1 \rightarrow 2
\begin{align*}
PV &= nRT_1 \\
P_1 &= \frac{nRT_1}{V_1} = \frac{(2000)(8.314)(300)}{2 \text{ m}^3} = 2.55 \times 10^6 \text{ Pa} \\
P_2 &= \frac{nRT_2}{V_1} = \frac{4}{3} P_1 = 3.33 \times 10^6 \text{ Pa}
\end{align*}

W = 0
\Delta U = \frac{3}{2} n R \Delta T = \frac{3}{2} (2000)(8.314)(100) = +2.50 \times 10^6 \text{ J}
Q = \Delta U = +2.50 \times 10^6 \text{ J}

2 \rightarrow 3
\begin{align*}
P_3 &= \frac{nRT_3}{V_3} = \frac{(2000)(8.314)(400)}{10} = 6.65 \times 10^5 \text{ Pa}
W &= nRT \ln \left( \frac{V_3}{V_2} \right) = (2000)(8.314)(400) \ln (5) = +1.07 \times 10^7 \text{ J}
\Delta U &= 0 \\
Q &= W = +1.07 \times 10^7 \text{ J}
\end{align*}

3 \rightarrow 4
\begin{align*}
P_4 &= \frac{nRT_4}{V_4} = \frac{(2000)(8.314)(200)}{10} = 4.99 \times 10^5 \text{ Pa}
W &= 0
\Delta U &= \frac{3}{2} n R \Delta T = \frac{3}{2} (2000)(8.314)(100) = -2.50 \times 10^6 \text{ J}
Q = \Delta U = -2.50 \times 10^6 \text{ J}
\end{align*}
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\[ W = nRT \ln \left( \frac{V_i}{V_f} \right) = (2000)(8.314)(300) \ln \left( \frac{1}{6} \right) \]
\[ = -8.03 \times 10^6 \text{J} \]

\[ \Delta U = 0 \]

\[ Q = W = -8.03 \times 10^6 \text{J} \]

\[ \eta = \frac{W_{net}}{Q_{in}} = \frac{1.07 \times 10^7 - 8.03 \times 10^6}{1.07 \times 10^7 + 2.5 \times 10^6} = 0.203 \]

\[ \eta_c = 1 - \frac{T_c}{T_H} = 1 - \frac{300}{400} = 0.25 \checkmark \]

It's less, so good.

b) 400K

1.32 \times 10^7 \text{J}

\[ \rightarrow 1.05 \times 10^7 \text{J} \rightarrow 300K \]

\[ 2.68 \times 10^6 \text{J} \]

c) hot one \[ \Delta S = \frac{-1.32 \times 10^7}{900 \text{K}} = -33,000 \text{J/K} \]

cold one \[ \Delta S = \frac{1.05 \times 10^7}{300 \text{K}} = 35.668 \text{J/K} \]

NET: 2668 J/K \checkmark
d) Consider this working as a refrigerator.

The temperature inside the "refrigerator" (where we put the stuff we want to keep cool) is our cold reservoir. Here, this must be 300K (which isn't very cold).

1 → 2 Our gas absorbs heat from the inside of the refrigerator at 300K. Our gas expands. \( Q_c = 8.03 \times 10^6 \) J.

2 → 3 Our gas also absorbs heat BUT NOT FROM THE INSIDE OF THE REFRIGERATOR. The inside of the fridge is 300K, but along here, our gas's \( T \) ≥ 300K. Heat will not flow from cold to hot. So this \( Q_c \) is NOT heat removed from fridge.

\[
K_b = \frac{Q_c}{W} = \frac{8.03 \times 10^6}{2.68 \times 10^6} = 3.0 \quad (k_b = \frac{T_c}{T_h - T_c})
\]

300K

So net heat flow from hot to cold is \( \approx 2 \times 10^6 \) J.