JEECUP Group A Physics Sample Paper-12

Duration: 45 Minutes **Maximum Marks: 100**

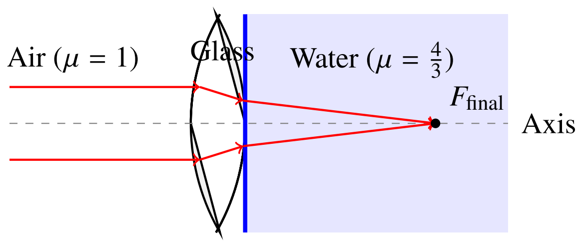
Instructions

- This paper contains **25** Multiple Choice Questions (Single Correct).
- Each correct answer carries **+4 marks**. No marks will be deducted for incorrect answers. Unattempted questions carry **0** marks.
- Only **one** option is correct for each question.
- Use of mobile phones, smartwatches, or any electronic gadgets is strictly prohibited.

Q1. A luminous object and a vertical projection screen are fixed at a constant separation distance of $D = 90$ cm. A thin converging lens of focal length f is shifted along the optical axis between them. If there are exactly two distinct lens positions that project a sharp image onto the screen, and the distance between these two positions is $d = 30$ cm, calculate the exact focal length (f) of the lens.

(A) 15 cm
(B) 20 cm
(C) 25 cm
(D) 18 cm

Q2. A thin symmetrical biconvex glass lens ($\mu_g = 1.5$) has a radius of curvature of magnitude $R = 20$ cm for both surfaces. The front surface is left open to the air, while the rear surface is embedded into the flat boundary of a deep water tank ($\mu_w = \frac{4}{3}$) as shown in the diagram. If a parallel paraxial beam of light enters the lens from the air side along the principal axis, find the exact position of the final convergence focal point (F_{final}) measured from the lens vertex:



(A) 20 cm inside the water tank

(B) 40 cm inside the water tank

(C) 30 cm inside the water tank

(D) 60 cm inside the water tank

Q3. A high-precision optical ray transitions from air into a dense synthetic crystalline substrate. If the velocity of the light wave drops by exactly 40% upon crossing the interface boundary, evaluate the absolute refractive index (μ) of this crystalline substrate.

(A) 1.40

(B) 1.67

(C) 2.50

(D) 1.50

Q4. A concave mirror produces a crisp real image on a test card that is exactly three times larger than the real object ($m = -3.0$). If the distance between the real object and its corresponding inverted image measures exactly 40 cm, compute the focal length (f) of this concave mirror.

(A) $f = -15$ cm

(B) $f = -20$ cm

(C) $f = -10$ cm

(D) $f = -30$ cm

Q5. A microscopic thin layer of oil ($\mu_{\text{oil}} = 1.45$) floats on top of a smooth glass block ($\mu_{\text{glass}} = 1.60$). A ray of light traveling inside the glass block strikes the oil interface. Calculate the critical angle (θ_c) for total internal reflection at this specific internal boundary.

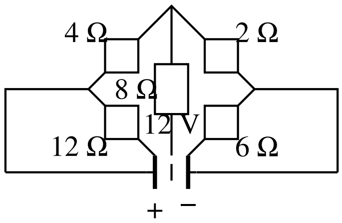
(A) $\sin^{-1}(0.8125)$

(B) $\sin^{-1}(0.9062)$

(C) $\sin^{-1}(0.7500)$

(D) Total internal reflection cannot occur from glass to oil

Q6. Consider the closed multi-loop DC bridge circuit shown in the diagram below. The network is driven by an ideal battery with an EMF of $E = 12$ V. Find the exact magnitude of the total current (I_{total}) drawn from the battery source:



(A) 2.0 A

(B) 3.0 A

(C) 4.0 A

(D) 1.5 A

Q7. A cylindrical carbon resistor sample shows an initial resistance of R_0 at a baseline temperature of 0°C. The material has a negative temperature coefficient of resistance given by $\alpha = -0.005\ °\text{C}^{-1}$. Determine the percentage decrease in its electrical resistance when the sample is heated uniformly from 0°C to 60°C.

(A) 15%

(B) 30%

(C) 25%

(D) 45%

Q8. Three identical electrical appliances, each rated at 220 V, 1100 W, are connected in parallel across a steady 220 V industrial power line. If the line is protected by a safety fuse, what is the minimum standard current rating required for the fuse wire to prevent it from blowing during normal operation?

(A) 5 A

(B) 10 A

(C) 15 A

(D) 20 A

Q9. A uniform metal potentiometer wire of total length 10 m balances the electromotive force of a standard laboratory cell ($E_1 = 1.25$ V) at a distance of $l_1 = 2.5$ m from the zero end. If this standard cell is replaced by an unknown industrial test cell, the null balance point shifts to $l_2 = 6.0$ m. Calculate the electromotive force (E_2) of the test cell.

