1) A 210 g, 22-cm-diameter plastic disk is spun on a horizontal axle through its center by an electric motor.
   a) What torque must the motor supply to take the disk from 0 to 1800 rpm (revolutions per minute) in 4.0 s?
   b) What is the magnitude of the force that the disk exerts onto the axle?

\[ \text{a) } 0.060 \text{ N.m} \]

\[ \text{b) } 2.1 \text{ N} \]

2) A merry-go-round is a common piece of playground equipment. A 3.0-m-diameter merry-go-round with a mass of 250 kg is spinning at 22 rpm. John runs tangent to the merry-go-round at 5.0 m/s, in the same direction that it is turning, and jumps onto the outer edge. John's mass is 34 kg. What is the merry-go-round's angular velocity, in rpm, after John jumps on?

\[ \omega_2 = 24 \text{ rpm} \]

\[ \omega_1 = 2.30 \frac{\text{rad}}{s} \]

\[ I \omega_1 + r (m_j v) = (I + \frac{1}{2} m_j r^2) \omega_2 \]

\[ \frac{1}{2} (250 \text{ kg})(1.5 \text{ m})^2 (2.30 \frac{\text{rad}}{s}) + (1.5 \text{ m})(34 \text{ kg})(5 \text{ m/s}) = \frac{1}{2} (250 \text{ kg})(1.5 \text{ m})^2 + (34 \text{ kg})(5 \text{ m/s}) \omega_2 \]

\[ \omega_2 = 2.52 \frac{\text{rad}}{s} \left( \frac{60 \text{ s}}{\text{min}} \right) \left( \frac{1 \text{ rpm}}{\frac{\text{rad}}{s}} \right) = 24.1 \text{ rpm} \]
3) Two friends are carrying a 200. kg crate up a flight of stairs. The crate is 1.25 m long and 0.500 m high, and its center of gravity is at its center. The stairs make a 45.0° angle with respect to the floor. The crate also is carried at a 45.0° angle, so that its bottom side is parallel to the slope of the stairs.
   a) If the force each person applies is vertical, what is the magnitude of each of these forces?
   b) Is it better to be the person above or below on the stairs?

\[
\begin{align*}
N_A &= 1370 \text{ N} \\
N_B &= 589 \text{ N}
\end{align*}
\]

\[
\mathbf{\sum F}_y = N_A - mg + N_B = 0
\]

\[
\Rightarrow N_A = mg - N_B = -589.4 \text{ N} + 200 \text{ kg} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \times 0.500 \text{ m}
\]

\[
N_A = 1373.4 \text{ N}
\]

\[
\mathbf{\sum L}_A = -mg \text{cos} 45° + N_B \left( 1.25 \text{ m} \cdot \text{cos} 45° \right)
\]

\[
\Rightarrow N_B = \frac{200 \text{ kg} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \cdot \text{cos} 45°}{1.25 \text{ m} \cdot \text{cos} 45°}
\]

\[
N_B = 589.6 \text{ N}
\]

4) **Stress on the Shin Bone.** Compressive strength of our bones is important in everyday life. Young's modulus for bone is about \(1.4 \times 10^{10}\) Pa. Bone can take only about a 1.0% change in its length before fracturing. What is the maximum force that can be applied to a bone whose minimum cross-sectional area is 3.0 cm\(^2\)? (This is approximately the cross-sectional area of a tibia, or shin bone, at its narrowest point.)

\[
F = 42,000 \text{ N}
\]

\[
\epsilon = \frac{A_f}{L} = 0.01
\]

\[
\sigma = F \epsilon = 1.4 \times 10^{10} \frac{\text{N}}{\text{m}^2} \times (0.01) = 1.4 \times 10^8 \frac{\text{N}}{\text{m}^2}
\]

\[
\sigma = \frac{F}{A} \Rightarrow F = \sigma A = 1.4 \times 10^8 \frac{\text{N}}{\text{m}^2} \left( 3 \text{ cm}^2 \right) \left( \frac{1 \text{ m}}{100 \text{ cm}} \right)^2
\]

\[
F = 42,000 \text{ N}
\]

about 9400 lb
5) A simple harmonic oscillator consists of a mass of 2.2 kg sliding back and forth along a horizontal frictionless track while pushed and pulled by a spring with \( k = 810 \text{ N/m} \). Suppose that when the mass is at the equilibrium point, it has an instantaneous speed of 3.2 m/s.

