Rajasthan JET Physics Sample Paper-5

Duration: 40 Minutes **Maximum Marks: 160**

Instructions

- This paper contains **40** Multiple Choice Questions (Single Correct).
- Each correct answer carries **+4 marks**.
- Each incorrect answer carries: **−1 marks**.
- Use of mobile phones, smartwatches, calculators, or any electronic gadgets is strictly prohibited.

Q1. A particle of mass m is moving in a horizontal circle of radius r under a centripetal force given by $-\frac{k}{r^2}$, where k is a constant. The total energy of the particle is:

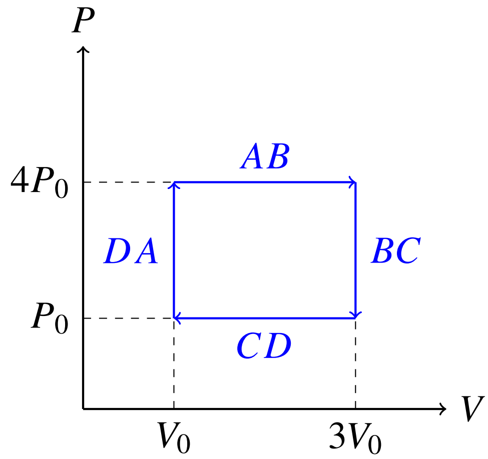
(A) $-\frac{k}{2r}$

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

(C) $-\frac{k}{r}$

(D) $\frac{2k}{r}$

Q2. A thermodynamic system undergoes a cyclic process $ABCDA$ as shown in the $P-V$ diagram. The net work done by the system in one complete cycle is:



(A) $3P_0V_0$

(B) $6P_0V_0$

(C) $2P_0V_0$

(D) Zero

Q3. In a forward-biased $p-n$ junction diode, when the potential barrier is overcome, the current:

(A) decreases exponentially with applied voltage.

(B) remains constant irrespective of voltage.

(C) increases linearly with applied voltage.

(D) increases exponentially with applied voltage.

Q4. Two bodies of masses 1 kg and 4 kg are moving with equal kinetic energies. The ratio of the magnitudes of their linear momenta is:

(A) 4 : 1

(B) 2 : 1

(C) 1 : 2

(D) 1 : 4

Q5. An astronomical telescope has an objective of focal length 140 cm and an eyepiece of focal length 5.0 cm. The magnifying power of this telescope for viewing distant objects in normal adjustment is:

(A) 28

(B) 35

(C) 70

(D) 145

Q6. A copper wire is stretched to make it 0.1% longer. The percentage change in its electrical resistance will be:

(A) 0.1%

(B) 0.2%

(C) 0.4%

(D) 0.05%

Q7. If the absolute error in the measurement of the radius of a sphere is 0.2%, then the permissible error in the measurement of its volume will be:

(A) 0.2%

(B) 0.4%

(C) 0.6%

(D) 0.8%

Q8. A gas mixture consists of 2 moles of oxygen and 4 moles of argon at temperature T. Neglecting all vibrational modes, the total internal energy of the system is:

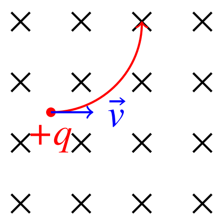
(A) $4RT$

(B) $15RT$

(C) $9RT$

(D) $11RT$

Q9. A charged particle moves through a magnetic field perpendicular to its direction of velocity. During this motion:



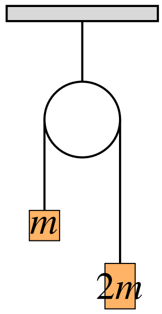
(A) both the kinetic energy and momentum of the particle remain constant.

(B) the kinetic energy changes but momentum remains constant.

(C) the kinetic energy remains constant but momentum changes.

(D) both kinetic energy and momentum change.

Q10. A body of mass m hangs from a smooth fixed pulley via a light string. To another end of the string, a mass $2m$ is tied. If the system is released from rest, the acceleration of the center of mass of the system is:



(A) $g/3$

(B) $g/6$

(C) $g/9$

(D) $g/2$

Q11. The displacement of a particle executing simple harmonic motion is given by $y = 5\sin\left(20t + \frac{\pi}{3}\right)$ cm. The maximum velocity of the particle is:

(A) 100 cm/s

(B) 5 cm/s

(C) 20 cm/s

(D) 50 cm/s

Q12. When a metallic surface is illuminated with radiation of wavelength λ, the stopping potential is V. If the same surface is illuminated with radiation of wavelength 2λ, the stopping potential becomes $V/4$. The threshold wavelength for the metallic surface is:

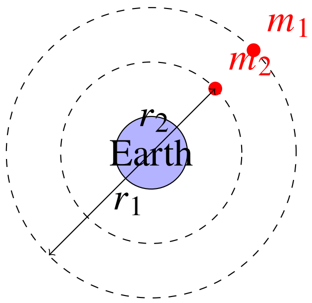
(A) 4λ

(B) 3λ

(C) 2.5λ

(D) 5λ

Q13. Two satellites of masses m_1 and m_2 ($m_1 > m_2$) are revolving around the Earth in circular orbits of radii r_1 and r_2 ($r_1 > r_2$) respectively. Which of the following statements is true regarding their orbital velocities v_1 and v_2?



(A) $v_1 > v_2$

(B) $v_1 < v_2$

(C) $v_1 = v_2$

(D) The relation depends on the values of m_1 and m_2.

Q14. In a Young's double-slit experiment, the slit separation is doubled and the distance between the slits and the screen is halved. The fringe width becomes:

(A) one-fourth

(B) half

(C) double

(D) four times

Q15. An alternating current is given by the equation $I = I_1 \cos\omega t + I_2 \sin\omega t$. The root-mean-square value of the current is:

(A) $\frac{I_1+I_2}{\sqrt{2}}$

(B) $\frac{|I_1-I_2|}{\sqrt{2}}$

(C) $\sqrt{\frac{I_1^2+I_2^2}{2}}$

(D) $\sqrt{I_1^2 + I_2^2}$

Q16. The work done in pulling a small body of mass m up a smooth inclined hill of height h and base length l at a constant slow speed depends on:

(A) the steepness of the path chosen.

(B) only the height h.

(C) only the base length l.

(D) both the path length and the height h.

Q17. Liquid drops are spherical in shape because of:

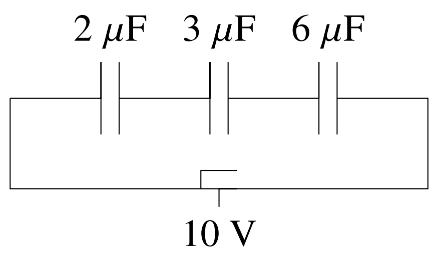
(A) surface tension

(B) viscosity

(C) gravitational force

(D) atmospheric pressure

Q18. Three capacitors of capacitances 2 μF, 3 μF, and 6 μF are connected in series across a 10 V battery. The charge on the 3 μF capacitor is:



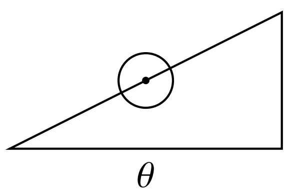
(A) 10 μC

(B) 15 μC

(C) 6 μC

(D) 30 μC

Q19. A solid sphere and a solid cylinder of same mass and radius roll down the same inclined plane without slipping from rest. The ratio of their accelerations $a_{\text{sphere}}/a_{\text{cylinder}}$ is:



(A) 15 : 14

(B) 14 : 15

(C) 5 : 4

(D) 1 : 1

Q20. An ideal gas heat engine operates in a Carnot cycle between 227°C and 127°C. It absorbs 6×10^4 cal of heat at the higher temperature. The amount of heat converted into work is:

(A) 4.8×10^4 cal

(B) 3.5×10^4 cal

(C) 1.6×10^4 cal

(D) 1.2×10^4 cal

Q21. The half-life of a radioactive substance is 20 minutes. The time taken between 20% decay and 80% decay of the substance is:

(A) 20 minutes

(B) 30 minutes

(C) 40 minutes

(D) 25 minutes

Q22. A projectile is thrown with an initial velocity of $\vec{v} = a\hat{i} + b\hat{j}$, where $\hat{i}$ is along the horizontal and $\hat{j}$ is vertically upwards. If the range of the projectile is twice its maximum height, then:

