<table>
<thead>
<tr>
<th>Thermal Expansion</th>
<th>Work of Thermal Systems</th>
<th>Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear: ( \Delta V = d_v \Delta T )</td>
<td>Isotonic (constant pressure) ( W = p(V_B - V_A) )</td>
<td>( Q ) - heat</td>
</tr>
<tr>
<td>Linear Stresses: ( \sigma = aE\Delta T )</td>
<td>Isobaric (constant volume) ( W = nc_p\Delta T )</td>
<td>( c ) - specific heat</td>
</tr>
<tr>
<td>Volumetric: ( \Delta V = \beta V \Delta T )</td>
<td>Isothermal (constant temp) ( W = nRT \ln \left( \frac{V_f}{V_i} \right) )</td>
<td>( k ) - thermal conductivity</td>
</tr>
<tr>
<td>Ideal Gas Law</td>
<td>( \Delta Q = nc'_p\Delta T )</td>
<td>( R ) - thermal resistance</td>
</tr>
<tr>
<td>( pV = nRT )</td>
<td>( \Delta Q = W )</td>
<td><strong>Heat Capacity</strong> ( Q = mc\Delta T )</td>
</tr>
<tr>
<td>( R = 8.314 \text{ J/(mol-K)} )</td>
<td>Adiabatic (( \Delta Q = 0 )) ( W = \frac{1}{\gamma - 1} (p_A V_A - p_B V_B) ) Thermal Conductivity ( \Delta Q = -\kappa A \frac{T_2 - T_1}{L} = -A \frac{T_2 - T_1}{R} )</td>
<td></td>
</tr>
<tr>
<td>Avogadro's Number: 6.02x10^{23}</td>
<td>( pV' = \text{constant} )</td>
<td><strong>Thermal Resistance</strong> ( R = \frac{L}{\kappa} )</td>
</tr>
<tr>
<td>Standard Pressure and Temp</td>
<td>( TV^\gamma = \text{constant} )</td>
<td>Thermal Resistance, Series ( R_{\text{eff}} = R_1 + R_2 )</td>
</tr>
<tr>
<td>273K 1.00 atm (101.3kPa)</td>
<td>( Tp^\gamma = \text{constant} )</td>
<td>Thermal Resistance, Parallel ( \frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2} \left( \frac{A_1}{A_2} + \frac{A_2}{A_1} \right) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1st Law of Thermodynamics</th>
<th>Macroscopic Definitions</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U ) - internal energy</td>
<td>( m ) - mass</td>
<td>General</td>
</tr>
<tr>
<td>( W ) - work done by thermal system</td>
<td>( M ) - molar mass</td>
<td>( K ) - coefficient of performance</td>
</tr>
<tr>
<td>( Q ) - heat flow into thermal system</td>
<td>( n ) - number of moles</td>
<td>( H ) - heat current</td>
</tr>
<tr>
<td>( \Delta U = -W_{A\rightarrow B} + Q_{A\rightarrow B} )</td>
<td>( N ) - total number of molecules</td>
<td>( P ) - power input</td>
</tr>
<tr>
<td>( N_A ) - Avogadro's Number</td>
<td>( k ) - Boltzmann constant = 1.38065 x 10^{-23} J/K</td>
<td>( \left</td>
</tr>
<tr>
<td>( n = \frac{m}{M} )</td>
<td>( k = \frac{R}{N_A} )</td>
<td>( K = \frac{\left</td>
</tr>
<tr>
<td>( n = \frac{N}{N_A} )</td>
<td></td>
<td>EER = 3.413 K</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Carnot</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( K_{\text{Carnot}} = \frac{T_c}{T_h - T_c} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversions</th>
<th>Water Properties</th>
<th>Latent Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cal = 4.186 J</td>
<td>( c = 1 \text{ cal/(g•°C)} = 4.186 \text{J/(g•°C)} )</td>
<td>( L_l = 79.6 \text{ cal/g} )</td>
</tr>
<tr>
<td>1 L = 1000 cm³</td>
<td>( \rho = 1 \text{ g/cm}^3 = 1 \text{ kg/L} )</td>
<td>( L_v = 540 \text{ cal/g} )</td>
</tr>
<tr>
<td>1 m³ = 1000 L</td>
<td>( = 1000 \text{ kcal/m}^3 = 62.4 \text{ lb/ft}^3 )</td>
<td>( L_f = \text{ Latent heat of fusion} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( L_v = \text{ Latent heat of vaporization} )</td>
</tr>
</tbody>
</table>
1. (2 pts) Which of the following is FALSE?
   A. The van der Walls equation can be used to calculate the relationship between state variables when a gas is non-ideal based on gas-specific empirical constants.
   B. The transfer of heat by radiation is proportional to (Temperature)$^4$
   C. The maximum possible COP of a refrigerator is the Carnot efficiency.
   D. An irreversible process has more heat efficiency than a reversible process.
   E. The coefficient of performance of a refrigerator can be greater than 1.

