Rajasthan JET Physics Sample Paper-2

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. The dimensional formula for the universal gravitational constant (G) is:

(A) $[M^{-1}L^3T^{-2}]$

(B) $[M^1L^3T^{-2}]$

(C) $[M^{-1}L^2T^{-1}]$

(D) $[M^0L^2T^{-2}]$

Q2. A car travels the first half of a total distance with a speed v_1 and the second half with a speed v_2. The average speed of the car for the entire journey is:

(A) $\frac{v_1+v_2}{2}$

(B) $\sqrt{v_1v_2}$

(C) $\frac{2v_1v_2}{v_1+v_2}$

(D) $\frac{v_1v_2}{v_1+v_2}$

Q3. A projectile is thrown with an initial velocity $\vec{v} = a\hat{i} + b\hat{j}$. If the range of the projectile is equal to its maximum height, then the relation between a and b is:

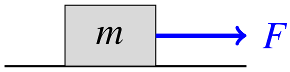
(A) $b = a$

(B) $b = 2a$

(C) $b = 4a$

(D) $a = 4b$

Q4. A block of mass m is placed on a smooth horizontal surface and pulled by a constant horizontal force F as shown below. Find the acceleration of the block.



(A) $\frac{F}{m}$

(B) $\frac{m}{F}$

(C) $F \cdot m$

(D) Zero

Q5. A body of mass 5 kg is moving in a circle of radius 1 m with an angular velocity of 2 rad/s. The centripetal force acting on the body is:

(A) 10 N

(B) 20 N

(C) 5 N

(D) 40 N

Q6. If the linear momentum of a body is increased by 50%, its kinetic energy will increase by:

(A) 50%

(B) 100%

(C) 125%

(D) 225%

Q7. A bullet of mass m moving with velocity v strikes a suspended wooden block of mass M and gets embedded in it. The loss of kinetic energy in this completely inelastic collision is:

(A) $\frac{1}{2}\frac{mM}{m+M}v^2$

(B) $\frac{1}{2}\frac{m^2}{m+M}v^2$

(C) $\frac{1}{2}\frac{M^2}{m+M}v^2$

(D) $\frac{1}{2}(m + M)v^2$

Q8. The moment of inertia of a uniform circular disc of mass M and radius R about an axis passing through its center and perpendicular to its plane is:

(A) MR^2

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

(C) $\frac{1}{4}MR^2$

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

Q9. A solid sphere and a solid cylinder of same mass and radius roll down the same inclined plane without slipping from rest. Which one reaches the bottom first?

(A) Solid sphere

(B) Solid cylinder

(C) Both reach at the same time

(D) Depends on the angle of inclination

Q10. The acceleration due to gravity g at a height $h = R$ (where R is the radius of the Earth) above the surface of the Earth becomes:

(A) $g/2$

(B) $g/4$

(C) $g/9$

(D) Zero

Q11. The escape velocity from the surface of the Earth is approximately 11.2 km/s. If a planet has twice the radius and twice the mass density of Earth, the escape velocity from that planet will be:

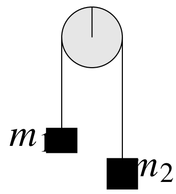
(A) 11.2 km/s

(B) 22.4 km/s

(C) 44.8 km/s

(D) 5.6 km/s

Q12. A light string passes over a frictionless pulley connecting two masses m_1 and m_2 ($m_2 > m_1$) as shown below. The acceleration of the system is:



(A) $\frac{m_2-m_1}{m_1+m_2}g$

(B) $\frac{m_1+m_2}{m_2-m_1}g$

(C) $\frac{2m_1m_2}{m_1+m_2}g$

(D) $\frac{m_2}{m_1}g$

Q13. The work done in stretching a wire of length L and Young's modulus Y by an amount x is:

(A) $\frac{YAx^2}{2L}$

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

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

(D) $\frac{YA^2x}{2L}$

Q14. According to Kepler's third law, the square of the time period of revolution (T) of a planet around the Sun is proportional to:

(A) R

(B) R^2

(C) R^3

(D) $R^{3/2}$

Q15. The terminal velocity v of a small spherical ball of radius r falling through a viscous liquid is proportional to:

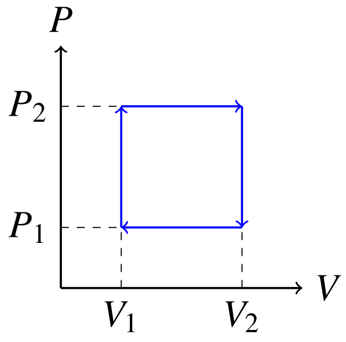
(A) r

(B) r^2

(C) $1/r$

(D) $1/r^2$

Q16. An ideal gas undergoes a thermodynamic cyclic process as shown in the P-V diagram below. The net work done during the cycle is:



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

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

(C) $P_2V_2 - P_1V_1$

(D) Zero

Q17. In an adiabatic process, the relation between pressure P and volume V is given by PV^γ = constant. The value of γ for a monoatomic gas is:

(A) $5/3$

(B) $7/5$

(C) $4/3$

(D) $9/7$

Q18. An engine works between temperatures 300 K and 600 K. The maximum possible efficiency of this engine is:

(A) 25%

(B) 50%

(C) 75%

(D) 100%

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

(A) T

(B) T^2

(C) $\sqrt{T}$

(D) $1/\sqrt{T}$

Q20. A particle executing simple harmonic motion has maximum velocity at:

(A) The extreme positions

(B) The mean position

(C) Reaching half of maximum amplitude

(D) The starting point only

Q21. The equation of a traveling wave is given by $y = 0.5\sin(10\pi t - 2\pi x)$, where x and y are in meters and t is in seconds. The wave velocity is:

(A) 5 m/s

(B) 10 m/s

(C) 2 m/s

(D) 20 m/s

Q22. When a ray of light passes from an optically denser medium to a rarer medium, the critical angle θ_c is related to the refractive index of the denser medium (μ) relative to the rarer medium by:

(A) $\sin\theta_c = \mu$

(B) $\sin\theta_c = 1/\mu$

(C) $\cos\theta_c = 1/\mu$

(D) $\tan\theta_c = 1/\mu$

Q23. An object is placed at a distance of 20 cm in front of a convex lens of focal length 10 cm. The image is formed at a distance of:

(A) 10 cm behind the lens

(B) 20 cm behind the lens

(C) 20 cm in front of the lens

(D) Infinity

Q24. In Young's double-slit experiment, if the distance between the slits is halved and the distance between the slits and the screen is doubled, the fringe width becomes:

(A) Unchanged

(B) Doubled

(C) Four times

(D) Halved

Q25. The phenomenon of polarization demonstrates that light waves are:

(A) Longitudinal waves

(B) Transverse waves

(C) Matter waves

(D) Stationary waves

Q26. The focal length of a plane mirror is:

(A) Zero

(B) Infinite

(C) 25 cm

(D) −25 cm

Q27. Two coherent light sources of intensity ratio 4 : 1 interfere. The ratio of maximum to minimum intensity in the interference pattern is:

(A) 4 : 1

(B) 9 : 1

(C) 5 : 3

(D) 2 : 1

Q28. Two point charges $+q$ and $-q$ are separated by a distance $2a$. The electric dipole moment of this system is:

