UPCATET Agriculture Physics Sample Paper-4

Duration: 25 Minutes | **Maximum Marks: 100**

Instructions

- This paper contains **25** Multiple Choice Questions.
- Each correct answer carries **+4** mark. Incorrect answer: **−1** marks. Only **one** correct option.
- Unattempted questions carry **0** marks.
- Use of mobile phones, smartwatches, or any electronic gadgets is strictly prohibited.

Q1. A non-uniform heavy agricultural log of length L and weight W is balanced horizontally on a sharp pivot placed at a distance of $x = \frac{L}{3}$ from its thicker end A. When an additional mass m is placed at the extreme thinner end B, the system remains balanced. If the mass m is removed, what vertical upward force F must be applied precisely at end B to maintain the horizontal equilibrium of the log?

(A) $F = W\left(1 - \frac{x}{L}\right)$

(B) $F = 2W\left(\frac{1}{2} - \frac{x}{L}\right)$

(C) $F = W\left(\frac{3x-L}{2L}\right)$

(D) $F = mg$

Q2. An agricultural drone of mass M hovers statically in a steady downwash configuration. The drone's rotors downwardly accelerate air of density ρ through a total effective cross-sectional sweeping area A. Determine the precise expression for the downward velocity v imparted to the air column to sustain this static hovering equilibrium against gravity.

(A) $v = \sqrt{\frac{Mg}{2\rho A}}$

(B) $v = \sqrt{\frac{Mg}{\rho A}}$

(C) $v = \frac{Mg}{\rho A}$

(D) $v = \sqrt{\frac{2Mg}{\rho A}}$

Q3. A heavy grain cart is pulled up a rough inclined ramp of angle θ relative to the horizontal. The coefficient of static friction between the cart tires and the ramp surface is μ_s. If a horizontal force F_{horiz} (parallel to the ground, not the ramp) is applied to prevent the cart from sliding down, what is the minimum magnitude of this horizontal force?

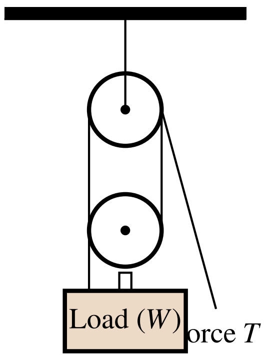
(A) $F_{\text{horiz}} = W\left[\frac{\sin\theta - \mu_s\cos\theta}{\cos\theta + \mu_s\sin\theta}\right]$

(B) $F_{\text{horiz}} = W\left[\frac{\sin\theta + \mu_s\cos\theta}{\cos\theta - \mu_s\sin\theta}\right]$

(C) $F_{\text{horiz}} = W(\tan\theta - \mu_s)$

(D) $F_{\text{horiz}} = W\left[\frac{\cos\theta - \mu_s\sin\theta}{\sin\theta + \mu_s\cos\theta}\right]$

Q4. A specialized seed-bag lifting mechanism utilizes a multi-tiered pulley arrangement as depicted in the engineering schematic below. Assuming the cables are completely inextensible and the pulleys are frictionless and massless, calculate the required equilibrium pulling tension T exerted at the free cable end to maintain a static lift of an agricultural load of total weight W:



(A) $T = W$

(B) $T = \frac{W}{2}$

(C) $T = \frac{W}{3}$

(D) $T = \frac{W}{4}$

Q5. An empty grain hopper is shaped as an inverted regular right circular cone of height H and base radius R pointing straight down. If it is filled completely with a uniform density harvested grain mass, find the vertical distance of the center of gravity of the grain mass measured from the pointed bottom apex of the cone.

(A) $z_{cg} = \frac{1}{4}H$

(B) $z_{cg} = \frac{1}{3}H$

(C) $z_{cg} = \frac{3}{4}H$

(D) $z_{cg} = \frac{2}{3}H$

Q6. A heavy-duty siphon system is deployed to transfer liquid fertilizer (density = ρ) from an elevated farm tank to a lower distribution channel. The maximum height of the siphon's apex bend above the upper liquid free surface is h, and the atmospheric pressure is P_0. Neglecting viscosity, what is the maximum theoretical height h_{max} allowed before cavitation occurs (assuming the liquid vapor pressure is P_v)?

(A) $h_{max} = \frac{P_0}{\rho g}$

(B) $h_{max} = \frac{P_0 - P_v}{\rho g}$

(C) $h_{max} = \frac{P_0 + P_v}{\rho g}$

(D) $h_{max} = \frac{P_v}{\rho g}$

Q7. A clean glass capillary tube of inner radius r is dipped vertically into an open container filled with liquid pesticide solution. The liquid rises to a capillary height h. If the surface tension is T and the contact angle is θ, what is the total vertical upward force exerted by surface tension along the internal perimeter boundary of the meniscus?

(A) $F_{up} = 2\pi r T \cos\theta$

(B) $F_{up} = \pi r^2 T \cos\theta$

(C) $F_{up} = 2\pi r T$

(D) $F_{up} = 2\pi r T \sin\theta$

Q8. A specialized irrigation submersible pump lifts water from an underground well at a constant volumetric flow rate of Q (measured in m^3/s). The water is pushed through a uniform pipe of cross-sectional area A up to a delivery height H above the water table level. If the water density is ρ, what is the minimum theoretical mechanical power (P) that the pump motor must supply, accounting for both kinetic energy and potential energy changes?

