



Homework 4 Key



Follows Instructions Solutions

ECHE 363 – Thermodynamics of Chemical Systems
Homework #4

100 points total. Complete the following problems and upload your solutions to the Canvas assignment dropbox by the due date/time.

You are strongly encouraged to collaborate with your classmates on the homework, but each student is required to come up with a unique solution to the homework problems. For full credit, you must show all work. This includes showing all steps involving algebra and/or calculus. Your calculator can only be used for the final evaluation of numerical answers and may not be used for solving algebraic equations and/or integrals.

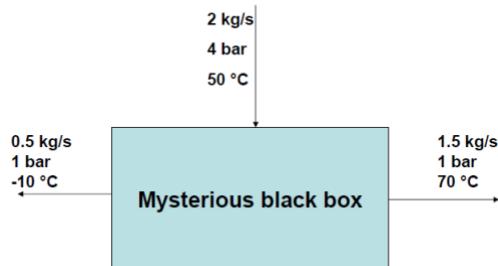
1. Develop a general expression for Δs_m for an ideal gas that goes from (P_1, T_1) to (P_2, T_2) , where the heat capacity is given by:

$$\frac{c_{p,m}}{R} = A + BT + CT^2 + \frac{D}{T}$$

where A, B, and C are constants.

2. Calculate the change in entropy for the system for each of the following cases. Explain the sign that you obtain by physical argument.
 - a. A gas undergoes a reversible, adiabatic expansion from an initial state at 500 K, 1 MPa, and 8.314 L to a final volume of 16.628 L.
 - b. One mole of methane vapor is condensed at its boiling point, 111 K; $\Delta h_{v,m} = 8.2$ kJ/mol.
 - c. One mole of liquid from 100 °C to 0 °C. Take the average heat capacity of water to be 4.2 J/g-K.
 - d. Two blocks of the same metal with equal mass are at different temperatures, 200 °C and 100 °C. These blocks are brought together and allowed to come to the same temperature. Assume that these blocks are isolated from their surroundings. The average heat capacity of the metal is 24 J/mol-K.

3. A fast-talking salesperson comes to your doorstep and says she is down on her luck and is willing to sell you the patent rights to her most glorious invention. She brings out a mysterious black box and says it can take an inlet stream of ideal gas at 2 kg/s and 4 bar and cool part of it (0.5 kg/s) from 50 °C to –10 °C with no external parts, as shown below.



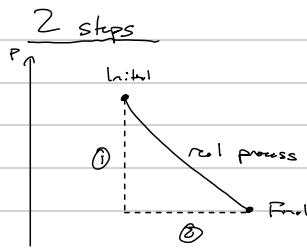
You are feeling somewhat adventurous and are tempted by this offer, but must ask the fundamental question: “Can it work?” Can it? Explain. If necessary, you may assume that the system is adiabatic.

4. What is the minimum amount of work required to separate an inlet stream of air flowing at 20 °C and 1 bar into exit streams of pure O₂ and N₂ at 20 °C and 1 bar? Assume that air has 20% O₂ and 80% N₂.
5. A steam turbine in a small electric power plant is designed to accept 4500 kg/hr of steam at 60 bar and 500 °C and exhaust the steam at 10 bar.
- Assuming that this turbine is adiabatic and generates the maximum possible power, compute the exit temperature of the steam and the power generated by the turbine.
 - The efficiency of a turbine is defined to be the ratio of the work actually obtained from the turbine to the work that would be obtained if the turbine operated isentropically between the same inlet and exit pressures. If the turbine in (a) is adiabatic but only 80% efficient, what would be the exit temperature of the steam? At what rate would entropy be generated within the turbine?
6. A portable power supply consists of a 28 L bottle of compressed helium, charged to 13.8 MPa at 300 K, connected to a small turbine. During the operation, the helium drives the turbine continuously until the pressure in the bottle drops to 0.69 MPa. The turbine exhausts at 0.1 MPa. Neglecting heat transfer, calculate the maximum possible work from the turbine. Assume helium to be an ideal gas with $c_{p,m} = 20.9 \text{ J/mol}\cdot\text{K}$.

1. Develop a general expression for ΔS_m for an ideal gas that goes from (P_1, T_1) to (P_2, T_2) , where the heat capacity is given by:

$$\frac{C_{p,m}}{R} = A + BT + CT^2 + \frac{D}{T}$$

where A, B, and C are constants.



① Isothermal & Reversible

$$1^{\text{st Law}}: dU_m = \delta q_{\text{rev},m} + \delta w_{\text{rev},m} \Rightarrow \delta q_{\text{rev},m} = -\delta w_{\text{rev},m}$$

isothermal
ideal gas

$$\text{1st Law: } dU_m = \delta q_{\text{rev},m} = \frac{PdV_m}{T} = \frac{RT}{V-T} dV_m = \frac{RT}{V_m} dV_m = PdV_m \quad (\text{rewritten})$$

$$\text{"2nd Law": } dS_m = \frac{\delta q_{\text{rev},m}}{T} = \frac{PdV_m}{T} = \frac{RT}{V-T} dV_m = \frac{RT}{V_m} dV_m$$

$$\Rightarrow \Delta S_{m,1} = \int_{V_{m,1}}^{V_{m,2}} \frac{RT}{V_m} dV_m = RT \ln\left(\frac{V_{m,2}}{V_{m,1}}\right) = -RT \ln\left(\frac{P_2}{P_1}\right)$$

① Isothermal, reversible

② Const. Pressure, reversible

② $P = P_2$ & reversible

$$1^{\text{st Law}}: dU_m = \delta q_{\text{rev},m} + \delta w_{\text{rev},m}$$

$$\delta q_{\text{rev},m} = dU_m - \delta w_{\text{rev},m}$$

$$= dU_m + PdV_m$$

$$= dU_m + d(PV_m)$$

$$= dU_m + d(U_m + PV_m) = dU_m + dH$$

$$\text{"2nd Law": } dS_m = \frac{\delta q_{\text{rev},m}}{T} = \frac{dH}{T} = \frac{C_p m}{T} dT = \left(\frac{A}{T} + B + CT + \frac{D}{T^2}\right) R dT$$

$$\Rightarrow \Delta S_{m,2} = R \int_{T_1}^{T_2} \left(\frac{A}{T} + B + CT + \frac{D}{T^2}\right) dT$$

$$= R \left[A \ln\left(\frac{T_2}{T_1}\right) + B(T_2 - T_1) + \frac{C}{2}(T_2^2 - T_1^2) - D \left(\frac{1}{T_2} - \frac{1}{T_1}\right) \right]$$

$$\rightarrow \Delta S_m = \Delta S_{m,1} + \Delta S_{m,2}$$

So

$$\Delta S_m = R \left[A \ln\left(\frac{T_2}{T_1}\right) + B(T_2 - T_1) + \frac{C}{2}(T_2^2 - T_1^2) - D \left(\frac{1}{T_2} - \frac{1}{T_1}\right) - \ln\left(\frac{P_2}{P_1}\right) \right]$$

2. Calculate the change in entropy for the system for each of the following cases. Explain the sign that you obtain by physical argument.