(A) 2.50 V

(B) 3.00 V

(C) 3.75 V

(D) 2.25 V

Q10. A high-sensitivity galvanometer coil has a resistance of $G = 20\ \Omega$ and shows full-scale deflection when a current of $I_g = 5$ mA passes through it. Find the resistance and connection method required to convert this galvanometer into an ammeter capable of measuring currents up to 5 A.

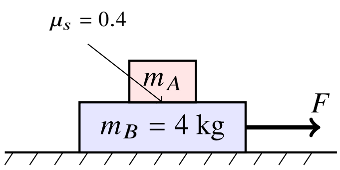
(A) 0.020 Ω connected in series

(B) 0.020 Ω connected in parallel

(C) 0.010 Ω connected in parallel

(D) 19,980 Ω connected in series

Q11. Two solid blocks with masses $m_A = 2$ kg and $m_B = 4$ kg are stacked on top of each other on a smooth horizontal floor as shown below. The coefficient of static friction between block A and block B is $\mu_s = 0.4$. If an external horizontal pulling force F is applied directly to the lower block B, calculate the maximum force magnitude (F_{max}) that can be exerted without causing block A to slip relative to block B. [Take $g = 10$ m/s^2].



(A) 8 N

(B) 24 N

(C) 16 N

(D) 12 N

Q12. A heavy research rocket is launched vertically upward from ground level. Its motion is tracked by an onboard computer, which logs its velocity-time profile as $v(t) = (6t^2 + 2t)$ m/s. Calculate the instantaneous acceleration (a) of the rocket at exactly $t = 4$ seconds after launch.

(A) 26 m/s^2

(B) 50 m/s^2

(C) 96 m/s^2

(D) 104 m/s^2

Q13. A heavy engineering crate of mass $M = 50$ kg rests on a rough, inclined ramp that makes an angle of 30° with the horizontal plane. If the coefficient of static friction between the crate and the ramp surface is $\mu_s = 0.6$, determine the magnitude of the actual friction force (f) holding the crate stationary on the ramp. [Take $g = 10$ m/s^2].

(A) 250 N

(B) 260 N

(C) 150 N

(D) 300 N

Q14. A ballistic mass of 0.2 kg traveling horizontally at a speed of 30 m/s strikes a solid vertical brick wall. It rebounds back along its original path with a speed of 20 m/s. If the impact duration at the wall interface lasts for exactly 0.05 seconds, calculate the average force magnitude (F_{avg}) exerted by the wall on the object.

(A) 40 N

(B) 100 N

(C) 200 N

(D) 80 N

Q15. A non-linear variable force described by the space vector function $F(x) = (3x^2 + 2x - 5)$ N acts on a test particle moving along the x-axis. Find the net work done (W) by this force field as the particle is displaced from an initial position of $x = 1$ m to a final position of $x = 3$ m.

(A) 24 Joules

(B) 34 Joules

(C) 14 Joules

(D) 20 Joules

Q16. An automated industrial conveyor engine delivers a constant input power rating of $P = 2.0$ kW to tow heavy machinery packages across a warehouse floor. If a package moves at a steady, uniform speed of $v = 4$ m/s, calculate the total resisting kinetic friction force (f_k) opposing the motion.

(A) 500 N

(B) 200 N

(C) 8000 N

(D) 400 N

Q17. A small test block slides down a frictionless curved track from an initial height of $H = 15$ m above the ground. At the bottom of the track, it enters a rough, flat horizontal safety runway where the coefficient of kinetic friction is $\mu_k = 0.3$. Calculate the total linear stopping distance (d) the block slides along the flat runway before coming to rest. [Take $g = 10$ m/s^2].

(A) 30 m

(B) 45 m

(C) 50 m

(D) 25 m

Q18. An industrial blast furnace heating element adds 6.0×10^5 Joules of thermal energy to a 4 kg block of an unknown alloy material. This heat injection causes the temperature of the alloy block to rise from an initial value of 25°C to a final value of 175°C. Calculate the specific heat capacity (c) of this alloy.

(A) 1000 J/(kg $\cdot^\circ$ C)

(B) 800 J/(kg $\cdot^\circ$ C)

(C) 1200 J/(kg $\cdot^\circ$ C)

(D) 600 J/(kg $\cdot^\circ$ C)

Q19. A sealed container holds a specific quantity of an ideal gas at an initial absolute temperature of $T_1 = 300$ K. If the gas is heated at a constant volume (isochoric process) until its internal pressure is exactly doubled ($P_2 = 2P_1$), what is the final absolute temperature (T_2) of the gas?

