

1. (25pts) Answer the following questions. Justify your answers. (Use the space provided below and on the next page)

- a). Heat transfer between objects is through conduction, convection, and/or radiation. Identify the predominant form of heat transfer involved in each of the following situations: i) You feel the heat from the sun when you are laying on the beach. ii) You feel the heat on the handle of a metal spoon after it has been sitting in a cup of hot coffee. iii) The air within your house is being cooled by an air-conditioner unit.
- b). An ideal gas is being compressed by a piston in an isothermal process. Will the temperature rise, fall, or stay the same? Answer the same question for an adiabatic compression.
- c). With the same number of moles, does a diatomic gas have a larger or smaller heat capacity than a monoatomic gas at the same temperature? Explain.
- d). In a particular process, a system interacts with its environment and the entropy of the system decreases by  $\Delta S$ . According to the second law of thermodynamics, what can you conclude about the entropy change of the environment if the process is i) reversible and ii) irreversible?

a). i) radiation ; ii) conduction ; iii) convection

b). isothermal  $\rightarrow$  stay the same by definition  
 adiabatic  $\rightarrow$  rise :  $\Delta E_{int} = -W$  and  $W$  is neg for compression (work done on gas)  
 $\Rightarrow \Delta E_{int}$  is +  
 $\Rightarrow \Delta T$  is +

c). diatomic will have a larger heat capacity due to its access to more degree of freedom.

d). i).  $\Delta S_{env} = +\Delta S$  so that the net change is zero.  
 ii).  $\Delta S_{env} > \Delta S$  : the entropy change in the environment must be larger so the net change in entropy for this irreversible process is +.

2. (25 pts)

An unknown amount of steam initially at  $100^\circ\text{C}$  is added to 12.0 grams of ice at  $0.00^\circ\text{C}$ . If the resulting mixture reaches a final equilibrium temperature of  $7.00^\circ\text{C}$ , what is the original amount of steam? [For water,  $L_f = 3.33 \times 10^5 \text{ J/kg}$ ,  $L_v = 2.26 \times 10^6 \text{ J/kg}$ , and  $c = 4186 \text{ J/kg}\cdot^\circ\text{C}$ .]

Let  $m$  be the amount of steam needed,

$$Q_{\text{cold}} = -Q_{\text{hot}}$$

$$\underbrace{(12.0\text{g})L_f + (12.0\text{g})c(7.00^\circ\text{C} - 0^\circ\text{C})}_{\text{heat absorbed by ice}} = - \underbrace{[mL_v + mc(7.00^\circ\text{C} - 100^\circ\text{C})]}_{\text{heat released by steam}}$$

$$m = \frac{(12.0\text{g})(3.33 \times 10^5 \text{ J/kg} + 4186 \text{ J/kg}\cdot^\circ\text{C} \cdot 7.00^\circ\text{C})}{(2.26 \times 10^6 \text{ J/kg} + 4186 \text{ J/kg}\cdot^\circ\text{C} \cdot 93.0^\circ\text{C})}$$

$$m = 1.64\text{g}$$

3. (25 pts)

Calculate the amount of work required to compress 3.00 mol of a monoatomic gas at  $20.0^\circ\text{C}$  and 1.00 atm to one fifth of the original volume by a) an isothermal process and b) an adiabatic process? c) What is the final pressure in each case?

