**Gibb's Free Energy and Equilibrium**

*G*o = - *R T*ln *K*

*G*o *= - ne­- F E*o

*G*o = *H - T* *S*

**(From http://www.science.uwaterloo.ca/~cchieh/cact/applychem/gibbsenergy.html)**

1. **Find the enthalpy and entropy changes for the reaction:**

**H2(g) + I2(s) -> 2 HI(g)**

1. **Calculate the standard entropy of formation of H2O(l), its standard Gibb's energy of formation, and the equilibrium constant *K* for the reaction.**

**H2(g) + ½ O2(g) -> H2O(l)**

1. **Estimate the standard Gibb's free energy of formation for ammonia.**
2. **Evaluate *G*oreaction for the reaction:**

**4 NH3(g) + 3 O2(g) -> 2 N2 + 6 H2O(g)**

1. **A zinc copper battery has a voltage of 1.10 V. How much is the Gibb's energy for the redox reaction:**

**Zn + Cu2+ -> Zn2+ + Cu**

**Answers:**

1. **Find the enthalpy and entropy changes for the reaction:**

**H2(g) + I2(s) -> 2 HI(g)**

***Solution***  
For simplicity, we write the standard enthalpies below the chemical formula of the equation:

H2 (g) + I2 (s) -> 2 HI (g)  
  0           0          2\*26.5 kJ/mol

Horeaction =  Hfo(products) -  Hfo(reactants)  
  = 2\*26.5 - (0 + 0) kJ/equation.  
  = 53.0 kJ/equation.

The standard entropy of reaction at standard conditions. Soreaction can be evaluated in a similar fashion. For convenience, we again write the standard entropies below the chemical formula of the equation:

H2 (g)   +     I2 (s) ->   2 HI (g)  
130.68   116.14   2\*206.59 J mol-1 K-1

Soreaction = So(products) - o(reactants)  
  = 2\*206.59 - (130.68 + 116.14) J eqn-1 K-1  
  = 166.36 J eqn-1 K-1

***Discussion***  
This is an endothermic reaction, and 53 kJ is required for the formation of 2 moles of HI. The decomposition of HI is exothermic.

Note that Soreaction is different from standard entropy So, which is NOT entropy of formation.

Since the reaction is the formation of HI, the entropy so calculated is twice the entropy of formation of HI. Thus, we have  
Sof(HI) = (166.36/2) = 83.18 J mol-1 K-1

**Calculate the standard entropy of formation of H2O(l), its standard Gibb's energy of formation, and the equilibrium constant *K* for the reaction.**

**H2(g) + ½ O2(g) -> H2O(l)**

***Solution***  
All the required data have already been found in Example 1. Again, we write the standard entropies below the formula

H2(g)   +   ½ O2(g)   ->   H2O(l)   
130.680   ½(205.152)     69.95

*S*of = *S*o(products) - *S*o(reactants)  
    = 69.95 - (130.680 + &189; (205.152) J mol-1 K-1  
    = - 163.306 J/(mol K)  
The standard Gibb's free energy of formation is,  
*G*of = *H*of - *T* *S*of  
    = -285.83 kJ/mol - (298 K)(-0.163306) kJ/(mol K)  
    = -237.16 kJ/mol

The equilibrium constant is evaluated by

237160 J mol-1

ln *K* = ------------------------- = 95.746

8.312 J (mol K)-1 \* 298 K

Thus, *K* = e95.746  
= 13.82\*1041,  
a very large number indeed indicating a reaction to almost exhaust at least one of the reactants.

***Discussion***  
This example illustrates how you may use a thermodynamic data table.

**Estimate the standard Gibb's free energy of formation for ammonia.**

***Solution***  
The data required are:

Substance Hfo So

kJ/mol J/(mol K)

H2(g) 0 130.680

N2(g) 0 191.609

NH3(g) -45.94 192.77

Again, we write the standard entropies below the formula

3/2 H2(g)   +   ½ N2(g)     ->   NH3(g)  
3/2\*130.680   ½\*191.609       192.77

*S*of = *S*o(products) - *S*o(reactants)  
      = 192.77 - (3/2\*130.680 + ½\*191.609)  
      = -99.125 kJ/mol  
The standard Gibb's free energy of formation is,  
*G*of = *H*of - *T* *S*of  
      = -45.94 - 298\*(-0.099125) kJ/mol       = -16.40 kJ/mol

***Discussion***  
Results from the previous and this examples are used in the next example.

**Evaluate *G*oreaction for the reaction:**

**4 NH3(g) + 3 O2(g) -> 2 N2 + 6 H2O(g)**

***Solution***  
Let us write the standard Gibb's energies of formation below the formula

4 NH3(g)  + 3 O2(g) -> 2 N2 + 6 H2O(g)  
4\*(-16.40)   3\*0           2\*0     6\*(-237.16) kJ/mol

*G*oreaction = = (2\*0 - 6\*237.16) - (3\*0 -4\*16.40) kJ/mol  
      = -1357.36 kJ/mol

***Discussion***  
Note the general rule for the evaluation of the standard Gibb's free energy of reaction introduced in this example.

**A zinc copper battery has a voltage of 1.10 V. How much is the Gibb's energy for the redox reaction:**

**Zn + Cu2+ -> Zn2+ + Cu**

***Solution***  
Since the number of reaction transferred per Zn or Cu atom is 2, Gibb's energy is evaluated by

*G*o = - 2\*96485\*1.10 J  
      = 212.2 kJ

***Discussion***  
Gibb's energy is the maximum electric energy derived from a battery.