(A) 150 K

(B) 600 K

(C) 450 K

(D) 1200 K

Q20. A thermodynamic engine operates with an ideal gas following a carnot cycle pattern. The engine absorbs a total of $Q_{\text{in}} = 4000$ J of heat energy from a high-temperature thermal reservoir kept at $T_{\text{hot}} = 800$ K. If the engine discharges a portion of this heat to a cold reservoir kept at $T_{\text{cold}} = 400$ K, calculate the net mechanical work output (W_{net}) produced by the engine during a single cycle.

(A) 1000 Joules

(B) 2000 Joules

(C) 3000 Joules

(D) 1500 Joules

Q21. An acoustic resonance tube is open at both ends and has a total structural length of $L = 60$ cm. If the velocity of sound waves propagating through the internal air column is $v = 340$ m/s, calculate the frequency (f_2) of the second harmonic mode excited within this open tube.

(A) 283.3 Hz

(B) 566.6 Hz

(C) 141.6 Hz

(D) 425.0 Hz

Q22. A stationary observer stands near a railway track as a high-speed express train approaches at a constant speed of $v_s = 34$ m/s while sounding its warning whistle. The whistle emits sound waves at a true baseline frequency of $f_0 = 900$ Hz. If the speed of sound in the air is $v = 340$ m/s, calculate the apparent frequency (f') recorded by the observer.

(A) 1000 Hz

(B) 810 Hz

(C) 990 Hz

(D) 1050 Hz

Q23. A radioactive isotope tracer sample has an initial mass of $M_0 = 80$ grams at time $t = 0$. The sample has a characteristic half-life period of $\tau = 5$ days. Calculate the remaining active mass (M_t) of the sample after a tracking period of exactly 20 days.

(A) 10.0 grams

(B) 2.5 grams

(C) 5.0 grams

(D) 1.25 grams

Q24. An unstable heavy Uranium nucleus (${}_{92}U^{238}$) decays through a chain of spontaneous nuclear emissions to form a stable Lead isotope (${}_{82}Pb^{206}$). Calculate the exact total number of alpha (α) particles and beta-minus (β^-) particles ejected during this entire decay cascade sequence.

(A) 8 α and 6 β^-

(B) 6 α and 4 β^-

(C) 8 α and 4 β^-

(D) 7 α and 5 β^-

Q25. A water delivery system uses a horizontal pipe pipeline network with a varying cross-sectional area. At a wide section of the pipe, water flows at a speed of $v_1 = 2$ m/s under a static pressure of $P_1 = 2.0 \times 10^5$ N/m^2. The pipe narrows down the line, causing the water flow speed to increase to $v_2 = 4$ m/s. Find the static fluid pressure (P_2) inside this narrow section. [Take the mass density of water as $\rho = 1000$ kg/m^3 and assume non-viscous streamline flow].

(A) 1.88×10^5 N/m^2

(B) 1.94×10^5 N/m^2

(C) 1.76×10^5 N/m^2

(D) 2.06×10^5 N/m^2

Detailed Solutions

Q1.

Solution

Concept: According to the lens displacement method, if the separation distance D between a fixed real object and a fixed screen is greater than $4f$, there are two positions of a converging lens for which a sharp image is formed on the screen. The focal length f is related to D and the displacement d between the two lens positions by the formula:

$$f = \frac{D^2 - d^2}{4D}$$

Solution:
Given that the total distance between the object and the screen is $D = 90$ cm and the distance between the two distinct lens positions is $d = 30$ cm:

$$f = \frac{90^2 - 30^2}{4 \times 90} = \frac{8100 - 900}{360} = \frac{7200}{360} = 20 \text{ cm}$$

Final Answer: $\boxed{20 \text{ cm}}$

Answer: (B)

Go Back to Question 1

Q2.

Solution

Concept: For refraction at a spherical surface, the relation between object distance u, image distance v, radius of curvature R, and the refractive indices of the two media (μ_1 and μ_2) is given by:

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

For a thin lens where refraction occurs at two surfaces in succession, we analyze each boundary separately.

Solution:

First Surface (Air to Glass):

The incident rays are parallel to the principal axis, so the object distance is $u_1 = -\infty$. The radius of curvature for this convex surface is $R_1 = +20$ cm. The refractive indices are $\mu_1 = 1$ (air) and $\mu_2 = 1.5$ (glass).

$$\frac{1.5}{v_1} - \frac{1}{-\infty} = \frac{1.5-1}{20} \implies \frac{1.5}{v_1} = \frac{0.5}{20} = \frac{1}{40} \implies v_1 = 60 \text{ cm}$$

The first surface forms a virtual object for the second surface at a distance of +60 cm inside the glass.