- A gas undergoes a reversible, adiabatic expansion from an initial state at 500 K, 1 MPa, and 8.314 L to a final volume of 16.628 L.
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- Two blocks of the same metal with equal mass are at different temperatures, 200 °C and 100 °C. These blocks are brought together and allowed to come to the same temperature. Assume that these blocks are isolated from their surroundings. The average heat capacity of the metal is 24 J/mol-K.

a) Reversible: $\Delta S_{m,rev} = 0$ } $\Delta S_m = \Delta S_{m,sys} + \Delta S_{m,surr}$
 Adiabatic: $\Delta S_{m,surr} = 0$ } $\therefore \Delta S_{m,sys} = 0$

b) $dS_m = \frac{dq_{rev}}{T} = \frac{dh_m}{T}$ (at constant pressure)

$$\Delta S_m = \int_{V_{\text{vap}}}^{V_{\text{liq}}} \frac{dh_m}{T} = -\frac{1}{T_{\text{boil}}} \Delta h_{v,m} = -\frac{1}{111 \text{ K}} (6.2 \frac{\text{kJ}}{\text{mol}}) = -73.9 \frac{\text{J}}{\text{mol}\cdot\text{K}}$$

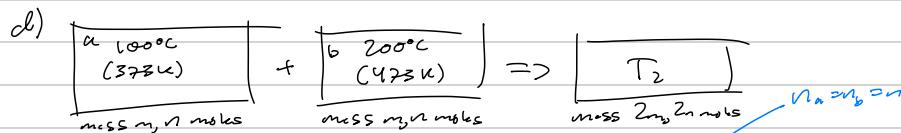
$\Delta S_m < 0$ bc liq has low entropy (more order) than vapor

c) $T_f = 0^\circ\text{C} = 273 \text{ K}$ & $T_i = 100^\circ\text{C} = 373 \text{ K}$

$$d\hat{S} = \frac{d\hat{q}_{rev}}{T} = \frac{d\hat{h}}{T} = \frac{C_p}{T} dT$$

$$\Delta \hat{S} = \int_{T_1}^{T_2} \frac{C_p}{T} dT = 4.2 \ln\left(\frac{273}{373}\right) = -1.31 \frac{\text{J}}{\text{g}\cdot\text{K}} \times \frac{18 \text{ g}}{1 \text{ mol H}_2\text{O}} = -23.6 \frac{\text{J}}{\text{mol}\cdot\text{K}}$$

ΔS_{cal} bc @ lower temp, molecules are slower and have fewer possible configurations (more ordered)



$$dS_m = \frac{dq_{rev,m}}{T} = \frac{dh_m}{T} = \frac{d(n_a h_{m,a} + n_b h_{m,b})}{T} = \frac{d(h_{m,a} + h_{m,b})}{T}$$

$$\Rightarrow \Delta S_m = \int_{T_a}^{T_2} \frac{C_{p,m}}{T} dT + \int_{T_b}^{T_2} \frac{C_{p,m}}{T} dT = C_{p,m} \ln\left(\frac{T_2}{373}\right) + C_{p,m} \ln\left(\frac{T_2}{473}\right)$$

What is T_2 ?

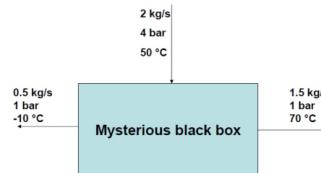
$$\text{1st Law: } \Delta U_m = 0 = n_a C_{v,m} (T_2 - T_a) + n_b C_{v,m} (T_2 - T_b)$$

$$\Rightarrow T_2 = \frac{T_a + T_b}{2} = 423 \text{ K}$$

$$\therefore \Delta S_m = 24 \ln\left(\frac{423}{373}\right) + 24 \ln\left(\frac{423}{473}\right) = 0.34 \frac{\text{J}}{\text{mol}\cdot\text{K}}$$

$\Delta S_m > 0$ bc energy, motion, and vibrations becoming more randomly distributed \rightarrow more random.

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You are feeling somewhat adventurous and are tempted by this offer, but must ask the fundamental question: "Can it work?" Can it? Explain. If necessary, you may assume that the system is adiabatic.

Need to be true:

(i) Mass balance

(ii) 1st Law (Energy Conserved)

(iii) 2nd Law ($\Delta S_{\text{univ}} \geq 0$)

(i) Mass balance

$$\frac{dm}{dt} = 0 = \dot{m}_{in} - \dot{m}_{out} = \dot{m}_1 - (\dot{m}_2 + \dot{m}_3) \Rightarrow \dot{m}_1 = \dot{m}_2 + \dot{m}_3$$

$\checkmark = \text{L.S. eqs}$

good!



(ii) Energy Balance

$$\text{1st Law: } \dot{Q} = \dot{m}_1 \dot{h}_1 - (\dot{m}_2 \dot{h}_2 + \dot{m}_3 \dot{h}_3) + \cancel{Q + W_S}^{\text{no mass puts}}_{\text{adab. to}}$$

$$\Rightarrow \dot{Q} = (\dot{m}_2 + \dot{m}_3) \dot{h}_1 - \dot{m}_2 \dot{h}_2 - \dot{m}_3 \dot{h}_3$$

$$\dot{Q} = \dot{m}_2 (\dot{h}_1 - \dot{h}_2) - \dot{m}_3 (\dot{h}_1 - \dot{h}_3)$$

$$\stackrel{\text{Assume const. } C_p}{=} \dot{m}_2 \int_{T_2}^{T_1} \dot{C}_p dT + \dot{m}_3 \int_{T_3}^{T_1} \dot{C}_p dT$$

$$\Rightarrow \dot{Q} = \dot{m}_2 (T_1 - T_2) + \dot{m}_3 (T_1 - T_3) = 0.5(323 - 263) + 1.5(323 - 313) = 30 - 30 = 0$$

(iii) 2nd Law Holds? $\frac{dS_{\text{univ}}}{dt} \geq 0$?

$$0 \leq \frac{dS}{dt} + \text{inlet } S_{m, \text{out}} - \text{exit } S_{m, \text{in}} - \frac{\dot{Q}}{T_{\text{univ}}} \text{ adiab. to}$$

$$\dot{m}_3 S_{m,3} + \dot{m}_2 S_{m,2} - \dot{m}_1 S_{m,1} \geq 0 \quad \text{mass balance}$$

$$\dot{m}_3 (S_{m,3} - S_{m,1}) - \dot{m}_2 (S_{m,2} - S_{m,1}) \geq 0 \quad \dot{m}_1 = \dot{m}_2 + \dot{m}_3$$

$$3\dot{m}_2 \left[\int_{T_1}^{T_3} \frac{C_{p,m}}{T} dt - \int_{P_1}^{P_3} \frac{R}{P} dP \right] + \dot{m}_3 \left[\int_{T_1}^{T_2} \frac{C_{p,m}}{T} dt - \int_{P_1}^{P_2} \frac{R}{P} dP \right] \geq 0$$

ideal gas
 $\dot{m}_3 = 3\dot{m}_2$

$$3\dot{m}_2 \left[C_{p,m} \ln\left(\frac{T_3}{T_1}\right) - R \ln\left(\frac{P_3}{P_1}\right) \right] + \dot{m}_3 \left[C_{p,m} \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right) \right] \geq 0$$

$$3C_{p,m} \ln\left(\frac{T_3}{T_1}\right) + C_{p,m} \ln\left(\frac{T_2}{T_1}\right) - 3[R \ln\left(\frac{P_3}{P_1}\right) + \frac{R}{3} \ln\left(\frac{P_2}{P_1}\right)] \geq 0$$

$$\frac{C_{p,m}}{R} \left[3 \ln\left(\frac{343}{323}\right) + \ln\left(\frac{263}{323}\right) \right] - 3 \left[\ln\left(\frac{1}{4}\right) + \frac{1}{3} \ln\left(\frac{1}{4}\right) \right] \geq 0$$