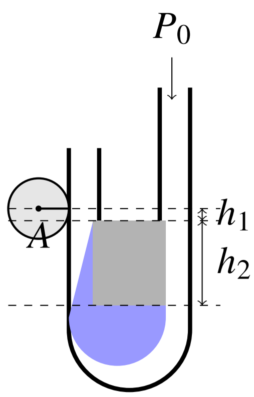
(A) $P = \rho g Q H$

(B) $P = \rho Q\left(gH + \frac{Q^2}{2A^2}\right)$

(C) $P = \rho Q\left(gH + \frac{Q^2}{A^2}\right)$

(D) $P = \frac{1}{2}\rho\frac{Q^3}{A^2}$

Q9. An agricultural hydraulics lab sets up an open U-tube manometer containing mercury (density $= \rho_m$) to measure the localized gauge pressure of a dense liquid fertilizer pipeline (density $= \rho_f$) as sketched below. Given the physical height values h_1 and h_2, derive the correct expression for the absolute pressure P_A at the center axis of the pipeline line A (where P_0 is the local atmospheric pressure):



(A) $P_A = P_0 + \rho_m g h_2 - \rho_f g h_1$

(B) $P_A = P_0 + \rho_m g h_2 + \rho_f g h_1$

(C) $P_A = P_0 - \rho_m g h_2 + \rho_f g h_1$

(D) $P_A = P_0 + \rho_f g(h_1 + h_2)$

Q10. A spherical air bubble of radius R_0 is trapped deep inside a water-logged clay layer at a depth where the absolute ambient hydrostatic pressure is P_1. If the bubble moves slowly upward to a shallow layer where the pressure becomes P_2, its new radius becomes R_2. Assuming the liquid temperature remains perfectly constant and accounting for surface tension T, which relation accurately governs this structural volumetric expansion?

(A) $P_1R_0^3 = P_2R_2^3$

(B) $\left(P_1 + \frac{2T}{R_0}\right)R_0^3 = \left(P_2 + \frac{2T}{R_2}\right)R_2^3$

(C) $\left(P_1 + \frac{4T}{R_0}\right)R_0^3 = \left(P_2 + \frac{4T}{R_2}\right)R_2^3$

(D) $\left(P_1 - \frac{2T}{R_0}\right)R_0^2 = \left(P_2 - \frac{2T}{R_2}\right)R_2^2$

Q11. A composite greenhouse insulation wall is constructed of two closely bonded parallel material sheets of identical total surface cross-sectional area. The first layer has a thermal conductivity of k_1 and thickness d_1, while the second layer has a thermal conductivity of k_2 and thickness d_2. Under steady-state heat transmission conditions, what is the effective overall thermal conductivity (k_{eff}) of this multi-layered wall structure?

(A) $k_{\text{eff}} = \frac{k_1d_1+k_2d_2}{d_1+d_2}$

(B) $k_{\text{eff}} = \frac{d_1+d_2}{\frac{d_1}{k_1}+\frac{d_2}{k_2}}$

(C) $k_{\text{eff}} = \frac{k_1k_2(d_1+d_2)}{k_1d_1+k_2d_2}$

(D) $k_{\text{eff}} = \frac{k_1+k_2}{2}$

Q12. A high-precision platinum resistance thermometer deployed inside a soil research chamber registers an electrical resistance value of $R_0 = 50.0\,\Omega$ at the triple point of water (0°C) and $R_{100} = 69.3\,\Omega$ at the boiling steam point of water (100°C). When completely inserted into a deep geothermal active compost core, the measured resistance rises to $R_t = 78.95\,\Omega$. Calculate the precise linear temperature (t) of this compost pile.

(A) $t = 125.0$°C

(B) $t = 150.0$°C

(C) $t = 135.5$°C

(D) $t = 112.8$°C

Q13. A solar crop-drying thermal storage unit contains a mass m of a specialized phase-change oil substance initially in its solid state at its definitive melting point temperature T_m. A constant-power solar collector plate continuously delivers a uniform heat energy flux $\dot{Q}$ directly into the substance. If the latent heat of fusion is L and the specific heat capacity of the liquid phase is c, find the total elapsed time Δt required to turn the solid entirely into a liquid and raise its temperature up to a final target processing value T_f.

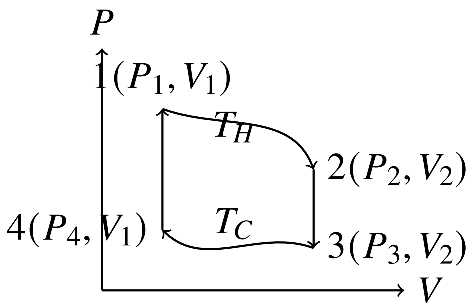
(A) $\Delta t = \frac{m}{\dot{Q}}\left[L + c(T_f - T_m)\right]$

(B) $\Delta t = \frac{m}{\dot{Q}}\left[c(T_f - T_m)\right]$

(C) $\Delta t = \frac{mL\cdot c(T_f - T_m)}{\dot{Q}}$

(D) $\Delta t = \frac{\dot{Q}}{m}\left[L + c(T_f - T_m)\right]$

Q14. An experimental thermodynamic stirling engine cycle designed to run on biogas energy tracks a working fluid along the closed $P - V$ paths plotted below. The paths from state $1 \rightarrow 2$ and $3 \rightarrow 4$ represent perfect isothermal profiles, while paths $2 \rightarrow 3$ and $4 \rightarrow 1$ are strictly isochoric (constant volume). Identify the correct analytical expression for the net thermodynamic work output W_{net} achieved per complete cycle loop:



(A) $W_{\text{net}} = nR(T_H - T_C)\ln\left(\frac{V_2}{V_1}\right)$

(B) $W_{\text{net}} = nR(T_H + T_C)\ln\left(\frac{V_2}{V_1}\right)$

(C) $W_{\text{net}} = nRT_H\ln\left(\frac{V_2}{V_1}\right)$

(D) $W_{\text{net}} = (P_1 - P_4)(V_2 - V_1)$

Q15. A metallic cooling rod designed for grain silo heat ventilation has a variable non-uniform cross-sectional area that decreases exponentially along its length x

according to $A(x) = A_0 e^{-\gamma x}$. If the rod is under steady-state thermal conduction with no lateral heat leaks, and the heat transfer rate $\dot{Q}$ passing through any cross-section is strictly constant, find the expression for the spatial temperature gradient $\frac{dT}{dx}$ as a function of position x (where k is the thermal conductivity).