(A) $a = 2b$

(B) $b = 2a$

(C) $a = b$

(D) $b = 4a$

Q23. A capillary tube of radius r is immersed in water and water rises in it to a height h. The mass of water in the capillary tube is M. If another capillary tube of radius $2r$ is immersed in water, the mass of water that will rise in this tube is:

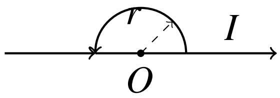
(A) M

(B) $2M$

(C) $M/2$

(D) $4M$

Q24. A straight wire carrying a current of 10 A is bent into a semi-circular loop of radius 5 cm. The magnetic field at the center of this loop is:



(A) 6.28×10^{-5} T

(B) 3.14×10^{-5} T

(C) 1.57×10^{-5} T

(D) Zero

Q25. The dimensions of torque are same as that of:

(A) momentum

(B) power

(C) force

(D) work

Q26. Two sound waves having wavelengths 5.0 m and 5.5 m propagates in a gas with velocity 330 m/s. The number of beats produced per second is:

(A) 6

(B) 3

(C) 5

(D) 12

Q27. The electric potential at any point (x, y, z) in meters is given by $V = 4x^2$ volts. The electric field at the point $(1, 0, 2)$ m is:

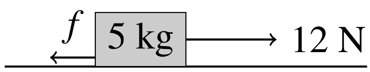
(A) $8\hat{i}$ V/m

(B) $-8\hat{i}$ V/m

(C) $-16\hat{i}$ V/m

(D) $4\hat{i}$ V/m

Q28. A block of mass 5 kg is resting on a rough horizontal surface. The coefficient of static friction between the block and the surface is 0.4. If a horizontal force of 12 N is applied to the block, the frictional force acting on the block is (take $g = 10$ m/s^2):



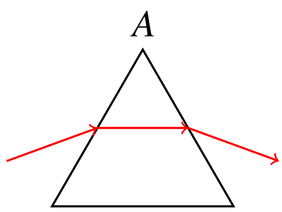
(A) 20 N

(B) 12 N

(C) 8 N

(D) Zero

Q29. A ray of light passes through an equilateral glass prism such that the angle of incidence is equal to the angle of emergence. If the angle of emergence is 3/4 times the angle of the prism, the angle of deviation is:



(A) 30°

(B) 45°

(C) 60°

(D) 37.5°

Q30. In an electromagnetic wave, the amplitude of the electric field component is 90 V/m. The amplitude of its magnetic field component is:

(A) 3×10^{-7} T

(B) 9×10^{-7} T

(C) 2.7×10^{10} T

(D) 6×10^{-8} T

Q31. A passenger train 100 m long is moving with a constant velocity of 10 m/s. A bird flying near the track with a velocity of 5 m/s in the opposite direction crosses the train. The time taken by the bird to cross the train is:

(A) 20 s

(B) 10 s

(C) 6.67 s

(D) 15 s

Q32. At what temperature will the root-mean-square speed of oxygen molecules be double of their root-mean-square speed at 27°C?

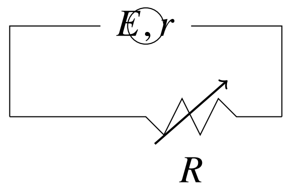
(A) 54°C

(B) 108°C

(C) 927°C

(D) 1200°C

Q33. A cell of emf E and internal resistance r is connected across an external variable resistance R. The maximum power delivered to the external resistor happens when:



(A) $R = r$

(B) $R \gg r$

(C) $R \ll r$

(D) $R = 0$

Q34. The angular momentum of an electron orbiting in the third Bohr orbit of a hydrogen atom is:

(A) 3.16×10^{-34} J · s

(B) 1.05×10^{-34} J · s

(C) 2.11×10^{-34} J · s

(D) 4.22×10^{-34} J · s

Q35. A light body and a heavy body have equal linear momentum. Which one has greater kinetic energy?

(A) The heavy body

(B) The light body

(C) Both have equal kinetic energy

(D) Cannot be predicted without mass values

Q36. A soap bubble of radius r is blown up to a radius $2r$ under isothermal conditions. If the surface tension of the soap solution is T, the work done in the process is:

(A) $12\pi r^2 T$

(B) $24\pi r^2 T$

(C) $4\pi r^2 T$

(D) $8\pi r^2 T$

Q37. A transformer has 500 turns in the primary coil and 1000 turns in the secondary coil. If an AC voltage of 220 V is applied across the primary, the output voltage across the secondary under ideal conditions is:

(A) 110 V

(B) 440 V

(C) 55 V

(D) 220 V

Q38. If the distance between two point charges is doubled and their individual magnitudes are also doubled, the electrostatic force between them:

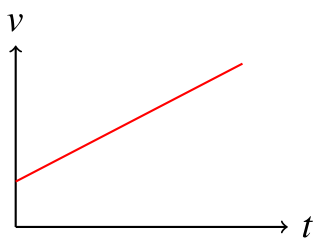
(A) becomes double

(B) becomes half

(C) remains unchanged

(D) becomes four times

Q39. The velocity-time graph of a particle moving along a straight line is a straight line inclined to the time axis at a non-zero angle. This implies that the particle is moving with:



(A) uniform velocity

(B) uniform acceleration

(C) non-uniform acceleration

(D) zero acceleration

Q40. A monochromatic light ray travels from a rarer medium to a denser medium. During this refraction process, which of the following properties of light remains constant?

(A) Velocity

(B) Wavelength

(C) Frequency

(D) Amplitude

Detailed Solutions

Q1.

Solution

Concept:

The total mechanical energy E of a particle revolving in a circular orbit under a central force is the sum of its kinetic energy K and its potential energy U. The centripetal force required for circular motion is provided by the given central conservative force field, which allows us to determine the velocity and kinetic energy. The potential energy is obtained by integrating the force with respect to the radius.

Solution:

Step 1: Write down the condition for the circular motion of the particle. The magnitude of the centripetal force balancing the orbit is given by:

$$\frac{mv^2}{r} = \frac{k}{r^2}$$

Step 2: Simplify the expression to find the kinetic energy K of the particle. Multiplying both sides by $\frac{1}{2}r$, we get:

$$K = \frac{1}{2}mv^2 = \frac{k}{2r}$$

Step 3: Find the potential energy U by integrating the conservative force function. The relationship between a conservative force and potential energy is expressed as:

$$F = -\frac{dU}{dr} \implies dU = -F\,dr$$

$$U = -\int \left(-\frac{k}{r^2}\right) dr = k \int r^{-2}\,dr = -\frac{k}{r}$$

Step 4: Calculate the total mechanical energy E by adding the kinetic energy and potential energy equations derived in Step 2 and Step 3:

$$E = K + U = \frac{k}{2r} + \left(-\frac{k}{r}\right) = \frac{k - 2k}{2r} = -\frac{k}{2r}$$

Final Answer: $\boxed{-\frac{k}{2r}}$

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept:
On a $P - V$ diagram, the net work done by a thermodynamic system during a complete cyclic process is geometrically equal to the area enclosed by the loop of the cycle. For a rectangular cycle on the graph, the area is calculated simply as the product of its length along the volume axis and its height along the pressure axis. If the cycle is clockwise, the net work done is positive.

Solution:
Step 1: Identify the dimensions of the rectangular cyclic loop $ABCDA$ from the given $P - V$ coordinates. The change in pressure along the vertical side is:

$$\Delta P = 4P_0 - P_0 = 3P_0$$

Step 2: Identify the change in volume along the horizontal side of the closed rectangular path:

$$\Delta V = 3V_0 - V_0 = 2V_0$$

Step 3: Calculate the area enclosed by the rectangular loop to determine the magnitude of the work done by the system:

$$\text{Area} = \Delta P \times \Delta V = (3P_0) \times (2V_0) = 6P_0V_0$$

Step 4: Determine the sign of the work done based on the direction of the cycle. Since the process moves in a clockwise direction on the $P - V$ grid, the work done during expansion at higher pressure dominates, making the net work positive:

$$W_{\text{net}} = +6P_0V_0$$

Final Answer: $6P_0V_0$

Answer: (B)

Go Back to Question 2

Q3.

Solution

Concept:

The behavior of a $p-n$ junction diode under forward bias is governed by the ideal diode equation derived from semiconductor physics. Initially, when the external voltage is less than the barrier potential, the current is negligible. Once the external forward voltage exceeds the built-in potential barrier, the depletion region narrows significantly, allowing majority charge carriers to diffuse rapidly across the junction.