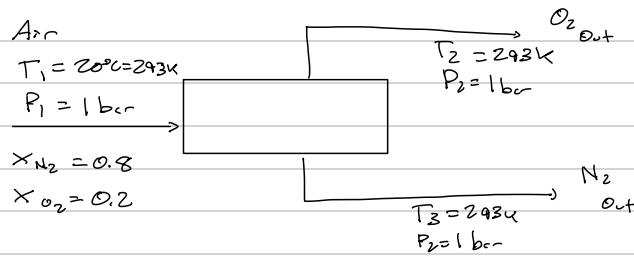
$$-0.02526 \left(\frac{C_{p,m}}{R}\right) + 5.545 \geq 0$$

$$\Rightarrow C_{p,m} \leq 219.5 R$$

Only possible if $C_{p,m} \leq 219.5 R$

Method
Algebra

4. What is the minimum amount of work required to separate an inlet stream of air flowing at 20 °C and 1 bar into exit streams of pure O₂ and N₂ at 20 °C and 1 bar? Assume that air has 20% O₂ and 80% N₂.



mol balance:
 $\frac{d\dot{n}}{dt} = 0 = \dot{n}_{in} - \dot{n}_{out} = 0$
 $\dot{n}_i - (\dot{n}_{O_2} + \dot{n}_{N_2}) = 0$
 $\dot{n}_i = \dot{n}_{O_2} + \dot{n}_{N_2}$
 $\dot{n}_{N_2} = 0.8 \dot{n}_i$
 $\dot{n}_{O_2} = 0.2 \dot{n}_i$

1st Law: $\dot{Q} = \dot{n}_i h_{m,i} - (\dot{n}_{N_2} h_{m,N_2} + \dot{n}_{O_2} h_{m,O_2}) + \dot{W}_{re} + \dot{Q}$
(state₁-state₂) ideal g.s. const T ideal g.s. const T $\Rightarrow \dot{W}_{re} = -\dot{Q}$

2nd Law: Minimum work \rightarrow reversible

$$\frac{dS_{uni}}{dt} = \frac{dS}{dt} + \dot{n}_{N_2} S_{m,N_2} + \dot{n}_{O_2} S_{m,O_2} - \dot{n}_i S_{m,i} - \frac{\dot{Q}_{rev}}{T_{sum}} = 0$$

(state₁-state₂)

ideal Gas
 $dS_m = \frac{C_p}{T} dT - \frac{R}{P} dP$

$$\dot{n}_{N_2} S_{m,N_2} + \dot{n}_{O_2} S_{m,O_2} - \dot{n}_i S_{m,i} - \frac{\dot{Q}_{rev}}{T_{sum}} = 0$$

$$\dot{n}_{N_2} S_{m,N_2} + \dot{n}_{O_2} S_{m,O_2} - \dot{n}_{O_2} S_{m,i} - \dot{n}_{N_2} S_{m,i} = \frac{\dot{Q}_{rev}}{T_{sum}} \quad \text{mass balance}$$

$$\dot{n}_{N_2} \left(\begin{array}{c} N_2 \text{ out} \\ N_2 \text{ in} \end{array} \right) dS_m + \dot{n}_{O_2} \left(\begin{array}{c} O_2 \text{ out} \\ O_2 \text{ in} \end{array} \right) dS_m = -\frac{\dot{W}_{rev}}{T_{sum}} \quad \text{1st Law}$$

$$-\dot{n}_{N_2} \left(\begin{array}{c} P_{N_2 \text{ out}} \\ P_{N_2 \text{ in}} \end{array} \right) \frac{R}{P} dP - \dot{n}_{O_2} \left(\begin{array}{c} P_{O_2 \text{ out}} \\ P_{O_2 \text{ in}} \end{array} \right) \frac{R}{P} dP = -\frac{\dot{W}_{rev}}{T_{sum}} \quad \text{const } T, \text{ change } P \\ \text{(treat as ideal gas)}$$

$$\frac{\dot{W}_{rev}}{T_{sum}} = \dot{n}_{N_2} R \ln \left(\frac{P_{N_2 \text{ out}}}{P_{N_2 \text{ in}}} \right) + \dot{n}_{O_2} R \ln \left(\frac{P_{O_2 \text{ out}}}{P_{O_2 \text{ in}}} \right) \quad \dot{n}_{N_2} = 0.8 \dot{n}_i, \quad P_{N_2 \text{ in}} = 0.8 \text{ bar} \\ \dot{n}_{O_2} = 0.2 \dot{n}_i, \quad P_{O_2 \text{ in}} = 0.2 \text{ bar}$$

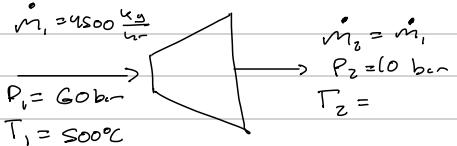
$$\Rightarrow \frac{\dot{W}_{rev}}{\dot{n}_i} = RT_{sum} \left[0.8 \ln \left(\frac{P_{N_2 \text{ out}}}{P_{N_2 \text{ in}}} \right) + 0.2 \ln \left(\frac{P_{O_2 \text{ out}}}{P_{O_2 \text{ in}}} \right) \right] \quad R = 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}} \\ T_{sum} = 293\text{K} \quad \text{(assume no press temp)}$$

$$= 8.314 \cdot 293 \cdot (0.500 \text{ J}) = 1218.48 \frac{\text{kJ}}{\text{mol}}$$

$$\frac{\dot{W}_{rev}}{\dot{n}_i} = 1218.48 \frac{\text{kJ}}{\text{mol}}$$

5. A steam turbine in a small electric power plant is designed to accept 4500 kg/hr of steam at 60 bar and 500 °C and exhaust the steam at 10 bar.

- Assuming that this turbine is adiabatic and generates the maximum possible power, compute the exit temperature of the steam and the power generated by the turbine.
- The efficiency of a turbine is defined to be the ratio of the work actually obtained from the turbine to the work that would be obtained if the turbine operated isentropically between the same inlet and exit pressures. If the turbine in (a) is adiabatic but only 80% efficient, what would be the exit temperature of the steam? At what rate would entropy be generated within the turbine?



mass balance: $\frac{dm}{dt} = 0 = \dot{m}_{in} - \dot{m}_{out}$
 $\rightarrow \dot{m}_1 = \dot{m}_2 = \dot{m}$

a) Adiabatic $\dot{Q} = 0$

1st Law: $\frac{dU}{dt} = \dot{Q} = \dot{m}(h_1 - h_2) + \dot{m}\hat{s}_1 - \dot{m}\hat{s}_2 + \dot{W}_{adibatic}$

2nd Law: $\frac{dS_{univ}}{dt} = \frac{ds}{dt} + \dot{m}_1\hat{s}_1 - \dot{m}_2\hat{s}_2 + \frac{\dot{Q}}{T_{sun}}_{adibatic}$

$$\dot{W}_s = \dot{m}(h_1 - h_2)$$

$$\hat{s}_1 = \hat{s}_2 \quad \text{isentropic}$$

Table B.4

① 500°C, 60 bar, $\hat{h}_1 = 3422.2 \frac{\text{kJ}}{\text{kg}}$, $\hat{s}_1 = 6.8802 \frac{\text{kJ}}{\text{kgK}} = \hat{s}_2$

② 10 bar, $\hat{s}_2 = 6.8802 \frac{\text{kJ}}{\text{kgK}}$

$\rightarrow L_{in, p, T, \dot{m}}$

$T_2 = 240.4^\circ\text{C} \rightarrow \hat{h}_2 = 2920.6 \frac{\text{kJ}}{\text{kg}}$