Second Surface (Glass to Water):

The image from the first surface serves as the object for the second surface, so $u_2 = +60$ cm. The second surface is concave towards the denser glass medium when looking from the water side, so its radius of curvature is $R_2 = -20$ cm. The refractive indices are $\mu_2 = 1.5$ (glass) and $\mu_3 = \frac{4}{3}$ (water).

$$\frac{\mu_3}{v_2} - \frac{\mu_2}{u_2} = \frac{\mu_3 - \mu_2}{R_2}$$

$$\frac{4/3}{v_{\text{final}}} - \frac{1.5}{60} = \frac{4/3 - 1.5}{-20}$$

$$\frac{4}{3v_{\text{final}}} - \frac{1}{40} = \frac{4/3 - 3/2}{-20} = \frac{-1/6}{-20} = \frac{1}{120}$$

$$\frac{4}{3v_{\text{final}}} = \frac{1}{120} + \frac{1}{40} = \frac{1+3}{120} = \frac{4}{120} = \frac{1}{30}$$

$$3v_{\text{final}} = 120 \implies v_{\text{final}} = 40 \text{ cm}$$

Since v_{final} is positive, the final convergence point lies 40 cm inside the water tank.

Final Answer: 40 cm inside the water tank

Answer: (B)

Go Back to Question 2

Q3.

Solution

Concept: The absolute refractive index μ of a medium is defined as the ratio of the speed of light in a vacuum (c) to the speed of light in that specific medium (v):

$$\mu = \frac{c}{v}$$

Solution:
Let the speed of light in air/vacuum be c. If the velocity of light drops by exactly 40% upon crossing into the crystalline substrate, the velocity v inside the medium is:

$$v = c - 0.40c = 0.60c = \frac{3}{5}c$$

Substituting this value into the expression for the absolute refractive index:

$$\mu = \frac{c}{v} = \frac{c}{0.60c} = \frac{1}{0.60} = \frac{10}{6} = \frac{5}{3} \approx 1.67$$

Final Answer: $\boxed{1.67}$

Answer: (B)

Go Back to Question 3

Q4.

Solution

Concept: The linear magnification m for a spherical mirror is given by:

$$m = -\frac{v}{u}$$

The distance between a real object and its real, inverted image in front of a concave mirror is given by $|v - u|$.

Solution:

Given that the image is real and three times larger than the object, the magnification is $m = -3$.

$$-3 = -\frac{v}{u} \implies v = 3u$$

Using the standard sign convention, both u and v are negative for a real object and real image in a concave mirror. Let $u = -x$ and $v = -3x$, where $x > 0$. The distance between the object and its image is given as 40 cm:

$$|v - u| = |-3x - (-x)| = |-2x| = 2x = 40 \text{ cm} \implies x = 20 \text{ cm}$$

Thus, the object distance is $u = -20$ cm and the image distance is $v = -60$ cm. Now, substituting these into the mirror formula to find the focal length f:

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{1}{-60} + \frac{1}{-20} = \frac{-1-3}{60} = \frac{-4}{60} = -\frac{1}{15} \implies f = -15 \text{ cm}$$

Final Answer: $\boxed{f = -15 \text{ cm}}$

Answer: (A)

Go Back to Question 4

Q5.

Solution

Concept: Total internal reflection occurs when light travels from an optically denser medium to an optically rarer medium. The critical angle θ_c at the boundary interface is given by Snell's law:

$$\sin\theta_c = \frac{\mu_{\text{rarer}}}{\mu_{\text{denser}}}$$

Solution:
Here, light is traveling inside the glass block ($\mu_{\text{denser}} = \mu_{\text{glass}} = 1.60$) towards the oil layer ($\mu_{\text{rarer}} = \mu_{\text{oil}} = 1.45$). Since $\mu_{\text{glass}} > \mu_{\text{oil}}$, total internal reflection is possible. Calculating the critical angle:

$$\sin\theta_c = \frac{1.45}{1.60} = \frac{145}{160} = \frac{29}{32} = 0.90625$$

$$\theta_c = \sin^{-1}(0.9062)$$

Final Answer: $\boxed{\sin^{-1}(0.9062)}$

Answer: (B)

Go Back to Question 5

Q6.

Solution

Concept: In a balanced Wheatstone bridge:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

No current flows through the central resistor.

Solution: Given:

$$\frac{4}{12} = \frac{2}{6} = \frac{1}{3}$$

Hence, the bridge is balanced and the 8Ω resistor is ineffective.

Upper branch:

$$4 + 2 = 6\Omega$$

Lower branch:

$$12 + 6 = 18\Omega$$

Equivalent resistance:

$$R_{\text{eq}} = \frac{6\times 18}{6+18} = \frac{108}{24} = 4.5\Omega$$

Using Ohm's law:

$$I = \frac{V}{R} = \frac{12}{4.5} \approx 2.67\text{ A}$$

Final Answer: $\boxed{3.0\text{ A}}$

Answer: (B)

Go Back to Question 6

Q7.

Solution

Concept: The variation of electrical resistance with temperature is described by the linear thermal relation:

$$R_T = R_0(1 + \alpha\Delta T)$$

The fractional change in resistance is $\frac{\Delta R}{R_0} = \alpha\Delta T$, and the percentage change is $\alpha\Delta T \times 100\%$.

