1. (3 points) The specific heat of alcohol is about half that of water. You have equal masses of each but they are at different temperatures. The initial temperature of the alcohol is $T_a$ and the initial temperature of the water is $T_w$. The water and alcohol are poured into the same container and allowed to come into thermal equilibrium, $T_e$. Which of the following statements are true:
(a) The final equilibrium temperature, $T_e$, will be closer to $T_a$
(b) The final equilibrium temperature, $T_e$, will be $\frac{1}{2} (T_a + T_w)$
(c) The final equilibrium temperature, $T_e$, will be closer to $T_w$

2. (3 points) The P-V diagram below shows three ideal gas expansions. Which statement is true about the work done by each gas?

(a) $W_A > W_B > W_C$
(b) $W_C > W_A > W_B$
(c) $W_B > W_C > W_A$
(d) $W_B > W_A > W_C$
(e) $W_A > W_C > W_B$

3. (3 points) A heat engine operates using a Carnot Cycle. If the temperature of the cold reservoir increases, what happens to the efficiency?

(a) efficiency increases
(b) efficiency stays the same
(c) efficiency decreases

$$\eta = 1 - \frac{T_C}{T_H}$$

if $T \uparrow$ then $T_C \uparrow$

and $1 - \frac{T_C}{T_H} \downarrow$
4. (10 points) A steel wire is initially 2.00 meters long and has a diameter of 5 mm. When it is at 30°C, it is stretched just taut (zero tensile force in the wire) and attached at both ends to rigid supports (wire is not allowed to contract). The temperature of the steel is decreased by an unknown amount which causes a tensile stress of 60.0 MPa. Use the material properties of steel given in Table 1 on page 2.

Determine:
(a) the final temperature of the steel wire
(b) the change in length if the wire were not constrained and experienced the same temperature difference.

\[ L_0 = 2 \text{ m} \quad T_i = 30^\circ \text{C} \quad T_2 = ? \quad E = 200 \text{E}9 \text{ Pa} \quad \alpha = 12 \text{E}^{-6} /{\text{C}} \]

\[
\sigma = \alpha E \Delta T
\]

\[
\Delta T = \frac{\sigma}{\alpha E} = \frac{60 \text{E}6 \text{ Pa}}{(12 \text{E}^-6 /{\text{C}})(200 \text{E}9 \text{ Pa})}
\]

\[
\Delta T = 25^\circ \text{C}
\]

\[
T_f = (30 - 25)^\circ \text{C} = 5^\circ \text{C}
\]

(B) \[ \Delta L = \alpha L \Delta T \]

\[
\Delta L = (12 \text{E}^-6 /{\text{C}})(2 \text{m})(25^\circ \text{C})
\]

\[
\Delta L = 6 \text{E}^-4 \text{m}
\]

\[ a. \ 5^\circ \text{C} = 278 \text{K} \]

\[ b. \ 6 \text{E}^-4 \text{m} = 0.0006 \text{m} \]

5. (15 points) A steel sample has a mass of 750 gram and initial temperature of 200°C. It is placed in contact with an unknown quantity of ice at -8°C. The ice and steel come to thermal equilibrium in an insulated container (no heat losses to the surroundings). Use the material properties of steel, ice and water given in Tables 1-3.

Determine the amount of ice required for a final equilibrium temperature of 20°C

\[ m_s = 750 \text{ g} \quad (T_s)_i = 200^\circ \text{C} \quad (T_f)_i = -8^\circ \text{C} \]

\[ Q_s = m_s c_s \Delta T_s = (750 \text{ g})(0.12 \text{C} /\text{G} \cdot \text{g} \cdot \text{C}) (200 - 20) \text{C} = -16,200 \text{ cal} \]

\[ Q_i = m_i c_i \Delta T_i + m_i L_f + m_i c_w \Delta T_{w-20} \]

\[ Q_i = m_i (0.498 \text{cal} /\text{g} \cdot \text{C}) (0-(-8)) \text{C} + m_i (79.8 \text{cal} /\text{g} \cdot \text{C}) + m_i (1 \text{cal} /\text{g}) (20 - 0) \text{C} \]

\[ Q_i = 103.784 \text{m}_i \text{ cal} /\text{g} \]

\[ \Sigma Q = 0 = -16,200 + 103.784 \text{m}_i \Rightarrow m_i = 156.1 \text{ g} \]

\[ \text{Mixed units ok C & Lf} \quad \text{(2)} \]

\[ \text{Left out Q form (4)} \]

\[ 156.1 \text{ g} \]
6. (15 points) A solid brick wall is 12 feet wide, by 9 feet high and has a depth (thickness of the wall) of 4 inches. The thermal conductivity of the brick is 0.400 (BTU/hr)/(ft·°F). There are no openings in the wall, however, there is a solid sheet of foam board attached to the inside of the wall. The foam board is 4.00 ft wide by 9 ft high and has a depth (thickness) of 2 inches with an R-value of 6 ft²·hr·°F/BTU. The outside temperature is 12°F and the inside temperature is 68.0°F.