$\dot{W}_s = 4500 \frac{\text{kg}}{\text{hr}} (2920.6 - 3422.2) = -2.26 \times 10^6 \frac{\text{kJ}}{\text{hr}}$

$$\dot{W}_s = -627 \text{ kW}$$

$$T_2 = 240.4^\circ\text{C}$$

b) $\eta_{turbine} = 80\%$

$\dot{W}_s = 0.8(-627 \text{ kW}) = -501.6 \text{ kW}$

$\rightarrow \hat{h}_2 = \frac{\dot{W}_s}{\dot{m}} + \hat{h}_1 = 3020.86 \frac{\text{kJ}}{\text{kg}}$

Table B.4

$P_2 = 10 \text{ bar}, \hat{h}_2 = 3020.86 \frac{\text{kJ}}{\text{kg}}$

$T_{in, p} = 250^\circ\text{C} \quad \hat{s}_{in, p} = 6.4246 \frac{\text{kJ}}{\text{kgK}}$

$T_2 = ? \quad \hat{s}_2 = ?$

$T_{in, s} = 300^\circ\text{C} \quad \hat{s}_{in, s} = 7.1228 \frac{\text{kJ}}{\text{kgK}}$

$\hat{h}_{in, p} = 2827.9 \frac{\text{kJ}}{\text{kg}}$

$\hat{h}_2 = 3020.86 \frac{\text{kJ}}{\text{kg}}$

$\hat{h}_{in, s} = 3051.2 \frac{\text{kJ}}{\text{kg}}$

$\rightarrow L_{in, p, T, \dot{m}}$

$T_2 = 286.7^\circ\text{C} \rightarrow \hat{s}_2 = 7.0677 \frac{\text{kJ}}{\text{kgK}}$

2nd Law: $\frac{dS_{univ}}{dt} = \frac{ds}{dt} + \dot{m}_2\hat{s}_2 - \dot{m}_1\hat{s}_1 + \frac{\dot{Q}}{T_{sun}}_{adibatic}$

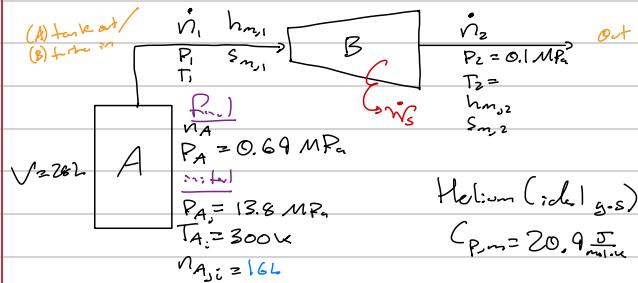
(real process) (not $\dot{Q} = 0$)

$= \dot{m}(\hat{s}_2 - \hat{s}_1) = -\dot{m}(\hat{s}_1 - \hat{s}_2)$

$\frac{dS_{univ}}{dt} = -\dot{m}(\hat{s}_1 - \hat{s}_2) = -4500 \frac{\text{kg}}{\text{hr}} (6.8803 \frac{\text{kJ}}{\text{kgK}} - 7.0677 \frac{\text{kJ}}{\text{kgK}}) = 843.3 \frac{\text{kJ}}{\text{hr}}$

6. A portable power supply consists of a 28 L bottle of compressed helium, charged to 13.8 MPa at 300 K, connected to a small turbine. During the operation, the helium drives the turbine continuously until the pressure in the bottle drops to 0.69 MPa. The turbine exhausts at 0.1 MPa. Neglecting heat transfer, calculate the maximum possible work from the turbine. Assume helium to be an ideal gas with $c_{p,m} = 20.9 \text{ J/mol-K}$.

Max work occurs for
 $dS_{\text{sur}} = 0$ & adiabatic systems
 (no heat loss to surroundings)



Tank A: $\frac{dn_A}{dt} = \dot{m}_{in} - \dot{m}_{out} = -\dot{m}_{out}$

1st law: $\frac{dU_A}{dt} = \dot{m}_{in} h_{in} - \dot{m}_{out} h_{out} + Q + \dot{W}_{ad} \quad \text{no shaft work}$
 only heat, no inlet

$\frac{dU_A}{dt} = -\dot{m}_{out} h_{out} = -\dot{m}_{out} h_{m,A} \quad (\text{gas out has same properties as the tank at } t)$

$\frac{dU_A}{dt} = \frac{dn_A}{dt} h_{m,A} \xrightarrow{\text{dilute}} dU_A = dn_A h_{m,A} \xrightarrow{U_A = n_A U_{m,A}} d(n_A U_{m,A}) = dn_A h_{m,A}$

$d(n_A U_{m,A}) = n_A dU_{m,A} + U_{m,A} dn_A = n_A dU_{m,A}$

$\rightarrow n_A dU_{m,A} = (h_{m,A} - U_{m,A}) dn_A \Rightarrow \int n_A C_v dT = \int R T dn_A$
 C_v and T for ideal gas

$\int_{T_{A,i}}^{T_A} \frac{C_v}{R} dT = \int_{n_{A,i}}^{n_A} \frac{1}{n_A} dn_A \Rightarrow \frac{C_v}{R} \ln \left(\frac{T_A}{T_{A,i}} \right) = \ln \left(\frac{n_A}{n_{A,i}} \right) \rightarrow \left(\frac{T_A}{T_{A,i}} \right)^{\frac{C_v}{R}} = \left(\frac{n_A}{n_{A,i}} \right)$

$\frac{n_A}{n_{A,i}} = \frac{P_A \sqrt{A} R T_{A,i}}{P_{A,i} \sqrt{A_i} R T_A} = \frac{P_A T_{A,i}}{P_{A,i} T_A} \rightarrow \left(\frac{T_A}{T_{A,i}} \right)^{\frac{C_v}{R}} = \left(\frac{P_A}{P_{A,i}} \right) \left(\frac{T_{A,i}}{T_A} \right) \Rightarrow \left(\frac{T_A}{T_{A,i}} \right)^{\frac{C_v}{R}+1} = \left(\frac{P_A}{P_{A,i}} \right)$

$\frac{C_v}{R} + 1 = \frac{C_p, m + R}{R} = \frac{C_p, m}{R} \Rightarrow T_A = T_{A,i} \left(\frac{P_A}{P_{A,i}} \right)^{\frac{C_p, m}{R}}$

2nd law: $\frac{dS_A}{dt} = -\dot{m}_{out} S_{m,A} - \frac{Q}{T_{sur}} \quad \text{adiabatic} \rightarrow \frac{dS_A}{dt} = \frac{dn}{dt} S_{m,A} \quad dS_A = S_{m,A} dn$

$S_A = n_A S_{m,A} \Rightarrow d(n_A S_{m,A}) = dn_A S_{m,A} \xrightarrow{\text{chain rule}} n_A dS_{m,A} + S_{m,A} dn_A = S_{m,A} dn$

$n_A dS_{m,A} = 0 \Rightarrow dS_{m,A} = 0 \quad \therefore S_{m,A} \text{ is constant through stream!}$

Turbine B: $\frac{d\dot{n}}{dt} = 0 = \dot{n}_2 - \dot{n}_1 \Rightarrow \dot{n}_1 = \dot{n}_2 = \dot{n}_B$

1st Law: $\frac{dY}{dt} = 0 = \dot{n}_1 h_{m,1} - \dot{n}_2 h_{m,2} + \dot{W}_S + \dot{Q}$ admits $\Rightarrow \dot{n}_B (h_{m,2} - h_{m,1}) = \dot{W}_S$

$$\dot{W}_S = \dot{n}_B \int_{B_{in}}^{B_{out}} dh_{m,B} = \dot{n}_B \int_{T_A}^{T_2} C_{p,m} dT \rightarrow \dot{W}_S = \dot{n}_B C_{p,m} (T_2 - T_A)$$

