1. (10 points, 5 points each): A microwave can heat up 1 cup of water (237mL) from room temperature (20°C) to 80°C in 90 seconds. Recall the specific heat of water is 4.19 kJ/(kg·K), the latent heat of fusion is 333 kJ/kg, and the latent heat of vaporization is 2260 kJ/kg.

(a) What is the power delivered to the water?
(b) Assuming the same rate of power delivered to the water, how much additional time would it take to completely boil all of the water?

(a) \[ \text{Power} = \frac{\text{heat energy}}{\text{time}} = \frac{Q}{\Delta t} = \frac{m c_{\text{water}} \Delta T}{\Delta t} \]

\[ \text{Power} = \frac{(0.378)(4.19 \frac{\text{J}}{\text{g} \cdot \text{K}})(60 \text{°C})}{90 \text{ sec}} = 660 \text{ W} \]

(b) \[ Q_{\text{total}} = Q_{20^\circ \text{C} \rightarrow 100^\circ \text{C}} + Q_{\text{water steam}} \]

\[ = (0.378)(4.19 \frac{\text{J}}{\text{g}})(30 \text{K}) + (0.378)(2260 \frac{\text{J}}{\text{g}}) \]

\[ = 19.9 \text{ kJ} + 536 \text{ kJ} = 555 \text{ kJ} \]

\[ t = \frac{555 \times 10^3 \text{ J}}{660 \text{ J/sec}} = 840 \text{ sec} \]

\[ = 14 \text{ min} \]
2. (15 points, 5 points each) A sample of a monoatomic ideal gas is taken through the cyclic process \( abca \) shown in the figure below. The pressures satisfy \( p_b = 3.00 \times 10^5 \) Pa and \( p_{ac} = 1.00 \times 10^5 \) Pa. In addition, point \( a \) is when the gas is at temperature 100.0 K.

(a) Find the temperature of the gas at point \( b \) and the number of moles of gas. 
(b) Find the work done by the gas along the path \( ab \).
(c) Find the heat added to the gas along the path \( ab \).

\[
\text{(a) } T \propto P V. \text{ If } P \text{ triples, and } V \text{ also triples, then } T \text{ inc by 9x.} \\
\Rightarrow T_b = 900K. \text{ Also, } n = \frac{P_a V_a}{RT_a} = \frac{10^5 J}{8.31 \text{ J/mol} \cdot \text{K}} = 120. \text{ mol} \\
\text{(b) } W_{by} = \int_a^b P \text{d}V = 4 \left[ \text{area of 1 square} \right] = 4 \left[ 10^5 \text{ J} \right] = 400. \text{ kJ} \\
\text{(c) } \Delta E_{th}^{(ab)} = n C_v \Delta T = (120. \text{ mol}) \left( \frac{3}{2} \right) (8.31 \text{ J/mol} \cdot \text{K}) (800 K) \\
\text{ } = 1000 \text{ kJ} \\
C_v = \frac{3}{2} R \text{ for monoatomic gases} \ \\
\text{1st law of thermo: } \Delta E_{th}^{(ab)} = Q^{(ab)} - W_{by}^{(ab)} \\
1200 \text{ kJ} = Q^{(ab)} - 400 \text{ kJ} \\
\Rightarrow Q^{(ab)} = 1600 \text{ kJ} \]
3. (15 points, 5 points each) 1.00 mol of diatomic gas adiabatically expands such that it cools from 300.0 K to 270.0 K. Assume that, throughout the expansion, rotational modes are excited in the gas, but not vibrational modes. The initial volume of the gas is $V_0$.

(a) Find the amount of work that the gas does on its surroundings. You should be able to get a number (your answer should not depend on $V_0$).

(b) Find the final volume of the gas in terms of $V_0$.

(c) Suppose, instead, it was 1.00 mol of monoatomic gas that adiabatically expanded such that $T_i = 300.0 \, \text{K}$ to $T_f = 270.0 \, \text{K}$ (also with initial volume $V_0$). Does this gas do more work on its surroundings, or less? Explain using a pV diagram.

\begin{align*}
(a) \quad W_{\text{surf}} &= W_{\text{by\ gas}} = -W_{\text{by\ gas}} = -\Delta E_{\text{th,\ gas}} = -nC_v \Delta T \\
&= -(1.00 \, \text{mol})(\frac{5}{2}R)(-30 \, \text{K}) \\
&= +623 \, \text{J} \\
(b) \quad \frac{T_0}{V_0^{\frac{1}{5}}} = \frac{T_f}{V_f^{\frac{1}{5}}} \implies V_f &= V_0 \left(\frac{T_0}{T_f}\right)^{\frac{5}{4}} = V_0 \left(\frac{300}{270}\right)^{\frac{5}{4}} \\
&= V_0 \left(\frac{5}{3}\right)^{\frac{5}{4}} \\
&= 1.301 \, V_0
\end{align*}
4. (10 points, 5 points each) A long rod, insulated to prevent heat loss along its sides, is in perfect thermal contact with boiling water at one end and with an ice-water mixture at the other. The rod consists of a 1.00 m section of copper (one end in boiling water) joined end-to-end to a length $L_2$ of steel (one end in the ice-water mixture). Both sections of the rod have the same cross-sectional area:

![Diagram of the rod setup](image)

The temperature of the copper-steel junction is 65.0° C after a steady state has been set up (i.e., the heat transfer rate is the same through the copper and the steel). The thermal conductivities for copper and steel are $k_{Cu} = 401 \text{ W/(m·K)}$ and $k_{steel} = 46 \text{ W/(m·K)}$, respectively.

