Review #6: Equilibrium Theory

1. Know the meanings of, and be able to apply, the following terms:

enthalpy | Gibb's Free energy | equilibrium
entropy | spontaneous reaction

2. What are four conditions that must be met in order for equilibrium to be established?

3. For each of the following reactions, identify whether:

i) maximum entropy favours the products or reactants
ii) minimum enthalpy favours the products or reactants
iii) the reaction will be spontaneous at any temperature, non-spontaneous at any temperature, or will form an equilibrium mixture of products and reactants:

a) $H_2SO_4\,(l) + 2\,H_2O\,(l) \leftrightarrow 2\,H_3O^+\,(aq) + SO_4^{2-}\,(aq) + \text{heat}$

b) $C_2H_2\,(g) + 2\,CaO\,(s) \leftrightarrow CaC_2\,(s) + H_2O_2\,(l) + \text{heat}$

c) $3\,O_2\,(g) + \text{energy} \leftrightarrow 2\,O_3\,(g)$

d) $H_2O\,(l) + \text{heat} \leftrightarrow H_2O\,(g)$

e) $Zn\,(s) + 2\,HCl\,(aq) \leftrightarrow ZnCl_2\,(aq) + H_2\,(g) + \text{heat}$

e) $PbI_2\,(s) + \text{heat} + H_2O\,(l) \leftrightarrow Pb^{2+}\,(aq) + 2\,I^{1-}\,(aq)$

4. Which of the following reactions has the greatest increase in entropy?

a) $3\,O_2\,(g) \leftrightarrow 2\,O_3\,(g)$

b) $N_2H_4\,(l) + 2\,H_2O_2\,(l) \leftrightarrow N_2\,(g) + 4\,H_2O\,(g)$

c) $H_2O\,(l) + \frac{1}{2}\,O_2\,(g) \leftrightarrow H_2O_2\,(l)$

d) $2\,AgNO_3\,(aq) + Na_2S\,(aq) \leftrightarrow 2\,NaNO_3\,(aq) + Ag_2S\,(s)$

e) $C_2H_4\,(g) + 2\,O_2\,(g) \leftrightarrow 2\,CO_2\,(g) + 2\,H_2O\,(g)$

5. For the following reaction at 25°C : $\mathbf{N_2\,(g) + 3\,H_2\,(g) \leftrightarrow 2\,NH_3\,(g)}$

ΔH = -91.8 kJ and ΔS = - 197 J/K. Calculate ΔG for this reaction. Which direction is favoured at this temperature? (ΔG=-33.1 kJ, forward rxn favoured)

6. Use Le Chatelier's principle to predict the effect of the following stresses on the reaction:

$$2\,N_2O_2\,(g) + H_2\,(g) \leftrightarrow 2\,N_2O\,(g) + H_2O\,(g) + \text{heat}$$

a) increasing concentration of H_2 (g)
b) increasing the total pressure
c) adding N_2O (g)
d) decreasing the amount of H_2O (g)
e) adding helium to the reaction vessel
f) removing N_2O_2 (g)
g) adding a catalyst
h) increasing temperature
i) increasing the volume of the reaction vessel
j) removing N_2O (g) as it forms

7. Write the K_{eq} expressions for the following equilibrium reactions (careful of heterogeneous systems):

a) $S\,(s) + O_2\,(g) \leftrightarrow SO_2\,(g)$

b) $2\,NO\,(g) + O_2\,(g) \leftrightarrow 2\,NO_2\,(g)$

c) $Pb(NO_3)_2\,(aq) + Zn\,(s) \leftrightarrow Zn(NO_3)_2\,(aq) + Pb\,(s)$

d) $N_2H_4\,(l) + H_2O_2\,(l) \leftrightarrow N_2\,(g) + 4\,H_2O\,(g)$

e) $Ba(OH)_2\,(s) \leftrightarrow Ba^{2+}\,(aq) + 2\,OH^{1-}\,(aq)$

f) $Na_2CO_3\,(s) + H_2O\,(g) + CO_2\,(g) \leftrightarrow 2\,NaHCO_3\,(s)$

8. For the equilibrium reaction: $2\ N_2O_2\ (g) + H_2\ (g) \leftrightarrow 2\ N_2O\ (g) + H_2O\ (g) +$ heat

At equilibrium, the concentrations of each species are measured. $[N_2O_2] = 0.073$ mol/L, $[H_2] = 0.012$ mol/L, $[N_2O] = 0.634$ mol/L , $[H_2O] = 0.484$ mol/L.

a) Calculate the value of K_{eq} for the reaction at this temperature (3.0×10^3)

b) Does the equilibrium favour the reactants or products at this temperature? (products)

c) What is the value of K_{eq} for the reverse reaction at this temperature? (3.3×10^{-4})

9. For the reaction: $2\ HI\ (g) \leftrightarrow H_2\ (g) + I_2\ (g)$ $K_{eq} = 62.5$ at 520°C

a) Does this reaction favour the reactants or products at this temperature?

b) If the reaction is endothermic and the temperature is increased, what happens to the value of K_{eq}?

c) If 2.22 moles of HI are placed in a 5.00 L reaction vessel and allowed to come to equilibrium at 520°C,

   i) calculate the concentration of each species at equilibrium ($[H_2]=[I_2]= 0.209$ M, $[HI]= 0.026$M)

   ii) at equilibrium, how many **moles** of H_2 are present? (1.05 mol)

d) If the volume of the vessel is decreased, which way will the equilibrium shift? Why?

10. For the reaction: $N_2O_2\ (g) \leftrightarrow N_2\ (g) + O_2\ (g)$

1.40 moles of N_2O_2 (g) are placed in a 2.00 L reaction vessel and allowed to come to equilibrium. At equilibrium, there are 0.76 moles of O_2 present in the vessel. Calculate the K_{eq} for this reaction. (0.45)