You can use a calculator.

\[
\Delta S = \int \frac{dQ}{T}, \quad P = \left| \frac{\Delta Q}{\Delta T} \right| = k_A \frac{T_B - T_c}{\ell}, \quad \bar{E} = \sum k_i \frac{q_i}{v_i^2}, \quad \bar{p} = q \bar{E}
\]

\[
k_s = 9 \times 10^9 \frac{N.m^2}{C^2}, \quad R = 8.314 \frac{J}{mol.K}, \quad 1.0 atm = 1.01 \times 10^5 \text{ pa}, \quad 1.0L = 10^{-3} \text{ m}^3.
\]

\[
\Delta Q = mC\Delta T, \quad \Delta Q = mL_v, \quad \Delta Q = mL_f
\]

Duration 90 minutes.

<table>
<thead>
<tr>
<th>Problem 1: (8 points)</th>
<th>Problem 2: (6 points)</th>
<th>Problem 3: (13 points)</th>
<th>Total: (27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[d) \text{ Energy Conservation in a cycle: } Q_v = \text{l}w_1 + \text{l}Q_c \]

\[= \text{l}w_1 = Q_v - \text{l}Q_c = 16437.75 - 11514 = 4923.75 \text{ J} \]

\[e) \Delta S_{AB} = \int_{A}^{B} \frac{dQ}{T} = 0 \quad (\text{adiabatic process } dQ=0) \]

\[\Delta S_{BC} = \int_{B}^{C} \frac{dQ}{T} = \int_{B}^{T_c} \frac{nC_p dT}{T} = nC_p \ln \left( \frac{T_c}{T_B} \right) \]

\[= nC_p \ln \left( \frac{P_c V_c / nR}{P_B V_B / nR} \right) = 2 \times \frac{7}{2}R \ln \left( \frac{V_c}{V_B} \right) = 7R \ln \left( \frac{30}{20} \right) \]

Finally \[\Delta S_{BC} = 23.597 \approx 23.6 \text{ J/K} \]

S. Habib Marhamasari
P-1:

a) A copper (Cu) rod and an aluminum (Al) rod of the same length and same cross-sectional area are attached end to end. As shown in the figure below, the copper end is placed in a furnace maintained at a constant temperature of 232°C. The aluminum end is placed in an ice bath held at a constant temperature of 0.0°C. Calculate the temperature of the point where the two rods are joined. (4 points)

\[ k_{\text{Copper}} = 380 \frac{J}{\text{s.m.} \cdot \text{C}}, k_{\text{Aluminum}} = 200 \frac{J}{\text{s.m.} \cdot \text{C}} \]

\[ P_{\text{Cu}} = P_{\text{Al}} \Rightarrow \\
\frac{k_{\text{Cu}} A}{232 - T} = \frac{k_{\text{Al}} A}{T - 0} \]

\[ \Rightarrow k_{\text{Cu}} (232 - T) = k_{\text{Al}} T \Rightarrow T = 152°C \]

b) How much energy is required to change a 50g ice cube from ice at -10°C to steam at 150°C. (4 points)

\( C_{\text{Ice}} = C_{\text{Steam}} = 2093 \frac{J}{\text{kg} \cdot \text{C}}, C_{\text{w}} = 4186 \frac{J}{\text{kg} \cdot \text{C}}, L_r = 2.26 \times 10^6 \frac{J}{\text{kg}} \) and \( L_f = 333 \times 10^3 \frac{J}{\text{kg}} \)

\[ \begin{align*}
\text{ice} & \xrightarrow{Q_1} \text{ice} \\
-10°C & \xrightarrow{Q_2} 0°C \\
\text{water} & \xrightarrow{Q_3} \text{water} \\
0°C & \xrightarrow{Q_4} 100°C \\
\text{steam} & \xrightarrow{Q_5} \text{steam} \\
100°C & \xrightarrow{Q_5} 150°C
\end{align*} \]

\[ Q_{\text{tot}} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 \]

\[ = m C_{\text{Ice}} (0 - (-10)) + m L_f + m C_w (100 - 0) + m L_v + m C_{\text{Steam}} (150 - 100) \]

