Assignment II: Spontaneous Processes

1. Using the data table of standard molar entropies, calculate ΔS^0 for the chemical reaction:

$$N_{2\,(g)} + 2\ O_{2\,(g)} \longrightarrow 2\ NO_{2\,(g)}$$

with reactants and products at a temperature of 25 ^{0}C and a pressure of 101.3 kPa. From your calculation of ΔS^0, predict if the reaction is spontaneous.

2. Calculate ΔG^0 for the following reaction, using your data table values for ΔG^0_f :

$$3\ NO_{(g)} \longrightarrow N_2O_{(g)} + NO_{2\,(g)}$$

3. The molar enthalpy of fusion of solid ammonia is +5.65 kJ mol^{-1}, and the molar entropy of fusion is 28.9 J K^{-1} mol^{-1}**.**
   a) Calculate the Gibbs free energy change for the melting of 1.0 mol of ammonia at 170 K.
   b) Calculate the Gibbs free energy change for the conversion of 3.60 g of solid ammonia to liquid ammonia at 170 K.
   c) Will ammonia melt spontaneously at 170 K?
   d) At what temperature are solid and liquid ammonia in equilibrium?

4. Consider the reaction:

$$C_{(s)} + O_{2\,(g)} \longrightarrow CO_{2\,(g)}$$

ΔH^0 and ΔS^0 for this reaction are known to be - 393.5 kJ and 3.05 J K^{-1}, respectively, calculate ΔG^0 at 298 K. Will $C_{(s)}$ burn to form $CO_{2\,(g)}$ spontaneously at 298 K ? Explain.

5. Consider the reaction:

$$2\ SO_{2\,(g)} + O_{2\,(g)} \longrightarrow 2\ SO_{3\,(g)}$$

carried out at 25 ^{0}C and 101.3 kPa. Calculate ΔH^0, ΔS^0, and ΔG^0**,** using your data table. Predict if this reaction is spontaneous at 298 K.

6. Using the following data, at 25 ^{0}C:

$$C_{\text{diamond (s)}} + O_{2\,(g)} \longrightarrow CO_{2\,(g)} \qquad \Delta G^0 = -397 \text{ kJ}$$

$$C_{\text{graphite (s)}} + O_{2\,(g)} \longrightarrow CO_{2\,(g)} \qquad \Delta G^0 = -394 \text{ kJ}$$

Calculate ΔG^0 for the reaction:

$$C_{\text{diamond (s)}} \longrightarrow C_{\text{graphite (s)}}$$

Under these conditions, should diamond spontaneously change to graphite. Explain. Is diamonds kinetically or thermodynamically stable with respect to graphite?

7. Methanol is a high-octane fuel used in high performance racing engines. Calculate ΔG^0 for the reaction:

$$2\ CH_3OH_{(g)} + 3\ O_{2\,(g)} \longrightarrow 2\ CO_{2\,(g)} + 4\ H_2O_{(g)}$$

Is this reaction thermodynamically favourable?

8. a) Using the information provided **below** and your data table, calculate the ΔH_f^0 of $NaCl_{(s)}$ **and** ΔS^0 for the formation of sodium chloride according to the following reaction:

$$Na_{(s)} + \tfrac{1}{2} Cl_{2\,(g)} \longrightarrow NaCl_{(s)}$$

$Na_{(s)} + H_2O_{(l)} \longrightarrow NaOH_{(aq)} + \tfrac{1}{2} H_{2\,(g)}$ $\quad \Delta H^0 = -184.62$ kJ mol^{-1}

$HCl_{(aq)} \longrightarrow \tfrac{1}{2} H_{2\,(g)} + \tfrac{1}{2} Cl_{2\,(g)}$ $\quad \Delta H^0 = 167.24$ kJ mol^{-1}

$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$ $\quad \Delta H^0 = -55.72$ kJ mol^{-1}

$NaCl_{(s)} \longrightarrow NaCl_{(aq)}$ $\quad \Delta H^0 = 3.87$ kJ mol^{-1}

b) Use ΔG, to predict if this reaction is spontaneous.
c) At which temperatures does the ***reverse reaction*** become favourable.

9. When ignited, ammonium dichromate, $(NH_4)_2 Cr_2O_7$, decomposes violently. The decomposition produces nitrogen gas $N_{2\,(g)}$, water vapour and $Cr_2O_{3\,(s)}$

Substance	**ΔH_f (kJ mol^{-1})**	**S^0 (kJ mol^{-1} K^{-1})**
$Cr_2O_{3\,(s)}$	- 1140	0.0812
$H_2O_{(g)}$	- 242	0.1187
$N_{2\,(g)}$	0	0.1915
$(NH_4)_2 Cr_2O_{7(s)}$	- 22.5	0.1137

a) Write a balanced equation for the decomposition of $(NH_4)_2 Cr_2O_{7\,(s)}$.
b) Why is the value of ΔH_f for $N_{2\,(g)}$ zero?
c) Calculate ΔH^0, ΔS^0, and ΔG^0 for the reaction
d) How many grams of ammonium dichromate are needed to produce 10.0 kJ of heat and what would be the pressure of the final gas mixture at 100 ^{0}C in a 10 L container?

10. Solid tin exists in two forms: white and grey. For the transformation:

$$Sn_{(s,\,white)} \longrightarrow Sn_{(s,\,grey)}$$

the enthalpy change is - 2.1 kJ and the entropy change is - 7.4 J K^{-1}.
a) Calculate the Gibbs free energy change for the conversion of 1.00 mol of white tin to grey tin at - 30 ^{0}C .
b) Calculate the Gibbs free energy change for the conversion of 2.50 mol of white tin to grey tin at - 30 ^{0}C.
c) Will white tin convert spontaneously to grey tin at - 30 ^{0}C?
d) At what temperature are white and grey tin in equilibrium ?

11. The melting point of tungsten is the second highest among the elements (only that of carbon is higher). The melting point of tungsten is 3410 ^{0}C , and has an enthalpy change of fusion of 35.4 kJ mol^{-1}. Calculate the entropy of fusion of tungsten.

12. In the following equation: $\Delta G = \Delta H - T\Delta S$

a. Explain the meaning of each term, the units and the significance of the sign of each term.
b. Calculate the value of ΔS for the following reaction at 25 ^{O}C:

$$CaO_{(s)} + H_2O_{(l)} \longrightarrow Ca(OH)_{2(s)}$$

($\Delta G = -55.2$ kJ mol^{-1}, $\Delta H = -65.2$)
c. Calculate the amount of calcium hydroxide produced when 100 g of calcium oxide are treated with water and the yield is 84 %.