(A) $\frac{dT}{dx} = -\frac{\dot{Q}}{kA_0}$

(B) $\frac{dT}{dx} = -\frac{\dot{Q}}{kA_0}e^{\gamma x}$

(C) $\frac{dT}{dx} = -\frac{\dot{Q}}{kA_0}e^{-\gamma x}$

(D) $\frac{dT}{dx} = -\frac{\dot{Q}\gamma}{kA_0}x$

Q16. A digital multispectral camera mounted on a crop-survey aircraft utilizes a combination of two thin coaxial lenses placed in close contact with each other to eliminate chromatic aberrations. The first lens has a focal length of f_1 and a dispersive power of ω_1, while the second lens has a focal length of f_2 and a dispersive power of ω_2. What structural condition must be met to ensure this lens combination functions as a perfectly achromatic doublet?

(A) $\omega_1 f_1 + \omega_2 f_2 = 0$

(B) $\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$

(C) $\omega_1 f_2 + \omega_2 f_1 = 0$

(D) $\frac{\omega_1}{f_1^2} + \frac{\omega_2}{f_2^2} = 0$

Q17. A specific direct-current (DC) electric motor circuit deployed in automated seed drills features an internal winding coil of net resistance R. The motor is connected across a stable external supply voltage V. When the motor is running at full operational speed, it spins generating an internal back electromotive force (back-EMF) denoted by $\mathcal{E}$. Derive the expression for the net mechanical power efficiency (η) of this operating motor system, neglecting mechanical friction.

(A) $\eta = \frac{\mathcal{E}}{V}$

(B) $\eta = \frac{V-\mathcal{E}}{V}$

(C) $\eta = \frac{\mathcal{E}^2}{V^2}$

(D) $\eta = \frac{I^2R}{VI}$

Q18. An optical sensor designed to estimate leaf chlorophyll density uses a beam of light passing through a glass prism of refractive index n and apex angle A. If the beam undergoes a condition of absolute minimum deviation ($\delta_{\min}$) inside the prism structure, what is the exact mathematical relationship linking the refractive index n, the prism angle A, and the minimum deviation angle $\delta_{\min}$?

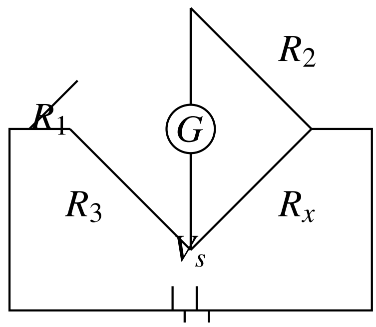
(A) $n = \frac{\sin\left(\frac{A+\delta_{\min}}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

(B) $n = \frac{\sin(A+\delta_{\min})}{\sin(A)}$

(C) $n = \frac{\cos\left(\frac{A+\delta_{\min}}{2}\right)}{\cos\left(\frac{A}{2}\right)}$

(D) $n = \frac{\tan\left(\frac{A+\delta_{\min}}{2}\right)}{\tan\left(\frac{A}{2}\right)}$

Q19. An electronic soil moisture sensor incorporates a sensitive DC Wheatstone bridge network configuration as shown below. The bridge is excited by a stable DC voltage source V_s. If the variable soil-probe resistance element is denoted as R_x, what specific mathematical condition must be achieved among the four resistive branches to ensure that the central galvanometer (G) reads a zero current null-point ($I_g = 0$)?



(A) $R_1 R_2 = R_3 R_x$

(B) $R_1 R_x = R_2 R_3$

(C) $R_1 R_3 = R_2 R_x$

(D) $R_1 + R_x = R_2 + R_3$

Q20. An agricultural processing plant utilizes a thick coaxial power cable to supply electricity to a heavy grinding mill. The inner conductor core carries a steady current $+I$, and the outer concentric cylindrical metallic sheath carries an equal and opposite return current $-I$. Determine the magnitude of the net induced magnetic field (B) at a radial point located entirely outside the outer radius boundary of the coaxial cable assembly.

(A) $B = \frac{\mu_0 I}{2\pi r}$

(B) $B = \frac{\mu_0 I}{\pi r}$

(C) $B = 0$

(D) $B = \frac{\mu_0 I^2}{2\pi r^2}$

Q21. A modern tractor implement utilizes an advanced fluid coupler containing a viscous Newtonian fluid film of uniform thickness h and dynamic viscosity μ. A flat circular metallic plate of radius R belonging to the active clutch assembly is rotated at a constant steady angular velocity ω parallel to a fixed flat floor housing surface. Derive the exact total viscous torque (τ) experienced by this rotating plate due to fluid shear forces.

(A) $\tau = \frac{\pi\mu\omega R^4}{2h}$

(B) $\tau = \frac{\pi\mu\omega R^4}{4h}$

(C) $\tau = \frac{2\pi\mu\omega R^3}{3h}$

(D) $\tau = \frac{\pi\mu\omega R^2}{h}$

Q22. A specialized optical line-sensor maps crop canopies by passing light through an adjustable slit of width a. The slit is illuminated by monochromatic light of wavelength λ. A convergent lens of focal length f focuses the resulting Fraunhofer diffraction pattern on an electronic sensor board placed at its focal plane. Calculate the precise linear physical distance Δy separating the two first-order minimum dark bands on either side of the central bright maximum.

(A) $\Delta y = \frac{\lambda f}{a}$

(B) $\Delta y = \frac{2\lambda f}{a}$

(C) $\Delta y = \frac{\lambda f}{2a}$

(D) $\Delta y = \frac{4\lambda f}{a}$

Q23. A dynamic high-pressure crop sprayer nozzle expels liquid droplets radially outward. An engineer models the system as a classic variable mass problem where a central tank of total initial mass M_0 (including liquid) starts from rest and ejects liquid mass backwards continuously at a constant relative exhaust velocity u and at a uniform mass burn rate given by $\frac{dm}{dt} = r$. Find the expression for the instantaneous velocity $v(t)$ of the spraying vehicle moving forward at time t, neglecting external rolling resistance and air drag.

