South Pasadena • AP Chemistry

Name _____

Period ___ Date ___/___/___

16 • Chemical Equilibrium

STUDY QUESTIONS & PROBLEMS

1. Write the expressions for the equilibrium constant K_c for the following reactions:
   a. $4\ NH_3(g) + 7\ O_2(g) \rightleftharpoons 4\ NO_2(g) + 6\ H_2O(l)$
   b. $HCN\ (aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$
   c. $PCl_5(g) + \rightleftharpoons PCl_3(g) + Cl_2(g)$
   d. $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
   e. $3\ O_2(g) \rightleftharpoons 2\ O_3(g)$
   f. $2\ H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$
   g. $3\ Zn(s) + 2\ Fe^{3+}(aq) \rightleftharpoons 2\ Fe(s) + 3\ Zn^{2+}(aq)$

2. Write the equilibrium constant expressions for the following reactions. How are they related to one another?
   a. $2\ N_2O(g) + 3\ O_2(g) \rightleftharpoons 4\ NO_2(g)$
   b. $N_2O(g) + {}^3/_2\ O_2(g) \rightleftharpoons 2\ NO_2(g)$
   c. $4\ NO_2(g) \rightleftharpoons 2\ N_2O(g) + 3\ O_2(g)$

3. Calculate the value of the equilibrium constant for the following system, given the data shown:

   $$H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g)$$

   Concentrations at equilibrium:

   $[H_2] = 1.5\ mol\ Liter^{-1}$
   $[CO_2] = 2.5\ mol\ Liter^{-1}$
   $[H_2O] = 0.5\ mol\ Liter^{-1}$
   $[CO] = 3.0\ mol\ Liter^{-1}$

4. Chlorine molecules will dissociate at high temperatures into chlorine atoms. At 3000°C, for example, K_c for the equilibrium shown is 0.55. If the partial pressure of chlorine molecules is 1.5 atm, calculate the partial pressure of the chlorine atoms: $Cl_2(g) \rightleftharpoons 2\ Cl(g)$

5. Suppose that 0.50 moles of hydrogen gas, 0.50 moles of iodine gas, and 0.75 moles of hydrogen iodide gas are introduced into a 2.0 Liter vessel and the system is allowed to reach equilibrium.

   $$H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$$

   Calculate the concentrations of all three substances at equilibrium. At the temperature of the experiment, K_c equals 2.0×10^{-2}.

6. If the mechanism of a chemical equilibrium consists of two reversible elementary steps, each with its own equilibrium constant K_{c1} and K_{c2}, what expression relates the equilibrium constant Kc for the overall equilibrium to the two constants K_{c1} and K_{c2}?

7. When 2.0 mol of carbon disulfide and 4.0 mol of chlorine are placed in a 1.0 Liter flask, the following equilibrium system results. At equilibrium, the flask is found to contain 0.30 mol of carbon tetrachloride. What quantities of the other components are present in this equilibrium mixture?

   $$CS_2(g) + 3\ Cl_2(g) \rightleftharpoons S_2Cl_2(g) + CCl_4(g)$$

8. 3.0 moles each of carbon monoxide, hydrogen, and carbon are placed in a 2.0 Liter vessel and allowed to come to equilibrium according to the equation: $CO(g) + H_2(g) \rightleftharpoons C(s) + H_2O(g)$
If the equilibrium constant at the temperature of the experiment is 4.0, what is the equilibrium concentration of water vapor?

9. Nitrosyl chloride NOCl decomposes to nitric oxide and chlorine when heated:

$$2\ NOCl(g) \rightleftharpoons 2\ NO(g) + Cl_2(g)$$

At 600K, the equilibrium constant K_p is 0.060. In a vessel at 600K, there is a mixture of all three gases. The partial pressure of NOCl is 675 torr, the partial pressure of NO is 43 torr and the partial pressure of chlorine is 23 torr.
   a. What is the value of the reaction quotient?
   b. Is the mixture at equilibrium?
   c. In which direction will the system move to reach equilibrium?
   d. When the system reaches equilibrium, what will be the partial pressures of the components in the system?

10. Sulfuryl chloride decomposes at high temperatures to produce sulfur dioxide and chlorine gases:

$$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g)$$

At 375°C, the equilibrium constant K_c is 0.045. If there are 2.0 grams of sulfuryl chloride, 0.17 gram of sulfur dioxide, and 0.19 gram of chlorine present in a 1.0 Liter flask,
   a. What is the value of the reaction quotient?
   b. Is the system at equilibrium?
   c. In which direction will the system move to reach equilibrium?

11. Ammonium chloride is placed inside a closed vessel where it comes into equilibrium at 400°C according to the equation shown. Only these three substances are present inside the vessel. If K_p for the system at 400°C is 0.640, what is the pressure inside the vessel?

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

12. Bromine and chlorine react to produce bromine monochloride according to the equation. $K_c = 36.0$ under the conditions of the experiment. $Br_2(g) + Cl_2(g) \rightleftharpoons 2\ BrCl(g)$
If 0.180 moles of bromine gas and 0.180 moles of chlorine gas are introduced into a 3.0 Liter flask and allowed to come to equilibrium, what is the equilibrium concentration of the bromine monochloride? How much BrCl is produced?

13. When ammonia is dissolved in water, the following equilibrium is established. If the equilibrium constant is 1.8×10^{-5}, calculate the hydroxide ion concentration in the solution if 0.100 mol of ammonia is dissolved in sufficient water to make 500 mL of solution.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

14. The following reaction is exothermic:

$$Ti(s) + 2\ Cl_2(g) \rightleftharpoons TiCl_4(g)$$

List all the ways the yield of the product $TiCl_4$ could be increased.