On my honor as a Texas A&M University student, I will neither give nor receive unauthorized help on this exam.

Name (printed)    Solution

The multiple-choice problems carry no partial credit. Circle the correct answer or answers. An answer is approximately correct if it is correct to 2 significant figures. **In the work-out problems, you are graded on your work, with partial credit.** (The answer by itself is not enough, and you receive credit only for your work.) Be sure to include the correct units in the answers, and give your work in the space provided.

[Note that maximum credit on exam = 170 points. Use your time wisely.]

heat of fusion for water = 334 × 10³ J/kg
heat capacity of water = 4.19 × 10³ J/(kg K)
heat capacity of ice = 2.01 × 10³ J/(kg K)

1. (5) If a 5 lb force is required to keep a block of wood 1 ft beneath the surface of water, the force required to keep it 2 ft below the surface is

(a) 2.5 lb
(b) 5 lb
(c) 10 lb

**same buoyant force, same weight**

2. (5) There is a great deal of ice floating on the oceans near the North Pole. If this ice were to melt due to global warming, what would happen to the level of the oceans?

(a) The level would rise.
(b) The level would fall.
(c) The level would stay the same.

**Ice and water that it turns into have to be supported by the same buoyant force, so they displace the same amount of other water**

3. (5) Which of the following processes would be a violation of the second law of thermodynamics? (There may be more than one correct choice.)

(a) All of the kinetic energy of an object is transformed into heat.
(b) All the heat put into the operating gas of a heat engine during one cycle is transformed into work.
(c) A refrigerator removes 100 cal of heat from milk while using only 75 cal of electrical energy to operate.
(d) A heat engine does 25 J of work while expelling only 10 J of heat to the cold reservoir.
4. (5) Consider an ideal gas, and let \( U \) be the internal energy, \( n \) the number of moles, \( C_V \) the molar heat capacity at constant volume, and \( T \) the temperature.

The formula \( \Delta U = nC_V \Delta T \) is true for (circle all correct answers)

(a) an isothermal process  
(b) an adiabatic process  
(c) a process at constant volume  
(d) a process at constant pressure  

always true for any process

5. (5) In an inelastic collision, which of the following are conserved?

(a) kinetic energy  
(b) momentum  
(c) entropy  
(d) none of the above

6. (5) Four objects are allowed to roll (without slipping) down a wide inclined plane, all starting from rest at the same time: a solid cylinder, a thin-walled hollow cylinder, a solid sphere, and a thin-walled hollow sphere. Each has a mass \( M \) and a radius \( R \).

Which is the LAST to reach the bottom?

Moment of inertia = \( \frac{2}{5} MR^2 \) for solid sphere

= \( \frac{1}{2} MR^2 \) for solid cylinder

= \( \frac{2}{3} MR^2 \) for thin-walled hollow sphere

= \( MR^2 \) for thin-walled hollow cylinder

(a) solid sphere  
(b) solid cylinder  
(c) thin-walled hollow sphere  
(d) thin-walled hollow cylinder  
(e) They all arrive at the same time.

as seen in class, in demonstration:

largest total inertia \( \Rightarrow \) smallest acceleration

7. (5) Imagine a toy gun in which a ball is shot out when a spring is released. The force constant of the spring is 10 N/m, and it is compressed by 0.050 m. The mass of the ball is 0.020 kg.

If no energy is lost to friction, approximately what is the speed of the ball when it is shot out?

(a) 250 m/s  
(b) 25 m/s  
(c) 28.3 m/s  
(d) 1.12 m/s  
(d) none of the above

\[ \frac{1}{2} mv^2 = \frac{1}{2} k \Delta x^2 \]

\[ \Rightarrow v^2 = \frac{k \Delta x}{m} \]

\[ \Rightarrow v = \sqrt{\frac{k \Delta x}{m}} = \sqrt{\frac{10 \text{ N/m}}{0.020 \text{ kg}}} (0.050 \text{ m}) = 1.12 \text{ m/s} \]
8. (5) A steel ball is dropped from the top of the Leaning Tower of Pisa, which is 56 m high. With air resistance neglected, approximately how long does it take the ball to hit the ground?