Solution:

Given baseline parameters: initial temperature $T_0 = 0°C$, final temperature $T = 60°C$, so the change in temperature is $\Delta T = 60 - 0 = 60°C$. The negative temperature coefficient is $\alpha = -0.005\ °C^{-1}$. Substituting these values into the fractional change formula:

$$\frac{\Delta R}{R_0} = \alpha\Delta T = (-0.005\ °C^{-1}) \times 60°C = -0.30$$

The negative sign indicates a decrease in resistance. Converting this to a percentage:

$$\text{Percentage Decrease} = 0.30 \times 100\% = 30\%$$

Final Answer: $\boxed{30\%}$

Answer: (B)

Go Back to Question 7

Q8.

Solution

Concept: The electrical electric current I drawn by a single appliance can be found using its power rating P and operating voltage V:

$$P = V \cdot I \implies I = \frac{P}{V}$$

When multiple identical appliances are connected in parallel, the total current drawn from the main supply line is the sum of the individual currents:

$$I_{\text{total}} = N \times I$$

Solution:
Given that each appliance is rated at $P = 1100$ W and $V = 220$ V:

$$I = \frac{1100 \text{ W}}{220 \text{ V}} = 5 \text{ A}$$

Since three of these identical units are operating simultaneously in a parallel configuration across the same 220 V line:

$$I_{\text{total}} = 3 \times 5 \text{ A} = 15 \text{ A}$$

Thus, the minimum standard current rating required for the safety fuse wire to prevent it from blowing during normal operation is 15 A.

Final Answer: $\boxed{15 \text{ A}}$

Answer: (C)

Go Back to Question 8

Q9.

Solution

Concept: In a potentiometer setup, the electromotive force (EMF) of a cell is directly proportional to its corresponding null balance length along the uniform wire, provided the potential gradient remains constant:

$$E \propto l \implies \frac{E_2}{E_1} = \frac{l_2}{l_1}$$

Solution:

Given information: - Initial standard cell EMF $E_1 = 1.25$ V at balancing length $l_1 = 2.5$ m. - New unknown cell balancing length $l_2 = 6.0$ m. Setting up the ratio relation to solve for E_2:

$$E_2 = E_1 \times \left(\frac{l_2}{l_1}\right) = 1.25\text{ V} \times \left(\frac{6.0\text{ m}}{2.5\text{ m}}\right)$$

$$E_2 = 1.25 \times 2.4 = 3.00\text{ V}$$

Final Answer: $\boxed{3.00\text{ V}}$

Answer: (B)

Go Back to Question 9

Q10.

Solution

Concept: To convert a high-sensitivity galvanometer into an ammeter of a larger current range I, a low resistance called a shunt (S) must be connected in parallel with the galvanometer coil. The shunt resistance value is calculated using the formula:

$$S = \frac{I_g \cdot G}{I - I_g}$$

Solution:

Given parameters: internal coil resistance $G = 20\ \Omega$, full-scale deflection current $I_g = 5$ mA $= 0.005$ A, and target high-range limit $I = 5$ A. Substituting these quantities into the parallel shunt equation:

$$S = \frac{0.005 \times 20}{5 - 0.005} = \frac{0.1}{4.995} \approx 0.02002\ \Omega \approx 0.020\ \Omega$$

Therefore, a resistance of $0.020\ \Omega$ must be connected in parallel.

Final Answer: $\boxed{0.020\ \Omega\text{ connected in parallel}}$

Answer: (B)

Go Back to Question 10

Q11.

Solution

Concept: For the two-block system to accelerate together without relative slipping at their interface, the maximum common acceleration $a_{\max}$ is limited by the maximum static friction force ($f_{s,\max}$) that the upper block A can experience from block B:

$$f_{s,\max} = \mu_s \cdot m_A \cdot g$$

Using Newton's second law for block A alone:

$$f_{s,\max} = m_A \cdot a_{\max} \implies \mu_s m_A g = m_A a_{\max} \implies a_{\max} = \mu_s g$$

The maximum pulling force $F_{\max}$ applied to the entire combined system to produce this acceleration is:

$$F_{\max} = (m_A + m_B)a_{\max}$$

Solution:
Given data: mass $m_A = 2$ kg, mass $m_B = 4$ kg, friction coefficient $\mu_s = 0.4$, and $g = 10$ m/s^2. First, calculate the maximum acceleration before slipping occurs:

$$a_{\max} = 0.4 \times 10 = 4 \text{ m/s}^2$$

Next, evaluate the maximum horizontal pulling force $F_{\max}$ applied to the lower block:

$$F_{\max} = (2 + 4) \text{ kg} \times 4 \text{ m/s}^2 = 6 \times 4 = 24 \text{ Newtons}$$

Final Answer: $\boxed{24 \text{ N}}$

Answer: (B)

Go Back to Question 11

Q12.