2nd Law: $\frac{dS_B}{dt} = 0 = \dot{n}_B (S_{m,2} - S_{m,1}) - \frac{\dot{Q}}{T_{surround}}$ $S_{m,1} = S_{m,A} \therefore S_{m,2} = S_{m,A}$

$$S_{m,2} = S_{m,A} (T_2, P_2) \quad P_2 \text{ is const} \therefore T_2 \text{ must also be const}$$

$$\Delta S = 0 = \int_{T_A}^{T_2} \frac{C_{p,m}}{P} dT = \int_{P_A}^{P_2} \frac{R}{P} dP$$

$$C_{p,m} \ln \left(\frac{T_2}{T_A} \right) = \ln \left(\frac{P_2}{P_A} \right) \rightarrow T_2 = T_A \left(\frac{P_2}{P_A} \right)^{\frac{R}{C_{p,m}}} \text{ Use the same path taken in A}$$

$$\text{From A: } T_A = T_{A,i} \left(\frac{P_A}{P_{A,i}} \right)^{\frac{R}{C_{p,m}}} \Rightarrow T_2 = T_{A,i} \left(\frac{P_2}{P_A} \right)^{\frac{R}{C_{p,m}}} \left(\frac{P_A}{P_{A,i}} \right)^{\frac{R}{C_{p,m}}}$$

$$T_2 = 300K \left(\frac{0.1 \text{ MPa}}{0.69 \text{ MPa}} \right)^{\frac{8.314}{20.9}} \left(\frac{0.69 \text{ MPa}}{13.8 \text{ MPa}} \right)^{\frac{8.314}{20.9}} = 42.255 \text{ K}$$

$$T_A = 300K \left(\frac{0.69 \text{ MPa}}{13.8 \text{ MPa}} \right)^{\frac{8.314}{20.9}} = 91.11 \text{ K} \quad * \text{ For L-tors } \frac{R}{C_{p,m} R} = \frac{R}{C_{p,m} R} = 0.66$$

Work of turbine from 1st law:

$$\int_0^{\dot{W}_{S,\text{tot},1}} \delta \dot{W}_S = \int_0^{\text{molsto1}} C_{p,m} (T_2 - T_F) d\dot{n}_B \quad d\dot{n}_B = -d\dot{n}_A \quad (\text{Avl molsto A gas to B})$$

$$\text{From A: } \left(\frac{T_A}{T_{A,i}} \right)^{\frac{C_{p,m}}{R}} = \frac{V_A}{V_{A,i}} \Rightarrow T_A = T_{A,i} \left(\frac{V_A}{V_{A,i}} \right)^{\frac{R}{C_{p,m}}}$$

$$\text{so, } \dot{W}_S = - \int_{V_{A,i}}^{V_{A,F}} C_{p,m} \left[T_2 - T_{A,i} \left(\frac{V_A}{V_{A,i}} \right)^{\frac{R}{C_{p,m}}} \right] dV_A$$

$$= -C_{p,m} \left[T_2 (V_{A,F} - V_{A,i}) - \left(\frac{T_{A,i}}{V_{A,i}^{0.66}} \right) \left(\frac{1}{1.66} \right) \left(V_{A,F}^{1.66} - V_{A,i}^{1.66} \right) \right]$$

$$\left\{ \begin{array}{l} V_{A,i} = \frac{P_{A,i} V_{A,i}}{R T_{A,i}} = \frac{(138 \text{ bar})(28 \text{ L})}{(0.08314 \frac{\text{L bar}}{\text{mol K}})(300 \text{ K})} = 154.9 \text{ mol} \\ V_{A,F} = \frac{P_A V_A}{R T_A} = \frac{(6.9)(28)}{(0.08314)(91.1)} = 28.6 \text{ mol} \end{array} \right.$$

$$V_A = V_{A,i} \quad (\text{Rigid})$$

$$\Rightarrow \dot{W}_{S,\text{max}} = -441.4 \text{ WJ}$$

Midterm 1 Practice



Review Lecture

Entropy Calculations

$$\text{2nd Law: } \Delta S_{\text{uni}} = \Delta S + \Delta S_{\text{sur}} \geq 0$$

① System - reversible calculation path

$$\Rightarrow dS_m = \frac{C_p}{T} dT - \frac{R}{P} dP \quad \text{for ideal gas (on eqn sheet)}$$

↳ equiv. to $\int \frac{S \, dQ}{T}$

↳ valid for reversible
processes

\Rightarrow Use steam tables for steam/ H_2O

② Surroundings - real heat transfer ($Q \rightarrow 1^{\text{st}}$ Law to determine)

$$\Delta S_{\text{sur}} = \frac{Q_{\text{sur}}}{T_{\text{sur}}} = - \frac{Q}{T_{\text{sur}}} \quad \leftarrow \text{real system heat transfer}$$

Additive process $\rightarrow Q=0 \rightarrow Q_{\text{sur}}=0 \rightarrow \Delta S_{\text{sur}}=0!$

\hookrightarrow any changes \Rightarrow universe stems from the system only! (isolated)

Open Systems - Multiple Flows & Non-Steady States

\rightarrow ignoring KE, PE

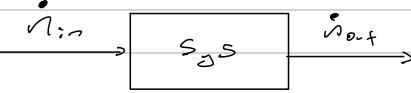
$$1^{\text{st}} \text{ Law} \rightarrow \frac{dU}{dt} = \dot{m}_{in} h_{m,in} - \dot{m}_{out} h_{m,out} + \dot{W}_s + \dot{Q}$$

(on eqn sheet)

• General Strategy: always start with mass balance!

\hookrightarrow use it as another equation to help solve 1st & 2nd law problems

1) Steady-state - one in, one out



$$\text{Mass Balance: } \frac{d}{dt} = 0 = \dot{m}_{in} - \dot{m}_{out} \rightarrow \dot{m}_{in} = \dot{m}_{out} = \dot{m}$$

$$1^{\text{st}} \text{ Law: } \frac{dU}{dt} = 0 = \dot{m}_{in} h_{m,in} - \dot{m}_{out} h_{m,out} + \dot{W}_s + \dot{Q}$$

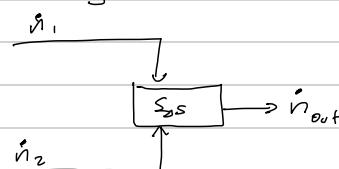
\hookrightarrow no accumulation
 $\Rightarrow \dot{m} = \dot{m} (h_{m,in} - h_{m,out}) + \dot{W}_s + \dot{Q}$

\hookrightarrow \dot{m} must be constant
 \hookrightarrow \dot{m} is constant
 \hookrightarrow want terms that look like this!

$$\Rightarrow \Delta h_m = \int_{h_{m,out}}^{h_{m,in}} dh_m = \int_{T_{out}}^{T_{in}} C_p dT \quad \text{assuming ideal gas}$$

Eqn sheet

2) Steady-state - two in, one out (mixing)



$$\text{MB: } \frac{d}{dt} = 0 = \dot{m}_1 + \dot{m}_2 - \dot{m}_{out} \Rightarrow \dot{m}_{out} = \dot{m}_1 + \dot{m}_2$$

$$1^{\text{st}} \text{ Law: } \frac{dU}{dt} = 0 = \dot{m}_1 h_{m,1} + \dot{m}_2 h_{m,2} - \dot{m}_{out} h_{m,out} + \dot{Q} + \dot{W}_s$$

$$= \dot{m}_1 h_{m,1} + \dot{m}_2 h_{m,2} - \dot{m}_1 h_{m,out} - \dot{m}_2 h_{m,out} + \dot{Q} + \dot{W}_s$$

$$= \dot{m}_1 (h_{m,1} - h_{m,out}) + \dot{m}_2 (h_{m,2} - h_{m,out}) + \dot{Q} + \dot{W}_s$$