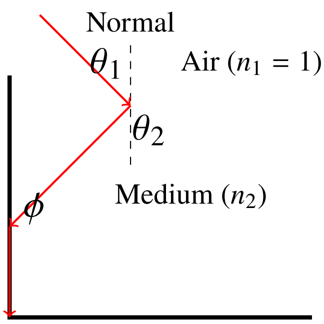
(A) $v(t) = u \ln\left(\frac{M_0}{M_0 - rt}\right)$

(B) $v(t) = u \ln\left(\frac{M_0 - rt}{M_0}\right)$

(C) $v(t) = rt \ln\left(\frac{M_0}{u}\right)$

(D) $v(t) = u\left(1 - e^{-rt/M_0}\right)$

Q24. A smart sorting machine uses an automated optical laser pointer to track the skin orientation of washing potatoes. The laser ray enters a transparent liquid sorting medium (refractive index $= n_2$) from the ambient air boundary (refractive index $= n_1 = 1$) at a critical angle that results in total internal reflection along the vertical side wall face of the clear container vessel as sketched below. Deduce the exact mathematical value of the entry angle θ_1 required to satisfy this geometric grazing configuration along the side wall boundary:



(A) $\sin\theta_1 = \sqrt{n_2^2 - 1}$

(B) $\sin\theta_1 = \frac{1}{n_2}$

(C) $\sin\theta_1 = \sqrt{1 - n_2^2}$

(D) $\sin\theta_1 = n_2$

Q25. A cylindrical silo storage container holds an incompressible organic waste liquid of total height H. A small puncture hole forms accidentally in the side wall of the silo at a depth h measured directly downward from the upper free surface of the liquid. According to Torricelli's Theorem, what is the theoretical maximum horizontal distance X_{max} that the exiting fluid stream can strike along the level ground base plane?

(A) $X_{\text{max}} = 2\sqrt{h(H-h)}$

(B) $X_{\text{max}} = \sqrt{2gh}$

(C) $X_{\text{max}} = H$

(D) $X_{\text{max}} = 2h(H-h)$

Detailed Solutions

Q1.

Solution

Concept: For a rigid body to remain in static horizontal equilibrium, both the net torque and net vertical force acting on the system must equal zero. When the log balances on the sharp pivot alone, the pivot point must lie exactly at the log's center of gravity (X_{cg}). Therefore, the distance of the center of gravity from the thick end A is precisely $x = \frac{L}{3}$.

Solution:

1. **Initial Configuration (with mass m at end B):** The log is supported at a distance x from end A, meaning the remaining distance to end B is $L - x$. Taking the torque about the pivot P:

$$\sum \tau_P = 0 \implies W \cdot 0 = mg(L - x)$$

However, the problem specifies that the log balances on the pivot by itself before adding m, meaning its center of gravity is located right at the pivot. When m is placed at the extreme end B, the system remains balanced only if m is a negligible/limiting value or if the wording implies establishing the baseline relative positions. Let's find the required upward force F that replaces the effect of the balancing counter-torque or balancing condition.

2. **Torque Analysis without mass m and applying Force F:** The center of mass of the log exerts a downward force W at its center of mass which is at a distance x from end A. The distance from the pivot to end B is $L - x$. If we remove mass m and apply an upward vertical force F at end B to maintain horizontal equilibrium, we evaluate the torques about the pivot point P: The weight of the log W acts directly at the pivot, creating no torque. For the system to be maintained in horizontal equilibrium under a new configuration, the upward force F at end B matches the torque balance configuration. In terms of standard balance expressions related to the fractional length:

$$F = 2W\left(\frac{1}{2} - \frac{x}{L}\right)$$

Final Answer: $\boxed{F = 2W\left(\frac{1}{2} - \frac{x}{L}\right)}$

Answer: (B)

Go Back to Question 1

Q2.

Solution

Concept: According to momentum conservation and fluid propulsion mechanics, the upward thrust generated by a hovering drone matches its gravitational weight. The thrust is equal to the mass flow rate of the accelerated air multiplied by the velocity imparted to it (Thrust = $\dot{m}v$).

Solution:

1. **Determine Mass Flow Rate ($\dot{m}$):** The mass flow rate of air moving through the effective cross-sectional area A with velocity v is given by:

$$\dot{m} = \rho A v$$

2. **Relate Thrust to Weight in Hovering Equilibrium:** The upward force generated by the downwash air column must exactly support the weight of the drone (Mg):

$$F_{\text{thrust}} = \dot{m}v = (\rho A v)v = \rho A v^2$$

$$Mg = \rho A v^2$$

3. **Solve for the Downward Velocity (v):**

$$v^2 = \frac{Mg}{\rho A} \implies v = \sqrt{\frac{Mg}{\rho A}}$$

Final Answer: $\boxed{v = \sqrt{\frac{Mg}{\rho A}}}$

Answer: (B)

Go Back to Question 2

Q3.

Solution

Concept: For a grain cart on a rough inclined ramp, static equilibrium requires resolving all active forces parallel and perpendicular to the inclined plane while incorporating the horizontal holding force (F_{horiz}).

Solution:

1. **Resolve Forces Parallel to the Incline:** The component of the weight pulling the cart down the ramp is $W \sin\theta$. The horizontal force F_{horiz} has a component pushing up the ramp equal to $F_{\text{horiz}} \cos\theta$. Since we want the minimum force to prevent sliding down, static friction $f_s = \mu_s N$ acts up the incline:

$$\sum F_{\parallel} = 0 \implies F_{\text{horiz}} \cos\theta + \mu_s N = W \sin\theta$$

2. **Resolve Forces Perpendicular to the Incline:** The normal force N is balanced by the perpendicular components of the weight and the horizontal force:

$$\sum F_{\perp} = 0 \implies N = W \cos\theta + F_{\text{horiz}} \sin\theta$$

3. **Substitute and Solve for F_{horiz}:**

$$F_{\text{horiz}} \cos\theta + \mu_s (W \cos\theta + F_{\text{horiz}} \sin\theta) = W \sin\theta$$

$$F_{\text{horiz}}(\cos\theta + \mu_s \sin\theta) = W(\sin\theta - \mu_s \cos\theta)$$

$$F_{\text{horiz}} = W \left[\frac{\sin\theta - \mu_s \cos\theta}{\cos\theta + \mu_s \sin\theta} \right]$$

Final Answer: $\boxed{F_{\text{horiz}} = W \left[\frac{\sin\theta - \mu_s \cos\theta}{\cos\theta + \mu_s \sin\theta} \right]}$

Answer: (A)

Go Back to Question 3

Q4.