Solution:

Step 1: Recall the mathematical relationship between the forward current I and the applied forward bias voltage V across a semiconductor diode:

$$I = I_0 \left(e^{\frac{eV}{\eta k_B T}} - 1 \right)$$

where I_0 is the reverse saturation current, e is the electronic charge, k_B is the Boltzmann constant, T is the absolute temperature, and η is the ideality factor.

Step 2: Analyze the condition when the applied potential completely overcomes the built-in potential barrier. For a significant forward voltage, the exponential term becomes much larger than 1:

$$e^{\frac{eV}{\eta k_B T}} \gg 1 \implies I \approx I_0 e^{\frac{eV}{\eta k_B T}}$$

Step 3: Conclude the nature of the variation. The equation directly confirms that the forward current increases at an exponential rate with further small increases in the applied voltage, leading to a steep rise in conduction.

Final Answer: increases exponentially with applied voltage.

Answer: (D)

Go Back to Question 3

Q4.

Solution

Concept:

The relationship between the linear momentum p of a moving body and its kinetic energy K is derived from their fundamental formulas involving mass m and velocity v. By expressing momentum as $p = mv$ and kinetic energy as $K = \frac{1}{2}mv^2$, we can eliminate the velocity term to establish a direct formula linking momentum, mass, and kinetic energy.

Solution:

Step 1: Write down the standard formula relating linear momentum to kinetic energy:

$$K = \frac{p^2}{2m} \implies p = \sqrt{2mK}$$

Step 2: Set up the ratio for two different bodies using subscripts 1 and 2 to represent their respective masses and momenta:

$$\frac{p_1}{p_2} = \frac{\sqrt{2m_1K_1}}{\sqrt{2m_2K_2}}$$

Step 3: Use the given condition that both bodies possess equal kinetic energies, which means $K_1 = K_2 = K$. Substitute this condition into the ratio equation:

$$\frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}}$$

Step 4: Substitute the values of the masses $m_1 = 1$ kg and $m_2 = 4$ kg into the simplified radical expression:

$$\frac{p_1}{p_2} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

Thus, the ratio of the magnitudes of their linear momenta is 1 : 2.

Final Answer: 1 : 2

Answer: (C)

Go Back to Question 4

Q5.

Solution

Concept:

An astronomical telescope in normal adjustment means that the final image is formed at infinity, which provides comfortable viewing for the human eye. In this structural setup, the objective lens forms a real image of a distant object at its focal point, and this image acts as an object exactly at the focal plane of the eyepiece lens. The magnifying power in this specific operational state is determined by the ratio of the focal lengths.

Solution:

Step 1: Identify the formula for the magnifying power m of an astronomical telescope when adjusted for normal vision (image at infinity):

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

where f_o represents the focal length of the objective lens and f_e represents the focal length of the eyepiece lens.

Step 2: Note the values provided in the problem statement:

$$f_o = 140 \text{ cm}$$

$$f_e = 5.0 \text{ cm}$$

Step 3: Substitute the values into the formula to compute the numerical magnification:

$$m = \frac{140}{5.0} = 28$$

The magnifying power is a dimensionless quantity and equals 28.

Final Answer: 28

Answer: (A)

Go Back to Question 5

Q6.

Solution

Concept:

When a conducting metal wire is stretched mechanically, its length increases while its cross-sectional area decreases simultaneously because the total volume of the material remains perfectly constant. The electrical resistance of a uniform conductor is proportional to its length and inversely proportional to its cross-sectional area. By combining the volume conservation constraint with the resistance formula, we find how resistance scales purely with length.

Solution:

Step 1: Write the expression for electrical resistance R of a wire:

$$R = \rho \frac{l}{A}$$

where ρ is the resistivity, l is the length, and A is the cross-sectional area.

Step 2: Incorporate the constant volume condition ($V = A \times l \implies A = V/l$) into the resistance equation to express it solely in terms of length:

$$R = \rho \frac{l}{V/l} = \rho \frac{l^2}{V}$$

Since ρ and V are constants for a given wire, we can write $R \propto l^2$.

Step 3: Take the natural logarithm on both sides and differentiate to obtain the fractional error or small percentage change relation:

$$\ln R = \ln(\text{constant}) + 2\ln l \implies \frac{dR}{R} = 2\frac{dl}{l}$$

Step 4: Convert the fractional relation into a percentage change by multiplying by 100:

$$\% \text{ change in } R = 2 \times (\% \text{ change in } l) = 2 \times 0.1\% = 0.2\%$$

Final Answer: 0.2%

Answer: (B)

Go Back to Question 6

Q7.

Solution

Concept:

The theory of error propagation helps determine how errors in basic dimensions affect calculated geometric quantities like area or volume. For a perfect geometrical sphere, the total volume depends solely on its radius raised to the third power. When analyzing small fractional or percentage errors, the relative error in a calculated quantity is found by multiplying the relative error of the independent variable by its exponent power.

Solution:

Step 1: Write down the mathematical formula for calculating the volume V of a solid sphere of radius r:

$$V = \frac{4}{3}\pi r^3$$

Step 2: Differentiate the equation logarithmically to relate the relative error in volume to the relative error in the measurement of the radius:

$$\ln V = \ln\left(\frac{4}{3}\pi\right) + 3\ln r \implies \frac{\Delta V}{V} = 3\frac{\Delta r}{r}$$

Step 3: Express the error relation in terms of percentage values by multiplying both sides of the equation by 100:

$$\left(\frac{\Delta V}{V} \times 100\right) = 3 \times \left(\frac{\Delta r}{r} \times 100\right)$$

Step 4: Substitute the given value of the absolute percentage error in the radius ($\frac{\Delta r}{r} \times 100 = 0.2\%$) into the equation:

$$\% \text{ error in volume} = 3 \times 0.2\% = 0.6\%$$

Final Answer: $\boxed{0.6\%}$

Answer: (C)

Go Back to Question 7

Q8.

Solution

Concept:

The total internal energy of an ideal gas mixture is equal to the sum of the individual internal energies of the component gases. The internal energy of an ideal gas depends on its temperature, the number of moles, and the specific number of degrees of freedom associated with its molecular structure. Oxygen (O_2) is a diatomic gas, while Argon (Ar) is a monatomic noble gas.

Solution:

Step 1: Identify the degrees of freedom (f) for each gas component at ordinary temperatures, neglecting vibrational modes. For a diatomic gas like oxygen, $f_1 = 5$ (3 translational + 2 rotational). For a monatomic gas like argon, $f_2 = 3$ (3 translational).

Step 2: Recall the formula for the internal energy of n moles of an ideal gas with f degrees of freedom at temperature T:

$$U = \frac{f}{2}nRT$$

Step 3: Calculate the individual internal energy contributions for both gases in the mixture:

$$U_{\text{oxygen}} = \frac{5}{2} \times 2 \times RT = 5RT$$

$$U_{\text{argon}} = \frac{3}{2} \times 4 \times RT = 6RT$$

Step 4: Sum these individual contributions to find the total internal energy of the system:

$$U_{\text{total}} = U_{\text{oxygen}} + U_{\text{argon}} = 5RT + 6RT = 11RT$$

Final Answer: $\boxed{11RT}$

Answer: (D)

Go Back to Question 8

Q9.

Solution

Concept:

The magnetic force acting on a moving charged particle in a magnetic field is described by the Lorentz force equation: $\vec{F} = q(\vec{v} \times \vec{B})$. The direction of this magnetic force is always perpendicular to both the velocity vector of the particle and the magnetic field vector. Because the force vector remains perpendicular to the displacement vector at every instant, the instantaneous power delivered by the magnetic field is zero.

Solution:

Step 1: Write down the expression for the work done by a force over an infinitesimal displacement $d\vec{r}$:

$$dW = \vec{F} \cdot d\vec{r} = \vec{F} \cdot \vec{v}\, dt$$

Step 2: Substitute the magnetic force vector into the dot product equation:

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

Since the cross product $(\vec{v} \times \vec{B})$ yields a vector that is orthogonal to $\vec{v}$, its dot product with $\vec{v}$ must be zero. Therefore, $dW = 0$.

Step 3: Apply the work-energy theorem. Since no work is done on the particle by the magnetic field, its kinetic energy (K) must remain perfectly constant, meaning its speed does not change.

Step 4: Analyze the momentum vector $\vec{p} = m\vec{v}$. Although the magnitude of velocity (speed) is constant, the magnetic force continuously deflects the particle, changing the direction of motion. Since direction changes, the momentum vector is not constant.