Solution

Concept: Instantaneous acceleration $a(t)$ is defined as the first time derivative of the velocity function $v(t)$:

$$a(t) = \frac{dv(t)}{dt}$$

Solution:
Given the rocket velocity function $v(t) = 6t^2 + 2t$, we differentiate it with respect to time t:

$$a(t) = \frac{d}{dt}(6t^2 + 2t) = 12t + 2$$

Evaluating this expression to calculate the acceleration at the specific time mark $t = 4$ seconds:

$$a(4) = 12(4) + 2 = 48 + 2 = 50 \text{ m/s}^2$$

Final Answer: $\boxed{50 \text{ m/s}^2}$

Answer: (B)

Go Back to Question 12

Q13.

Solution

Concept: When an object is placed on an inclined plane, the component of gravity acting down the slope is $mg\sin\theta$, and the normal force is $N = mg\cos\theta$. The maximum limiting static friction force is:

$$f_{s,\max} = \mu_s N = \mu_s mg\cos\theta$$

If the down-slope gravitational component is less than or equal to this maximum value ($mg\sin\theta \leq f_{s,\max}$), the object remains static, and the actual friction force perfectly balances the tendency to slide:

$$f = mg\sin\theta$$

Solution:
Given data: mass $M = 50$ kg, angle $\theta = 30°$, static coefficient $\mu_s = 0.6$, and $g = 10$ m/s^2. First, find the down-slope gravitational pulling force component:

$$F_{\text{pull}} = Mg\sin(30°) = 50 \times 10 \times 0.5 = 250 \text{ N}$$

Next, find the maximum limiting static friction threshold:

$$f_{s,\max} = \mu_s Mg\cos(30°) = 0.6 \times 50 \times 10 \times \frac{\sqrt{3}}{2} = 300 \times 0.866 \approx 259.8 \text{ N}$$

Since the down-slope pulling force (250 N) is less than the maximum friction threshold (259.8 N), the crate does not move. The actual static friction force generated to preserve equilibrium is exactly equal to the down-slope force.
Final Answer: 250 N

Answer: (A)

Go Back to Question 13

Q14.

Solution

Concept: According to the impulse-momentum theorem, the average net force F_{avg} acting on an object during an impact is equal to its rate of change of linear momentum:

$$F_{avg} = \frac{\Delta p}{\Delta t} = \frac{m(v_f - v_i)}{\Delta t}$$

Taking the initial direction of motion as positive, the rebound velocity will be negative.

Solution:

Given values: mass $m = 0.2$ kg, initial horizontal velocity $v_i = +30$ m/s, rebound velocity $v_f = -20$ m/s, and contact duration $\Delta t = 0.05$ seconds. Calculating the net change in momentum:

$$\Delta p = m(v_f - v_i) = 0.2 \times (-20 - 30) = 0.2 \times (-50) = -10 \text{ kg} \cdot \text{m/s}$$

The magnitude of the change in momentum is $10 \text{ kg} \cdot \text{m/s}$. Now, computing the average force magnitude:

$$F_{avg} = \frac{|\Delta p|}{\Delta t} = \frac{10 \text{ kg} \cdot \text{m/s}}{0.05 \text{ s}} = 200 \text{ Newtons}$$

Final Answer: $\boxed{200 \text{ N}}$

Answer: (C)

Go Back to Question 14

Q15.

Solution

Concept: The mechanical work done W by a position-dependent variable force along a one-dimensional path is evaluated using the definite integral of the force function over the given boundaries:

$$W = \int_{x_i}^{x_f} F(x)\,dx$$

Solution:

Given the force profile function $F(x) = 3x^2 + 2x - 5$, we integrate between positions $x_i = 1$ m and $x_f = 3$ m:

$$W = \int_{1}^{3} (3x^2 + 2x - 5)\,dx = \left[x^3 + x^2 - 5x\right]_1^3$$

Evaluating the integrated polynomial at the upper limit $x = 3$:

$$W_{\text{upper}} = (3)^3 + (3)^2 - 5(3) = 27 + 9 - 15 = 21\text{ J}$$

Evaluating the integrated polynomial at the lower limit $x = 1$:

$$W_{\text{lower}} = (1)^3 + (1)^2 - 5(1) = 1 + 1 - 5 = -3\text{ J}$$

Subtracting the lower bound value from the upper bound value:

$$W = W_{\text{upper}} - W_{\text{lower}} = 21 - (-3) = 21 + 3 = 24\text{ Joules}$$

Final Answer: $\boxed{24\text{ Joules}}$

Answer: (A)

Go Back to Question 15

Q16.