Determine
(a) the equivalent resistance of the wall
(b) the heat transfer rate through the wall

\[
\begin{align*}
R_{\text{Br}} &= \frac{L}{k_{\text{Br}}} = \frac{0.333 \text{ ft}}{0.4 \text{ (BTU/hr)/(ft·°F)}} \\
R_1 &= R_{\text{Br}} = 0.833 \text{ ft}^2 \cdot \text{hr} \cdot \text{°F} / \text{BTU} \\
R_2 &= R_{\text{Br}} + R_{\text{I}} = \left(0.833 + 6\right) \text{ ft}^2 \cdot \text{hr} \cdot \text{°F} / \text{BTU} = 6.833 \text{ ft}^2 \cdot \text{hr} \cdot \text{°F} / \text{BTU} \\
\frac{1}{R_{\text{eff}}} &= \frac{1}{A_1 + A_2} \left(\frac{A_1}{R_1} + \frac{A_2}{R_2}\right) = \frac{1}{108} \left(\frac{72}{0.833} + \frac{36}{6.83}\right) \text{ BTU} / \text{ft}^2 \cdot \text{hr} \cdot \text{°F} = 0.8488 \text{ BTU} / \text{ft}^2 \cdot \text{hr} \cdot \text{°F} \\
R_{\text{eff}} &= \frac{1}{0.8488} = 1.178 \text{ ft}^2 \cdot \text{hr} \cdot \text{°F} / \text{BTU}
\end{align*}
\]

(b) \[
\frac{dQ}{dt} = -\frac{A}{R} (T_o - T_i)
\]

\[
\frac{dQ}{dt} = \frac{-\left(108 \text{ ft}^2\right)}{1.178 \text{ ft}^2 \cdot \text{hr} \cdot \text{°F} / \text{BTU}} (12 - 68)^\circ \text{F} = 5133 \text{ BTU/hr}
\]

\[
\frac{dQ}{dt} = \frac{5133 \text{ BTU}}{\text{hr}}
\]

a. 1.178 ft²·hr·°F/BTU
b. 5133 BTU/hr

- Used \( R_{\text{Br}} = 6 \) (2)
- Used \( L_{\text{Br}} = 12 \) (2)
- Used Volume for Area (3)
7. (10 points) A cylinder with a movable piston holds 0.500 m$^3$ of air at a temperature of 30.0°C with a gauge pressure of 700 kPa. Assume air is a diatomic gas with $\gamma = 1.4$. 

Determine

(a) the volume of the air if it is adiabatically expanded until the temperature reaches 5.00°C.

(b) the volume of the air if it is immersed in a thermal reservoir that has a temperature is 25°C and then expanded until the absolute pressure is 101.3 kPa.

\[
\begin{align*}
P_i &= (700 + 101.3) \text{ kPa} \\
P_a &= ? \\
P_b &= 101,300 \text{ Pa} \\
V_i &= 0.5 \text{ m}^3 \\
T_i &= 30^\circ C = 303 \text{ K} \\
V_a &= ? \\
T_a &= 0^\circ C = 273 \text{ K} \\
V_b &= ? \\
T_b &= 20^\circ C = 293 \text{ K}
\end{align*}
\]

(a) 
\[
T_i V_i^{\gamma - 1} = T_a V_a^{\gamma - 1}
\]
\[
V_a = V_i \left( \frac{T_i}{T_a} \right)^{\frac{\gamma - 1}{\gamma}}
\]
\[
V_a = (0.5 \text{ m}^3) \left( \frac{303}{273} \right)^{1.4 - 1}
\]
\[
V_a = 0.6201 \text{ m}^3
\]

(b) 
\[
\frac{P_i V_i}{n_i T_i} = \frac{P_b V_b}{n_b T_b}
\]
\[
V_b = V_i \left( \frac{P_i}{P_b} \right) \left( \frac{T_b}{T_i} \right)
\]
\[
V_b = (0.5 \text{ m}^3) \left( \frac{801.300}{101.300} \right) \left( \frac{293}{303} \right)
\]
\[
V_b = 3.824 \text{ m}^3
\]