Final Answer: the kinetic energy remains constant but momentum changes.

Answer: (C)

Go Back to Question 9

Q10.

Solution

Concept:

For a system consisting of multiple moving bodies, the acceleration of the center of mass $\vec{a}_{cm}$ is determined by taking a mass-weighted average of the individual acceleration vectors of each body. In an Atwood machine setup with masses suspended over a frictionless pulley, the individual accelerations are equal in magnitude but opposite in direction. We first calculate this acceleration magnitude and then apply it to the center of mass formula.

Solution:

Step 1: Calculate the magnitude of the linear acceleration a of the suspended masses using Newton's laws of motion:

$$a = \frac{m_2 - m_1}{m_1 + m_2} g = \frac{2m - m}{m + 2m} g = \frac{m}{3m} g = \frac{g}{3}$$

Step 2: Assign directional signs to the individual acceleration vectors. Let the downward direction be positive $(+\hat{j})$ and the upward direction be negative $(-\hat{j})$. The mass $2m$ moves downward with acceleration $\vec{a}_2 = \frac{g}{3}\hat{j}$, while the mass m moves upward with acceleration $\vec{a}_1 = -\frac{g}{3}\hat{j}$.

Step 3: Apply the formula for the acceleration of the center of mass of a two-body system:

$$\vec{a}_{cm} = \frac{m_1\vec{a}_1 + m_2\vec{a}_2}{m_1 + m_2} = \frac{m\left(-\frac{g}{3}\hat{j}\right) + 2m\left(\frac{g}{3}\hat{j}\right)}{m + 2m}$$

$$\vec{a}_{cm} = \frac{\left(-\frac{mg}{3} + \frac{2mg}{3}\right)\hat{j}}{3m} = \frac{\frac{mg}{3}\hat{j}}{3m} = \frac{g}{9}\hat{j}$$

The magnitude of the acceleration of the center of mass is $g/9$.

Final Answer: $g/9$

Answer: (C)

Go Back to Question 10

Q11.

Solution

Concept:

Simple harmonic motion (SHM) describes the oscillatory movement of a particle about an equilibrium position. The instantaneous velocity of the particle is found by taking the first time derivative of its displacement equation. The maximum value of this velocity function occurs as the particle passes through its mean position, where the cosine or sine time-dependent term equals its maximum value of unity.

Solution:

Step 1: Write down the given time-dependent equation for the displacement $y(t)$ of the oscillating particle:

$$y = 5\sin\left(20t + \frac{\pi}{3}\right)$$

Comparing this with the standard SHM displacement equation $y = A\sin(\omega t + \phi)$, we identify the parameters:

$$\text{Amplitude, } A = 5 \text{ cm}$$

$$\text{Angular frequency, } \omega = 20 \text{ rad/s}$$

Step 2: Differentiate the displacement equation with respect to time t to find the expression for instantaneous velocity $v(t)$:

$$v = \frac{dy}{dt} = 5 \times 20\cos\left(20t + \frac{\pi}{3}\right) = 100\cos\left(20t + \frac{\pi}{3}\right)$$

Step 3: Identify the maximum velocity v_{max}. The maximum value of the cosine function is 1. Therefore, the peak velocity magnitude is simply the product of the amplitude and the angular frequency:

$$v_{max} = A\omega = 5 \text{ cm} \times 20 \text{ rad/s} = 100 \text{ cm/s}$$

Final Answer: 100 cm/s

Answer: (A)

Go Back to Question 11

Q12.

Solution

Concept:

The photoelectric effect is described by Einstein's photoelectric equation, which states that the energy of an incident photon is split into two parts: overcoming the work function of the metal and providing maximum kinetic energy to the emitted photoelectron. The maximum kinetic energy can be expressed in terms of the electronic charge and the stopping potential. By setting up simultaneous equations for two different incident wavelengths, we can find the threshold wavelength.

Solution:

Step 1: Express Einstein's photoelectric equation in terms of incident wavelength λ and stopping potential V:

$$eV = \frac{hc}{\lambda} - \phi = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$$

where ϕ is the work function and λ_0 is the threshold wavelength. For the first case, we have:

$$eV = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} \quad \text{— (Equation 1)}$$

Step 2: Write the equation for the second experimental case where the wavelength is 2λ and the stopping potential decreases to $V/4$:

$$e\left(\frac{V}{4}\right) = \frac{hc}{2\lambda} - \frac{hc}{\lambda_0} \quad \text{— (Equation 2)}$$

Step 3: Multiply Equation 2 by 4 to align the left-hand sides of both equations:

$$eV = \frac{4hc}{2\lambda} - \frac{4hc}{\lambda_0} = \frac{2hc}{\lambda} - \frac{4hc}{\lambda_0} \quad \text{— (Equation 3)}$$

Step 4: Equate the right-hand sides of Equation 1 and Equation 3:

$$\frac{hc}{\lambda} - \frac{hc}{\lambda_0} = \frac{2hc}{\lambda} - \frac{4hc}{\lambda_0}$$

Step 5: Cancel the common constant terms hc from all terms and rearrange to solve for λ_0:

$$\frac{4}{\lambda_0} - \frac{1}{\lambda_0} = \frac{2}{\lambda} - \frac{1}{\lambda}$$

$$\frac{3}{\lambda_0} = \frac{1}{\lambda} \implies \lambda_0 = 3\lambda$$

Final Answer: $\boxed{3\lambda}$

Answer: (B)

Go Back to Question 12

Q13.

Solution

Concept:

The stable orbital motion of a satellite revolving around a massive astronomical planet in a circular path requires that the gravitational force of attraction provides the exact centripetal force. By balancing these two forces, we can derive the formula for the satellite's orbital velocity. This equation shows how the velocity depends on the mass of the central planet and the radius of the orbit, and it reveals whether the satellite's own mass affects its speed.

Solution:

Step 1: Set up the gravitational force balancing equation for a satellite of mass m orbiting a body of mass M at a radial distance r:

$$\frac{mv^2}{r} = \frac{GMm}{r^2}$$

Step 2: Solve the force equation for the orbital velocity v by canceling the mass of the satellite m from both sides:

$$v^2 = \frac{GM}{r} \implies v = \sqrt{\frac{GM}{r}}$$

This shows that the orbital speed is inversely proportional to the square root of the orbit radius ($v \propto \frac{1}{\sqrt{r}}$) and completely independent of the satellite's mass.

Step 3: Analyze the given inequalities. We are given $r_1 > r_2$. Taking the reciprocal square root reverses the inequality sign:

$$\frac{1}{\sqrt{r_1}} < \frac{1}{\sqrt{r_2}} \implies v_1 < v_2$$

Thus, the satellite in the larger orbit travels at a lower speed.

Final Answer: $\boxed{v_1 < v_2}$

Answer: (B)

Go Back to Question 13

Q14.

Solution

Concept:

In wave optics, Young's double-slit experiment demonstrates the interference of light, producing alternating bright and dark bands on a screen. The distance between any two consecutive bright or dark bands is defined as the fringe width β. The fringe width depends directly on the wavelength of the monochromatic light source, the distance separating the slits from the screen, and the distance between the two slits.

Solution:

Step 1: Recall the mathematical formula for the fringe width β in a standard double-slit setup:

$$\beta = \frac{\lambda D}{d}$$

where λ is the light wavelength, D is the slit-to-screen distance, and d is the center-to-center separation between the slits.

Step 2: Express the modified parameters given in the new experimental setup:

$$\text{New slit separation, } d' = 2d$$

$$\text{New screen distance, } D' = \frac{D}{2}$$

Step 3: Substitute these modified values into the formula to find the expression for the new fringe width β':

$$\beta' = \frac{\lambda D'}{d'} = \frac{\lambda\left(\frac{D}{2}\right)}{2d} = \frac{\lambda D}{4d}$$

Step 4: Relate the new fringe width back to the original value:

$$\beta' = \frac{1}{4}\left(\frac{\lambda D}{d}\right) = \frac{\beta}{4}$$

The fringe width is reduced to one-fourth of its initial value.

Final Answer: one-fourth

Answer: (A)

Go Back to Question 14

Q15.

Solution

Concept:

The root-mean-square (rms) value of an alternating current represents the effective direct current value that would produce the same heating effect in a resistor. For a complex AC signal composed of orthogonal sinusoidal components (like a sine and a cosine wave of the same frequency), the total effective rms current can be found by evaluating the integral definition of the root-mean-square value over a complete period, or by combining the independent rms contributions.