\[ y_f - y_0 = v_{0y} t + \frac{1}{2} a_y t^2 \]

\[ \Rightarrow -56 = 0 + \frac{1}{2} (-9.8 \frac{m}{s^2}) t^2 \]

\[ \Rightarrow t^2 = \frac{2 \times 56}{9.8 \frac{m}{s^2}} \]

\[ \Rightarrow t = \sqrt{\frac{2 \times 56}{9.8 \frac{m}{s^2}}} = 3.45 \text{ s} \]

9. (5) Now suppose that you are climbing the Leaning Tower, and you throw your cellphone to a friend on the ground, who catches it at a point 30 m below the point where you released it.

You threw it straight out, with an initial horizontal velocity of 10 m/s (and zero initial vertical velocity).

Again neglecting air resistance, what is the speed of the cellphone when your friend catches it?

\[ v_{y}^2 = 0^2 + 2 (-9.8 \frac{m}{s^2})(30 \text{ m}) \]

\[ = 588 \frac{m^2}{s^2} \]

\[ \Rightarrow v^2 = v_x^2 + v_y^2 = \left(10 \frac{m}{s}\right)^2 + 588 \frac{m^2}{s^2} \]

\[ \Rightarrow v = \sqrt{26} \frac{m}{s} \]

Texas A&M students at the Leaning Tower of Pisa (in Study Abroad Program)

On the left is the cathedral of Pisa, where Galileo, as a 20 year old student watching the chandelier, and using his pulse as a clock, discovered that the period of a pendulum is independent of the amplitude of its swinging.
10. Prof. George Bass of Texas A&M (our version of Indiana Jones -- "Raiders of the Undersea Treasures") leads an expedition to retrieve an ancient Greek statue from the Mediterranean. It has a mass of 300 kg, and it is composed of stone with a density of $2.0 \times 10^3 \text{ kg/m}^3$. It is in water with a density of $1.0 \times 10^3 \text{ kg/m}^3$.

(a) (6) Calculate the volume of the statue.

\[
\text{volume} = \frac{0.15 \text{ m}^3}{\rho} \Rightarrow V = \frac{m}{\rho} = \frac{300 \text{ kg}}{2.0 \times 10^3 \text{ kg/m}^3} = 0.15 \text{ m}^3
\]

(b) (6) Calculate the buoyant force on the statue.

\[
F_B = \frac{1470 \text{ N}}{\text{Weight of water displaced}} = (\rho_{\text{water}} V) g = (1.0 \times 10^3 \text{ kg/m}^3)(0.15 \text{ m}^3)(9.8 \frac{m}{s^2}) = 1470 \text{ N}
\]

(c) (6) Calculate the tension in the wire that is used to hoist the statue.

\[
F_T = mg - F_B = (300 \text{ kg})(9.8 \frac{m}{s^2}) - 1470 \text{ N} = 1470 \text{ N}
\]
11. A chunk of ice with a mass of 20 kg falls into the ocean and melts. Initially, and throughout the melting process, it is at a temperature of $0^\circ$ C. The temperature of the very large body of ocean water around it is fixed at $5^\circ$ C.

(a) (6) Calculate the change in the entropy of the ice, as it is converted to liquid water, still at $0^\circ$ C.

change in entropy of ice = \[ \frac{24,455 \text{ J/K}}{273.15 \text{ K}} \]

\[
\begin{align*}
Q_{\text{ice}} &= m_{\text{ice}} L_f \\
&= (20 \text{ kg})(334 \times 10^3 \text{ J/kg}) \\
&= 6.68 \times 10^6 \text{ J} \\
(\Delta S)_{\text{ice}} &= \frac{Q_{\text{ice}}}{T_{\text{ice}}} \\
&= \frac{6.68 \times 10^6 \text{ J}}{273.15 \text{ K}} \\
&= 24,455 \frac{\text{J}}{\text{K}}
\end{align*}
\]

(b) (6) Calculate the change in the entropy of the ocean water as it supplies the heat to melt the ice.