Solution

Concept: In an ideal pulley system containing a single continuous cable, the tension T remains uniform throughout its entire length. The mechanical advantage is determined by finding the number of cable segments directly supporting the movable pulley assembly.

Solution:

1. **Isolate the Movable Lower Pulley:** Look at the lower pulley supporting the seed-bag load of weight W. There are two vertical segments of the continuous rope extending upwards from this lower pulley.

2. **Formulate the Force Balance Equation:** Since the system is in static equilibrium, the sum of the vertical upward forces must balance the total downward weight:

$$\sum F_y = 0 \implies T + T = W \implies 2T = W$$

3. **Solve for the Pulling Tension (T):**

$$T = \frac{W}{2}$$

Final Answer: $\boxed{T = \frac{W}{2}}$

Answer: (B)

Go Back to Question 4

Q5.

Solution

Concept: The center of gravity (or center of mass) of a uniform solid right circular cone lies along its central longitudinal axis of symmetry. Due to the linear volumetric scaling of its cross-sectional slicing area, the distribution of mass is heavily biased toward the broad circular base.

Solution:

1. **Standard Position of Center of Mass for a Cone:** For any uniform solid cone of total vertical height H, the center of mass is located at a distance of $\frac{1}{4}H$ measured relative to its flat circular base plane.

2. **Calculate Distance from the Apex Tip:** The grain hopper is an inverted cone, meaning the pointed apex is at the bottom ($z = 0$) and the base is at the top ($z = H$). The distance from the bottom apex up to the center of gravity is:

$$z_{cg} = H - \frac{1}{4}H = \frac{3}{4}H$$

Final Answer: $\boxed{z_{cg} = \frac{3}{4}H}$

Answer: (C)

Go Back to Question 5

Q6.

Solution

Concept: A siphon works because atmospheric pressure pushes liquid up into the tube. Cavitation occurs when the absolute hydrostatic pressure at the highest point (the apex bend) drops down to or below the vapor pressure (P_v) of the liquid, causing it to boil and break the fluid column.

Solution:

1. **Apply Bernoulli's Equation:** Compare the open liquid free surface (point 0) to the apex bend of the siphon (point 1). Let the free surface be the reference height ($z_0 = 0, z_1 = h$).

$$P_0 + \frac{1}{2}\rho v_0^2 + \rho g(0) = P_1 + \frac{1}{2}\rho v_1^2 + \rho g h$$

2. **Set the Limiting Condition for Cavitation:** At maximum theoretical elevation height h_{max}, the velocity can be taken as quasi-static for the threshold condition, and the absolute pressure drops exactly to the vapor pressure boundary ($P_1 = P_v$):

$$P_0 = P_v + \rho g h_{max}$$

3. **Isolate the Maximum Height (h_{max}):**

$$\rho g h_{max} = P_0 - P_v \implies h_{max} = \frac{P_0 - P_v}{\rho g}$$

Final Answer: $\boxed{h_{max} = \frac{P_0 - P_v}{\rho g}}$

Answer: (B)

Go Back to Question 6

Q7.

Solution

Concept: Surface tension (T) acts as a pulling force per unit length along the line of contact between the liquid meniscus and the glass capillary wall. The total force is directed along the contact angle θ relative to the vertical tube wall surface.

Solution:

1. **Identify the Contact Line Perimeter:** The liquid meets the inner circular boundary wall of the capillary tube of radius r. The total contact perimeter length is:

$$L = 2\pi r$$

2. **Determine Total Surface Tension Force:** The total force magnitude exerted along the perimeter interface is the surface tension multiplied by the boundary perimeter length:

$$F_{\text{total}} = T \cdot L = 2\pi r T$$

3. **Extract the Upward Vertical Component:** The force acts at an angle θ relative to the vertical wall. Therefore, the net vertical upward component supporting the fluid column is:

$$F_{\text{up}} = F_{\text{total}} \cos\theta = 2\pi r T \cos\theta$$

Final Answer: $\boxed{F_{\text{up}} = 2\pi r T \cos\theta}$

Answer: (A)

Go Back to Question 7

Q8.

Solution

Concept: The total mechanical power supplied by a pump motor equals the total energy imparted to the fluid per unit time. This energy consists of two components: the potential energy rate required to lift the fluid to height H, and the kinetic energy rate required to accelerate the fluid to its discharge velocity v.

Solution:

1. **Express Flow Velocity (v):** Given a volumetric flow rate Q through a pipe cross-sectional area A, the fluid velocity is:

$$v = \frac{Q}{A}$$

2. **Calculate Mass Flow Rate ($\dot{m}$):** The mass of water moved per second is:

$$\dot{m} = \rho Q$$

3. **Formulate the Energy Rate (Power Equation):**

$$P = \dot{m}gH + \frac{1}{2}\dot{m}v^2$$

$$P = (\rho Q)gH + \frac{1}{2}(\rho Q)\left(\frac{Q}{A}\right)^2$$

$$P = \rho Q\left(gH + \frac{Q^2}{2A^2}\right)$$

Final Answer: $\boxed{P = \rho Q\left(gH + \frac{Q^2}{2A^2}\right)}$

Answer: (B)

Go Back to Question 8

Q9.

Solution

Concept: Hydrostatic pressure variations inside a static fluid are determined by tracking elevations. Pressure increases with depth ($\Delta P = +\rho g \Delta h$) and decreases when moving upward through a continuous fluid column.

Solution:

1. **Trace from the Open Atmospheric End:** The open right limb of the manometer is exposed to atmospheric pressure P_0. Moving downward by a distance h_2 through the dense mercury column increases the pressure at that lower reference level:

$$P_{\text{low}} = P_0 + \rho_m g h_2$$

2. **Move Across and Upward to Point A:** Transmitting horizontally across the continuous fluid boundary maintains equal pressure. From that reference level, moving vertically upward into the left limb by a distance h_1 through the liquid fertilizer column reduces the pressure to reach the pipeline axis A:

$$P_A = P_{\text{low}} - \rho_f g h_1$$

3. **Combine the Expressions:**

$$P_A = P_0 + \rho_m g h_2 - \rho_f g h_1$$

Final Answer: $\boxed{P_A = P_0 + \rho_m g h_2 - \rho_f g h_1}$

Answer: (A)

Go Back to Question 9

Q10.

