The Equilibrium Constant

Note: all concentrations are expressed in molarities. All concentration symbols have been omitted. An alternate symbol for K_{eq} is K_c.

1. Write the expression for the equilibrium constant for each of the following reactions.

a. $H_2 + Cl_2 <==> 2\ HCl$ b. $2\ SO_2 + O_2 <==> 2\ SO_3$ c. $N_2 + 3\ H_2 <==> 2\ NH_3$

d. $2\ CO + O_2 <==> 2\ CO_2$ e. $N_2 + 1/2\ O_2 <==> N_2O$ f. $HCN <==> H^+ + CN^-$

g. $H_2SO_4 <==> H^+ + HSO_4^-$ h. $NO + 1/2\ O_2 <==> NO_2$ i. $PbF_2 <==> Pb^{2+} + 2F^-$

2. From the data provided below, calculate the value of the equilibrium constant for the reactions listed in problem one above.

a. $[H_2] = [Cl_2] = 1.0 \times 10^{-2}$; $[HCl] = 1.0 \times 10^{-4}$

b. $[H_2] = 2.0 \times 10^{-2}$; $[Cl_2] = 2.5 \times 10^{-2}$; $[HCl] = 1.5 \times 10^{-3}$

c. $[SO_2] = 1.0 \times 10^{-3}$; $[O_2] = 2.0 \times 10^{-3}$; $[SO_3] = 3.0 \times 10^{-3}$

d. $[SO_2] = 1.0$; $[O_2] = 1.0$; $[SO_3] = 2.0$

e. $[N_2] = 4.4 \times 10^{-2}$; $[H_2] = 1.2 \times 10^{-1}$; $[NH_3] = 3.4 \times 10^{-3}$

f. $[N_2] = 0.25$; $[H_2] = 0.10$; $[NH_3] = 0.010$

g. $[CO] = 2.5 \times 10^{-3}$; $[O_2] = 1.6 \times 10^{-3}$; $[CO_2] = 3.2 \times 10^{-2}$

h. $[CO] = 0.5$; $[O_2] = 0.5$; $[CO_2] = 2.5$

i. Find $[CO]$ if $[O_2] = 1.3 \times 10^{-3}$; $[CO_2] = 2.5 \times 10^{-4}$: $K_c = 3.6 \times 10^{-3}$

j. Find $[O_2]$ if $K_c = 45.0$; $[N_2] = 1.00$; $[N_2O] = 1.00$

k. Find $[NO]$ if $[O_2] = 0.100$; $[NO_2] = 0.200$; $K_c = 10.0$

3. For the reaction, $2\ NO_2 <==> N_2O_4$, the equilibrium concentrations are: $[NO_2] = 3.1 \times 10^{-2}$ and $[N_2O_4] = 4.5 \times 10^{-3}$. From these data, calculate K_c for the reaction at this temperature.

4. In reaction 1a above, assume the equilibrium constant to be 55.0. During one experiment, the equilibrium concentrations of hydrogen and chlorine were measured to be 4.8×10^{-3} and 2.1×10^{-3} respectively. What was the concentration of the hydrogen chloride at this point?

5. Consider the reaction $PCl_5 <==> PCl_3 + Cl_2$. The equilibrium mixture in a 9.0 L container was found to include 0.250 mol PCl_5, 0.360 mol PCl_3, and 0.360 mol Cl_2. From these data, calculate the equilibrium constant for this dissociation at the reaction temperature of 225 °C

6. Nitrogen and hydrogen react together in a 4.00 liter container at 450 °C. At equilibrium, $[N_2] = 0.130$, $[H_2] = 0.220$, and $[NH_3] = 0.650$. Calculate the equilibrium constant for this reaction.

7. K_c for $H_2 + I_2 <==> 2HI$ is 32.0. At equilibrium, $[H_2] = 0.400$ and $[I_2] = 0.0500$. What does [HI] equal?

8. For the reaction $H_2 + I_2 <==> 2HI$, the following equilibrium concentrations were observed: [H2] = 0.562; [I2] = 0.130, [HI] = 7.89. What is the value for K_c?

9. At equlibrium, $[NH_3] = 0.00150$; $[H_2] = 0.0320$; $[N_2] = 0.0690$. What is the K_c for the dissociation of NH_3, given these conditions? Please solve this problem two ways using the two reaction equations supplied. a. $2\ NH_3 <==> N_2 + 3\ H_2$ b. $NH_3 <==> 1/2\ N_2 + 3/2\ H_2$

Writing Equilibrium Expressions/Calculating Equilibrium Constants

Instructions: Write the equilibrium expression for each equation, then calculate the value of the equilibrium concentration. In each case, the concentrations listed are in the order of compounds in the equation.