Solution:

Step 1: Write down the current equation:

$$I = I_1 \cos \omega t + I_2 \sin \omega t$$

Using trigonometric identities, this sum of a sine and cosine function can be combined into a single phase-shifted sine wave:

$$I = I_0 \sin(\omega t + \phi)$$

where the combined peak amplitude I_0 is given by $I_0 = \sqrt{I_1^2 + I_2^2}$.

Step 2: Recall the general relation between the peak value I_0 and the root-mean-square value I_{rms} for a purely sinusoidal wave:

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

Step 3: Substitute the expression for the peak amplitude I_0 derived in Step 1 into the rms formula:

$$I_{\text{rms}} = \frac{\sqrt{I_1^2 + I_2^2}}{\sqrt{2}} = \sqrt{\frac{I_1^2 + I_2^2}{2}}$$

Final Answer: $\boxed{\sqrt{\frac{I_1^2 + I_2^2}{2}}}$

Answer: (C)

Go Back to Question 15

Q16.

Solution

Concept:
Gravitational force is a classic example of a conservative force field. A key property of a conservative force field is that the total work done on a body moving between two points depends strictly on the initial and final position coordinates of the body, and is completely independent of the geometric path taken between them. When a body is raised slowly at a constant speed, the net kinetic energy change is zero, meaning the applied work equals the change in gravitational potential energy.

Solution:
Step 1: State the definition of work done against gravity for a conservative field. The work done by an external agent to move a mass slowly without acceleration depends only on its change in vertical height.

$$W = \Delta U = mgh$$

where m is the mass, g is the acceleration due to gravity, and h is the net vertical height gained.
Step 2: Analyze the geometric features of the smooth hill, such as its base length l or the steepness of the incline profile. Because the surface is perfectly frictionless ("smooth"), there are no dissipative losses like heat from friction along the incline.
Step 3: Conclude that the work done depends only on the vertical height parameter h. It does not depend on the horizontal base length l or the specific curvature/steepness of the hill path.
Final Answer: only the height h.

Answer: (B)

Go Back to Question 16

Q17.

Solution

Concept:
Surface tension is a fundamental property of liquids that arises from cohesive intermolecular forces. Molecules inside the liquid are attracted equally in all directions, whereas molecules at the surface experience a net inward cohesive pull. This inward force causes the surface layer to behave like a stretched elastic membrane, creating a natural tendency for the fluid volume to minimize its exposed surface area.

Solution:
Step 1: Identify the geometric property of shapes relative to their volume. For a given volume of fluid, a sphere is the solid shape that naturally possesses the minimum possible surface area compared to any other configuration.
Step 2: Relate surface area to potential energy. The surface potential energy of a liquid is directly proportional to its surface area ($U = T \times A$). Since systems naturally seek a state of minimum potential energy, a free liquid mass will adjust its shape to minimize its surface area.
Step 3: Conclude that this minimization forces a falling or suspended liquid droplet to assume a spherical geometry. This phenomenon is driven entirely by surface tension, which overcomes minor external forces for small volumes.

Final Answer: surface tension

Answer: (A)

Go Back to Question 17

Q18.

Solution

Concept:

When multiple electrical capacitors are connected together in a single series circuit configuration, the electrical charge stored on each individual capacitor is exactly the same, regardless of its capacitance value. This occurs because charge is transferred sequentially from one plate to the next via induction. To find the charge on any capacitor in the series chain, we can calculate the equivalent total capacitance of the entire network and find the total charge drawn from the voltage source.

Solution:

Step 1: Write down the formula for the equivalent capacitance C_{eq} of three capacitors connected in series:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Step 2: Substitute the given values $C_1 = 2\ \mu F$, $C_2 = 3\ \mu F$, and $C_3 = 6\ \mu F$ into the reciprocal equation:

$$\frac{1}{C_{eq}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{3+2+1}{6} = \frac{6}{6} = 1\ \mu F^{-1}$$

$$C_{eq} = 1\ \mu F$$

Step 3: Calculate the total charge Q delivered by the 10 V battery source using the equivalent capacitance:

$$Q = C_{eq} \times V = 1\ \mu F \times 10\ V = 10\ \mu C$$

Step 4: Since the capacitors are in series, the charge on each individual unit is equal to the total circuit charge. Therefore, the charge on the 3 μF capacitor is exactly 10 μC.

Final Answer: $\boxed{10\ \mu C}$

Answer: (A)

Go Back to Question 18

Q19.

Solution

Concept:

The acceleration of a symmetrical rigid body rolling down an inclined plane without slipping depends on both the angle of the incline and the body's mass distribution, which is quantified by its moment of inertia. The moment of inertia determines how much potential energy is converted into rotational kinetic energy versus translational kinetic energy. The general formula for linear rolling acceleration involves a geometric shape factor.

Solution:

Step 1: Recall the standard formula for the linear acceleration a of a body rolling without slipping down an incline of angle θ:

$$a = \frac{g\sin\theta}{1 + \frac{I}{mR^2}}$$

where I is the moment of inertia about the central rotation axis, m is the mass, and R is the radius.

Step 2: Identify the moment of inertia and calculate the denominator factor for a solid sphere:

$$I_{\text{sphere}} = \frac{2}{5}mR^2 \implies 1 + \frac{I_{\text{sphere}}}{mR^2} = 1 + \frac{2}{5} = \frac{7}{5}$$

$$a_{\text{sphere}} = \frac{5}{7}g\sin\theta$$

Step 3: Identify the moment of inertia and calculate the denominator factor for a solid cylinder:

$$I_{\text{cylinder}} = \frac{1}{2}mR^2 \implies 1 + \frac{I_{\text{cylinder}}}{mR^2} = 1 + \frac{1}{2} = \frac{3}{2}$$

$$a_{\text{cylinder}} = \frac{2}{3}g\sin\theta$$

Step 4: Compute the ratio of the two accelerations by dividing the expressions derived in Step 2 and Step 3:

$$\frac{a_{\text{sphere}}}{a_{\text{cylinder}}} = \frac{\frac{5}{7}g\sin\theta}{\frac{2}{3}g\sin\theta} = \frac{5}{7} \times \frac{3}{2} = \frac{15}{14}$$

Final Answer: 15 : 14

Answer: (A)

Go Back to Question 19

Q20.

Solution

Concept:

A Carnot engine is a theoretical ideal thermodynamic cycle that operates at maximum efficiency between two temperature reservoirs: a high-temperature source and a low-temperature sink. The efficiency of a Carnot engine depends solely on the absolute thermodynamic temperatures of these reservoirs. Once the efficiency is determined, the mechanical work output can be calculated directly from the total heat energy absorbed from the source.

Solution:

Step 1: Convert the given operating temperatures from the Celsius scale to the absolute Kelvin scale:

$$\text{Source Temperature, } T_1 = 227^\circ\text{C} + 273 = 500 \text{ K}$$

$$\text{Sink Temperature, } T_2 = 127^\circ\text{C} + 273 = 400 \text{ K}$$

Step 2: Calculate the thermal efficiency η of the Carnot cycle using the absolute temperature ratio:

$$\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{400}{500} = 1 - 0.8 = 0.2 \implies 20\%$$

Step 3: Relate the engine efficiency to the mechanical work done (W) and the input heat energy absorbed (Q_1):

$$\eta = \frac{W}{Q_1} \implies W = \eta \times Q_1$$

Step 4: Substitute the values $\eta = 0.2$ and $Q_1 = 6 \times 10^4$ cal into the work equation to calculate the converted energy:

$$W = 0.2 \times (6 \times 10^4 \text{ cal}) = 1.2 \times 10^4 \text{ cal}$$

Final Answer: $\boxed{1.2 \times 10^4 \text{ cal}}$

Answer: (D)

Go Back to Question 20

Q21.

Solution

Concept:

Radioactive decay is a first-order kinetic process described by an exponential decay law. The half-life ($T_{1/2}$) is the constant time interval required for a given quantity of a radioactive isotope to decrease to exactly half of its initial value. By tracking the fraction of remaining active nuclei at different stages of the process, we can calculate the time elapsed between those stages in terms of half-life intervals.