(A) $q \cdot a$

(B) $2q \cdot a$

(C) Zero

(D) $q/(2a)$

Q29. Three resistors each of resistance R are connected in parallel. Their equivalent resistance is:

(A) $3R$

(B) $R/3$

(C) R

(D) $R/9$

Q30. A circular coil of radius r carrying a current I creates a magnetic field B at its center. If the current is doubled and the radius is halved, the new magnetic field will be:

(A) B

(B) $2B$

(C) $4B$

(D) $B/2$

Q31. According to Lenz's law, the induced electromotive force (emf) in a circuit always opposes the change in magnetic flux. This law is a direct consequence of the principle of conservation of:

(A) Charge

(B) Momentum

(C) Energy

(D) Mass

Q32. An alternating current circuit contains a pure inductor of inductance L. If the frequency of the AC source is f, the inductive reactance (X_L) is given by:

(A) $2\pi f L$

(B) $\frac{1}{2\pi f L}$

(C) $2\pi\sqrt{LC}$

(D) $\frac{f}{L}$

Q33. The de-Broglie wavelength λ associated with an electron accelerated through a potential difference of V volts is proportional to:

(A) V

(B) $\sqrt{V}$

(C) $1/V$

(D) $1/\sqrt{V}$

Q34. In Bohr's model of the hydrogen atom, the total energy of the electron in the ground state is -13.6 eV. The kinetic energy of the electron in this state is:

(A) -13.6 eV

(B) $+13.6$ eV

(C) 27.2 eV

(D) -27.2 eV

Q35. During a β^- (beta-minus) decay process from a nucleus:

(A) Atomic number increases by 1, mass number remains same

(B) Atomic number decreases by 1, mass number remains same

(C) Both atomic number and mass number decrease by 2

(D) Mass number increases by 1, atomic number remains same

Q36. The forbidden energy gap in a typical semiconductor material is of the order of:

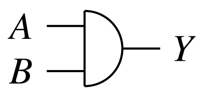
(A) 1 eV

(B) 10 eV

(C) 0.01 eV

(D) Zero

Q37. Identify the logic gate represented by the circuit symbol shown below:



(A) OR gate

(B) AND gate

(C) NOT gate

(D) NAND gate

Q38. The work function of a certain metal surface is 4.0 eV. If light of photon energy 3.5 eV strikes the surface, the maximum kinetic energy of emitted photoelectrons will be:

(A) 0.5 eV

(B) 7.5 eV

(C) No photoelectrons will be emitted

(D) 4.0 eV

Q39. The capacitance of a parallel plate capacitor filled with a dielectric material of dielectric constant K is related to its capacitance in vacuum (C_0) by:

(A) $C = C_0/K$

(B) $C = K \cdot C_0$

(C) $C = K^2 C_0$

(D) $C = C_0$

Q40. A step-up transformer converts:

(A) Low voltage alternating current to high voltage alternating current

(B) High voltage alternating current to low voltage alternating current

(C) Direct current to alternating current

(D) Alternating current to direct current

Detailed Solutions

Q1.

Solution

Concept:

The universal gravitational constant (G) appears in Newton's law of universal gravitation. To determine its dimensional formula, the equation can be rearranged in terms of force, distance, and mass. This allows the derived unit to be converted into fundamental base dimensions (M, L, and T).

Solution:

(a) Newton's gravitational law states that the force between two masses is expressed by the formula $F = G\frac{m_1 m_2}{r^2}$.

(b) Rearranging the equation to solve for the constant gives $G = \frac{F \cdot r^2}{m_1 m_2}$.

(c) The dimensional formula for force (F) is basic mechanics and is represented as $[M^1 L^1 T^{-2}]$.

(d) The dimensional formula for the distance squared (r^2) is $[L^2]$, and the product of the two masses ($m_1 m_2$) in the denominator is represented as $[M^2]$.

(e) Substituting these dimensions into the rearranged formula yields the expression: $[G] = \frac{[M^1 L^1 T^{-2}][L^2]}{[M^2]}$.

(f) Simplifying the powers of base dimensions results in the final formula $[M^{-1} L^3 T^{-2}]$.

Final Answer: The dimensional formula is $[M^{-1} L^3 T^{-2}]$.

Answer: (A)

Go Back to Question 1

Q2.

Solution

Concept:
Average speed over a total journey is defined as the total distance traveled divided by the total time taken. When a journey is divided into equal distance intervals with different constant speeds, the total time must be computed as the sum of the time intervals spent on each segment.
Solution:

(a) Let the total distance of the journey be denoted as $2d$, making each half of the journey exactly equal to d.

(b) The time taken to cover the first half of the distance at a speed of v_1 is given by $t_1 = \frac{d}{v_1}$.

(c) The time taken to cover the second half of the distance at a speed of v_2 is given by $t_2 = \frac{d}{v_2}$.

(d) The total time for the entire trip is the sum of both intervals: $t_{total} = t_1 + t_2 = \frac{d}{v_1} + \frac{d}{v_2} = d\left(\frac{v_1+v_2}{v_1 v_2}\right)$.

(e) The average speed is calculated using the total distance divided by this total time: $v_{avg} = \frac{2d}{t_{total}} = \frac{2d}{d\left(\frac{v_1+v_2}{v_1 v_2}\right)}$.

(f) Canceling out the distance variable d simplifies the expression directly to the harmonic mean: $\frac{2v_1 v_2}{v_1+v_2}$.

Final Answer: The average speed of the car for the entire journey is $\frac{2v_1 v_2}{v_1+v_2}$.

Answer: (C)

Go Back to Question 2

Q3.

Solution

Concept:
A projectile's initial velocity vector provides its horizontal and vertical components. The horizontal range and maximum height formulas depend on these components. Equating the two expressions reveals the required mathematical relationship between the horizontal and vertical velocity parameters.

Solution:

(a) The initial velocity vector is $\vec{v} = a\hat{i} + b\hat{j}$. The horizontal component is $v_x = a$ and the vertical component is $v_y = b$.

(b) The standard formula for the maximum height attained by a projectile is expressed as $H = \frac{v_y^2}{2g} = \frac{b^2}{2g}$.

(c) The standard formula for the horizontal range of the projectile is expressed as $R = \frac{2v_x v_y}{g} = \frac{2ab}{g}$.

(d) The problem states that the horizontal range is equal to the maximum height, giving the equation: $\frac{2ab}{g} = \frac{b^2}{2g}$.

(e) Canceling out the acceleration due to gravity g and one factor of b from both sides simplifies the expression to $2a = \frac{b}{2}$.

(f) Multiplying both sides of the equation by 2 yields the clean linear relationship: $b = 4a$.

Final Answer: The relation between a and b is $b = 4a$.

Answer: (C)

Go Back to Question 3

Q4.

Solution

Concept:
Newton's second law of motion describes the relationship between the net external force acting on an object, its mass, and its resulting acceleration. When a block moves on a perfectly smooth horizontal surface, friction is absent, and the applied horizontal force is the sole cause of horizontal acceleration.

Solution:

(a) According to the provided TikZ schematic, a block of mass m is experiencing a single external horizontal pulling force denoted by F.

(b) Because the horizontal surface is completely smooth, the coefficient of kinetic friction is zero, meaning there is no resistive force opposing the motion.

(c) In the vertical direction, the gravitational force acting downward is perfectly balanced by the normal reaction force exerted upward by the surface.