(a) What is the length $L_2$ of the steel section?

(b) Suppose we remove the steel section, so that it just just the 1.00 m copper rod connecting the two ends. Would the energy per unit time transferred through the rod increase or decrease? By what factor? Explain.

\[ (a) \quad \text{Combine sum for both rods} \Rightarrow \quad k_{Cu} \frac{A}{L_1} (\Delta T)_{Cu} = k_{steel} \frac{A}{L_2} (\Delta T)_{steel} \]

\[ L_2 = (1.00m) \left| \frac{\Delta T_{steel}}{\Delta T_{Cu}} \right| \frac{k_{steel}}{k_{Cu}} = \left( \frac{65.0}{35.0} \right) \left( \frac{46}{401} \right) \text{ meters} \]

\[ L_2 = 0.01 \text{ m} \]

\[ (b) \quad \text{The power would increase:} \]

\[ P_{cond}^{(new)} = k_{Cu} \frac{A}{L_1} (100^\circ C) = \frac{100}{35} \left[ k_{Cu} \frac{A}{L_1} (35^\circ C) \right] = \frac{100}{35} P_{cond}^{(old)} \]

\[ [i.e., \, \text{the } \Delta T \text{ increases, and so } P_{cond} \text{ increases}] \]
5. Which of the following statements is TRUE?

- [ ] When a fixed amount of ideal gas goes through an isobaric expansion, its thermal energy decreases.
- [ ] An ideal gas is compressed in a well-insulated chamber using a well-insulated piston. This process is best described as isobaric.
- [ ] For the Nitrogen and Oxygen molecules in this room (all at the same temperature), the Oxygen is moving at a larger rms-speed than the Nitrogen molecules.
- [ ] In an adiabatic expansion, the thermal energy of a gas decreases. √true
- [ ] In an adiabatic compression, the thermal energy of a gas remains constant.

6. The surface area of a penny increases by 0.1% when heated 160°C. Which of the following is closest to the average coefficient of linear expansion for the metal alloy that comprises the penny? [note: these numbers are not real world data, to discourage people from trying to look up the answer during the exam!]

- [ ] 3 × 10^{-6} per Kelvin
- [ ] 5 × 10^{-6} per Kelvin
- [ ] 8 × 10^{-6} per Kelvin
- [ ] 3 × 10^{-5} per Kelvin
- [ ] 5 × 10^{-5} per Kelvin
- [ ] 8 × 10^{-5} per Kelvin

\[
\frac{dA}{A} = 0.001 = (2\alpha)(160 \text{ K})
\]

\[
\alpha = \frac{10^{-3}}{300 \text{ K}} = \frac{1}{3.2 \times 10^{-5}} \text{ per K}
\]

\[
\approx 3 \times 10^{-6} \text{ per K.}
\]

7. The surface temperature of a star is 8530 K, and the power output of the star is \(5.34 \times 10^{26}\) W. Assuming the star is a perfect blackbody, what is the radius of the (spherical) star? (express your answer in meters to 3 sig figs).

\[
P = \sigma A T^4
\]

\[
5.34 \times 10^{26} \text{ W} = \left(5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \cdot \text{K}^4}\right) \left(4\pi\right) R^2 \left(8530 \text{ K}\right)^4
\]

\[
R \approx 3.76 \times 10^8 \text{ m}
\]
8. Shown below are three processes: 1, 2, and 3. All three processes have the same starting point, \( a \), and the same final point, \( b \). \( V_b = 5V_i \), and the heat added to the gas in process 1 is \( 10p_iV_i \). What is the change in internal energy the gas undergoes in process 3?

\[
\Delta E_{\text{process 3}} = \Delta E_{\text{process 1}}
\]
\[
= Q - W_{\text{by}}
\]
\[
= 10p_iV_i - (4V_i)(p_i)p_i
\]
\[
= 6p_iV_i
\]

- \( 2p_iV_i \)
- \( 4p_iV_i \)
- \( 6p_iV_i \)
- \( 8p_iV_i \)
- \( 10p_iV_i \)

9. What is the rms-speed of oxygen molecules in your car tires? Note O\(_2\) mass \( 32.0 \) grams/mol. Take the absolute pressure of gas in your tires to be 3.8 atm and take the temperature to be 40°C.

\[
\frac{3}{2}kT = \frac{3}{2}mV_m^2 \Rightarrow \quad V_m = \sqrt{\frac{3kT}{m}}
\]

\[
m_{O_2} = \frac{32.0}{6.02 \times 10^{23}} = 5.32 \times 10^{-26} \text{ kg}
\]