Solution:

Step 1: Determine the remaining fraction of active nuclei at the first checkpoint (20% decay). If 20% of the initial sample has decayed, the remaining active fraction N_1 is:

$$N_1 = 100\% - 20\% = 80\% = 0.8N_0$$

Step 2: Determine the remaining fraction of active nuclei at the second checkpoint (80% decay). If 80% of the initial sample has decayed, the remaining active fraction N_2 is:

$$N_2 = 100\% - 80\% = 20\% = 0.2N_0$$

Step 3: Analyze the ratio of active nuclei between the first and second states to find how much the sample decayed during this interval:

$$\frac{N_2}{N_1} = \frac{0.2N_0}{0.8N_0} = \frac{1}{4} = \left(\frac{1}{2}\right)^2$$

Step 4: Interpret this ratio in terms of half-lives. A reduction to $\frac{1}{4}$ of the intermediate starting value requires exactly 2 half-life periods ($n = 2$). Calculate the total time interval Δt:

$$\Delta t = 2 \times T_{1/2} = 2 \times 20 \text{ minutes} = 40 \text{ minutes}$$

Final Answer: 40 minutes

Answer: (C)

Go Back to Question 21

Q22.

Solution

Concept:

In projectile motion, horizontal and vertical movements are independent but linked by time. When the initial velocity vector is given in Cartesian component form as $\vec{v} = a\hat{i} + b\hat{j}$, the horizontal velocity component is $u_x = a$ and the vertical velocity component is $u_y = b$. The formulas for the horizontal range (R) and maximum height (H) can be expressed directly using these components.

Solution:

Step 1: Write down the equations for the maximum vertical height H and horizontal range R using the initial velocity components u_x and u_y:

$$H = \frac{u_y^2}{2g} = \frac{b^2}{2g}$$

$$R = \frac{2u_x u_y}{g} = \frac{2ab}{g}$$

Step 2: State the given condition relating the horizontal range to the maximum height:

$$R = 2H$$

Step 3: Substitute the component expressions from Step 1 into the given condition equation:

$$\frac{2ab}{g} = 2\left(\frac{b^2}{2g}\right)$$

Step 4: Simplify the equation by canceling common terms (g and 2) from both sides:

$$\frac{2ab}{g} = \frac{b^2}{g} \implies 2ab = b^2$$

Dividing both sides by the non-zero vertical component b yields:

$$2a = b \implies b = 2a$$

Final Answer: $\boxed{b = 2a}$

Answer: (B)

Go Back to Question 22

Q23.

Solution

Concept:

When a narrow capillary tube is dipped vertically into a liquid like water, the liquid rises to a certain height due to surface tension forces balancing the weight of the fluid column. This equilibrium height is described by Jurin's Law. By examining how the total mass of the elevated liquid column scales with the tube's inner radius, we can determine how the total mass changes when a tube with a different radius is used.

Solution:

Step 1: State Jurin's Law for the equilibrium height h of a liquid column in a capillary tube of radius r:

$$h = \frac{2T\cos\theta}{\rho g r} \implies h \propto \frac{1}{r}$$

where T is surface tension, θ is the contact angle, and ρ is fluid density.

Step 2: Express the total mass M of the liquid column inside the cylindrical tube in terms of its radius and height:

$$M = \text{Volume} \times \rho = (\pi r^2 h) \times \rho$$

Step 3: Substitute the proportionality $h \propto \frac{1}{r}$ into the mass equation to find how mass scales with radius:

$$M \propto r^2 \times \left(\frac{1}{r}\right) \implies M \propto r$$

This shows that the mass of the liquid column is directly proportional to the radius of the capillary tube.

Step 4: Calculate the new mass M' when the capillary tube radius is doubled to $2r$:

$$\frac{M'}{M} = \frac{2r}{r} = 2 \implies M' = 2M$$

Final Answer: $\boxed{2M}$

Answer: (B)

Go Back to Question 23

Q24.

Solution

Concept:

The magnetic field produced by a current-carrying wire of any shape can be calculated using the Biot-Savart Law. For a complete circular loop carrying a steady current, the magnetic field at its center is well-known. For a semi-circular arc loop, the magnetic field at the center of curvature is exactly half that of a full circle because only half the loop length contributes to the field. Straight wire sections pointing directly toward or away from the center contribute zero field.

Solution:

Step 1: Write down the formula for the magnetic field magnitude B at the center of a full circular loop of radius r carrying current I:

$$B_{\text{circle}} = \frac{\mu_0 I}{2r}$$

Step 2: Divide the full circle formula by 2 to get the expression for a semi-circular arc segment:

$$B = \frac{1}{2} B_{\text{circle}} = \frac{\mu_0 I}{4r}$$

Step 3: Convert the given values into standard SI units:

$$I = 10 \text{ A}$$

$$r = 5 \text{ cm} = 0.05 \text{ m} = 5 \times 10^{-2} \text{ m}$$

$$\text{Permeability constant, } \mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$$

Step 4: Substitute these values into the semi-circle formula and calculate the field strength:

$$B = \frac{(4\pi \times 10^{-7}) \times 10}{4 \times (5 \times 10^{-2})} = \frac{\pi \times 10^{-6}}{5 \times 10^{-2}} = \frac{\pi}{5} \times 10^{-4} \text{ T}$$

$$B = 0.2\pi \times 10^{-4} = 0.2 \times 3.1416 \times 10^{-4} = 6.28 \times 10^{-5} \text{ T}$$

Final Answer: $\boxed{6.28 \times 10^{-5} \text{ T}}$

Answer: (A)

Go Back to Question 24

Q25.

Solution

Concept:
The dimensional formula of any physical quantity expresses its dependence on the fundamental dimensions of mass (M), length (L), and time (T). Torque is a vector quantity that measures the rotational effect of a force, defined mathematically as the cross product of a position vector and a force vector. To find which option matches, we determine the dimensional formula for torque and compare it with the other mechanical quantities.

Solution:
Step 1: Derive the dimensional formula for torque (τ). Torque is given by the formula:

$$\tau = \text{Force} \times \text{perpendicular distance}$$

$$\text{Dimensions of Force} = [MLT^{-2}]$$

$$\text{Dimensions of Distance} = [L]$$

$$\text{Dimensions of Torque} = [MLT^{-2}] \times [L] = [ML^2T^{-2}]$$

Step 2: Determine the dimensional formula for mechanical work (W). Work is defined as the dot product of force and displacement vectors:

$$W = \text{Force} \times \text{displacement} = [MLT^{-2}] \times [L] = [ML^2T^{-2}]$$

Step 3: Compare the derived dimensional expressions. Both torque and work share the exact same dimensional formula ($[ML^2T^{-2}]$), reflecting that both represent a product of force and distance, even though torque is a vector and work is a scalar.

Final Answer: work

Answer: (D)

Go Back to Question 25

Q26.

Solution

Concept:

When two sound waves of slightly different frequencies travel through the same medium in the same direction, they interfere with each other. This interference causes the perceived loudness to fluctuate over time, a phenomenon known as beats. The beat frequency, which is the number of intensity peaks or beats heard per second, is simply equal to the absolute difference between the frequencies of the two individual sound waves.

Solution:

Step 1: Use the standard wave equation $v = f\lambda$ to find the frequency of each sound wave from its wavelength and speed:

$$f_1 = \frac{v}{\lambda_1} = \frac{330}{5.0} = 66 \text{ Hz}$$

$$f_2 = \frac{v}{\lambda_2} = \frac{330}{5.5} = \frac{3300}{55} = 60 \text{ Hz}$$

Step 2: State the formula for calculating the beat frequency (f_b) produced by the interference of these two waves:

$$f_b = |f_1 - f_2|$$

Step 3: Substitute the calculated frequency values into the absolute difference formula:

$$f_b = |66 - 60| = 6 \text{ Hz}$$

This means 6 distinct beats are produced and heard every second.

Final Answer: 6

Answer: (A)

Go Back to Question 26

Q27.

Solution

Concept:

The electric field vector $\vec{E}$ and the scalar electric potential field V are related by a spatial gradient operation. The electric field points in the direction of the steepest decrease in electric potential. Mathematically, each component of the electric field vector is found by taking the negative partial derivative of the potential function with respect to that specific spatial coordinate axis.

Solution:

Step 1: State the general vector gradient relationship connecting the electric field to the potential function:

$$\vec{E} = -\nabla V = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right)$$

Step 2: Calculate the partial derivatives for the given spatial potential function $V = 4x^2$:

$$\frac{\partial V}{\partial x} = \frac{d}{dx}(4x^2) = 8x$$

$$\frac{\partial V}{\partial y} = 0, \quad \frac{\partial V}{\partial z} = 0$$

Step 3: Combine these partial derivatives into the full vector expression for the electric field:

$$\vec{E} = -8x\hat{i}$$

Step 4: Substitute the coordinates of the target point $(1, 0, 2)$ m into the electric field vector equation. Here, $x = 1$:

$$\vec{E} = -8(1)\hat{i} = -8\hat{i} \text{ V/m}$$

Final Answer: $-8\hat{i}$ V/m

Answer: (B)

Go Back to Question 27

Q28.