(d) Therefore, the net unbalanced force acting on the mass along the horizontal axis of motion is simply equal to F.

(e) Applying Newton's second law of motion ($F_{net} = m \cdot a$), the equation can be written as $F = m \cdot a$.

(f) Solving this linear equation for the acceleration variable isolated on one side yields: $a = \frac{F}{m}$.

Final Answer: The acceleration of the block is $\frac{F}{m}$.

Answer: (A)

Go Back to Question 4

Q5.

Solution

Concept:
An object executing uniform circular motion requires a continuous net inward force directed toward the center of rotation, known as centripetal force. This force can be derived using the mass of the object, the radius of the circular path, and its constant angular velocity.
Solution:

(a) The problem provides the fundamental parameters of the system: mass $m = 5$ kg, path radius $r = 1$ m, and angular velocity $\omega = 2$ rad/s.

(b) The standard formula calculating centripetal force in terms of angular parameters is given by the expression: $F_c = m \cdot \omega^2 \cdot r$.

(c) Substituting the given scalar values into the equation yields: $F_c = 5 \cdot (2)^2 \cdot 1$.

(d) Evaluating the squared term first simplifies the mathematical expression to: $F_c = 5 \cdot 4 \cdot 1$.

(e) Multiplying the remaining terms together gives a final numerical value of 20.

(f) The standard International System (SI) unit for force is Newtons (N), confirming that the required centripetal force magnitude is exactly 20 N.

Final Answer: The centripetal force acting on the body is 20 N.

Answer: (B)

Go Back to Question 5

Q6.

Solution

Concept:
Kinetic energy and linear momentum are fundamentally interlinked parameters for any moving body. When the linear momentum of an object changes while its mass remains constant, the corresponding change in kinetic energy follows a quadratic relationship that can be analyzed using percentages.

Solution:

(a) The relationship between kinetic energy (K) and the magnitude of linear momentum (p) for an object of mass m is expressed as $K = \frac{p^2}{2m}$.

(b) Let the initial linear momentum be denoted as p_1. The initial kinetic energy is therefore $K_1 = \frac{p_1^2}{2m}$.

(c) The linear momentum is increased by 50%, which means the new value is $p_2 = p_1 + 0.50p_1 = 1.5p_1$.

(d) The new kinetic energy after this change is calculated as: $K_2 = \frac{p_2^2}{2m} = \frac{(1.5p_1)^2}{2m} = 2.25\left(\frac{p_1^2}{2m}\right) = 2.25K_1$.

(e) The percentage increase in kinetic energy is determined by: $\left(\frac{K_2 - K_1}{K_1}\right) \times 100\% = \left(\frac{2.25K_1 - K_1}{K_1}\right) \times 100\%$.

(f) Simplifying the fraction gives $1.25 \times 100\%$, which yields a final value of 125%.

Final Answer: Its kinetic energy will increase by 125%.

Answer: (C)

Go Back to Question 6

Q7.

Solution

Concept:
In a completely inelastic collision, two colliding objects stick together after the impact and move forward with a single common velocity. While the total linear momentum of the system is strictly conserved, mechanical kinetic energy is lost to internal work, heat, and sound deformation.
Solution:

(a) Let a bullet of mass m move horizontally with an initial velocity v toward a stationary wooden block of mass M ($v_{block} = 0$).

(b) The initial kinetic energy stored in the system before impact is solely from the bullet: $K_i = \frac{1}{2}mv^2$.

(c) According to the law of conservation of linear momentum, $m \cdot v = (m + M) \cdot V$, where V is the shared final velocity: $V = \frac{mv}{m+M}$.

(d) The final kinetic energy of the combined system after impact is: $K_f = \frac{1}{2}(m + M)V^2 = \frac{1}{2}(m + M)\left(\frac{mv}{m+M}\right)^2 = \frac{1}{2}\frac{m^2v^2}{m+M}$.

(e) The net loss in kinetic energy (ΔK) is the difference between the initial and final states: $\Delta K = K_i - K_f = \frac{1}{2}mv^2 - \frac{1}{2}\frac{m^2v^2}{m+M}$.

(f) Taking out common factors and simplifying the fraction yields the standard relation: $\Delta K = \frac{1}{2}\frac{mM}{m+M}v^2$.

Final Answer: The loss of kinetic energy in this completely inelastic collision is $\frac{1}{2}\frac{mM}{m+M}v^2$.

Answer: (A)

Go Back to Question 7

Q8.

Solution

Concept:
The moment of inertia measures an object's resistance to rotational acceleration about a specific axis. For a uniform circular disc, the distribution of its total mass relative to its geometric center yields a standard integral formula when evaluated perpendicular to its main flat plane.
Solution:

(a) Consider a flat, uniform circular disc characterized by a total mass M and a continuous outer boundary radius R.

(b) The disc has a uniform surface mass density (σ) which is mathematically expressed as the total mass divided by the total area: $\sigma = \frac{M}{\pi R^2}$.

(c) To calculate the moment of inertia, the disc can be divided into infinitely thin concentric rings of radius r and radial width dr.

(d) The mass of an individual elemental ring is $dm = \sigma \cdot (2\pi r \cdot dr) = \frac{2M}{R^2} r \cdot dr$.

(e) The elemental moment of inertia for this single ring about the central perpendicular axis is $dI = dm \cdot r^2 = \frac{2M}{R^2} r^3 dr$.

(f) Integrating this expression from the inner boundary $r = 0$ to the outer boundary $r = R$ yields: $I = \int_0^R \frac{2M}{R^2} r^3 dr = \frac{2M}{R^2} \left[\frac{R^4}{4} \right] = \frac{1}{2} M R^2$.

Final Answer: The moment of inertia of a uniform circular disc is $\frac{1}{2} M R^2$.

Answer: (B)

Go Back to Question 8

Q9.

Solution

Concept:
When rigid bodies roll down an inclined plane without slipping, potential energy transforms into both translational and rotational kinetic energy. The acceleration of the rolling body depends on its geometric shape through its mass distribution factor ($\beta = I/MR^2$).

Solution:

(a) The linear acceleration (a) of any uniform symmetric body rolling down an incline of angle θ without slipping is given by: $a = \frac{g\sin\theta}{1+\frac{I}{MR^2}}$.

(b) For a solid sphere, the moment of inertia about its central axis is $I = \frac{2}{5}MR^2$, which means its geometric factor is $\frac{I}{MR^2} = \frac{2}{5} = 0.4$.

(c) Substituting this value gives the linear acceleration of the solid sphere: $a_{sphere} = \frac{g\sin\theta}{1+0.4} = \frac{g\sin\theta}{1.4} \approx 0.714g\sin\theta$.

(d) For a solid cylinder, the moment of inertia about its central axis is $I = \frac{1}{2}MR^2$, making its geometric factor $\frac{I}{MR^2} = \frac{1}{2} = 0.5$.

(e) Substituting this value gives the linear acceleration of the cylinder: $a_{cylinder} = \frac{g\sin\theta}{1+0.5} = \frac{g\sin\theta}{1.5} \approx 0.667g\sin\theta$.

(f) Since $a_{sphere} > a_{cylinder}$, the solid sphere accelerates faster and will reach the bottom of the incline first.

Final Answer: Solid sphere reaches the bottom first.

Answer: (A)

Go Back to Question 9

Q10.