a) What is the energy of the oscillator?

b) What is the amplitude of oscillation?

\[
\begin{align*}
\text{a) } & \quad 11 \text{ N-m (J)} \\
\text{b) } & \quad 0.17 \text{ m}
\end{align*}
\]

\[
\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{810 \text{ N/m}}{2.2 \text{ kg}}} = 19.2 \text{ rad/s}
\]

\( \text{Equil. (No stretch in spring)} \quad v = 3.2 \text{ m/s} = v_{\text{max}} \)

So for oscillator at equil,

\[ E = \frac{1}{2} k A^2 = \frac{1}{2} (810 \text{ N/m})(0.17 \text{ m})^2 = 11.3 \text{ N-m (J)} \]

6) A circular painting of 2.10 m diameter has uniform thickness. It hangs on a wall, suspended by a nail 12 cm from the top edge. If it is pushed slightly, what is the period of small oscillations of the painting?

\[
T = 2.5 \text{ sec}
\]

\[
\begin{align*}
\text{Physical Pendulum} \\
I = I_{cm} + ML^2 \\
= \frac{1}{2} MR^2 + M (0.93 \text{ m})^2 \\
\text{From Table} \\
= \frac{1}{2} M (1.05 \text{ m})^2 + M (0.93 \text{ m})^2 \\
= 1.42 M \text{ kg m}^2
\end{align*}
\]

\[
T = 2\pi \sqrt{\frac{I}{MgR}}
\]

\[
= 2\pi \sqrt{\frac{1.42 M}{9.81 \text{ m/s}^2} (0.93 \text{ m})^2}
\]

\[
= 2.48 \text{ sec}
\]
7) Water enters a house through a pipe with an inside diameter of 2.0 cm at an absolute pressure of 4.0 \times 10^5 \text{ Pa (about 4 atm). A 1.0-cm-diameter pipe leads to the second-floor bathroom 5.0 m above. The flow speed at the inlet pipe (point 1) is 1.5 m/s. Determine the pressure in the bathroom (point 2).}

\[
P_2 = 3.3 \times 10^5 \text{ Pa}
\]

\[
A_1 u_1 = A_2 u_2
\]

\[
\frac{u_1}{u_2} = \frac{A_2}{A_1}
\]

\[
u_1 = 1.5 \text{ m/s} \left( \frac{\left( \frac{2 \text{ cm}}{1 \text{ cm}} \right)^2}{\left( \frac{1 \text{ cm}}{1 \text{ cm}} \right)^2} \right)
\]

\[
u_2 = 6.0 \text{ m/s}
\]

\[
P_2 = P_1 + \frac{1}{2} \rho \left( u_1^2 - u_2^2 \right) - \rho g \Delta y
\]

\[
P_2 = 4.0 \times 10^5 \text{ Pa} + \frac{1}{2} (1000 \frac{\text{ kg}}{\text{ m}^3}) (1.5 \text{ m})^2 - (6.0 \text{ m})^2 - 1000 \frac{\text{ kg}}{\text{ m}^3} (9.8 \text{ m/s}^2) (5 \text{ m})
\]

\[
P_2 = 3.3 \times 10^5 \text{ Pa}
\]

8) A deep-sea diver is suspended beneath the surface of Loch Ness by a 102-m-long cable that is attached to a boat on the surface. The diver and his suit have a total mass of 122 kg and a volume of 0.0800 m\(^3\). The cable has a diameter of 2.00 cm and a linear mass density of 1.15 kg/m. Calculate the tension (\(T\)) in the cable at its upper end, where it is attached to the boat.