Solution

Concept:

When an external force is applied to a stationary solid block resting on a rough surface, the static frictional force matches the applied force to prevent motion, up to a certain maximum value. This maximum opposing force is called the limiting static friction. If the applied force is less than this limiting value, the block remains stationary, and the actual static friction force is exactly equal in magnitude to the applied force.

Solution:

Step 1: Calculate the normal force N acting on the resting block. On a horizontal surface with no vertical motion, the normal force balances the weight of the block:

$$N = mg = 5 \text{ kg} \times 10 \text{ m/s}^2 = 50 \text{ N}$$

Step 2: Calculate the maximum possible threshold for static friction, known as the limiting friction force f_{max}:

$$f_{\text{max}} = \mu_s \times N = 0.4 \times 50 \text{ N} = 20 \text{ N}$$

Step 3: Compare the applied horizontal force ($F_{\text{applied}} = 12$ N) with the calculated limiting friction value (20 N).

Step 4: Since $F_{\text{applied}} < f_{\text{max}}$ (12 N < 20 N), the applied force is not strong enough to overcome static friction and move the block. The block remains at rest, meaning the static friction force adjusts to perfectly balance the applied force:

$$f_{\text{static}} = F_{\text{applied}} = 12 \text{ N}$$

Final Answer: 12 N

Answer: (B)

Go Back to Question 28

Q29.

Solution

Concept:
When a ray of light passes through a triangular glass prism, it undergoes refraction at two surfaces, causing it to deviate from its original path. The total angle of deviation (δ) depends on the angle of incidence (i), the angle of emergence (e), and the internal angle of the prism (A). For any prism, these angles satisfy a fundamental geometric relationship.

Solution:
Step 1: Recall the fundamental relation for a light ray refracting through a prism:

$$i + e = A + \delta$$

Step 2: Note the properties of the prism given in the problem:

$$\text{Equilateral prism} \implies A = 60^\circ$$

$$\text{Symmetric path condition} \implies i = e$$

Step 3: Use the given condition that relates the emergence angle to the prism angle:

$$e = \frac{3}{4}A = \frac{3}{4} \times 60^\circ = 45^\circ$$

Since $i = e$, the angle of incidence is also $i = 45^\circ$.
Step 4: Substitute these values into the prism formula to solve for the angle of deviation δ:

$$45^\circ + 45^\circ = 60^\circ + \delta$$

$$90^\circ = 60^\circ + \delta \implies \delta = 90^\circ - 60^\circ = 30^\circ$$

Final Answer: $\boxed{30^\circ}$

Answer: (A)

Go Back to Question 29

Q30.

Solution

Concept:

Electromagnetic waves consist of oscillating electric and magnetic fields that propagate through space perpendicular to each other and to the direction of wave travel. In a vacuum or air, the amplitudes of these alternating electric (E_0) and magnetic (B_0) field components are locked in a strict constant ratio. This ratio is exactly equal to the speed of light (c) in a vacuum.

Solution:

Step 1: State the formula linking the peak electric field amplitude to the peak magnetic field amplitude via the speed of light:

$$c = \frac{E_0}{B_0} \implies B_0 = \frac{E_0}{c}$$

Step 2: Note the values required for the calculation:

$$\text{Electric field amplitude, } E_0 = 90 \text{ V/m}$$

$$\text{Speed of light constant, } c = 3 \times 10^8 \text{ m/s}$$

Step 3: Substitute these values into the rearranged equation to solve for the magnetic field amplitude B_0:

$$B_0 = \frac{90}{3 \times 10^8} = 30 \times 10^{-8} \text{ T} = 3 \times 10^{-7} \text{ T}$$

Thus, the amplitude of the magnetic field component is 3×10^{-7} Tesla.

Final Answer: $\boxed{3 \times 10^{-7} \text{ T}}$

Answer: (A)

Go Back to Question 30

Q31.

Solution

Concept:

When analyzing the relative motion of two moving objects, the kinematics can be simplified by observing the motion from the reference frame of one of the objects. When two objects move directly toward each other or in opposite directions, their relative speed is found by adding their individual speed magnitudes. The time required for them to completely cross each other is the total relative distance divided by this relative speed.

Solution:

Step 1: Determine the total relative distance d that must be covered for the bird to completely cross the train. Since the bird can be treated as a point object, this distance is equal to the length of the train:

$$d = 100 \text{ m}$$

Step 2: Calculate the relative velocity v_{rel} of the bird with respect to the train. Since they are moving in opposite directions, add their speeds:

$$v_{\text{rel}} = v_{\text{train}} + v_{\text{bird}} = 100 \text{ m/s} + 5 \text{ m/s} = 15 \text{ m/s}$$

Step 3: Use the relative motion formula to find the total time t taken for the crossing:

$$t = \frac{\text{Relative Distance}}{\text{Relative Velocity}} = \frac{d}{v_{\text{rel}}}$$

Step 4: Substitute the values into the equation to calculate the time:

$$t = \frac{100}{15} = \frac{20}{3} \approx 6.67 \text{ s}$$

Final Answer: 6.67 s

Answer: (C)

Go Back to Question 31

Q32.

Solution

Concept:

The root-mean-square speed (v_{rms}) of molecules in an ideal gas sample is derived from kinetic theory. This speed depends directly on the absolute temperature of the gas and inversely on its molar mass. For a specific gas like oxygen, the molar mass is constant, meaning the root-mean-square speed is directly proportional to the square root of its absolute temperature in Kelvin.

Solution:

Step 1: Write down the mathematical expression for the root-mean-square speed:

$$v_{rms} = \sqrt{\frac{3RT}{M}} \implies v_{rms} \propto \sqrt{T}$$

Step 2: Set up a ratio equation comparing two different temperature states:

$$\frac{v_2}{v_1} = \sqrt{\frac{T_2}{T_1}}$$

Step 3: Convert the initial temperature from Celsius to Kelvin:

$$T_1 = 27^\circ\text{C} + 273 = 300 \text{ K}$$

The problem states that the final speed must be double the initial speed ($v_2 = 2v_1 \implies \frac{v_2}{v_1} = 2$).

Step 4: Substitute the value 2 into the ratio equation and square both sides to solve for T_2:

$$2 = \sqrt{\frac{T_2}{300}} \implies 4 = \frac{T_2}{300}$$

$$T_2 = 4 \times 300 = 1200 \text{ K}$$

Step 5: Convert the final absolute temperature back to the Celsius scale:

$$t_2 = 1200 - 273 = 927^\circ\text{C}$$

Final Answer: $\boxed{927^\circ\text{C}}$

Answer: (C)

Go Back to Question 32

Q33.

Solution

Concept:

The Maximum Power Transfer Theorem is a fundamental principle in circuit analysis. It states that to obtain the maximum possible electrical power output from a source with a fixed internal resistance, the resistance of the external load connected across it must be adjusted to equal the source's internal resistance. We can prove this by setting up the power equation as a function of load resistance and finding its maximum.

Solution:

Step 1: Write down the expression for the total electrical current I flowing through a series circuit with a source emf E, internal resistance r, and external load resistor R:

$$I = \frac{E}{R + r}$$

Step 2: Express the power P dissipated across the external load resistor:

$$P = I^2 R = \left(\frac{E}{R + r}\right)^2 R = \frac{E^2 R}{(R + r)^2}$$

Step 3: To find the value of R that maximizes power, differentiate P with respect to R using the quotient rule and set the derivative to zero:

$$\frac{dP}{dR} = 0 \implies \frac{E^2 (R + r)^2 - E^2 R \cdot 2(R + r)}{(R + r)^4} = 0$$

Step 4: Simplify the numerator equation to find the matching condition:

$$(R + r) - 2R = 0 \implies r - R = 0 \implies R = r$$

Thus, maximum power transfer occurs when the external load resistance equals the internal resistance of the cell.

Final Answer: $\boxed{R = r}$

Answer: (A)

Go Back to Question 33

Q34.