\hookrightarrow Met our goal of getting changes

$$\Delta h_m = \int_{h_{m,out}}^{h_{m,in}} dh_m = \int_{T_{out}}^{T_{in}} C_p dT$$

3) Hot steady state - Tank Filling

$$\frac{dn}{dt} = \dot{V}_{in} - \dot{V}_{out} \Rightarrow \frac{dn}{dt} = \frac{dn_{in}}{dt} - \frac{dn_{out}}{dt}$$

MB: $\frac{dn}{dt} = n_{in} - n_{out} \Rightarrow \frac{dn}{dt} = dn_{in} - dn_{out}$

$\int_{n_0}^{n_f} dn = \int_{t_0}^{t_f} dn_{in} - \int_{t_0}^{t_f} dn_{out}$

$n_f = n_0 + \int_{t_0}^{t_f} dn_{in} - \int_{t_0}^{t_f} dn_{out}$

$\Rightarrow n_f - n_0 = \int_{t_0}^{t_f} dn_{in} - \int_{t_0}^{t_f} dn_{out}$ if tank starts empty (vacuum)

1st Law: $dU = h_{m,in}dn_{in} - h_{m,out}dn_{out} + SW_s + SQ$

$dU = h_{m,in}dn + SW_s + SQ$

(1) Integrating
This is a better way to do it!

$\int_{n_0}^{n_f} dU = h_{m,in} \int_{n_0}^{n_f} dn + \int_{t_0}^{t_f} SW_s dt + \int_{t_0}^{t_f} SQ dt$

$n_f U_{m,f} - n_0 U_{m,i} = (n_f - n_i) h_{m,in} + W_s + Q$

$Q = n_f(h_{m,in} - U_{m,f}) + n_i(h_{m,in} - U_{m,i}) + Q_s W_s$

$h_{m,in} = U_{m,in} + P_{in} V_{in}$
 $= U_{m,in} + RT_{in}$ (16)

(2) Substitution First

$d(U_{m,n}) = h_{m,in} dn + SW_s + SQ$

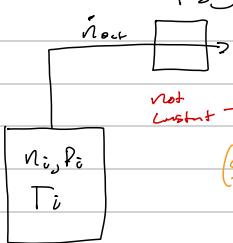
product rule $d(U_{m,n}) = h_{m,in} dn + h_{m,in} dn + SW_s + SQ$

$ndU_m = (h_{m,in} - U_m) dn + SW_s + SQ$

$\frac{dU_m}{h_{m,in} - U_m} = \frac{dn}{n}$ More work to do, but works

Cannot use P vacuum at start

4) Non-steady - emptying



Stream has properties
P fluid in tank
not constant $\rightarrow (P_f, h_f, s_f, m_f, \text{etc})$
(See #6 on HW 4)

$$\text{MB: } \frac{dn}{dt} = \dot{V}_{in} - \dot{V}_{out}$$

$$\frac{dn}{dt} = -\frac{dn_{out}}{dt}$$

$$\int_{n_0}^{n_f} dn = - \int_{t_0}^{t_f} dn_{out}$$

Q: no heat left for Q stat

$$n_f - n_0 = -n_{out}$$

Assumptions & Key words

1) Steady state: no accumulation/change in properties inside sys

$$\frac{dn}{dt} = 0, \frac{dU}{dt} = 0, \frac{dS}{dt} = 0 \Rightarrow h_{m,n}, U_{m,n}, T_{m,n}, P \text{ constant}$$

2) Adiabatic = (well) insulated = no heat transfer

$$\rightarrow Q = 0, SQ = 0$$

$$\rightarrow \Delta S_{\text{sum}} = -\frac{Q}{T_{\text{sum}}} = 0$$

Note/Caution: this does not mean isothermally

3) Shaft work, W_s

$\rightarrow \dot{V}_E = 0$ - if no mention of moving parts requiring extra power (like in compressor or turbine)

4) KE and PE: ignore unless otherwise stated or given information about velocity, or given pipe dimensions

5) Reversible Processes **Key input**

\rightarrow MAX WORK extracted for expansion

\rightarrow MIN WORK required for compression

general characteristics of reversible process:

$$\rightarrow \frac{dS_{\text{univ}}}{dt} = 0, \Delta S_{\text{univ}} = 0$$

• Key word "reversible" or equivalent "min/max work" tells you:

a) Closed System: $P_E = P$ (slow, \approx equilibrated mechanically w/ surrounding throughout)

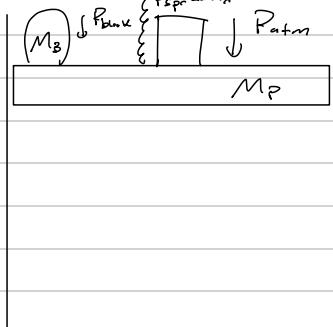
b) Open System: $\frac{dS_{\text{univ}}}{dt} = 0$ (2nd Law) \leftarrow also true for closed systems, just not as useful

PV Work

$$\text{Eqn Sheet: } \delta W_m = -P_E dV_m$$

↑ always external pressure

Account for sources of external pressure



↓ P_ext

Pressure / forces balance @ mechanical equilibrium

→ piston stops moving when $P_E = P_i$; $P_i = \frac{F_i}{A_{\text{piston}}}$ ← cross sectional area of piston

$$P_E = \frac{M_B g}{A} + \frac{M_B g}{A} + P_{\text{atm}} - \left(-\frac{k_x}{A} \right)$$

$$= \frac{M_p g}{A} + \frac{M_B g}{A} + P_{\text{atm}} + \frac{k(V - V_0)}{A^2}$$

✓ when spring exerts no force

Equations, Units, and Tables Midterm 1

If smthg is on the sheet,
you can use it w/o deriving

First Law for closed systems:

$$dU + dE_K + dE_P = \delta Q + \delta W$$

$$\frac{dU}{dt} + \frac{dE_K}{dt} + \frac{dE_P}{dt} = \dot{Q} + \dot{W}$$

PV work:

$$\delta w_m = -P_E dv_m$$

First Law for open systems with one input and one output stream:

$$\begin{aligned} dU + dE_K + dE_P &= dn_{in} \left[h_m + \frac{1}{2} |v|^2 (MW) + gz(MW) \right]_{in} \\ &\quad - dn_{out} \left[h_m + \frac{1}{2} |v|^2 (MW) + gz(MW) \right]_{out} \\ &\quad + \delta Q + \delta W_s \end{aligned}$$

$$\begin{aligned} \frac{dU}{dt} + \frac{dE_K}{dt} + \frac{dE_P}{dt} &= \dot{n}_{in} \left[h_m + \frac{1}{2} |v|^2 (MW) + gz(MW) \right]_{in} \\ &\quad - \dot{n}_{out} \left[h_m + \frac{1}{2} |v|^2 (MW) + gz(MW) \right]_{out} \\ &\quad + \dot{Q} + \dot{W}_s \end{aligned}$$

Enthalpy definition:

$$h_m = u_m + P v_m$$

Enthalpy of vaporization:

$$\Delta h_{m,vap}(T) = \Delta h_{m,vap}(T_0) + \int\limits_T^{T_0} c_{p,m}^{\text{liq}} dT + \int\limits_{T_0}^T c_{p,m}^{\text{vap}} dT$$

Property data for ideal gases:

$$du_m = c_{v,m} dT$$

$$dh_m = c_{p,m} dT$$

Carnot efficiency:

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

Entropy changes:

$$ds_m = \frac{\delta q_{rev,m}}{T}$$

Differential entropy change for an ideal gas:

$$ds_m = c_{p,m} \frac{dT}{T} - R \frac{dP}{P} \quad \text{System } ds_m \text{ for ideal gas}$$

Second Law for closed systems:

$$\frac{dS}{dt} - \frac{\dot{Q}}{T_{surr}} \geq 0$$

$$\Delta S - \frac{\dot{Q}}{T_{surr}} \geq 0$$

Second Law for open systems with one input and one output stream:

$$dS + s_{m,out} dn_{out} - s_{m,in} dn_{in} - \frac{\delta Q}{T_{surr}} \geq 0$$

$$\frac{dS}{dt} + s_{m,out} \dot{n}_{out} - s_{m,in} \dot{n}_{in} - \frac{\dot{Q}}{T_{surr}} \geq 0$$

Units and constants:

$$R = 8.314 \text{ J/(mol K)}$$

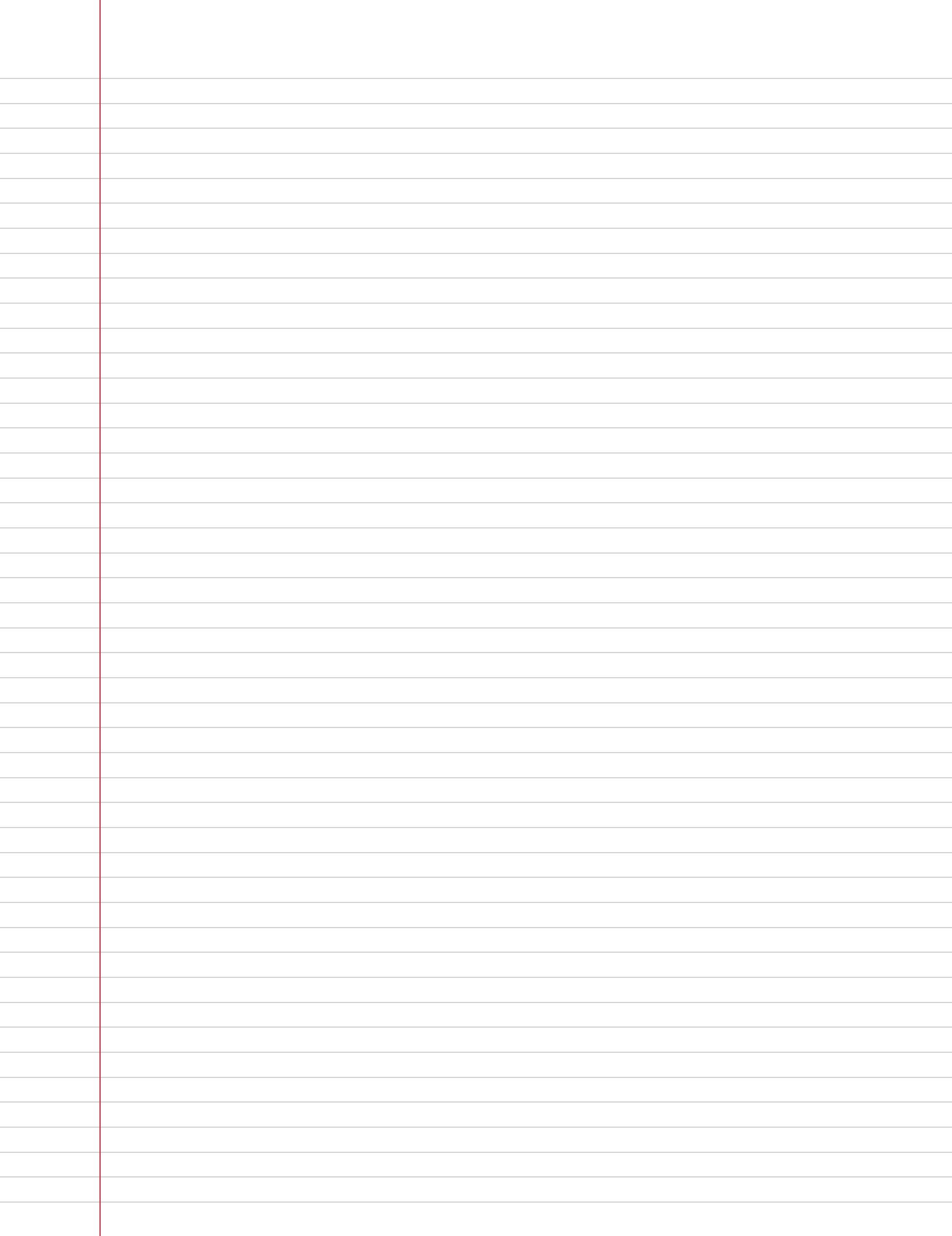
$$g = 9.8 \text{ m/s}^2$$

$$1 \text{ bar} = 10^5 \text{ Pa} = 10^5 \text{ kg/(m s}^2)$$

Midterm 1 extra practice problems

These problems are meant to provide opportunities for supplemental practice in addition to the homework problems, quiz problems, and examples from the lectures/textbook. Numerical answers are provided to check your solutions.

- Koretsky 2.24
 - Answers:
 - b) $W = -940 \text{ J}$
 - c) $Q = 940 \text{ J}$
- Koretsky 2.41
 - Answers:
 - $500 \text{ }^{\circ}\text{C}, 1200 \text{ kPa}, 0.167 \text{ m}$
- Koretsky 2.49
 - Answers:
 - $Q = 228 \text{ kJ}$
- Koretsky 3.22
 - Answers:
 - For Problem 2.28, $\Delta S_{\text{univ}} = 1.24 \text{ J/K}$
 - For Problem 2.29, $\Delta S_{\text{univ}} = 0.004 \text{ J/K}$
- Koretsky 3.41
 - Answers:
 - a) 650 K
 - b) $-55.1 \text{ kJ/s} = -55.1 \text{ kW}$
 - c) -78.7 kW
 - d) 819 K
- Koretsky 3.44
 - Answers:
 - 51.2 J/K



ECHE 363. Thermodynamics of Chemical Systems
Spring 2020 Midterm Exam 1

Name: _____

Date: _____

Instructions: You have seventy five minutes to answer all questions. Read the problems carefully and completely before starting to answer. State any assumptions if necessary. Show all steps as partial credit may be given even for a wrong final answer. The final part of the final question is a bonus question. If needed, use both sides of the sheet.