Solution

Concept:

The acceleration due to gravity (g) decreases with altitude above the Earth's surface. This variation follows an inverse-square relationship based on the distance measured directly from the center of the planet to the position of interest.

Solution:

(a) The value of acceleration due to gravity directly on the surface of the Earth is given by the standard formula $g = \frac{GM}{R^2}$.

(b) At a specific altitude h above the surface, the total distance from the center of the Earth becomes $r = R + h$.

(c) The modified acceleration due to gravity (g') at this height is given by the expression: $g' = \frac{GM}{(R+h)^2}$.

(d) The problem specifies that the altitude is exactly equal to the radius of the Earth ($h = R$).

(e) Substituting $h = R$ into the altitude equation yields the following expression: $g' = \frac{GM}{(R+R)^2} = \frac{GM}{(2R)^2} = \frac{GM}{4R^2}$.

(f) Factoring out the surface value term shows the relationship clearly: $g' = \frac{1}{4}\left(\frac{GM}{R^2}\right) = \frac{g}{4}$.

Final Answer: The acceleration due to gravity becomes $g/4$.

Answer: (B)

Go Back to Question 10

Q11.

Solution

Concept:

Escape velocity represents the minimum initial speed an object needs to break free from a celestial body's gravitational field without further acceleration. By expressing escape velocity in terms of the planet's radius and its uniform mass density, we can directly compare different astronomical bodies.

Solution:

(a) The standard formula for escape velocity from a planet of mass M and radius R is given by the foundational mechanics relation $v_e = \sqrt{\frac{2GM}{R}}$.

(b) Assuming a spherical planet with uniform mass density ρ, the total mass of the planet can be rewritten in terms of its volume as $M = \rho \cdot V = \rho \cdot \left(\frac{4}{3}\pi R^3\right)$.

(c) Substituting this mass expression back into the escape velocity formula gives $v_e = \sqrt{\frac{2G}{R} \cdot \left(\frac{4}{3}\pi \rho R^3\right)} = R\sqrt{\frac{8}{3}\pi G\rho}$.

(d) This mathematical manipulation clearly shows that escape velocity is directly proportional to both the planet's radius and the square root of its density ($v_e \propto R\sqrt{\rho}$).

(e) For the new planet, the parameters are given as $R' = 2R$ and $\rho' = 2\rho$. Substituting these values yields the ratio $v'_e = (2R)\sqrt{\frac{8}{3}\pi G(2\rho)} = 2\sqrt{2} \cdot v_e$.

(f) Calculating the final magnitude using the Earth's escape velocity gives $v'_e = 2\sqrt{2} \cdot 11.2$ km/s $= 2 \cdot 1.414 \cdot 11.2$ km/s, which numerically rounds to 31.68 km/s.

Final Answer: The escape velocity from that planet will be $2\sqrt{2}$ times the escape velocity of Earth, which is approximately 31.7 km/s.

Answer: (C)

Go Back to Question 11

Q12.

Solution

Concept:

An Atwood machine features two unequal masses connected by an inextensible string over a frictionless, massless pulley. Analyzing the tension and gravitational forces acting on each mass independently using separate free-body diagrams yields a system of linear equations that determines the net acceleration.

Solution:

(a) Let the constant tension throughout the light string be denoted as T and the common magnitude of linear acceleration for both blocks be denoted as a.

(b) According to the given condition, mass m_2 is heavier than mass m_1, which means mass m_2 accelerates downward while mass m_1 moves upward.

(c) Writing the net dynamic equation of motion for the heavier mass moving downward yields the expression: $m_2 g - T = m_2 a$.

(d) Writing the net dynamic equation of motion for the lighter mass moving upward yields the expression: $T - m_1 g = m_1 a$.

(e) Adding these two algebraic equations together cancels out the internal tension force variable, giving: $m_2 g - m_1 g = m_2 a + m_1 a$.

(f) Factoring out the gravitational acceleration g and system acceleration a yields $(m_2 - m_1)g = (m_1 + m_2)a$, which isolates to $a = \frac{m_2 - m_1}{m_1 + m_2} g$.

Final Answer: The acceleration of the system is $\frac{m_2 - m_1}{m_1 + m_2} g$.

Answer: (A)

Go Back to Question 12

Q13.

Solution

Concept:
When an external pulling force stretches an elastic metal wire, mechanical work is performed against the internal interatomic restorative forces. This work is stored completely within the material's molecular structure as elastic potential energy, which depends on Young's modulus.

Solution:

(a) Young's modulus (Y) relates tensile stress to tensile strain and is defined mathematically by the standard engineering formula: $Y = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{x/L}$.

(b) Rearranging this expression allows us to find the variable restorative force acting at any general extension value x, which gives: $F = \frac{YAx}{L}$.

(c) The small increment of mechanical work dW required to stretch the wire by an infinitesimal distance dx is expressed as $dW = F \cdot dx$.

(d) To find the total work done during the complete elongation from rest to a final position x, we integrate this function: $W = \int_0^x \frac{YA}{L} x \cdot dx$.

(e) Evaluating the polynomial integral from the zero boundary to upper limit x results in the standard expression: $W = \frac{YA}{L}\left[\frac{x^2}{2}\right]$.

(f) Simplifying the constants reveals the final total energy value: $W = \frac{1}{2}\frac{YAx^2}{L}$, which matches the classic form of half the product of force and extension.

Final Answer: The work done in stretching the wire is $\frac{YAx^2}{2L}$.

Answer: (A)

Go Back to Question 13

Q14.

Solution

Concept:
Kepler's laws of planetary motion describe the orbits of celestial bodies orbiting the Sun. The third law, often called the law of periods, provides a precise mathematical relationship between the time required to complete one full orbit and the radius of that orbit.

Solution:

(a) Kepler's third law states that the square of the orbital period of revolution (T) of a planet is directly proportional to the cube of the semi-major axis of its elliptical path.

(b) For a planet moving in an approximately circular orbit, the semi-major axis can be treated as the average orbital radius (R) measured from the center of the Sun.

(c) This proportionality can be written mathematically as $T^2 \propto R^3$, where a constant of proportionality balances the equation based on solar mass.

(d) This relation can also be verified by balancing Newton's gravitational pull with centripetal force: $\frac{GM_{sun}m}{R^2} = m\omega^2 R = m\left(\frac{2\pi}{T}\right)^2 R$.

(e) Simplifying this orbital dynamic equation yields $T^2 = \left(\frac{4\pi^2}{GM_{sun}}\right)R^3$, confirming that the term in parentheses remains constant for all planets.

(f) Therefore, the square of the time period depends directly on the orbital radius raised to the power of three.

Final Answer: The square of the time period of revolution is proportional to R^3.

Answer: (C)

Go Back to Question 14

Q15.

Solution

Concept:
When a small sphere falls through a viscous fluid, it experiences gravity, buoyancy, and a resistive drag force described by Stokes' law. As the speed increases, the drag increases until the forces balance, causing the object to reach a constant terminal velocity.
Solution:

(a) Stokes' law states that the viscous drag force acting on a sphere of radius r moving with velocity v through a fluid of viscosity η is $F_d = 6\pi\eta r v$.

(b) The net downward force when terminal velocity is achieved is the gravitational force minus the upward buoyant force: $F_{net} = \frac{4}{3}\pi r^3(\rho - \sigma)g$.