Solution

Concept:

Bohr's quantization postulate is a key component of the semiclassical Bohr model of the hydrogen atom. It states that an electron can only orbit the nucleus in specific stable paths without radiating energy. In these allowed orbits, the orbital angular momentum (L) of the electron must be an integer multiple of the reduced Planck constant.

Solution:

Step 1: State Bohr's quantization condition formula for angular momentum L:

$$L = \frac{nh}{2\pi}$$

where n is the principal quantum number of the orbit and h is Planck's constant.

Step 2: Identify the given values for an electron in the third Bohr orbit:

$$n = 3$$

$$\text{Planck's constant, } h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$$

Step 3: Substitute these values into the quantization formula:

$$L = \frac{3 \times (6.63 \times 10^{-34})}{2 \times 3.1416} = \frac{19.89 \times 10^{-34}}{6.2832}$$

Step 4: Perform the final numerical division to find the angular momentum:

$$L \approx 3.16 \times 10^{-34}\ \text{J} \cdot \text{s}$$

Final Answer: $\boxed{3.16 \times 10^{-34}\ \text{J} \cdot \text{s}}$

Answer: (A)

Go Back to Question 34

Q35.

Solution

Concept:

The kinetic energy K of a moving body can be related directly to its linear momentum p using the formula $K = \frac{p^2}{2m}$, where m represents the mass of the body. When comparing two bodies with different masses but equal linear momenta, this equation shows how kinetic energy scales inversely with mass, allowing us to see which body carries more energy.

Solution:

Step 1: Write down the equation that expresses kinetic energy as a function of linear momentum:

$$K = \frac{p^2}{2m}$$

Step 2: Analyze the mathematical behavior of this formula under the given condition that the momentum p is identical for both bodies. Since p^2 and the number 2 are constants, the kinetic energy is inversely proportional to the mass:

$$K \propto \frac{1}{m}$$

Step 3: Interpret this inverse relationship. A larger mass value in the denominator results in a smaller total kinetic energy value, while a smaller mass value results in a larger kinetic energy value.

Step 4: Conclude that the lighter body, having a smaller mass (m), will possess a greater kinetic energy than the heavy body when both share the same momentum magnitude.

Final Answer: The light body

Answer: (B)

Go Back to Question 35

Q36.

Solution

Concept:

When a hollow soap bubble is blown up and expanded, mechanical work must be done against surface tension forces to create the new surface area. A soap bubble floating in air has two distinct fluid interfaces: an inner spherical surface enclosing air and an outer spherical surface in contact with the atmosphere. Therefore, the total surface area is twice that of a solid sphere of the same radius.

Solution:

Step 1: Write down the formula for the total initial surface area A_1 of a soap bubble of radius r, accounting for both its inner and outer surfaces:

$$A_1 = 2 \times (4\pi r^2) = 8\pi r^2$$

Step 2: Calculate the total final surface area A_2 after the soap bubble is expanded to a larger radius of $2r$:

$$A_2 = 2 \times [4\pi(2r)^2] = 2 \times [4\pi(4r^2)] = 32\pi r^2$$

Step 3: Determine the net increase in surface area (ΔA) by subtracting the initial area from the final area:

$$\Delta A = A_2 - A_1 = 32\pi r^2 - 8\pi r^2 = 24\pi r^2$$

Step 4: Calculate the total mechanical work done (W) by multiplying the surface tension constant T by the net change in surface area:

$$W = T \times \Delta A = T \times (24\pi r^2) = 24\pi r^2 T$$

Final Answer: $\boxed{24\pi r^2 T}$

Answer: (B)

Go Back to Question 36

Q37.

Solution

Concept:

An electrical transformer operates on the principle of mutual electromagnetic induction between two nearby wire coils wound around a shared core. For an ideal transformer with no energy losses (such as flux leakage or resistive heating), the ratio of the voltages across the primary and secondary coils is exactly equal to the ratio of the number of turns in those respective coils.

Solution:

Step 1: State the transformer turn-ratio equation linking input/output voltages to their respective coil turn counts:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

where V_p and V_s are primary and secondary voltages, and N_p and N_s are the primary and secondary turn counts.

Step 2: Identify the specific values given in the problem statement:

$$N_p = 500 \text{ turns}$$

$$N_s = 1000 \text{ turns}$$

$$V_p = 220 \text{ V}$$

Step 3: Rearrange the turn-ratio equation to isolate and solve for the unknown secondary output voltage V_s:

$$V_s = V_p \times \left(\frac{N_s}{N_p}\right)$$

Step 4: Substitute the values into the rearranged equation:

$$V_s = 220 \times \left(\frac{1000}{500}\right) = 220 \times 2 = 440 \text{ V}$$

The output voltage across the secondary coil is 440 Volts.

Final Answer: 440 V

Answer: (B)

Go Back to Question 37

Q38.

Solution

Concept:
Coulomb's Law describes the electrostatic force of attraction or repulsion between two stationary, electrically charged point particles. According to this law, the magnitude of the force is directly proportional to the product of the magnitudes of the two charges and inversely proportional to the square of the distance separating their centers. We can analyze how the force changes by setting up a ratio of the initial and final states.

Solution:
Step 1: Write down the standard formula for Coulomb's electrostatic force F between two initial charges q_1 and q_2 separated by a distance r:

$$F = \frac{k \cdot q_1 \cdot q_2}{r^2}$$

Step 2: Express the modified charges and distance according to the changes described:

$$\text{New charges: } q_1' = 2q_1, \quad q_2' = 2q_2$$

$$\text{New separation distance: } r' = 2r$$

Step 3: Set up the equation for the new electrostatic force F' using these modified variables:

$$F' = \frac{k \cdot q_1' \cdot q_2'}{(r')^2} = \frac{k \cdot (2q_1) \cdot (2q_2)}{(2r)^2}$$

Step 4: Simplify the coefficients in the numerator and denominator to see how the new force compares to the original:

$$F' = \frac{4 \cdot (k \cdot q_1 \cdot q_2)}{4 \cdot r^2} = \frac{k \cdot q_1 \cdot q_2}{r^2} = F$$

The factors of 4 in the numerator and denominator cancel out completely, meaning the net electrostatic force remains unchanged.

Final Answer: remains unchanged

Answer: (C)

Go Back to Question 38

Q39.

Solution

Concept:
In kinematics, a velocity-time ($v - t$) graph visually represents an object's motion, where the instantaneous slope of the curve at any point equals the object's acceleration ($a = \frac{dv}{dt}$). A straight line on a graph has a constant slope throughout its length. Therefore, a straight line on a velocity-time graph indicates that the acceleration of the object is constant over time.

Solution:
Step 1: Interpret the geometric features of the given velocity-time graph. The graph is a straight line, which mathematically means its slope ($\frac{dv}{dt}$) is a constant value at every point along the line.
Step 2: Relate the slope of a $v - t$ graph to its physical definition. Since acceleration is defined as the rate of change of velocity with respect to time ($a = \frac{dv}{dt}$), the constant slope means the object is experiencing a constant acceleration.
Step 3: Analyze the given condition that the line is inclined at a non-zero angle to the time axis. A non-zero angle means the slope is neither zero nor infinite, confirming that the constant acceleration has a definite, non-zero magnitude.
Step 4: Conclude that this state of motion corresponds by definition to uniform acceleration, where velocity changes by equal amounts in equal time intervals.
Final Answer: uniform acceleration

Answer: (B)

Go Back to Question 39

Q40.

Solution

Concept:
When a wave, such as light, passes from one optical medium into another with a different refractive index, it undergoes refraction. The change in medium alters the propagation speed of the wave, and its wavelength changes proportionally to maintain wave continuity. However, the frequency of a wave is determined solely by its source and remains constant during refraction.

Solution:
Step 1: Identify the source dependency of wave properties. The frequency (f) of a light wave is defined as the number of wave cycles passing a point per second, which depends entirely on the oscillations of the atom or source that emitted the light.
Step 2: Analyze what happens at the boundary interface during refraction. To maintain continuity at the interface, the number of wave crests arriving per second from the first medium must exactly equal the number of crests entering the second medium per second. Thus, frequency cannot change at the boundary:

$$f_{\text{rarer}} = f_{\text{denser}}$$

Step 3: Contrast this with velocity and wavelength. When light enters a denser medium, its speed decreases ($v = c/n$), and its wavelength shortens proportionally ($\lambda = \lambda_0/n$) to satisfy the wave speed equation $v = f\lambda$ while keeping frequency constant.
Final Answer: Frequency

Answer: (C)

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Answer Key

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