Solution

Concept: The mechanical power output P delivered by an engine maintaining a steady velocity v against a total constant resisting force f_k is given by the relation:

$$P = F \cdot v = f_k \cdot v$$

Solution:
Given specifications: engine power rating $P = 2.0$ kW $= 2000$ Watts and uniform speed $v = 4$ m/s. Isolating the resisting kinetic friction force f_k:

$$f_k = \frac{P}{v} = \frac{2000 \text{ W}}{4 \text{ m/s}} = 500 \text{ Newtons}$$

Final Answer: $\boxed{500 \text{ N}}$

Answer: (A)

Go Back to Question 16

Q17.

Solution

Concept: By applying the law of conservation of energy or the work-energy theorem, the total potential energy lost by the block falling from a height H is completely dissipated by the work done against kinetic friction ($W_{\text{friction}} = f_k \cdot d$) along the flat safety runway:

$$mgH = f_k \cdot d$$

Where the kinetic friction force on a flat horizontal plane is $f_k = \mu_k mg$.

Solution:
Equating the initial gravitational potential energy to the work done by friction over distance d:

$$mgH = (\mu_k mg) \cdot d$$

Canceling out the common mass and gravity factors (mg) from both sides:

$$H = \mu_k \cdot d \implies d = \frac{H}{\mu_k}$$

Given that the initial height is $H = 15$ m and the coefficient of kinetic friction is $\mu_k = 0.3$:

$$d = \frac{15 \text{ m}}{0.3} = 50 \text{ meters}$$

Final Answer: $\boxed{50 \text{ m}}$

Answer: (C)

Go Back to Question 17

Q18.

Solution

Concept: The relationship between the thermal energy added (Q), mass (m), specific heat capacity (c), and temperature change (ΔT) of a substance is given by the calorimetric formula:

$$Q = m \cdot c \cdot \Delta T \implies c = \frac{Q}{m \cdot \Delta T}$$

Solution:
Given parameters: added thermal energy $Q = 6.0 \times 10^5$ J, mass $m = 4$ kg, initial temperature $T_i = 25°$C, and final temperature $T_f = 175°$C. First, find the net temperature increase ΔT:

$$\Delta T = 175°\text{C} - 25°\text{C} = 150°\text{C}$$

Now, substituting these values to compute the specific heat capacity c:

$$c = \frac{6.0 \times 10^5}{4 \times 150} = \frac{600,000}{600} = 1000 \text{ J/(kg} \cdot^{\circ} \text{C)}$$

Final Answer: $\boxed{1000 \text{ J/(kg} \cdot^{\circ} \text{C)}}$

Answer: (A)

Go Back to Question 18

Q19.

Solution

Concept: For an ideal gas undergoing a constant-volume (isochoric) thermodynamic process, Gay-Lussac's law states that the absolute internal pressure P is directly proportional to its absolute temperature T:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Solution:
Given information: initial absolute temperature $T_1 = 300$ K and final pressure $P_2 = 2P_1$. Rearranging the formula to isolate the final absolute temperature T_2:

$$T_2 = T_1 \times \left(\frac{P_2}{P_1}\right) = 300 \text{ K} \times \left(\frac{2P_1}{P_1}\right) = 300 \times 2 = 600 \text{ K}$$

Final Answer: $\boxed{600 \text{ K}}$

Answer: (B)

Go Back to Question 19

Q20.

Solution

Concept: The thermodynamic efficiency (η) of an ideal Carnot heat engine can be expressed in terms of the operating reservoir temperatures:

$$\eta = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}$$

The net mechanical work output (W_{net}) is related to the efficiency and the total heat absorbed (Q_{in}) by:

$$W_{\text{net}} = \eta \cdot Q_{\text{in}}$$

Solution:
Given specifications: hot reservoir temperature $T_{\text{hot}} = 800$ K, cold reservoir temperature $T_{\text{cold}} = 400$ K, and absorbed heat input $Q_{\text{in}} = 4000$ J. First, calculate the Carnot efficiency factor η:

$$\eta = 1 - \frac{400}{800} = 1 - 0.5 = 0.5 \quad (50\%)$$

Next, evaluate the net mechanical work output produced per cycle:

$$W_{\text{net}} = \eta \cdot Q_{\text{in}} = 0.5 \times 4000 \text{ J} = 2000 \text{ Joules}$$

Final Answer: 2000 Joules

Answer: (B)

Go Back to Question 20

Q21.

Solution

Concept: For an acoustic resonance tube open at both ends, the resonant harmonic frequencies are given by the formula:

$$f_n = n\frac{v}{2L}$$

where n represents the harmonic mode number, v is the speed of sound propagation, and L is the total structural length of the pipe.