change in entropy of ocean water = \[ -\frac{24,016 \text{ J/K}}{278.15 \text{ K}} \]

\[
\begin{align*}
(\Delta S)_{\text{ocean}} &= \frac{Q_{\text{ocean}}}{T_{\text{ocean}}} \\
&= \frac{-6.68 \times 10^6 \text{ J}}{278.15 \text{ K}} \\
&= -24,016 \frac{\text{J}}{\text{K}}
\end{align*}
\]

(c) (2) Calculate the total change in entropy, including its sign.

change in total entropy = \[ 439 \frac{\text{J}}{\text{K}} \]

\[
\begin{align*}
(\Delta S)_{\text{total}} &= 24,455 \frac{\text{J}}{\text{K}} - 24,016 \frac{\text{J}}{\text{K}} \\
&= 439 \frac{\text{J}}{\text{K}}
\end{align*}
\]
12. A Carnot refrigerator removes heat from the freezer at \(-10^\circ C\) and expels it into the room at \(20^\circ C\). You put a tray with \(0.50\) kg of water at \(30^\circ C\) into the freezer.

\[
T_C = 273 K - 10 K = 263 K \\
T_H = 273 K + 20 K = 293 K
\]

(a) Calculate the performance coefficient of this refrigerator.

\[
K_{carnot} = \frac{T_C}{T_H - T_C} = \frac{263 K}{293 K - 263 K} = 8.77
\]

(b) Calculate the heat energy extracted from this water when it is cooled and transformed to ice at \(-10^\circ C\).

\[
\frac{Q_c}{m_c} = m_{water} (30 K) + m_L f + m_{ice} (10 K)
\]

\[
= (0.50 \text{ kg}) (4.19 \times 10^3 \frac{J}{\text{kg} \cdot \text{K}}) (30 \text{ K}) \\
+ (0.50 \text{ kg}) (334 \times 10^3 \frac{J}{K}) \\
+ (0.50 \text{ kg}) (201 \times 10^3 \frac{J}{K}) (10 \text{ K})
\]

\[
= 62,850 J + 167,000 J + 10,050 J
\]

\[
= 239,900 J
\]

(c) Calculate the work done by the compressor of the refrigerator in order to achieve this transformation (of Part (b)).

\[
K = \frac{Q_c}{|W|} \Rightarrow |W| = \frac{Q_c}{K}
\]

\[
= \frac{239,900 J}{8.77}
\]

\[
= 27,460 J
\]

(d) Calculate the heat that the refrigerator expels into the room while achieving this transformation.

\[
|W| = |Q_H| - |Q_c|
\]

\[
\Rightarrow |Q_H| = 27,460 J + |Q_c|
\]

\[
= 27,460 J + 239,900 J
\]

\[
= 267,360 J
\]
13. In the $pV$ diagram on the right, 120 J of work was done by 0.12 mole of ideal gas during the adiabatic process $a \rightarrow b$.

1 atm = $1.013 \times 10^5$ Pa, 1 L = $10^{-3}$ m$^3$

(a) (4) How much heat entered or left this gas from $a$ to $b$?

heat = 0 [adiabatic]

(b) (4) By how much did the internal energy change?

change in internal energy = $-120$ J

\[ \Delta U = Q - W = -W = -120 \text{ J} \]

(c) (6) What is the temperature of the gas at $b$?

temperature at $b$ = 609 K

\[ pV = nRT \Rightarrow T = \frac{pV}{nR} \]

\[ = \frac{(1.013 \times 10^5 \text{ Pa})(6.00 \times 10^{-3} \text{ m}^3)}{(0.12 \text{ mol})(8.314 \text{ J mol}^{-1} \text{ K}^{-1})} \]

\[ = 609 \text{ K} \]
14. A 25 kg child plays on a swing having support ropes that are 3.0 m long. A friend pulls her back until the ropes are 45° from the vertical and releases her from rest.