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

(d) Equating the viscous drag force to this net gravitational force yields the balanced state equation: $6\pi\eta r v = \frac{4}{3}\pi r^3(\rho - \sigma)g$.

(e) Isolating the terminal velocity variable v on one side of the equation simplifies the expression to: $v = \frac{2}{9}\frac{r^2(\rho-\sigma)g}{\eta}$.

(f) Examining the geometric variables shows that all terms except radius are constant, meaning terminal velocity is directly proportional to r^2.

Final Answer: The terminal velocity is proportional to r^2.

Answer: (B)

Go Back to Question 15

Q16.

Solution

Concept:

In a pressure-volume (P-V) diagram, the total mechanical work performed during a thermodynamic process corresponds to the geometric area under the path curve. For a closed cyclic loop, the net work done equals the total area enclosed by the path boundary.

Solution:

(a) The thermodynamic cycle shown in the TikZ diagram forms a complete closed rectangle bounded by specific pressure and volume limits.

(b) The horizontal width of this rectangular cycle represents the change in volume and is given by the difference expression $\Delta V = (V_2 - V_1)$.

(c) The vertical height of this rectangular cycle represents the change in pressure and is given by the difference expression $\Delta P = (P_2 - P_1)$.

(d) The total area enclosed within a rectangular shape on a graph is calculated by multiplying its horizontal width by its vertical height.

(e) Therefore, the total work performed during one full cycle is given by the product of these dimensions: $W_{net} = \text{Area} = (P_2 - P_1)(V_2 - V_1)$.

(f) Because the cycle proceeds in a clockwise direction on the P-V coordinates, the net work done by the gas is thermodynamically positive.

Final Answer: The net work done during the cycle is $(P_2 - P_1)(V_2 - V_1)$.

Answer: (A)

Go Back to Question 16

Q17.

Solution

Concept:
The adiabatic exponent (γ), also known as the specific heat ratio, is defined as the ratio of molar heat capacity at constant pressure to that at constant volume (C_p/C_v). Its numerical value depends directly on the degrees of freedom of the gas molecules.

Solution:

(a) An ideal monoatomic gas consists of single atoms that can move freely in three independent spatial directions, giving them exactly three translational degrees of freedom ($f = 3$).

(b) The molar heat capacity at constant volume (C_v) can be expressed in terms of the degrees of freedom and the universal gas constant (R) as $C_v = \frac{f}{2}R = \frac{3}{2}R$.

(c) According to Mayer's relation, the molar heat capacity at constant pressure (C_p) is given by adding the gas constant: $C_p = C_v + R = \frac{3}{2}R + R = \frac{5}{2}R$.

(d) The adiabatic index γ is calculated by dividing these two specific heat capacities: $\gamma = \frac{C_p}{C_v} = \frac{(5/2)R}{(3/2)R}$.

(e) Canceling out the common factor of $\frac{1}{2}R$ from the numerator and denominator simplifies the ratio directly to the fractional value $\frac{5}{3}$.

(f) Converting this fraction into a decimal expansion yields approximately 1.67, which is a constant characteristic of all ideal monoatomic gases.

Final Answer: The value of γ for a monoatomic gas is $5/3$.

Answer: (A)

Go Back to Question 17

Q18.

Solution

Concept:

A Carnot engine operates on a reversible thermodynamic cycle that establishes the maximum possible theoretical efficiency for any heat engine operating between two temperatures. This efficiency depends solely on the absolute thermodynamic temperatures of the heat source and sink.

Solution:

(a) The absolute temperature values provided for the system are: source temperature T_{hot} = 600 K and sink temperature T_{cold} = 300 K.

(b) The standard formula calculating maximum thermal efficiency (η) for a reversible ideal engine is written as: $\eta = 1 - \frac{T_{cold}}{T_{hot}}$.

(c) Substituting the given absolute temperature values into the efficiency equation yields: $\eta = 1 - \frac{300}{600}$.

(d) Simplifying the fraction inside the expression reduces it to a value of one half: $\eta = 1 - 0.5 = 0.5$.

(e) To convert this fractional efficiency value into a standard percentage, multiply the decimal value by one hundred percent: $\eta\% = 0.5 \times 100\%$.

(f) Performing this multiplication shows that the maximum possible operating efficiency for this engine is exactly 50%.

Final Answer: The maximum possible efficiency of this engine is 50%.

Answer: (B)

Go Back to Question 18

Q19.

Solution

Concept:
The kinetic theory of gases describes an ideal gas as a collection of rapidly moving microscopic particles. The root-mean-square (v_{rms}) speed represents the square root of the average squared velocity of the molecules, which links their kinetic energy directly to temperature.

Solution:

(a) According to kinetic theory, the average translational kinetic energy of a gas molecule is directly proportional to its absolute temperature: $K_{avg} = \frac{3}{2}k_BT$.

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

(c) Equating these two expressions for kinetic energy gives the relation: $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$.

(d) Solving this equation to isolate the root-mean-square velocity variable yields the formula: $v_{rms} = \sqrt{\frac{3k_BT}{m}}$.

(e) In this expression, k_B represents Boltzmann's constant and m represents the mass of a single gas molecule, both of which are constant for a given gas.

(f) Since the values under the radical except temperature are constant, the root-mean-square speed is directly proportional to $\sqrt{T}$.

Final Answer: The root mean square speed of gas molecules is proportional to $\sqrt{T}$.

Answer: (C)

Go Back to Question 19

Q20.

Solution

Concept:
In simple harmonic motion (SHM), an object oscillates continuously between two fixed extreme positions around a central mean position. The mechanical energy shifts back and forth between potential energy and kinetic energy, changing the particle's velocity along its path.
Solution:

(a) The displacement (x) of a particle executing simple harmonic motion as a function of time t can be modeled using the equation: $x(t) = A\sin(\omega t)$.

(b) Differentiating this displacement function with respect to time gives the velocity equation of the particle: $v(t) = \frac{dx}{dt} = A\omega\cos(\omega t)$.

(c) The velocity can also be written as a function of position by eliminating the time variable: $v(x) = \omega\sqrt{A^2 - x^2}$.

(d) At the extreme positions of acceleration where $x = \pm A$, substituting this displacement value into the velocity function yields: $v = \omega\sqrt{A^2 - A^2} = 0$.

(e) At the central mean position where displacement is zero ($x = 0$), substituting this value yields: $v = \omega\sqrt{A^2 - 0} = A\omega$.

(f) This represents the maximum possible value of velocity during the cycle, meaning the particle moves fastest as it passes through the center point.

Final Answer: A particle executing simple harmonic motion has maximum velocity at the mean position.

Answer: (B)

Go Back to Question 20

Q21.

Solution

Concept:

A traveling wave equation mathematically represents a disturbance propagating through space over time. By comparing a given wave equation to the standard functional form of a sinusoidal wave, one can determine the angular frequency and the wave number, which combine to give the propagation velocity.

Solution:

(a) The standard mathematical equation for a sinusoidal wave traveling in the positive x-direction is represented as $y = A\sin(\omega t - kx)$.

(b) The problem provides the specific experimental wave equation: $y = 0.5\sin(10\pi t - 2\pi x)$.

(c) Comparing the coefficients of the time variable t reveals that the angular frequency is $\omega = 10\pi$ rad/s.

(d) Comparing the coefficients of the spatial variable x reveals that the wave propagation number is $k = 2\pi$ rad/m.