2. (2 pts) Under conditions of a fixed temperature and amount of gas, Boyle's law requires
   I. $P_1V_1 = P_2V_2$
   II. $PV = $ constant
   III. $(P_1V_1)^n = (P_2V_2)^n$
   A. I only
   B. I and II
   C. III
   D. none of the above

3. (2 pts) Which has higher thermal resistance ($m^2\cdot\circ C/W$)
   A. Air
   B. Glass
   C. Copper

4. (2 pts) Which of the following cycles best describes an internal combustion engine.
   A. Adiabatic compression. Heating at constant volume, Adiabatic expansion, cooling at constant volume
   B. Adiabatic compression. Heating at constant pressure, Adiabatic expansion, cooling at constant volume
   C. Adiabatic compression, Heating at constant temperature, Adiabatic expansion, cooling at constant temperature
   D. Adiabatic compression, Heating at constant pressure, Adiabatic expansion, cooling at constant pressure

5. (4 pts) A refrigerator absorbs 5 kJ of energy from a cold reservoir and rejects 8 kJ to a hot reservoir. Find the coefficient of performance of the refrigerator.

\[
\text{COP} = \frac{Q_c}{W} = \frac{5 \text{ kJ}}{8 \text{ kJ} - 5 \text{ kJ}} = 1.67
\]

Solving for Work or $Q_c$ +1
Correct equation but wrong values +2
COP reciprocal +3
$\text{COP} = \frac{Q_c}{Q_h - Q_c} + 4$
6. (12 pts) An oxygen holding tank has a volume of 30,000 L, an absolute pressure of 250 kPa and a temperature of 300 K. A cylinder contains 112 kg of compressed Oxygen (molecular mass of O₂=32 g/mol). If the gas in the cylinder is added to the holding tank, what is the new pressure in the holding tank at 300 K? Assume an ideal gas.

\[ P_{\text{cylinder}} = \frac{541 \text{ kPa}}{} \]

\[ n_c = \frac{112,000 \text{ g} \times 1 \text{ mol}}{32 \text{ g}} = 350 \text{ moles} + 4 \]

\[ n_t = \frac{P V}{RT} = \frac{(250,000 \text{ Pa}) \times 30 \text{ m}^3}{8.314 \times 300 \text{ K}} = 30 \times 7 \text{ moles} + 4 \]

\[ n_{\text{combined}} = \frac{(n_c + n_t)}{RT} = \frac{(350 \text{ mol} + 30 \times 7 \text{ mol})}{8.314 \times 300 \text{ K}} \]

\[ P = 541 \text{ kPa} + 4 \]

7. (16 pts) A piece of heated metal alloy has a mass of 325 g, density of 6.8 g/cm³, a specific heat of 0.12 cal/(g K) and a coefficient of volume expansion 3.3x10⁻⁵ °C. What amount of ice at 0°C is required to make the metal contract by 0.206 cm³ while just melting all of the ice?

\[ V_o = \frac{m}{\rho} = \frac{325 \text{ g}}{6.8 \text{ g/cm}^3} = 47.79 \text{ cm}^3 \]

\[ \Delta V = \beta V_o \Delta T \]

\[ 0.206 \text{ cm}^3 = 3.3 \times 10^{-5} \% \left( \frac{325 \text{ g}}{6.8 \text{ g/cm}^3} \right) \Delta T \]

\[ \Delta T = 130.6 \degree C = 130.6 \text{ K} + 4 \]

\[ m_{\text{cm}} \Delta T = m_{\text{L}} L_f \]

\[ 325 \text{ g } (0.12 \text{ cal/g K}) 130.6 \text{ K} = m_{\text{ice}} 79.6 \text{ cal/g} \]

\[ 509.4 \text{ cal} = m_{\text{ice}} (79.6 \text{ cal/g}) \]

\[ m_{\text{ice}} = 6.4 \text{ grams} + 5 \]
8. (14 points) 2.5 moles of an ideal gas is at 27°C. The gas is isochorically (at constant volume) cooled to a pressure 12 times smaller than the initial pressure. The gas is then expanded at constant pressure so that in the final state the temperature coincides with the initial temperature, 27°C. Calculate the work done by the gas.

\[ W = P(V_f - V_i) + 4 \]

\[ V_f = \frac{nRT}{P + 3} \]

\[ V_i = \frac{nRT}{12P + 3} \]

\[ W = P \left( \frac{nRT}{P} - \frac{nRT}{12P} \right) = nRT \left( 1 - \frac{1}{12} \right) \]

\[ = 2.5 \text{ moles} \times (8.314 \text{ J/mole K}) \times 300 \text{ K} \left( 1 - \frac{1}{12} \right) \]

\[ = 5716 \text{ J} \]