(a) (5) What is the height of the child above her lowest point, at the moment she is released?
(You may want to draw a sketch.)

\[
\text{height} = \frac{0.879 \text{ m}}{3.0 \text{ m} - (3.0 \text{ m}) \cos 45°} = 3.0 \text{ m} - 2.121 \text{ m} = 0.879 \text{ m}
\]

(b) (5) What is the potential energy for the child just as she is released, compared with the potential energy at the bottom of the swing?

\[
U_{\text{grav}} = mgh = (25 \text{ kg})(9.8 \text{ m/s}^2)(0.879 \text{ m}) = 215 \text{ J}
\]

(b) (5) How fast will she be moving at the bottom of the swing?

\[
\frac{1}{2} mv^2 = mg \Delta h
\]

\[
\Rightarrow v = \sqrt{2gh} = \sqrt{(2)(9.8 \text{ m/s}^2)(0.879 \text{ m})} = 4.15 \text{ m/s}
\]
15. A 2.0 kg wooden ball is suspended from a vertical wire 10 m long. Clint Eastwood fires a .44 Magnum bullet, with a mass of 0.02 kg, into the ball. The ball (with bullet embedded) swings out and upward until it has reached a height of 0.70 meter (relative to its starting point), when it stops and begins to swing back.

(a) (4) Calculate the potential energy of the system (ball plus bullet) at the highest point.

\[
\text{potential energy at highest point} = \frac{14 \text{ J}}{(M+m)g h} = (2.0 \text{ kg} + 0.02 \text{ kg})(9.8 \text{ m/s}^2)(0.70 \text{ m}) = 14 \text{ J}
\]

(b) (4) Calculate the velocity of the system (ball plus bullet) at the lowest point.

\[
\text{velocity at lowest point} = \frac{3.7 \text{ m/s}}{\frac{1}{2} (M+m) v^2} = (M+m)gh
\]

\[
\Rightarrow v = \sqrt{2gh} = \sqrt{(2)(9.8 \text{ m/s}^2)(0.70 \text{ m})} = 3.7 \text{ m/s}
\]

(c) (4) Calculate the speed of the bullet before it hit the ball. (So we have determined the gun’s muzzle velocity.)

\[
\text{speed of bullet before it hit ball} = \frac{370 \text{ m/s}}{m \nu_b} = (M+m) \nu
\]

\[
\Rightarrow \nu_b = \frac{M+m}{m} \nu = \frac{2.02 \text{ kg}}{0.02 \text{ kg}} (3.7 \text{ m/s}) = 370 \text{ m/s}
\]
16. A block with mass $M$ rests on a frictionless surface and is connected to a spring with force constant $k$. The other end of the spring is attached to a wall, as shown in the figure. A second block, with mass $m$, rests on top of the first block. The coefficient of static friction between the blocks is $\mu_s$.

We wish to calculate $A_{\text{max}} = \text{maximum amplitude of oscillation such that the top block will not slip on the bottom block, in terms of the relevant constants.}$

Summary of all constants: $M, k, m, \mu_s, \text{acceleration of gravity } g$.

(a) (3) Obtain the maximum frictional force $f_{\text{max}}$ in terms of $\mu_s$ and other relevant constants.

\[
f_{\text{max}} = \mu_s mg
\]

\[
f_{\text{max}} = \mu_s N, \quad N = mg
\]

\[
\Rightarrow f_{\text{max}} = \mu_s mg
\]

(b) (3) Obtain the maximum acceleration $a_{\text{max}}$ (for no slipping) in terms of $f_{\text{max}}$ and the relevant mass.

\[
a_{\text{max}} = \frac{f_{\text{max}}}{m}
\]

\[
f_{\text{max}} = ma_{\text{max}}
\]

\[
\Rightarrow a_{\text{max}} = \frac{f_{\text{max}}}{m}
\]

(c) (3) Now obtain $a_{\text{max}}$ in terms of $A_{\text{max}}$ and the relevant constants.

\[
a_{\text{max}} = \frac{k}{M+m} A_{\text{max}}
\]

\[
a_{\text{max}} = -\frac{k}{M+m} \alpha \quad \text{[since } F = -k\alpha \text{ and } F = (M+m) a_{\text{ax}}]\]

\[
\Rightarrow a_{\text{max}} = \frac{k}{M+m} A_{\text{max}}
\]

(d) (3) Finally, obtain $A_{\text{max}}$ in terms of only the relevant constants.

\[
A_{\text{max}} = \frac{f_{\text{max}}}{k} \mu_s g
\]

\[
A_{\text{max}} = \frac{f_{\text{max}}}{m} = \frac{\mu_s mg}{m} = \mu_s g
\]

\[
\Rightarrow A_{\text{max}} = \frac{M+m}{k} \mu_s g
\]
17. A solid disk has a radius of $R = 0.10$ m and a mass of $M = 2.0$ kg. It begins rolling up a slope without slipping. The slope is $\theta = 20^\circ$ above the horizontal, and the disk has an initial speed of $v_0 = 3.0$ m/s. We wish to calculate how long it will take for the disk to come to a stop.