(e) The physical relationship linking wave velocity (v), angular frequency, and wave number is given by the formula $v = \frac{\omega}{k}$.

(f) Substituting the extracted values into this fraction yields $v = \frac{10\pi}{2\pi}$, which simplifies exactly to 5 m/s.

Final Answer: The wave velocity is 5 m/s.

Answer: (A)

Go Back to Question 21

Q22.

Solution

Concept:
Total internal reflection happens when a ray of light traveling inside an optically denser medium strikes the boundary of an optically rarer medium. The critical angle is defined as the special angle of incidence that causes the resulting refracted light ray to travel exactly parallel to the boundary interface.

Solution:

(a) Let a light ray travel from an optically denser medium with a refractive index of μ toward a rarer medium, which can be approximated as air or vacuum with a refractive index of 1.

(b) Snell's law of refraction governs the boundary interface and is written as: $\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$.

(c) At the critical state, the angle of incidence inside the denser medium matches the critical angle ($\theta_1 = \theta_c$).

(d) The corresponding angle of refraction inside the rarer medium becomes exactly ninety degrees ($\theta_2 = 90°$).

(e) Substituting these boundary conditions into Snell's law yields the expression: $\mu \cdot \sin\theta_c = 1 \cdot \sin(90°)$.

(f) Since the sine of ninety degrees equals one, simplifying the algebraic equation isolates the critical angle term as: $\sin\theta_c = \frac{1}{\mu}$.

Final Answer: The critical angle is related to the refractive index by $\sin\theta_c = 1/\mu$.

Answer: (B)

Go Back to Question 22

Q23.

Solution

Concept:
The thin lens formula mathematically relates the focal length of a lens, the distance of an object from the optical center, and the resulting distance of the formed image. Cartesian sign conventions must be rigorously applied to these spatial values to ensure accurate calculations.

Solution:

(a) According to standard Cartesian sign convention, the object distance (u) placed in front of the lens is negative, giving $u = -20$ cm.

(b) A convex lens possesses a real, positive focal point, which sets the focal length parameter to $f = +10$ cm.

(c) The standard thin lens equation from optics is expressed as: $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$.

(d) Rearranging the terms of the equation to isolate the unknown image distance variable yields: $\frac{1}{v} = \frac{1}{f} + \frac{1}{u}$.

(e) Substituting the signed values into this expression gives: $\frac{1}{v} = \frac{1}{10} + \frac{1}{-20} = \frac{1}{10} - \frac{1}{20}$.

(f) Finding a common denominator simplifies the fraction to $\frac{1}{v} = \frac{2-1}{20} = \frac{1}{20}$, meaning that $v = +20$ cm. The positive sign proves that a real image is formed behind the lens.

Final Answer: The image is formed at a distance of 20 cm behind the lens.

Answer: (B)

Go Back to Question 23

Q24.

Solution

Concept:

Young's double-slit experiment demonstrates the wave nature of light by creating a steady interference pattern on a screen. The spatial width of each individual fringe depends directly on the optical wavelength, the slit separation distance, and the total distance separating the slits from the viewing screen.

Solution:

(a) The initial fringe width (β) in a standard double-slit arrangement is expressed by the formula: $\beta = \frac{\lambda D}{d}$.

(b) In this equation, λ represents the wavelength of light, D is the distance to the screen, and d is the distance between the slits.

(c) The problem details a modification where the distance between the slits is reduced by half, giving a new spacing of $d' = \frac{d}{2}$.

(d) Simultaneously, the distance from the slits to the observation screen is doubled, giving a new length of $D' = 2D$.

(e) Substituting these modified parameters into the fringe equation yields the new width: $\beta' = \frac{\lambda D'}{d'} = \frac{\lambda(2D)}{(d/2)}$.

(f) Simplifying the fraction shifts the denominator factor upward, giving: $\beta' = 4\left(\frac{\lambda D}{d}\right) = 4\beta$. This proves the pattern expands to four times its original size.

Final Answer: The fringe width becomes four times.

Answer: (C)

Go Back to Question 24

Q25.

Solution

Concept:
Wave propagation can be classified into longitudinal or transverse modes based on the direction of particle oscillation relative to the direction of wave travel. Polarization acts as a spatial filter that restricts these oscillations to a single plane, which is only possible for certain wave types.

Solution:

(a) Longitudinal waves, such as sound, oscillate parallel to their direction of propagation and pass through slit filters regardless of orientation. Thus, they cannot be polarized.

(b) Transverse waves oscillate perpendicular to their direction of travel, meaning their vibrations can be restricted to a single spatial direction.

(c) Polarization involves using a polarizing filter to block all vibration components of a wave except those aligned with the filter's transmission axis.

(d) Because light can be polarized using specialized crystalline filters, its underlying fields must oscillate perpendicular to the direction of wave travel.

(e) This experimental behavior provides definitive proof that light behaves as a transverse wave rather than a longitudinal one.

(f) This discovery was historically crucial in establishing that light consists of transverse electromagnetic fields traveling together through space.

Final Answer: The phenomenon of polarization demonstrates that light waves are transverse waves.

Answer: (B)

Go Back to Question 25

Q26.

Solution

Concept:
The focal length of a spherical mirror depends on its radius of curvature. A plane mirror can be thought of as a limiting case of a spherical mirror whose curved surface has been flattened out completely, altering its focal properties.

Solution:

(a) The focal length (f) of any standard reflective spherical mirror is mathematically equal to half of its radius of curvature (R), given by $f = \frac{R}{2}$.

(b) A plane mirror has a perfectly flat reflecting surface with no curvature.

(c) To form a perfectly flat surface from a curved spherical shape, the radius of that sphere must expand indefinitely.

(d) Therefore, a plane mirror can be mathematically modeled as a spherical mirror with an infinite radius of curvature ($R = \infty$).

(e) Substituting this infinite boundary value into the focal length relation yields: $f = \frac{\infty}{2} = \infty$.

(f) This infinite focal length indicates that parallel rays striking a plane mirror remain parallel upon reflection and never converge to a real focal point.

Final Answer: The focal length of a plane mirror is infinite.

Answer: (B)

Go Back to Question 26

Q27.

Solution

Concept:
When two coherent light waves overlap, the resulting interference pattern displays alternating regions of maximum and minimum intensity. These intensity limits depend on the individual wave amplitudes, which combine through vector superposition based on their relative phase.

Solution:

(a) The intensity of a light wave (I) is directly proportional to the square of its amplitude (A), meaning the amplitude can be expressed as $A \propto \sqrt{I}$.

(b) The problem states the intensity ratio of the two sources is $4:1$. This allows us to set $I_1 = 4$ and $I_2 = 1$.

(c) Calculating the corresponding wave amplitudes yields: $A_1 = \sqrt{4} = 2$ and $A_2 = \sqrt{1} = 1$.

(d) Constructive interference produces the maximum possible amplitude: $A_{max} = A_1 + A_2 = 2 + 1 = 3$. The maximum intensity is $I_{max} = (A_{max})^2 = 3^2 = 9$.

(e) Destructive interference produces the minimum possible amplitude: $A_{min} = A_1 - A_2 = 2 - 1 = 1$. The minimum intensity is $I_{min} = (A_{min})^2 = 1^2 = 1$.