\[
T = 12250 \text{ N}
\]

\[
\Sigma F_y = T + F_{bc} - m_c g + F_{bd} - m_D g = 0
\]

\[
T = (m_D + m_c) g - F_{bd} - F_{bc}
\]

\[
T = (m_D + m_c) g - (V_D + V_c) P_w g
\]

\[
T = (122 \text{ kg} + 1.15 \frac{\text{ kg}}{\text{ m}} (102 \text{ m}) - \left[ 0.08 \text{ m}^3 + \frac{7}{4} (0.02 \text{ m})^2 (102 \text{ m}) \right] \frac{1000 \frac{\text{ kg}}{\text{ m}^3}}{\text{ s}^2}
\]

\[
T = 1248 \text{ N}
\]
9) A Carbon Dioxide (CO₂) fire extinguisher has an interior volume of 2.8 \times 10^{-3} \text{ m}^3. The extinguisher has a mass of 5.9 \text{ kg} when empty and 8.2 \text{ kg} when fully charged. At a temperature of 20. \degree \text{C}, what is the pressure of CO₂ in the extinguisher?

\[ P = 45 \text{ MPa} \]
Assume CO₂ is an ideal gas.

\[ \frac{P}{V} = \frac{m}{RT} \]

\[ P \left(0.0028 \text{ m}^3\right) = \frac{2.3 \text{ kg} \times 8.315 \text{ J/mol K}}{(44 \text{ J/mol K})} \times (293 \text{ K}) \times \frac{1000}{\text{ kg}} \]

\[ P = 45.48 \text{ MPa} \]

10) A simple gadget for heating water for showers consists of a black plastic bag holding 12 liters of water. It has a surface area of 0.14 \text{ m}^2 on each side of the bag. When hung in the sun, the bag absorbs heat. On a clear, sunny day, the power delivered by sunlight per unit area facing the sun is 1,100 \text{ W/m}^2. How long would it take to heat the water from 20. \degree \text{C} to 50. \degree \text{C} with this device? Assume for this calculation that the bag loses no heat to the environment.

\[ \Delta t = 2.7 \text{ hr} \]
11) A ball of lead of mass 0.25 kg drops from a height of 0.80 m, hits the floor, and remains there at rest. Assume that all the heat generated during the impact remains within the lead.
   a) What are the values of $Q$, $W$, and $\Delta U$ for this process?
   b) What is the increase in temperature of the lead?

   (For full credit, you must define your thermodynamic system)

   \[ a) \ Q = 0 \quad b) \ \Delta T = 0.60^\circ C \]

   \[ \begin{align*}
   W &= -2.0 \text{ J} \\
   \Delta U &= 2.0 \text{ J}
   \end{align*} \]

   \[ \text{System = Lead Ball} \]

   \[ \Delta U = \delta Q - W \]

   \[ \text{No HT from surroundings} \]

   \[ W = m \cdot g \cdot \Delta h = 0.25 \text{ kg} \cdot (9.81 \text{ m/s}^2) \cdot (0.8 \text{ m}) \]

   \[ = -1.96 \text{ J (Boundary Deforms, Work on System)} \]

   \[ \Delta U = 0 - (-1.96) \text{ J} = m \cdot c \cdot \Delta T \]

   \[ 1.96 \text{ J} = (0.25 \text{ kg}) \cdot (0.3 \text{ kcal/kg}^\circ C) \cdot (\Delta T) \cdot (0.18 \text{ kcal}) \]

12) Uncle Joe is at it again. He knows the last heat engine he tried to get you to invest in didn’t work, so he’s fine-tuned his calculations and has a new proposal. He operates his device in reverse and claims it functions as a heat pump supplying 6.5 kJ to a house at 45 $^\circ$C, extracting 5.4 kJ of energy from the outside at -12 $^\circ$C, while requiring only 1.1 kJ of work input. Should you believe your uncle? Answer yes or no and state why or why not.

   \[ \text{NO, VIOLATES 2nd LAW} \]

   \[ \text{1st Law:} \quad Q_L + W = Q_H \]

   \[ 5.4 \text{ kJ} + 1.1 \text{ kJ} = 6.5 \text{ kJ} \quad \text{OR} \]

   \[ \text{2nd Law:} \quad \frac{Q_H}{W} = \frac{T_H}{T_H - T_L} \]

   \[ = \frac{5.4 \text{ kJ}}{1.1 \text{ kJ}} = \frac{45^\circ C}{45^\circ C - (-12^\circ C)} \]

   \[ \text{So for this HP, any HP can deliver no more than} \]

   \[ Q_H = 5.58 \text{ kcal} \cdot 1.1 \text{ kcal} = 6.14 \text{ kJ} \]

   \[ \text{(Joe Claims: 6.5 kJ)} \]