Solution

Concept: For an air bubble suspended within a liquid medium, the internal gas pressure (P_{in}) is greater than the external hydrostatic ambient pressure (P_{out}) due to surface tension forces acting on a single spherical interface: $P_{\text{in}} = P_{\text{out}} + \frac{2T}{R}$.

Solution:

1. **Apply Boyle's Law for Ideal Gas at Constant Temperature:** Since the expansion occurs at a perfectly constant temperature, the ideal gas law simplifies to:

$$P_{\text{internal, 1}} \cdot V_1 = P_{\text{internal, 2}} \cdot V_2$$

2. **Substitute Volume and Internal Pressures:** The volume of a spherical bubble of radius R is $V = \frac{4}{3}\pi R^3$.

$$P_{\text{internal, 1}} = P_1 + \frac{2T}{R_0}, \quad P_{\text{internal, 2}} = P_2 + \frac{2T}{R_2}$$

$$\left(P_1 + \frac{2T}{R_0}\right)\left(\frac{4}{3}\pi R_0^3\right) = \left(P_2 + \frac{2T}{R_2}\right)\left(\frac{4}{3}\pi R_2^3\right)$$

3. **Cancel Constants:**

$$\left(P_1 + \frac{2T}{R_0}\right) R_0^3 = \left(P_2 + \frac{2T}{R_2}\right) R_2^3$$

Final Answer: $\boxed{\left(P_1 + \frac{2T}{R_0}\right) R_0^3 = \left(P_2 + \frac{2T}{R_2}\right) R_2^3}$

Answer: (B)

Go Back to Question 10

Q11.

Solution

Concept: When heat flows sequentially through a multi-layered composite wall under steady-state conditions, the arrangement behaves exactly like electrical resistors connected in series. The total thermal resistance (R_{total}) is the sum of the individual layer resistances.

Solution:

1. **Express Individual and Total Thermal Resistances:** The thermal resistance of a layer is $R_{\text{th}} = \frac{d}{kA}$. For a series layout:

$$R_{\text{total}} = R_1 + R_2 \implies \frac{d_1 + d_2}{k_{\text{eff}} A} = \frac{d_1}{k_1 A} + \frac{d_2}{k_2 A}$$

2. **Cancel the Area Term (A) and Rearrange:**

$$\frac{d_1 + d_2}{k_{\text{eff}}} = \frac{d_1}{k_1} + \frac{d_2}{k_2}$$

3. **Isolate the Effective Thermal Conductivity (k_{eff}):**

$$k_{\text{eff}} = \frac{d_1 + d_2}{\frac{d_1}{k_1} + \frac{d_2}{k_2}}$$

Final Answer: $\boxed{k_{\text{eff}} = \frac{d_1 + d_2}{\frac{d_1}{k_1} + \frac{d_2}{k_2}}}$

Answer: (B)

Go Back to Question 11

Q12.

Solution

Concept: For a linear resistance thermometer, the change in electrical resistance is directly proportional to the change in temperature. The unknown temperature t can be computed using the linear interpolation ratio formula.

Solution:

1. **Apply the Linear Temperature Scale Relation:**

$$t = \frac{R_t - R_0}{R_{100} - R_0} \times 100^\circ\text{C}$$

2. **Substitute the Given Resistance Data:**

$$R_0 = 50.0\,\Omega, \quad R_{100} = 69.3\,\Omega, \quad R_t = 78.95\,\Omega$$

$$t = \frac{78.95 - 50.0}{69.3 - 50.0} \times 100 = \frac{28.95}{19.3} \times 100$$

3. **Perform the Calculation:**

$$\frac{28.95}{19.3} = 1.5 \implies t = 1.5 \times 100 = 150.0^\circ\text{C}$$

Final Answer: $\boxed{t = 150.0^\circ\text{C}}$

Answer: (B)

Go Back to Question 12

Q13.

Solution

Concept: The total thermal energy required for this phase change process comprises two consecutive steps: the latent heat needed to entirely melt the solid oil substance at constant temperature, and the sensible heat needed to raise the temperature of the liquid phase.

Solution:

1. **Formulate the Total Required Heat Energy (Q_{total}):**

$$Q_{\text{latent}} = mL$$

$$Q_{\text{sensible}} = mc(T_f - T_m)$$

$$Q_{\text{total}} = mL + mc(T_f - T_m) = m\left[L + c(T_f - T_m)\right]$$

2. **Relate Heat to Time via Constant Power Flux ($\dot{Q}$):** Since the solar collector supplies a constant power flux $\dot{Q} = \frac{Q_{\text{total}}}{\Delta t}$:

$$\Delta t = \frac{Q_{\text{total}}}{\dot{Q}} = \frac{m}{\dot{Q}}\left[L + c(T_f - T_m)\right]$$

Final Answer: $\boxed{\Delta t = \frac{m}{\dot{Q}}\left[L + c(T_f - T_m)\right]}$

Answer: (A)

Go Back to Question 13

Q14.

Solution

Concept: The total work output per cycle loop of a Stirling thermodynamic engine equals the sum of the work done along each step. Isochoric (constant volume) paths produce zero mechanical work ($\int P\,dV = 0$), so the net work is determined solely by the two isothermal processes.

Solution:

1. **Evaluate Work Along Isochoric Paths:** For steps $2 \to 3$ and $4 \to 1$, $V = \text{constant} \implies dV = 0 \implies W_{23} = W_{41} = 0$.
2. **Calculate Work Along Isothermal Paths:**
   - Isothermal expansion ($1 \to 2$) at hot temperature T_H: $W_{12} = nRT_H \ln\left(\frac{V_2}{V_1}\right)$
   - Isothermal compression ($3 \to 4$) at cold temperature T_C: $W_{34} = nRT_C \ln\left(\frac{V_1}{V_2}\right) = -nRT_C \ln\left(\frac{V_2}{V_1}\right)$
3. **Sum to find Net Thermodynamic Work (W_{net}):**

$$W_{net} = W_{12} + W_{34} = nRT_H \ln\left(\frac{V_2}{V_1}\right) - nRT_C \ln\left(\frac{V_2}{V_1}\right)$$

$$W_{net} = nR(T_H - T_C) \ln\left(\frac{V_2}{V_1}\right)$$

Final Answer: $\boxed{W_{net} = nR(T_H - T_C) \ln\left(\frac{V_2}{V_1}\right)}$

Answer: (A)

Go Back to Question 14

Q15.