There are 2 unknowns:
(i) the frictional force $f$ acting at the circumference of the disk, a distance $R$ from the center
(ii) the center of mass acceleration $a_{cm}$.

We will have 2 equations:
(1) the translational equation net force $= Ma_{cm}$
(2) the rotational equation torque $= I_{cm} \alpha$

A comment: $\alpha$ is negative (clockwise) as drawn here. The frictional force exerted by the slope on the disk is positive, since it is opposite to the force exerted by the disk on the slope.

(a) (2) Draw a picture, showing $\theta$ and taking the positive $x$ axis to point up along the inclined surface.

(b) (2) Write down Eq. (1) (involving force) in terms of $f$, $M$, the acceleration of gravity $g$, $\theta$, and $a_{cm}$.

\[ f - Mg \sin \theta = Ma_{cm} \]

(c) (2) Write down Eq. (2) (involving torque) in terms of $R$, $f$, $I_{cm}$, and $\alpha$.

\[ Rf = I_{cm} \alpha \]

(d) (2) Write $\alpha$ in term of $a_{cm}$ and $R$.

$\alpha$ is positive, but $a_{cm}$ is negative:

\[ -a_{cm} = R \alpha \Rightarrow \alpha = \frac{-a_{cm}}{R} \]

(e) (2) Using the fact that $I_{cm} = \frac{1}{2} MR^2$, and your answers in Parts (c) and (d), write $f$ in terms of $M$ and $a_{cm}$.

\[ f = \frac{I_{cm} \alpha}{R} \]
\[ = \frac{\left( \frac{1}{2} MR^2 \right) \left( - \frac{a_{cm}}{R} \right)}{R} \]
\[ = \frac{1}{2} M (-a_{cm}) \]
(f) (2) Substitute your result for $f$ in Part (e) into Eq. (1), so that you have an equation with only the single unknown $a_{cm}$.

$$\frac{1}{2} M (-a_{cm}) - Mg \sin \theta = Ma_{cm}$$

(g) (2) Show that $a_{cm} = -\frac{2}{3} g \sin \theta$.

$$-Mg \sin \theta = \frac{3}{2} Ma_{cm}$$

$$\Rightarrow a_{cm} = -\frac{2}{3} g \sin \theta$$

You may use the result of Part (g) for full credit in the parts below even if you did not derive it.

(h) (2) Write down the equation that relates the velocity $v$ at the highest point that the disk reaches (before starting to roll back down) to the initial velocity $v_0$, the acceleration $a_{cm}$, and the time $t$ that elapses until it reaches this point.

$$v = v_0 + a_{cm} t$$

(i) (2) Substitute the result of Part (g) into the equation of Part (h), and then find $t$ in terms of $v_0$, $g$, and $\sin \theta$.

$$0 = v_0 - \left( -\frac{2}{3} g \sin \theta \right) t$$

$$\Rightarrow t = \frac{3v_0}{2g \sin \theta}$$

(j) (2) Calculate the time $t$ required for the disk to come to a stop.

$$t = \frac{(3)(3.0 \text{ m/s})}{(2)(9.8 \text{ m/s}^2)(\sin 20^\circ)} = 1.34 \text{ s}$$
18. (5 extra credit for a clear answer). In class we did the geyser demonstration: A flask contains a small amount of water which is heated until it boils away. The flask is then immediately turned upside and its open end is placed in a beaker containing blue liquid. After a moment, the blue liquid shoots up into the flask, like a geyser.

Give a clear explanation of why this happens for extra credit.

The flask is filled with water vapor, which then condenses into liquid water that has a much smaller volume. The pressure inside the flask is then very low, and atmospheric pressure pushes the blue liquid rapidly into the empty volume inside the flask.

Happy Holidays!