\[ = 156659 J \]
P-2: Three point charges are located at the corners of a right angled triangle as shown in the figure. If \( a = 0.10 \text{m}, q_1 = 6.0 \mu \text{C}, q_2 = -2.0 \mu \text{C} \) and \( q_3 = 4.0 \mu \text{C} \) find the electric force vector on charge \( q_3 \). (6 points)

\[
\frac{1}{F} = \frac{q_1}{F} + \frac{q_2}{F} + \frac{q_3}{F} = \frac{\frac{q_1}{r_1^2}}{F} - \frac{\frac{q_2}{r_2^2}}{F} + \frac{\frac{q_3}{r_3^2}}{F}
\]

\[
4 \times 10^{-6} \times 9 \times 10^{-9} \left[ \frac{6 \times 10^{-6}}{(0.1 \sqrt{2})^2} (0.45 \hat{i} + 0.5 \sin 45 \hat{j}) + \frac{2 \times 10^{-6}}{(0.1 \sqrt{2})^2} \hat{i} \right] = 36 \times 10^{-3} \left( \frac{6}{0.02} \left( \frac{\hat{i}}{\sqrt{2}} + \frac{\hat{j}}{\sqrt{2}} \right) - \frac{2}{0.01} \hat{i} \right)
\]

\[
\Rightarrow \hat{F} = 3.6 \left( \frac{3 \sqrt{2}}{2} - 2 \right) \hat{i} + \frac{3}{\sqrt{2}} \hat{j} \text{ N}
\]

\[
= (0.44 \hat{i} + 7.6 \hat{j}) \text{ N}
\]
P-3: A heat engine operates under the following cyclic process. (Herein 2-moles of an ideal diatomic gas with $C_v = \frac{5}{2} R, C_p = \frac{7}{2} R$ and $\gamma = 1.4$ is taken through the cycle).

a) Using $P_aV_a^\gamma = P_bV_b^\gamma$, find the pressures at B, C and D. (4 points)

b) Find $Q_h$ and $Q_c$. (4 points)

c) Using $\epsilon = 1 - \frac{|Q_c|}{Q_h}$, find the efficiency of the engine. (1 point)

d) Using the energy conservation, without direct calculation, find the work done by the engine in one cycle. (2 points)

e) Find the change in entropy of the gas in processes AB and BC. (2 points)

\[
P_aV_a^\gamma = P_bV_b^\gamma \Rightarrow P_b = P_a \left( \frac{V_a}{V_b} \right)^{\gamma} = 1 \text{ atm} \left( \frac{60}{20} \right)^{1.4} = 4.65 \text{ atm}
\]

\[
P_c = P_B = 4.65 \text{ atm}
\]

\[
P_cV_c^\gamma = P_dV_d^\gamma \Rightarrow P_d = P_c \left( \frac{V_c}{V_d} \right)^{\gamma} = 4.65 \left( \frac{30}{60} \right)^{1.4} = 1.76 \text{ atm}
\]

b) $Q_h = Q_{bc} \Rightarrow Q_h = nC_v(T_C - T_B) = n \frac{7}{2} R(T_C - T_B) = \frac{7}{2} (nRT_C - nRT_B)$

\[
\Rightarrow Q_h = \frac{7}{2} (P_cV_c - P_BV_B) = \frac{7}{2} (4.65 \times 30 - 4.65 \times 20) \text{ atm.L}
\]

\[
= 162.75 \times 101 J = 16437.75 J
\]

$Q_c = Q_{da} = nC_v(T_A - T_D) = n \frac{5}{2} R(T_A - T_D) = \frac{5}{2} (nRT_A - nRT_D)$

\[
\Rightarrow Q_c = \frac{5}{2} (P_AV_A - P_DV_D) = \frac{5}{2} (1 \times 60 - 1.76 \times 60) \text{ atm.L}
\]

\[
Q_c = -114 \text{ atm.L} = -114 \times 101 J = -11514 J
\]

c) $\epsilon = 1 - \frac{|Q_c|}{Q_h} = 1 - \frac{11514}{16437.75} = 0.299 \approx 0.30$

\[
= \epsilon = 0.30
\]