like a net diverging lens.

Final Answer: -5 D

Answer: (B)

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Q50.

Solution

Concept:
The power factor of an alternating current series LCR circuit represents the efficiency of power transmission and is defined as the ratio of the real resistive power to the total apparent power. Mathematically, it equals the cosine of the phase angle between the total circuit voltage and current vectors.
Solution:

(a) The given series LCR electrical circuit contains a pure resistance $R = 30\,\Omega$, an inductive reactance $X_L = 80\,\Omega$, and a capacitive reactance $X_C = 40\,\Omega$.

(b) The net total reactance X of a series circuit is the difference between the inductive reactance and the capacitive reactance, written as $X = X_L - X_C = 80 - 40 = 40\,\Omega$.

(c) The total electrical impedance Z represents the combined opposition of the circuit to AC current and is calculated using the vector impedance triangle formula: $Z = \sqrt{R^2 + (X_L - X_C)^2}$.

(d) Substituting the values into the impedance equation yields $Z = \sqrt{30^2 + 40^2} = \sqrt{900 + 1600} = \sqrt{2500} = 50\,\Omega$.

(e) The power factor of the circuit is given by $\cos(\phi) = \frac{R}{Z}$, where R is the resistance and Z is the total impedance. Substituting the calculated values yields $\cos(\phi) = \frac{30}{50} = 0.6$.

Final Answer: 0.6

Answer: (A)

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Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	A	3	A	4	A	5	A	10	A
11	C	12	B	13	C	14	A	15	B
16	B	17	A	18	A	19	C	20	B
21	A	22	B	23	B	24	C	25	B
26	C	27	B	28	B	29	C	30	A
31	B	32	B	33	A	34	B	35	C
36	A	37	B	38	B	39	A	40	B
41	A	42	B	43	A	44	B	45	B
46	C	47	B	48	B	49	B	50	A