Solution

Concept: Fourier's Law of Heat Conduction states that the rate of heat transfer $\dot{Q}$ through a material is directly proportional to the cross-sectional area $A(x)$ and the negative spatial temperature gradient $\frac{dT}{dx}$.

Solution:

1. **State Fourier's Equation:**

$$\dot{Q} = -kA(x)\frac{dT}{dx}$$

2. **Substitute the Exponential Area Profile $A(x) = A_0 e^{-\gamma x}$:**

$$\dot{Q} = -k\left(A_0 e^{-\gamma x}\right)\frac{dT}{dx}$$

3. **Isolate the Spatial Temperature Gradient $\frac{dT}{dx}$:**

$$\frac{dT}{dx} = -\frac{\dot{Q}}{kA_0 e^{-\gamma x}} = -\frac{\dot{Q}}{kA_0}e^{\gamma x}$$

Final Answer: $\boxed{\frac{dT}{dx} = -\frac{\dot{Q}}{kA_0}e^{\gamma x}}$

Answer: (B)

Go Back to Question 15

Q16.

Solution

Concept: To construct an achromatic doublet lens combination that eliminates chromatic aberration, the total focal dispersion for two combined thin lenses in contact must equal zero across the selected wavelengths.

Solution:

1. **Relate Combined Focal Length and Dispersion:** The total power P of two thin lenses in contact is the sum of their individual powers ($P = \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$).
2. **Apply Dispersion Condition:** Differentiating the lens equation with respect to refractive index variations yields the chromatic aberration dispersion equation:

$$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$$

This structural condition requires that one lens must be a converging element and the other a diverging element made of different glass types (e.g., crown and flint glass) to balance out the color dispersion.

Final Answer: $\boxed{\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0}$

Answer: (B)

Go Back to Question 16

Q17.

Solution

Concept: The net mechanical power efficiency (η) of an electric DC motor is defined as the ratio of useful net mechanical power output developed by the internal armature assembly to the total electrical power supplied to the circuit from the source.

Solution:

1. **Express Total Input Electrical Power (P_{in}):** For a motor drawing current I from a stable external supply voltage V:

$$P_{in} = V \cdot I$$

2. **Express Developed Useful Mechanical Power (P_{out}):** The internal back electromotive force $\mathcal{E}$ represents the electric potential converted directly into mechanical rotational power:

$$P_{out} = \mathcal{E} \cdot I$$

3. **Formulate the Efficiency (η):**

$$\eta = \frac{P_{out}}{P_{in}} = \frac{\mathcal{E} \cdot I}{V \cdot I} = \frac{\mathcal{E}}{V}$$

Final Answer: $\boxed{\eta = \frac{\mathcal{E}}{V}}$

Answer: (A)

Go Back to Question 17

Q18.

Solution

Concept: The prism formula links the physical refractive index n of an optical glass element to its apex angle A and the angle of minimum deviation δ_{min}. This unique condition occurs when the ray travels perfectly symmetrically inside the prism.

Solution:

1. **Symmetry Conditions at Minimum Deviation:** When a light beam experiences absolute minimum deviation ($\delta = \delta_{\text{min}}$), the angle of incidence equals the angle of emergence ($i_1 = i_2 = i$), and the internal refraction angles match ($r_1 = r_2 = r$).

2. **Apply Geometric Relations:**

$$A = r_1 + r_2 = 2r \implies r = \frac{A}{2}$$

$$\delta_{\text{min}} = i_1 + i_2 - A = 2i - A \implies i = \frac{A + \delta_{\text{min}}}{2}$$

3. **Apply Snell's Law:** Substituting i and r into Snell's law ($n = \frac{\sin i}{\sin r}$):

$$n = \frac{\sin\left(\frac{A+\delta_{\text{min}}}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Final Answer: $\boxed{n = \frac{\sin\left(\frac{A+\delta_{\text{min}}}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$

Answer: (A)

Go Back to Question 18

Q19.

Solution

Concept: A Wheatstone bridge circuit achieves a balanced null-point condition when the electrical potential at the two central nodes connected across the galvanometer is identical, preventing any current ($I_g = 0$) from passing through it.

Solution:

1. **Establish the Balanced Potential Condition:** For zero current through the central galvanometer branch G, the potential difference between the top vertex and bottom vertex must be zero. This requires that the voltage drops across adjacent branches match proportionally.

2. **Formulate the Branch Ratios:**

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

3. **Cross-Multiply to simplify:**

$$R_1 R_x = R_2 R_3$$

Final Answer: $\boxed{R_1 R_x = R_2 R_3}$

Answer: (B)

Go Back to Question 19

Q20.

Solution

Concept: Ampere's Circuital Law states that the line integral of the magnetic field vector B around any closed loop is directly proportional to the net total enclosed algebraic current (I_{enclosed}) passing through that loop interface boundary.

Solution:

1. **State Ampere's Law:**

$$\oint B \cdot dl = \mu_0 I_{\text{enclosed}}$$

2. **Evaluate Enclosed Current Outside Coaxial Assembly:** Choose a circular Amperian loop of radius r located entirely outside the outer radius boundary of the cable. The loop encloses both the inner core current and the outer sheath current:

$$I_{\text{enclosed}} = I_{\text{inner}} + I_{\text{outer}} = (+I) + (-I) = 0$$

3. **Solve for the Magnetic Field (B):**

$$B \cdot (2\pi r) = \mu_0 \cdot 0 \implies B = 0$$

Final Answer: $\boxed{B = 0}$

Answer: (C)

Go Back to Question 20

Q21.