$$\text{monoatomic gas: } C_V = \frac{3}{2}R \quad ; \quad C_P = \frac{5}{2}R \quad ; \quad \gamma = \frac{5}{3}$$

$$n = 3.00 \text{ mol}$$

$$T_i = 20.0^\circ\text{C} = (273.15 + 20) = 293.15 \text{ K}$$

$$P_i = 1.00 \text{ atm}$$

$$V_i = V \quad \quad V_f = \frac{1}{5}V$$

$$\text{a. } W = nRT \ln(V_f/V_i) = (3.00 \text{ mol})(8.315 \text{ J/mol}\cdot\text{K})(293.15 \text{ K}) \ln\left(\frac{1}{5}\right)$$

$$\boxed{W = -11.8 \text{ kJ}}$$

↖ work done on system

$$\text{b. } Q = 0 \quad \Delta E_{\text{int}} = -W$$

$$\text{For an ideal gas, } \Delta E_{\text{int}} = nC_V \Delta T$$

$$\text{Since the process is adiabatic, } T_i V_i^{\gamma-1} = T_f V_f^{\gamma-1} \Rightarrow T_f = \left(\frac{V_i}{V_f}\right)^{\gamma-1} T_i$$

$$\text{So, } \Delta E_{\text{int}} = nC_V (T_f - T_i) = nC_V T_i \left(\left(\frac{V_i}{V_f}\right)^{\gamma-1} - 1\right)$$

$$= (3.00 \text{ mol}) \left(\frac{3}{2}R\right) (293.15 \text{ K}) (5^{5/3-1} - 1)$$

$$= 21.1 \text{ kJ}$$

$$\boxed{W = -\Delta E_{\text{int}} = -21.1 \text{ kJ}}$$

$$\text{c. Isothermal: } P_i V_i = P_f V_f \Rightarrow P_f = \frac{V_i}{V_f} P_i = (5) (1 \text{ atm}) = \boxed{5 \text{ atm}}$$

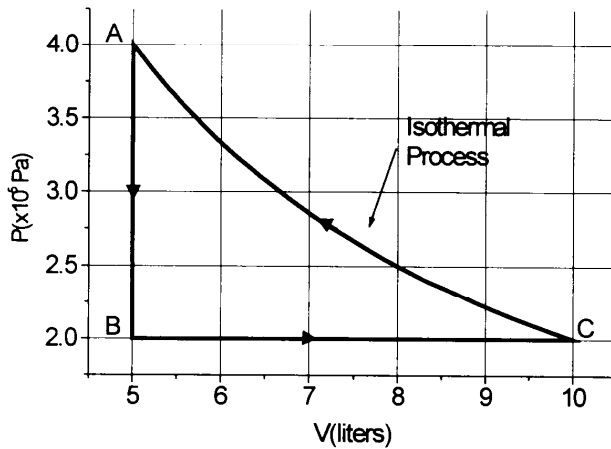
$$\text{adiabatic: } P_i V_i^\gamma = P_f V_f^\gamma \Rightarrow P_f = \left(\frac{V_i}{V_f}\right)^\gamma P_i$$

$$= 5^{5/3} \cdot 1 \text{ atm}$$

$$= \boxed{14.6 \text{ atm}}$$

4. (25 pts)

One mole of an ideal monoatomic gas is taken through the cycle shown below. The process  $C \rightarrow A$  is a reversible isothermal compression. Calculate a) the net work done by the gas in one cycle, b) the heat absorbed by the gas, c) the heat expelled by the gas, and d) the efficiency of the cycle. e) What is the net entropy change for the gas in the cycle? ( $1L = 10^{-3}m^3$ )



$$\text{monoatomic} = C_V = \frac{3}{2}R \quad \gamma = \frac{5}{3}$$

$$C_P = \frac{5}{2}R$$

Temp at diff. states:

$$T_A = \frac{P_A V_A}{nR} = \frac{(4.0 \times 10^5 \text{ Pa})(5.0 \times 10^{-3} \text{ m}^3)}{1 \text{ mol} (8.315 \text{ J/K.mol})}$$

$$= 240 \text{ K}$$

$$T_C = T_A = 240 \text{ K}$$

$$T_B = \frac{P_B V_B}{nR} = \frac{1}{2} T_A = 120 \text{ K}$$

a).  $W_{AB} = 0$  (isovolumic)