Instructor Use Only:

Problem 1 _____

Problem 2 _____

Problem 3 _____

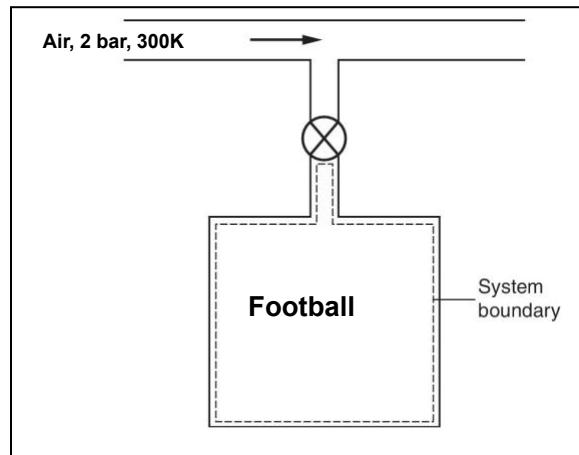
Total: _____ /100

1. **(40 points)** Consider a closed rigid container with 10 kg of H₂O at 2 bar. H₂O undergoes a process and reaches a final state 10 bar and 400 °C.
 - a. What is the volume (m³) of the container? (10 points)
 - b. What is the initial temperature (K)? (10 points)
 - c. If applicable, what is the initial quality? (10 points)
 - d. What is the heat transferred (Q, Joules) to the system? (10 points)

2. (40 points) **Deflategate:** Consider the dynamic inflation of a football. For the purpose of this problem, football is modeled as a rigid container that contains vacuum initially. Air (ideal gas) supply is available from a cylinder with a constant pressure of 2 bars and a constant temperature of 300K. You may assume that the c_p (specific heat capacity at constant pressure) for air is approximately constant: $c_p=3.5R$, where R is the universal gas constant.

a. The football is adiabatically filled until the

pressure inside reaches the inlet pressure of 2 bar. Perform mole and energy balance (15 points).



b. Determine the temperature of air in the football just after it is filled? (25 points)

- c. *Bonus part:* Once it is filled, the valve is closed and the football is left in a room ($T_R=298$ K) until thermal equilibrium is achieved. What is the pressure inside the football? (10 points)

3. **(20 points)** In a closed system, an ideal gas initially at a temperature of 350K and a pressure of 200 kPa undergoes a process in which the enthalpy change and the internal energy change are measured to be 2025 J/mol and 1580 J/mol respectively. What is the final temperature of the system?

Name _____

Wednesday, February 22nd

ECHE 363 – Thermodynamics of Chemical Systems
Midterm #1

Rules:

- 75 minutes total time. Once time is up, put aside answer sheets.
- Be sure to show all work to obtain maximum credit.
- Closed book and no notes.
- Write your name on every page.
- Please only write on the front side of each page. Ask for additional paper if necessary.

Name _____

For instructor use only:

Problem 1 / 25	
Problem 2 / 40	
Problem 3 / 35	
Total / 100 points	

Name _____

1. (25 points) An ideal gas, with a temperature-independent $c_{p,m} = 3.5R$ at 15°C has an initial volume of 60 m^3 . It is heated at constant pressure ($P = 1 \text{ bar}$) to 30°C by heat transfer from a reservoir that is also at a pressure of 1 bar. Calculate the total ΔS , ΔS_{surr} , and ΔS_{univ} if:
 - a. The surroundings are at 50°C .
 - b. The surroundings are at 20°C .
 - c. Which of the processes in (a) or (b) is thermodynamically possible?

Name _____

Name _____

Name _____

2. (40 points) Steam at 50.0 MPa, 600 °C and a volumetric flow rate of 0.0140 m³/s is fed to an adiabatic turbine operating at steady state. The turbine exit stream is saturated water vapor at 3.00 MPa. Calculate the power (kW) produced by this turbine and its efficiency. You may assume that the exit stream for a process with 100% efficiency is also at 3.00 MPa.

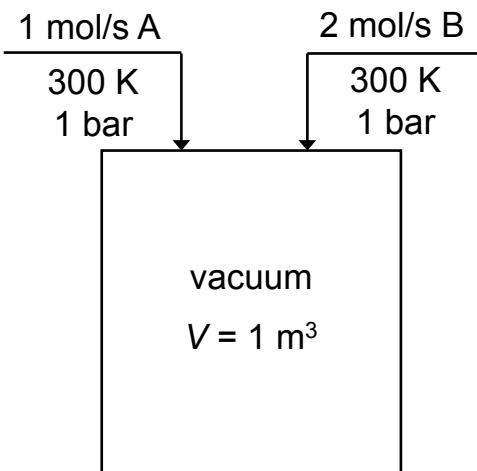
Name _____

Name _____

Name _____

3. (35 points) A rigid, 1 m^3 tank is initially evacuated. Two streams are then allowed to flow into the tank. One stream contains a gas (A) with a molar flow rate of 1 mol/s at $T_{A,\text{in}} = 300 \text{ K}$ and $P_{A,\text{in}} = 1 \text{ bar}$. The other stream contains a different gas (B) with a molar flow rate of 2 mol/s at $T_{B,\text{in}} = 300 \text{ K}$ and $P_{B,\text{in}} = 1 \text{ bar}$. Gas A has a constant $c_{p,m}^A$ of $5/2R$, and gas B has a different constant $c_{p,m}^B$ of $7/2R$. The two gases are flowed into the tank until it reaches a final pressure of 20 bar , whereupon the valve is closed. The temperature of the surroundings is 300 K . You may treat both "A" and "B" as an ideal gas throughout the entire process.

- Find the final temperature immediately after the valve is closed and the tank stops filling.
- Find the heat transferred (Q) and the final pressure after the tank is in storage for a long period of time, and comes to thermal equilibrium with the surroundings.



Name _____

Name _____

Name _____

Name Spring 2024

Wednesday, February 28th

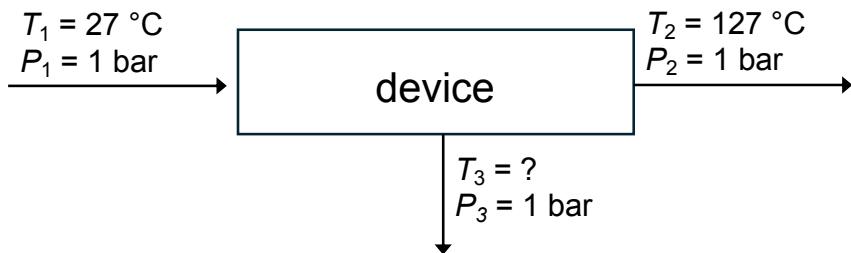
ECHE 363 – Thermodynamics of Chemical Systems
Midterm #1

Rules:

- 75 minutes total time. Once time is up, put aside answer sheets.
- Be sure to show all work to obtain maximum credit. This includes showing and simplifying any mass/mole, 1st Law, and 2nd Law balances that are needed to solve each problem.
- Closed book and no notes.
- Write your name on every page.
- Please only write on the front side of each page. Ask for additional paper if necessary.

Name _____

1. (25 points) Nitrogen gas at 27°C in “stream 1” flows into a well-insulated device operating at steady state. There is no shaft work. Two-thirds of the nitrogen, by moles, exits at 127°C and 1 bar in “stream 2”. The remainder of the nitrogen exit through “stream 3” at an unknown temperature and 1 bar. Find the temperature of the nitrogen in the “stream 3” outlet. Assume ideal gas behavior, where nitrogen has $c_{\text{p,m}} = 29.1 \text{ J/mol-K}$.



Name _____

Name _____

Name _____

2. (40 points) Steam is fed to an adiabatic turbine at 4 MPa and 500 °C. It exits at 0.2 MPa. Assuming that the process occurs at steady state, what is the maximum possible work (per kg of steam) that can be extracted from the turbine?

Hint: remember to determine the phase of both the input and output water streams.

Name _____

Name _____

Name _____

3. (35 points) One mole of an ideal gas contained within a piston–cylinder assembly has an initial pressure of $P_1 = 5$ bar and initial temperature of $T_1 = 500$ K. It undergoes a reversible expansion until it reaches a final pressure of $P_2 = 1$ bar and final temperature of $T_2 = 300$ K. The expansion is not adiabatic and thus heat transfer cannot be neglected. The surroundings have a temperature of $T_{\text{surr}} = 300$ K. The fluid has a constant-pressure heat capacity of:

$$c_{\text{p,m}}/R = A + BT, \text{ where } A = 3.5 \text{ and } B = 0.02 \text{ K}^{-1}$$

For the process described above, calculate: W , Q , ΔS_{sys} , ΔS_{surr} , ΔS_{univ} .

Name _____

Name _____