1. (30 pts) An ideal Rankine cycle has steam entering the turbine at \( P_1 = 25 \text{ bar} \) and \( T_1 = 450°C \). The outlet stream is then condensed at a pressure \( P_2 = 1 \text{ bar} \). Assume that the turbine and compressor operate isentropically. Determine the ideal Rankine engine efficiency and the mass flow rate (in \( \text{g/s} \)) of the steam in the cycle to achieve a power rating of 70 MW.

Data: 1) @ \((T_1, P_1)\): \( \hat{h}_1 = 3350.8 \frac{kJ}{kg}, \hat{s}_1 = 7.1745 \frac{kJ}{kg \cdot K} \)

2) @ \(P_2\) and saturated condition:
\[
\begin{align*}
\hat{h}_{2,\text{vap}} &= 2675.5 \frac{kJ}{kg}; \quad \hat{h}_{2,\text{liq}} = 417.44 \frac{kJ}{kg} \\
\hat{s}_{2,\text{vap}} &= 7.3593 \frac{kJ}{kg \cdot K}; \quad \hat{s}_{2,\text{liq}} = 1.3025 \frac{kJ}{kg \cdot K} \\
\hat{v}_{\text{liq}} &= 0.001043 \frac{m^3}{kg}
\end{align*}
\]

2. (15 pts) An ideal gas enters a nozzle at \( P_{in} = 2 \text{ bar} \), \( T_{in} = 140°C \) and leaves at \( P_{out} = 1 \text{ bar} \). Assuming the flow through the nozzle is isentropic, what is \( T_{out} \) (in °C)? The molar heat capacity of the gas is \( c_p = 2.3 \, R \).

3. (25 pts) An isolated rigid vessel has two compartments of equal volume separated by a thin membrane. Initially, one compartment contains 5 mol A and 5 mol B, while the other compartment contains 7 mol C and 3 mol D. After the membrane ruptures, the gases mix completely. Determine the change in entropy of the universe due to this process.
4. (30 pts) An engine was developed by Stirling to take air through the following cycle shown in Figure 1:
   i. Path 1 $\rightarrow$ 2, reversible isothermal expansion at $T_H$
   ii. Path 2 $\rightarrow$ 3, reversible isochoric cooling from $T_H$ to $T_C$
   iii. Path 3 $\rightarrow$ 4, reversible isothermal compression at $T_C$
   iv. Path 4 $\rightarrow$ 1, reversible isochoric heating from $T_C$ to $T_H$

Consider the engine with a volume expansion ratio of $(v_2/v_1) = (v_3/v_4) = 3$, together with hot and cold reservoir temperatures of $T_H = 500^\circ C$ and $T_C = 310^\circ C$, respectively. Assume air behaves as an ideal gas with a heat capacity given by

$$\frac{C_p}{R} = 3.35 + (5.75 \times 10^{-4})T$$

Obtain the net work done by the engine per mole of air in the cycle, and the efficiency of the ideal Stirling engine.

![Figure 1. Ideal Stirling engine cycle.](image)

5. (Bonus: 5 pts) Let the cold reservoir of a Carnot engine cycle be $T_C = 25^\circ C$. What is the temperature of the hot reservoir, $T_H$, (in °C) needed to obtain a Carnot efficiency of $\eta = 0.7$?