(f) Dividing these two values gives the intensity ratio of the interference pattern: $\frac{I_{max}}{I_{min}} = \frac{9}{1}$.

Final Answer: The ratio of maximum to minimum intensity is $9:1$.

Answer: (B)

Go Back to Question 27

Q28.

Solution

Concept:
An electric dipole consists of two equal and opposite point charges separated by a fixed distance. The electric dipole moment is a vector quantity that measures the overall strength and orientation of the dipole system.

Solution:

(a) Consider an electrostatic system composed of two discrete charges, $+q$ and $-q$, separated by a total spatial distance.

(b) According to the problem statement, the absolute distance separating these two opposite charges is given as $2a$.

(c) The magnitude of the electric dipole moment (p) is defined as the product of the magnitude of one of the charges and the total distance between them.

(d) Setting up this multiplication based on the definition yields the formula: $p = \text{Charge} \times \text{Separation Distance}$.

(e) Substituting the given parameters into this definition gives: $p = q \cdot (2a) = 2qa$.

(f) By convention, this vector points along the axis from the negative charge toward the positive charge, and its standard SI unit is Coulomb-meters $(\text{C} \cdot \text{m})$.

Final Answer: The electric dipole moment of this system is $2qa$.

Answer: (B)

Go Back to Question 28

Q29.

Solution

Concept:
When resistors are connected in a parallel circuit arrangement, they are all exposed to the exact same electrical potential difference. The reciprocal of the total equivalent resistance equals the sum of the reciprocals of each individual resistance value.

Solution:

(a) The general formula used to calculate the equivalent resistance (R_{eq}) of a parallel circuit network is: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

(b) The circuit contains three individual resistors, and each one has an identical resistance value given as $R_1 = R_2 = R_3 = R$.

(c) Substituting these identical values into the parallel combination formula gives: $\frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R}$.

(d) Combining these fractions since they share a common denominator yields: $\frac{1}{R_{eq}} = \frac{3}{R}$.

(e) To find the actual equivalent resistance, take the reciprocal of both sides of the equation.

(f) This mathematical inversion isolates the final equivalent resistance value as: $R_{eq} = \frac{R}{3}$. This proves that adding identical paths in parallel scales down the total resistance.

Final Answer: Their equivalent resistance is $R/3$.

Answer: (B)

Go Back to Question 29

Q30.

Solution

Concept:
The Biot-Savart law dictates the strength of the magnetic field generated by an electric current. For a circular coil carrying current, the magnetic field at its exact geometric center depends directly on the current magnitude and inversely on the coil's radius.

Solution:

(a) The standard formula for the magnetic field (B) at the center of a circular loop with radius r carrying current I is: $B = \frac{\mu_0 I}{2r}$.

(b) In this equation, μ_0 represents the magnetic permeability constant of free vacuum space.

(c) The problem introduces modifications to the loop: the current is doubled ($I' = 2I$) and the radius is cut in half ($r' = \frac{r}{2}$).

(d) Substituting these modified values into the magnetic field formula yields the new field strength: $B' = \frac{\mu_0 I'}{2r'} = \frac{\mu_0 (2I)}{2(r/2)}$.

(e) Simplifying the fraction by moving the denominator factor upward results in the expression: $B' = 4 \cdot \left(\frac{\mu_0 I}{2r}\right)$.

(f) Comparing this to the original equation shows that the new magnetic field strength is exactly four times the original value ($B' = 4B$).

Final Answer: The new magnetic field will be $4B$.

Answer: (C)

Go Back to Question 30

Q31.

Solution

Concept:
Lenz's law provides a fundamental method for determining the direction of an induced electromotive force or electric current resulting from electromagnetic induction. It links electromagnetic behavior directly to foundational physics principles regarding conservation laws.
Solution:

(a) Faraday's law of induction establishes that a changing magnetic flux through a conducting loop induces an electromotive force. Lenz's law specifies the physical direction of this resulting effect.

(b) According to Lenz's formulation, the induced current creates its own secondary magnetic field that counteracts the original change in magnetic flux that initiated it.

(c) If the induced current did not oppose the change but instead reinforced it, the magnetic flux would grow continuously without requiring an external input.

(d) This hypothetical positive feedback loop would create electrical energy out of nothing, violating fundamental laws governing physical systems.

(e) Therefore, mechanical work must be expended to overcome the resistive opposition described by Lenz's law, converting that work into electrical energy.

(f) This dynamic requirement confirms that Lenz's law is a direct consequence of the universal principle of the conservation of energy.

Final Answer: The law is a direct consequence of the principle of conservation of energy.

Answer: (C)

Go Back to Question 31

Q32.

Solution

Concept:
Inductive reactance represents the frequency-dependent electrical opposition an inductor offers to alternating current. It arises because the changing current inside the inductor creates a self-induced back electromotive force that opposes modifications to the charge flow.
Solution:

(a) When an alternating voltage source is applied across a pure inductor of inductance L, the instantaneous electric current oscillates back and forth at frequency f.

(b) The inductive reactance, denoted by X_L, measures this specific limitation to current flow, behaving analogously to traditional resistance in direct current applications.

(c) The mathematical formula derived from solving the alternating differential circuit equation establishes that reactance is directly proportional to both frequency and inductance: $X_L = \omega L$.

(d) The angular frequency (ω) of an alternating current source is related to the linear cyclic frequency (f) by the equation: $\omega = 2\pi f$.

(e) Substituting this definition into the reactance formula gives the standard final expression: $X_L = 2\pi f L$.

(f) This linear equation shows that if the operational frequency increases, the inductor's opposition increases proportionally.

Final Answer: The inductive reactance is given by $2\pi f L$.

Answer: (A)

Go Back to Question 32

Q33.

Solution

Concept:
The de-Broglie hypothesis proposes wave-particle duality, stating that moving material particles exhibit wave-like characteristics. By linking the momentum of an accelerated charge to its wavelength, a functional relationship with the potential difference can be established.

Solution:

(a) The de-Broglie relation establishes that the wavelength (λ) associated with any moving particle depends inversely on its linear momentum (p): $\lambda = \frac{h}{p}$.

(b) When an electron of mass m and charge e is accelerated from rest through an electric potential difference V, it gains kinetic energy: $K = eV$.

(c) The momentum of a particle can be expressed in terms of its translational kinetic energy using the mechanical relation: $p = \sqrt{2mK}$.

(d) Substituting the electrical work expression for kinetic energy yields the momentum in terms of voltage: $p = \sqrt{2meV}$.

(e) Plugging this momentum expression back into the de-Broglie relation gives the final equation: $\lambda = \frac{h}{\sqrt{2meV}}$.

(f) Since Planck's constant h, electron mass m, and charge e are invariant constants, the wavelength is proportional to $1/\sqrt{V}$.

Final Answer: The de-Broglie wavelength is proportional to $1/\sqrt{V}$.

Answer: (D)

Go Back to Question 33

Q34.

Solution

Concept:

Bohr's atomic model provides a structural framework for understanding electron configurations in hydrogenic atoms. The total mechanical energy of an electron in a stable orbit is the sum of its orbital kinetic energy and its electrostatic potential energy.

Solution:

(a) In a stable hydrogen orbit, the attractive Coulomb force between the proton and electron balances the required inward centripetal force: $\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$.