$$W_{BC} = P_B (V_C - V_B) \text{ (isobaric)}$$

$$= (2.0 \times 10^5 \text{ Pa})(5 \times 10^{-3} \text{ m}^3)$$

$$= 1 \text{ KJ}$$

$$W_{CA} = nRT_A \ln(V_A/V_C) = (1 \text{ mol})(8.315 \text{ J/K.mol})(240 \text{ K}) \ln(5/10)$$

$$= -1.383 \text{ KJ}$$

$$W_{\text{net}} = W_{AB} + W_{BC} + W_{CA} = \boxed{-0.38 \text{ KJ}} \quad \text{"-"} \text{ net work is done on gas}$$

b). & c).  $Q_{AB} = \Delta E_{\text{int}}(AB)$  (isovolumic  $\rightarrow$  NO work done)

$$= nC_V (T_B - T_A) = (1 \text{ mol}) \left(\frac{3}{2}R\right) (120 \text{ K} - 240 \text{ K})$$

$$= -1.497 \text{ KJ}$$

$$Q_{BC} = \Delta E_{\text{int}}(BC) + W_{BC} \text{ (isobaric)}$$

$$= nC_V (T_C - T_B) + 1 \text{ KJ} = (1 \text{ mol}) \left(\frac{3}{2}R\right) (240 \text{ K} - 120 \text{ K}) + 1 \text{ KJ}$$

$$= 1.497 \text{ KJ} + 1 \text{ KJ} \quad 7/8$$

$$Q_{BC} = 2.497 \text{ KJ}$$

$$Q_{CA} = \overset{0}{\Delta E_{int}(CA)} + W_{CA} \quad (\text{isothermal})$$

$$= -1.383 \text{ KJ}$$

$$Q_{abs} \text{ (heat "f" absorbed)} = Q_{BC} = 2.5 \text{ KJ}$$

$$Q_{exp} \text{ (heat "-" expelled)} = Q_{AB} + Q_{CA} = -2.9 \text{ KJ}$$

Since  $Q_{abs} < |Q_{exp}|$ ,  
this actually  
functions like  
a heat pump:  
work is done on  
gas to transfer  
heat from a  
cold res. to a  
hot res.

$$d). \quad \epsilon = \frac{|W_{net}|}{Q_{abs}} = \frac{0.38 \text{ KJ}}{2.5 \text{ KJ}} = 0.15 \quad (\text{or } 15\%)$$

$$COP = \frac{|Q_{exp}|}{|W_{net}|} = \frac{2.9 \text{ KJ}}{0.38 \text{ KJ}} = 7.6 \quad (\text{heating Mode})$$

e).  $\Delta S = 0$  for all reversible cyclic process.

5. (25 pts)

One mole of diatomic ideal gas, initially having pressure  $P$  and volume  $V$ , compresses so as to have pressure  $2.5P$  and volume  $0.30V$ . a) By what factor will the final temperature be changed and b) what is the entropy change of the gas in the process?

diatomic:  $C_V = \frac{5}{2}R$ ,  $C_P = \frac{7}{2}R$ ,  $\gamma = \frac{7}{5}$

$$\begin{aligned} \text{a). } \frac{P_i V_i}{T_i} &= \frac{P_f V_f}{T_f} \Rightarrow \frac{T_f}{T_i} = \frac{P_f V_f}{P_i V_i} \\ &= \left(\frac{P_f}{P_i}\right) \left(\frac{V_f}{V_i}\right) = (2.5)(0.30) \\ \frac{T_f}{T_i} &= \underline{\underline{0.75}} \text{ decrease} \end{aligned}$$

$$\begin{aligned} \text{b). } \Delta S &= nC_V \ln\left(\frac{T_f}{T_i}\right) + nR \ln\left(\frac{V_f}{V_i}\right) \quad n = 1 \text{ mol} \\ &= \frac{5}{2}R \ln(0.75) + R \ln(0.30) \end{aligned}$$

$$\Delta S = -16.0 \text{ J/K}$$