9. (16 pts) Determine the efficiency of the Ramanator Cycle, shown below. Assume air and an ideal gas (\( \gamma = 1.4 \), \( c_p = 7R/2 \), \( c_v = 5R/2 \)). The work input from 4 to 1 is 5940 Joules and the work output from 2 to 3 is 5682 Joules. The heat added, \( Q_h \), is 19890 Joules.

\[ \text{adiabatic } 3 \rightarrow 4 \]

\[ P V_{4}^{\gamma} = P_{3} V_{3}^{\gamma} \]

\[ 99 \text{ kPa} \times (0.02 \text{ m}^3)^{1.4} = 200 \text{ kPa} \times (V_{3})^{1.4} \]

\[ V_{3} = 0.0484 \text{ m}^3 \]

\[ W_{1 \rightarrow 2} = 0 \]

\[ W_{2 \rightarrow 3} = 5682 \text{ J} \]

\[ W_{4 \rightarrow 1} = -5940 \text{ J} \]

\[ Q_{H} = 19890 \text{ J} \]

\[ W_{3 \rightarrow 4} = \frac{1}{\gamma-1} \left( P_{3} V_{3} - P_{4} V_{4} \right) = \frac{1}{0.4} \left( 200000 \text{ Pa} \times (0.0484 \text{ m}^3) - 99000 \text{ Pa} \times (0.08 \text{ m}^3) \right) = 4406 \text{ J} \]

\[ W_{\text{Total}} = 5682 \text{ J} + 4406 \text{ J} - 5940 \text{ J} = 4148 \text{ J} \]

\[ \eta = \frac{W}{Q_{H}} = \frac{4148 \text{ J}}{19890 \text{ J}} = 0.2085 \]

\[ +2 \text{ sign} \]

\[ T_{2} = 1438 \text{ K} \]

\[ n = 0.81 \text{ moles} \]
10. (16 pts) Dr. Bennett's Donut Shop is 3 m high, 6 m long, and 6 m wide. The storefront is 3 m high by 6 m wide with a thermal resistance of 0.50 m²°C/W. The other three walls have a thermal resistance of 2.50 m²°C/W. The roof has a thermal resistance of 2.75 m²°C/W. Ignoring the effect of the floor and doors and any leakage, determine the electrical power required to run an air conditioner with an EER rating of 10 when it is 35 °C outside and 20 °C inside.

\[ A_{\text{TOTAL}} = 6 \text{m}(3 \text{m}) \cdot 4 \text{walls} + 6 \text{m}(6 \text{m}) = 108 \text{m}^2 \]

\[ R_{\text{eff}} = \frac{1}{A_{\text{TOTAL}}} \left[ \frac{A_{\text{roof}}}{R_{\text{roof}}} + \frac{A_{3\text{W}}}{R_{3\text{W}}} + \frac{A_{3\text{SF}}}{R_{3\text{SF}}} \right] = \frac{1}{108 \text{m}^2} \left[ \frac{36 \text{m}^2}{2.75 \text{m}^2 \cdot \text{W}} + \frac{54 \text{m}^2}{2.5 \text{m}^2 \cdot \text{W}} + \frac{18 \text{m}^2}{0.5 \text{m}^2 \cdot \text{W}} \right] \]

\[ R_{\text{eff}} = 1.528 \text{ m}^2 \cdot \text{C/W} \]

\[ \Delta Q = -\frac{A}{R} \Delta T = -\frac{108 \text{m}^2}{1.528 \text{ m}^2 \cdot \text{C/W}} (15^\circ \text{C}) = 1060 \frac{\text{J}}{\text{sec}} = 1060 \text{ W} \]

\[ EER = 3.413 \text{ K} \]

\[ P = \frac{1060 \text{ W}}{10/3.413} = 362 \text{ W} \]

11. (14 pts) A heat engine is used to blow up a balloon at a constant absolute pressure of 1 atm. The engine extracts 4 kJ from a hot reservoir at 120°C. The volume of the balloon increases by 5 L, and heat is exhausted to a cold reservoir at a temperature T_c. If the efficiency of the heat engine is 60% of the efficiency of a Carnot engine working between the same reservoirs, find the temperature T_c.

\[ W = 101300 \cdot (0.005 \text{ m}^3) = 506.5 \text{ J} \]

\[ \eta = 0.60 \eta_c = 0.60 \left( 1 - \frac{T_c}{T_H} \right) = \frac{W}{Q_H} \]

\[ \frac{W}{Q_H} = 0.60 \left( 1 - \frac{T_c}{393 \text{ K}} \right) = \frac{506.5 \text{ J}}{4000 \text{ J}} = 0.1266 \]

\[ T_c = 310 \text{ K} \]

310 K, 37.1°C