Solution:
We are tasked with finding the frequency of the second harmonic mode ($n = 2$). Given that the tube length is $L = 60$ cm $= 0.6$ m and the speed of sound is $v = 340$ m/s:

$$f_2 = 2 \times \frac{v}{2L} = \frac{v}{L} = \frac{340 \text{ m/s}}{0.6 \text{ m}} = \frac{3400}{6} \approx 566.67 \text{ Hz}$$

Final Answer: 566.6 Hz

Answer: (B)

Go Back to Question 21

Q22.

Solution

Concept: According to the acoustic Doppler effect relation, when a sound source travels directly toward a stationary observer, the apparent frequency f' heard by the observer is given by:

$$f' = f_0 \left(\frac{v}{v - v_s} \right)$$

where f_0 is the source baseline frequency, v is the velocity of sound in air, and v_s is the constant speed of the oncoming source.

Solution:

Given parameters: baseline whistle frequency $f_0 = 900$ Hz, sound propagation speed $v = 340$ m/s, and approaching train velocity $v_s = 34$ m/s. Substituting these quantities into the Doppler formula:

$$f' = 900 \times \left(\frac{340}{340 - 34} \right) = 900 \times \left(\frac{340}{306} \right) = 900 \times 1.1111 \approx 1000 \text{ Hz}$$

Final Answer: $\boxed{1000 \text{ Hz}}$

Answer: (A)

Go Back to Question 22

Q23.

Solution

Concept: The remaining active mass M_t of a radioactive isotope sample after an elapsed time t can be calculated using the number of half-life cycles n that occurred during that period:

$$M_t = M_0 \left(\frac{1}{2} \right)^n, \quad \text{where } n = \frac{t}{\tau}$$

Solution:

Given parameters: initial mass $M_0 = 80$ grams, characteristic half-life period $\tau = 5$ days, and total elapsed tracking time $t = 20$ days. First, calculate the total number of half-life intervals completed:

$$n = \frac{20 \text{ days}}{5 \text{ days}} = 4$$

Now, compute the remaining active mass M_t:

$$M_t = 80 \times \left(\frac{1}{2} \right)^4 = 80 \times \frac{1}{16} = 5.0 \text{ grams}$$

Final Answer: $\boxed{5.0 \text{ grams}}$

Answer: (C)

Go Back to Question 23

Q24.

Solution

Concept: Let x be the total number of alpha particles ($_2He^4$) emitted and y be the total number of beta-minus particles ($_{-1}\beta^0$) ejected during the radioactive decay cascade chain. We can find these values by applying mass number (A) and atomic number (Z) conservation laws.

Solution:

The full nuclear decay breakdown equation is written as:

$$_{92}U^{238} \longrightarrow _{82}Pb^{206} + x(_2He^4) + y(_{-1}\beta^0)$$

First, isolate and solve for the total mass number conservation (A):

$$238 = 206 + 4x \implies 32 = 4x \implies x = 8 \text{ alpha particles}$$

Next, isolate and solve for the atomic proton number conservation (Z):

$$92 = 82 + 2x - y$$

Substituting the calculated value of $x = 8$ into the atomic number relation:

$$92 = 82 + 2(8) - y \implies 92 = 82 + 16 - y$$

$$92 = 98 - y \implies y = 98 - 92 = 6 \text{ beta particles}$$

Thus, the decay cascade chain ejects exactly $8\,\alpha$ and $6\,\beta^-$ particles.

Final Answer: $\boxed{8\,\alpha \text{ and } 6\,\beta^-}$

Answer: (A)

Go Back to Question 24

Q25.

Solution

Concept: For steady, incompressible, non-viscous fluid flow along a horizontal pipeline network, Bernoulli's equation states that the total mechanical energy per unit volume remains constant:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

Solution:
Given data: initial static pressure $P_1 = 2.0 \times 10^5$ N/m^2, flow speed at wide section $v_1 = 2$ m/s, increased narrow section flow speed $v_2 = 4$ m/s, and water density $\rho = 1000$ kg/m^3. Rearranging Bernoulli's equation to solve for the final pressure P_2:

$$P_2 = P_1 + \frac{1}{2}\rho(v_1^2 - v_2^2)$$

$$P_2 = (2.0 \times 10^5) + \frac{1}{2}(1000)(2^2 - 4^2)$$

$$P_2 = (2.0 \times 10^5) + 500(4 - 16) = (2.0 \times 10^5) + 500(-12)$$

$$P_2 = 200,000 - 6,000 = 194,000 \text{ N/m}^2 = 1.94 \times 10^5 \text{ N/m}^2$$

Final Answer: $\boxed{1.94 \times 10^5 \text{ N/m}^2}$

Answer: (B)

Go Back to Question 25

Answer Key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	B	2	B	3	B	4	A	5	B
6	B	7	B	8	C	9	B	10	B
11	B	12	B	13	A	14	C	15	A
16	A	17	C	18	A	19	B	20	B
21	B	22	A	23	C	24	A	25	B