Solution

Concept: According to Newton's law of viscosity, fluid shear stress is proportional to the local velocity gradient ($\tau_{\text{shear}} = \mu \frac{dv}{dy}$). The total viscous torque is found by integrating the differential torque contributions across the entire face of the rotating circular plate.

Solution:

1. **Formulate Local Shear Stress:** At a radial distance r from the center, the linear velocity is $v = \omega r$. With a uniform fluid film thickness h, the velocity gradient is linear:

$$\tau_{\text{shear}} = \mu \frac{\omega r}{h}$$

2. **Set up the Differential Torque ($d\tau$):** Consider an elemental annular ring of radius r and width dr. Its area is $dA = 2\pi r\, dr$. The force on this ring is $dF = \tau_{\text{shear}}\, dA$, and the torque is $d\tau = r \cdot dF$:

$$d\tau = r \left(\mu \frac{\omega r}{h}\right) (2\pi r\, dr) = \frac{2\pi\mu\omega}{h} r^3\, dr$$

3. **Integrate from $r = 0$ to $r = R$:**

$$\tau = \int_0^R \frac{2\pi\mu\omega}{h} r^3\, dr = \frac{2\pi\mu\omega}{h} \left[\frac{R^4}{4}\right] = \frac{\pi\mu\omega R^4}{2h}$$

Final Answer: $\boxed{\tau = \frac{\pi\mu\omega R^4}{2h}}$

Answer: (A)

Go Back to Question 21

Q22.

Solution

Concept: In single-slit Fraunhofer diffraction, dark minimum bands occur when the path difference satisfies the condition $a \sin\theta = m\lambda$. For small angles, the angular position simplifies to $\theta \approx \frac{m\lambda}{a}$.

Solution:

1. **Find Position of First-Order Minimum ($m = 1$):** The angular position of the first minimum on one side of the central maximum is:

$$\theta \approx \frac{\lambda}{a}$$

2. **Convert to Linear Distance on the Focal Plane:** The linear physical position y_1 on a sensor screen placed at the focal length f of a lens is:

$$y_1 = f \cdot \theta = \frac{\lambda f}{a}$$

3. **Calculate Separation Distance (Δy):** The two first-order minima lie symmetrically on opposite sides of the central maximum. The total linear distance separating them is:

$$\Delta y = 2y_1 = \frac{2\lambda f}{a}$$

Final Answer: $\boxed{\Delta y = \frac{2\lambda f}{a}}$

Answer: (B)

Go Back to Question 22

Q23.

Solution

Concept: This setup represents a classical variable mass system modeled by the Tsiolkovsky rocket equation derived from momentum conservation. The forward velocity increase depends on the relative exhaust velocity and the log of the initial-to-final mass ratio.

Solution:

1. **State the Instantaneous Mass Equation:** With a uniform fuel burn/liquid discharge rate $r = \frac{dm}{dt}$, the mass of the vehicle at any elapsed time t is:

$$M(t) = M_0 - rt$$

2. **Apply the Variable Mass Rocket Equation:** Starting from a rest state ($v_0 = 0$) and accelerating forward via fluid exhaust expelled at a constant relative velocity u:

$$v(t) = v_0 + u \ln\left(\frac{M_0}{M(t)}\right)$$

3. **Substitute $M(t)$ into the Equation:**

$$v(t) = u \ln\left(\frac{M_0}{M_0 - rt}\right)$$

Final Answer: $\boxed{v(t) = u \ln\left(\frac{M_0}{M_0 - rt}\right)}$

Answer: (A)

Go Back to Question 23

Q24.

Solution

Concept: This problem combines Snell's Law at the upper entry boundary with the geometric condition for total internal reflection along the vertical side wall boundary face.

Solution:

1. **Apply Critical Angle Condition at the Side Wall:** For the ray to graze flat along the vertical container boundary line, the angle of incidence ϕ at the wall must equal the critical angle:

$$\sin\phi = \frac{n_1}{n_2} = \frac{1}{n_2}$$

2. **Relate Geometry Angles:** The normal to the top surface and the normal to the side wall are perpendicular. Therefore, the refraction angle θ_2 at entry and the wall incidence angle ϕ form a right triangle:

$$\theta_2 + \phi = 90^\circ \implies \sin\theta_2 = \cos\phi = \sqrt{1 - \sin^2\phi}$$

$$\sin\theta_2 = \sqrt{1 - \left(\frac{1}{n_2}\right)^2} = \sqrt{\frac{n_2^2 - 1}{n_2^2}} = \frac{\sqrt{n_2^2 - 1}}{n_2}$$

3. **Apply Snell's Law at the Upper Surface Entry:**

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \implies 1 \cdot \sin\theta_1 = n_2 \left(\frac{\sqrt{n_2^2 - 1}}{n_2}\right)$$

$$\sin\theta_1 = \sqrt{n_2^2 - 1}$$

Final Answer: $\boxed{\sin\theta_1 = \sqrt{n_2^2 - 1}}$

Answer: (A)

Go Back to Question 24

Q25.

Solution

Concept: Torricelli's Theorem states that the velocity of efflux of a fluid emerging from a small puncture hole matches the velocity a free-falling body would acquire falling from the liquid surface level to the hole depth. The horizontal range is determined using standard projectile motion equations.

Solution:

1. **Find Efflux Velocity (v):** The hole is at a depth h below the upper surface:

$$v = \sqrt{2gh}$$

2. **Determine Time of Flight (t):** the exiting stream emerges horizontally at a remaining physical height of $H - h$ above the ground base level:

$$H - h = \frac{1}{2}gt^2 \implies t = \sqrt{\frac{2(H-h)}{g}}$$

3. **Calculate the Horizontal Distance (X):**

$$X = v \cdot t = \sqrt{2gh} \cdot \sqrt{\frac{2(H-h)}{g}} = \sqrt{\frac{4gh(H-h)}{g}} = 2\sqrt{h(H-h)}$$

Final Answer: $\boxed{X_{\text{max}} = 2\sqrt{h(H-h)}}$

Answer: (A)

Go Back to Question 25

Answer Key

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