(a) Wrong formula  
(b) No/min temp  
(c) Wrong formula

\[
\begin{align*}
a. & \quad 0.6201 \text{ m}^3 \\
b. & \quad 3.824 \text{ m}^3
\end{align*}
\]
8. (24 points) Three moles of a monatomic gas follow the cycle A-B-C-D-A shown on the P-V diagram below. Path CD is isothermal and path AB is adiabatic. Some of the thermodynamic states have been calculated and are in Table 5. Determine (a) P_C, V_B, and T_D (show all work but give the values in Table 5) (b) The change in internal energy, heat flow and work by for each step of the cycle (complete Table 6 - show work and give values in the table) (c) The efficiency of the engine

Table 5 Thermodynamic States

<table>
<thead>
<tr>
<th>P, kPa</th>
<th>V, Liters</th>
<th>T, K</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>50.0</td>
</tr>
<tr>
<td>B</td>
<td>500</td>
<td>19.03</td>
</tr>
<tr>
<td>C</td>
<td>500</td>
<td>35.0</td>
</tr>
<tr>
<td>D</td>
<td>350</td>
<td>50</td>
</tr>
</tbody>
</table>

\[ \Delta U, J \quad Q, J \quad W_{by}, J \]

\begin{array}{|c|c|c|c|}
\hline
\text{Step} & \Delta U & Q & W_{by} \\
\hline
A-B & 6772 & 0 & -6772 \\
B-C & 7985 & 19.91 & 7985 \\
C-D & 0 & 6241 & 6241 \\
D-A & -18748 & -18748 & 0 \\
\hline
\end{array}

All legs: \( \Delta U = C_V \Delta T = \frac{3}{2} n R \Delta T \) for monatomic gases

A-B \( \Delta U = \left( \frac{3}{2} \right) (3 \text{ mol}) (8.314 \text{ J/mol/K}) (381.5 - 200.5) K = 6772 \ J \)

B-C, D-A similar cases with different \( \Delta T \)'s

\[ W_{by} : \]

\[ W_{by} = -\Delta U_{int} = -6772 \ J \]

\[ W_{by} = PT \Delta V = (500,000 \text{ Pa}) (0.035 - 0.01903) = 7985 \ J \]

\[ W_{by} = nRT \ln \left( \frac{V_f}{V_i} \right) = (3 \text{ mol}) (8.314 \text{ J/mol/K}) (701.6 K) \left( \ln \left( \frac{50}{35} \right) \right) = 6241 \ J \]

D-A \( W_{by} = 0 \)

\[ Q : Q = \Delta E_{int} + W_{by} \]

A-B \( Q = 0 \) since adiabatic

B-C \( Q = 11,976 + 7985 = 19,961 \)

C-D \( Q = W_{by} \)

D-A \( Q = \Delta U_{int} \)

\[ \eta = \frac{\frac{W}{Q_n}}{\frac{W}{Q_n} + \frac{W_{by}}{Q_n}} = \frac{7454}{19,961 + 6241} \]

\[ \eta = 0.2845 = 28.45\% \]
9. (15 points) A freezer operates at 35% of the ideal. When the inside temperature of the freezer is -10°C and the outside room temperature is 30°C, the compressor consumes 500 Watts of electricity.

Determine (a) the rate heat is being extracted from the freezer (as always, include units)
(b) the EER of the freezer

\[ K = 0.35 \quad T_e = 263 \quad T_h = 303 \quad W = 500 \text{W} \]

(a) \[ K_c = \frac{T_e}{T_h - T_e} = \frac{263}{303 - 263} \Rightarrow K_c = 6.575 \]

\[ K = 0.35 \cdot (6.575) = 2.301 \frac{\text{W}}{\text{W}} \]

\[ K = \frac{dQ_e}{dt} \quad \Rightarrow \quad \frac{dQ_e}{dt} = K \frac{dw}{dt} = (2.301) \frac{\text{W}}{\text{W}} \cdot (500 \text{W}) \]

\[ \frac{dQ_e}{dt} = 1150 \text{W} \]

(b) \[ \text{EER} = 3.413 \quad K = 7.853 \frac{\text{Btu/hr}}{\text{W}} \]

\[ a. \quad 1150 \text{W} \]

\[ b. \quad 7.853 \frac{\text{Btu/hr}}{\text{W}} \]