(b) Rearranging this force balance equation allows us to express the electron's orbital kinetic energy as: $K = \frac{1}{2}mv^2 = \frac{1}{8\pi\varepsilon_0}\frac{e^2}{r}$.

(c) The potential energy (U) arising from the position of the electron in the electrostatic field of the nucleus is: $U = -\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$.

(d) The total mechanical energy (E) is the sum of these two components: $E = K + U = \frac{1}{8\pi\varepsilon_0}\frac{e^2}{r} - \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} = -\frac{1}{8\pi\varepsilon_0}\frac{e^2}{r}$.

(e) Comparing these terms reveals that kinetic energy is equal in magnitude but opposite in sign to the total energy ($K = -E$).

(f) Given that the ground state total energy is $E = -13.6$ eV, the kinetic energy is $K = -(-13.6 \text{ eV}) = +13.6$ eV.

Final Answer: The kinetic energy of the electron is +13.6 eV.

Answer: (B)

Go Back to Question 34

Q35.

Solution

Concept:

Beta-minus decay is a nuclear transformation that occurs in neutron-rich unstable isotopes. It involves a fundamental weak interaction process that alters the proton-to-neutron ratio within the nucleus to achieve a more stable binding configuration.

Solution:

(a) During a beta-minus disintegration, a neutron inside the parent nucleus spontaneously transforms into a proton, an electron (the beta particle), and an electron antineutrino.

(b) The fundamental subatomic equation representing this nuclear reaction is given by: $n \rightarrow p + e^- + \bar{\nu}_e$.

(c) Because a neutron is converted into a proton, the total number of nucleons (protons + neutrons) inside the nucleus remains completely unchanged.

(d) This means the mass number (A), which tracks total nucleon count, remains constant during the transition.

(e) However, because an additional proton is created, the total number of protons increases by exactly one.

(f) This increases the atomic number (Z) by one, shifting the identity of the daughter element one position forward on the periodic table.

Final Answer: The atomic number increases by 1, while the mass number remains the same.

Answer: (A)

Go Back to Question 35

Q36.

Solution

Concept:
Solid-state band theory explains the electrical conductivity of materials using energy bands. The forbidden energy gap is the energy region between the valence band and the conduction band where no electron states can exist.

Solution:

(a) The valence band contains bound electrons, while the conduction band contains free charge carriers that contribute to electrical current flow.

(b) The size of the forbidden energy gap (E_g) determines how much energy an electron needs to jump from the valence band into the conduction band.

(c) In electrical conductors like metals, the valence and conduction bands overlap ($E_g \approx 0$), allowing electrons to move freely.

(d) In electrical insulators, this gap is very wide ($E_g > 5$ eV), making it difficult for valence electrons to cross.

(e) In semiconductor materials, the forbidden gap is narrow, allowing ambient thermal energy to excite some electrons across the threshold.

(f) For typical elemental semiconductors like silicon and germanium, this energy gap is on the order of 1 eV (1.1 eV for silicon and 0.7 eV for germanium).

Final Answer: The forbidden energy gap in a typical semiconductor is of the order of 1 eV.

Answer: (A)

Go Back to Question 36

Q37.

Solution

Concept:
Logic gates serve as the basic structural blocks for digital electronic systems, executing binary Boolean operations on inputs. By examining the geometric shape of a standard circuit symbol, the underlying logic function can be identified.

Solution:

(a) The provided TikZ diagram illustrates a digital logic gate symbol featuring two input channels, labeled A and B, and a single output channel, labeled Y.

(b) The back input side of the symbol is a straight vertical line, and the body extends into a semi-circular curved output profile.

(c) This geometry is the standard IEEE symbol for an AND gate, which performs logical multiplication on its binary inputs.

(d) The Boolean algebra expression representing this specific input-output mapping is written as: $Y = A \cdot B$.

(e) An OR gate would be distinguished by a curved input face and a pointed output tip, while a NOT gate is drawn as a single-input triangle.

(f) A NAND gate would require an inversion bubble at the output tip, which is absent here. This confirms the symbol represents an AND gate.

Final Answer: The circuit symbol represents an AND gate.

Answer: (B)

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Q38.

Solution

Concept:
The photoelectric effect involves the emission of electrons from a metal surface when light shines on it. Einstein's photoelectric equation applies energy conservation to this process, showing that light acts as discrete packets of energy called photons.

Solution:

(a) The work function (Φ) represents the minimum energy binding an electron to a metal surface, which must be overcome to cause emission.

(b) According to the problem parameters, the work function threshold for this metal surface is given as $\Phi = 4.0$ eV.

(c) The incoming monochromatic light delivers energy in discrete photon packets of magnitude $E = 3.5$ eV.

(d) Einstein's photoelectric equation is expressed as: $K_{max} = h\nu - \Phi = E - \Phi$.

(e) For photoemission to occur, the energy of the incident photon must be greater than or equal to the metal's work function ($E \geq \Phi$).

(f) Comparing the values shows that 3.5 eV $<$ 4.0 eV. Because the photon energy is less than the work function, no electrons will be emitted.

Final Answer: No photoelectrons will be emitted.

Answer: (C)

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Q39.

Solution

Concept:
A capacitor stores electrical charge and energy within an electric field between its plates. Inserting an insulating dielectric material between the plates alters the field strength due to atomic polarization, changing the overall capacitance.

Solution:

(a) The capacitance of an empty parallel plate capacitor separated by a vacuum gap of distance d is given by: $C_0 = \frac{\varepsilon_0 A}{d}$.

(b) When an insulating material with dielectric constant K fills the space between the plates, the molecules inside polarize in response to the electric field.

(c) This polarization produces an internal induced electric field that opposes and reduces the primary field by a factor of K: $E = \frac{E_0}{K}$.

(d) Because the electric field strength decreases, the potential difference ($V = E \cdot d$) across the plates decreases by the same factor: $V = \frac{V_0}{K}$.

(e) Capacitance is defined as the charge stored per unit potential ($C = \frac{Q}{V}$). Substituting the reduced voltage gives: $C = \frac{Q_0}{(V_0/K)} = K \cdot \left(\frac{Q_0}{V_0}\right)$.

(f) This shows the new capacitance scales linearly with the dielectric constant, giving the final relationship: $C = K \cdot C_0$.

Final Answer: The capacitance is related by $C = K \cdot C_0$.

Answer: (B)

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Q40.

Solution

Concept:
A transformer is an electrical device that changes alternating current voltage levels through electromagnetic induction between coupled coils. Based on the turns ratio between its windings, a transformer can either increase or decrease voltage.

Solution:

(a) A transformer consists of a primary input winding and a secondary output winding wound around a shared magnetic core.

(b) The operational voltage relationship is governed by the turns ratio equation: $\frac{V_{secondary}}{V_{primary}} = \frac{N_{secondary}}{N_{primary}}$.

(c) A step-up transformer is designed with more wire turns on its secondary output coil than on its primary input coil ($N_{secondary} > N_{primary}$).

(d) According to the turns ratio equation, this design causes the output voltage to be higher than the input voltage ($V_{secondary} > V_{primary}$).

(e) Because a transformer relies on a continuously changing magnetic flux to induce voltage, it can only operate using alternating current (AC).

(f) Thus, a step-up transformer converts low-voltage alternating current into high-voltage alternating current while conserving total power.

Final Answer: A step-up transformer converts low voltage alternating current to high voltage alternating current.

Answer: (A)

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Answer Key

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