

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$      $\Delta G = \Delta G^\circ + RT \ln Q$      $\Delta G^\circ = -RT \ln K$      $\Delta H^\circ = \sum nH^\circ_{(\text{products})} - \sum nH^\circ_{(\text{reactants})}$   
 $\Delta S^\circ = \sum nS^\circ_{(\text{products})} - \sum nS^\circ_{(\text{reactants})}$      $\Delta G^\circ = \sum nG^\circ_{(\text{products})} - \sum nG^\circ_{(\text{reactants})}$   
 $R = 0.08205783 \text{ (L}\cdot\text{atm)/(mol}\cdot\text{K)} = 8.314510 \text{ J/(mol}\cdot\text{K)}$

1. (4 Pts) Calculate  $\Delta S^\circ$  at 25°C for the reduction of PbO(s),  $2\text{PbO(s)} + \text{C(s)} \rightarrow 2\text{Pb(s)} + \text{CO}_2\text{(g)}$  given these absolute entropies:

	$S^\circ$ (J/K·mol)
PbO(s)	69.45
C(s)	5.7
Pb(s)	64.89
CO <sub>2</sub> (g)	213.6

$$\Delta S = (2(64.89) + 213.6) - (2(69.45) + 5.7)$$

$$\Delta S = \frac{+198.8 \text{ J}}{\text{K}}$$

2. (4 Pts) HI has a normal boiling point of -35.4°C, and its  $\Delta H_{\text{vap}}$  is 21.16 kJ/mol. Calculate the molar entropy of vaporization ( $\Delta S_{\text{vap}}$ ). Show work to receive credit.

- A) 598 J/K·mol    D) 0.068 J/K·mol  
 B) 68.6 J/K·mol    E) 89.0 J/K·mol  
 C) 75.2 J/K·mol

@  $E_b$  (Boiling)  $\Delta G = 0 = \Delta H - T\Delta S$

$$\Delta S = \frac{\Delta H}{T} = \frac{21.16 \times 10^3 \text{ J/mol}}{237.6 \text{ K}} = \frac{89.1 \text{ J}}{\text{K}\cdot\text{mol}}$$

3. (4 Pts) Calculate  $\Delta G^\circ$  for the reaction  $3\text{NO}_2\text{(g)} + \text{H}_2\text{O(l)} \rightarrow 2\text{HNO}_3\text{(l)} + \text{NO(g)}$ .

	$\Delta G^\circ_f$ (kJ/mol)
H <sub>2</sub> O(l)	-237.2
HNO <sub>3</sub> (l)	-79.9
NO(g)	86.7
NO <sub>2</sub> (g)	51.8

$$\Delta G = [2(-79.9) + 86.7] - [3(51.8) + -237.2]$$

$$\Delta G = 8.7 \text{ kJ/mol}$$

4. (4 Pts) Hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) decomposes according to the equation (Show work to receive credit)  $\text{H}_2\text{O}_2\text{(l)} \rightarrow \text{H}_2\text{O(l)} + \frac{1}{2}\text{O}_2\text{(g)}$ .

Calculate  $K_p$  for this reaction at 25°C. ( $\Delta H^\circ = -98.2 \text{ kJ/mol}$ ,  $\Delta S^\circ = 70.1 \text{ J/K}\cdot\text{mol}$ )

$$\Delta G = \Delta H - T\Delta S$$

$$= -98.2 \times 10^3 \text{ J/mol} - (298 \text{ K} \cdot 70.1 \text{ J/K}\cdot\text{mol})$$

$$\Delta G = -119089.9 \text{ J/mol}$$

$$\Delta G = -RT \ln K$$

$$-119089.9 = -8.314(298) \ln K$$

$$\ln K = 48.067$$

$$K = 7.5 \times 10^{20}$$

5. (4 Pts) At 1500°C the equilibrium constant for the reaction  $\text{CO(g)} + 2\text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH(g)}$  has the value  $K_p = 1.4 \times 10^{-7}$ . Calculate  $\Delta G^\circ$  for this reaction at 1500°C. Show work to receive credit.

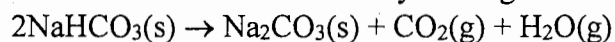
- A) 105 kJ/mol    B) 1.07 kJ/mol    C) -233 kJ/mol    D) -105 kJ/mol    E) 232 kJ/mol

$$\Delta G = -RT \ln K$$

$$= -8.314(1773 \text{ K}) \ln 1.4 \times 10^{-7}$$

$$= 232632 \text{ J/mol} = 232 \text{ kJ/mol}$$

6. (4 Pts) Sodium carbonate can be made by heating sodium bicarbonate:



Given that  $\Delta H^\circ = 128.9 \text{ kJ/mol}$  and  $\Delta G^\circ = 33.1 \text{ kJ/mol}$  at  $25^\circ\text{C}$ , above what minimum temperature will the reaction become spontaneous under standard state conditions?

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$\Delta S^\circ = \frac{\Delta H^\circ - \Delta G^\circ}{T}$$

$$\Delta S^\circ = 321 \frac{\text{J}}{\text{mol}\cdot\text{K}}$$

$$\Delta G = 0 = \Delta H - T\Delta S$$

$$0 = 128.9 \times 10^3 \frac{\text{J}}{\text{mol}} - T \left( 321 \frac{\text{J}}{\text{mol}\cdot\text{K}} \right)$$

$$T = 401 \text{ K}$$

$$\text{above } 401 \text{ K} \quad \text{or } > 128^\circ\text{C}$$

7. (1 Pt) Which of these species would you expect to have the highest standard entropy ( $S^\circ$ )?

A)  $\text{CH}_4(\text{g})$    B)  $\text{C}_2\text{H}_2(\text{g})$    C)  $\text{C}_2\text{H}_4(\text{g})$    D)  $\text{C}_2\text{H}_6(\text{g})$    E)  $\text{C}_3\text{H}_8(\text{g})$