1. N_2O_4 <==> 2 NO_2
Equilibrium Concentrations: 0.014 M, 0.072 M (at 520 °C)

2. N_2 + 3 H_2 <==> 2 NH_3
Equilibrium Concentrations: 0.200 M, 0.200 M, 0.0160 M (at 583 °C)

3. SO_2 + 1/2 O_2 <==> SO_3
Equilibrium Concentrations: 0.0200 M, 1.00 M, 0.400 M (at 500 °C)

4. PCl_3 + Cl_2 <==> PCl_5
Equilibrium Concentrations: 1.00 M, 0.900 M, 0.120 M (at room temperature)

5. 2 NH_3 <==> N_2 + 3 H_2
Equilibrium Concentrations: 0.102 M, 1.03 M, 1.62 M (at 1000 K)

6. H_2 + I_2 <==> 2 HI (at room temperature)
Equilibrium Concentrations: 0.0500 mol, 0.0500 mol, 0.387 mol in 500.0 mL

7. 2 NO + O_2 <==> 2 NO_2 (at 500 K)
Equilibrium Concentrations: 3.49 x 10^{-4} M, 0.800 M, 0.250 M

8. PCl_5 <==> PCl_3 + Cl_2 (at 500 K)
Equilibrium Concentrations: 0.861 M, 0.139 M, 0.139 M

9. CO_2 + H_2 <==> CO + H_2O (at 900 °C)
Equilibrium Concentrations: 0.648 M, 0.148 M, 0.352 M, 0.352 M

10. N_2O_4 <==> 2 NO_2 (at 520 °C)
Equilibrium Concentrations: 0.0350 mol and 0.180 mol per 2.50 liter

11. Fe^{3+} + SCN^- <==> $FeSCN^{2+}$ (at room temperature)
Equilibrium Concentrations: 2.225 x 10^{-4} mol, 2.225 x 10^{-4} mol, 0.275 x 10^{-4} mol in 250.0 mL

12. The reaction H_2 + I_2 <==> 2 HI has been studied under a variety of concentration conditions. The data is reproduced below:

Experiment	[H_2]	[I_2]	[HI]
1	0.00560	0.000590	0.0127
2	0.00460	0.000970	0.0147
3	0.00380	0.00150	0.0169
4	0.00170	0.00170	0.0118
5	0.00140	0.00140	0.0100
6	0.00420	0.00420	0.0294

Calculate the equilibrium constant (averaged) for this reaction.

Equilibrium Calculations Using the Quadratic Equation (and some maybe not)

1. Nitric oxide, NO, is formed in automobile exahaust by the reaction of the N_2 and O_2 in air. At 2127 °C K_c is 0.0125. Initially a mixture contains 0.850 mol of each N_2 and O_2 in a 15 liter vessel. Find the concentration of all species when equilibrium is reached at 2127 °C

2. Suppose the equilibrium mixture is disturbed by adding 0.0500 mol of N_2 with no temperature change. What will the new equilibrium concentrations become?

3. 0.500 mol of N_2 and O_2 are introduced into a 5.00 liter reaction flask at 2127 °C. What are the concentrations after equilibrium has been established?

4. Phosogene, $COCl_2$, is prepared from CO and Cl_2 according to the following equation: $CO + Cl_2 \text{---} > COCl_2$. K_c at 395 °C is 1.23×10^3. If 2.00 mol of CO and 3.50 mol of Cl_2 are added to a 5.00 liter reaction vessel at 395 °C, what would the equilibrium concentrations be for all species?

5. Hydrogen flouride decomposes according to the following equation: $2HF \Longleftrightarrow H_2 + F_2$ The value of K_c at room temperature is 1.0×10^{-95}. From the value of the equilibrium constant do you think the decomposion occurs to any great extent at room temperature? If an equilibrium mixture at room temperature in a 1.0 liter vessel contains 1.0 mol of HF, what is the concentration of H_2? Does this result agree with your prediction about the decomposition?

6. The equilibrium constant, K_c for the reaction $PCl_3 + Cl_2 \Longleftrightarrow PCl_5$ is 49 at 230 °C. If 0.500 mol each of phosphorus trichloride and chlorine are added to a 5.0 liter reaction vessel. What is the equilibrium composition of the mixture at 230 °C?

7. Iodine and bromine react to give iodine monobromide: $I_2 + Br_2 \text{---} > 2IBr$
At a temperature of 150 °C. a 5.0 liter reaction vessel initally contained 0.0015 mol each of iodine and bromine. At equilibrium if IBr was found at a concentration of 5.1×10^{-4} M what is the value of K_c?

A Few More Problems

1. What will happen to the equilibrium $N_2 + 3H_2 \Longleftrightarrow 2NH_3 +$ heat under the following conditions.
   (a). The pressure is increased
   (b). More nitrogen is introduced
   (c). The temperature is increased

2. $2NO_2 \Longleftrightarrow N_2O_4 +$ heat How is the quantity of N_2O_4 affected by :
   (a). Increasing the temperature.
   (b). increasing the pressure.

3. In aqueous solution the following equilibrium takes place. $NH_4OH \Longleftrightarrow NH_4^+ + OH^-$ what will happen to the concentration of unionized NH_4OH by addition of the following substances. Explain your answer.
(a) NH_4Cl (b) NaCl (c) HCl (d) NaOH (e) Pure water

4. Explain what happens when concentrated hydrochloric acid (HCl) is added to a saturated solution of potassium chloride (KCl).