**TOPIC G PROBLEMS**

**For problems 1-5, refer to the video *"Introducing Chemical Equilibrium"***
**(Note: this video is included in the current module.)**

1) List the defining characteristics of a dynamic equilibrium as described in the video.

2) a) The formation and decomposition ammonium chloride is provided as an example of a reversible chemical reaction. Describe the characteristics required of an experimental set-up in order to establish a dynamic chemical equilibrium.

b) Write the equation representing the chemical equilibrium for the system of ammonium chloride, ammonia, and hydrogen chloride.

3) a) What is a heterogeneous chemical equilibrium? Search the internet to find an example of a heterogeneous chemical equilibrium system (other than the one in the video.) Write the equilibrium equation for your example.

b) What is a homogenous chemical equilibrium? Search the internet to find an example of a homogeneous equilibrium system. Write the equilibrium equation for your example.

4) How can you tell from a graph of **reaction rate vs. time** when a system has established chemical equilibrium? (What is true for the rate of the forward reaction and the rate of the reverse reaction at equilibrium?)

5) How can you tell from a graph of **concentrations vs. time** when a system has established chemical equilibrium? (What is true for the concentrations of the products and the concentrations of the reactants at equilibrium?)

**For the remaining problems, refer to the textbook, lecture videos, etc.**

6) For the reaction below, the equilibrium constant K is greater than 1.

$$\text{fructose} \rightleftarrows \text{glucose} \qquad K >> 1$$

If a solution initially contains equal concentrations of fructose and glucose, which of the following statements must be true at that initial moment? Explain your answer.

a) The forward reaction (fructose → glucose) is faster than the reverse reaction.
b) The reverse reaction is faster than the forward reaction.
c) The forward and reverse reactions have equal rates.

7) Write the $K_c$ expressions for each of the following reactions. *Note: the subscript "c" tells you that this is the equilibrium constant in terms of concentrations (mol/L).*

a) $2\ NO(g) + O_2(g) \rightleftarrows 2\ NO_2(g)$
b) $4\ Ag(s) + O_2(g) \rightleftarrows 2\ Ag_2O(s)$
c) $CaCO_3(s) + CO_2(aq) + H_2O(l) \rightleftarrows Ca^{2+}(aq) + 2\ HCO_3^-(aq)$

8) a) Write the $K_p$ expressions for reactions a and b in the previous problem. *Note: the subscript "p" tells you that this is the equilibrium constant in terms of partial pressures(atm).*

b) If the value of $K_c$ for reaction (a) in the previous is $2.8 \times 10^{11}$ at 200ºC, what is the value of $K_p$ at this temperature?

9) For the reaction below, $K_c = 6.17$ at a certain temperature.

$$PCl_3(g) + Cl_2(g) \rightleftarrows PCl_5(g)$$

Determine whether each of the following mixtures is at equilibrium. Assume that each mixture is at the same temperature as that for the provided $K_c$. For each mixture that is not at equilibrium, tell whether the reaction will go forward or backward.

a) A mixture in which the concentration of $PCl_3$ is 0.0381 M, the concentration of $Cl_2$ is 0.0593 M, and the concentration of $PCl_5$ is 0.0139 M.

b) A mixture in which the concentration of $PCl_3$ is 0.0482 M, the concentration of $Cl_2$ is 0.289 M, and the concentration of $PCl_5$ is 0.0455 M.

c) A mixture that contains $PCl_3$ and $PCl_5$, but no $Cl_2$.

d) A mixture that contains 0.21 mol of $PCl_3$, 0.48 mol of $Cl_2$, and 0.39 mol of $PCl_5$ in an 8.00 L container.

10) If Q, the reaction quotient, is greater than K for a reaction mixture, which of the following will happen?

a) The reaction will go in the direction that increases Q.
b) The reaction will go in the direction that decreases Q.
c) The reaction will go in the direction that increases K.
d) The reaction will go in the direction that decreases K.

11) For the reaction $N_2(g) + 3\ H_2(g) \rightleftarrows 2\ NH_3(g)$, $K_p = 0.0489$ at 256˚C. For parts a through d, assume that the reaction is at this temperature.

a) An equilibrium mixture contains 0.100 atm of $N_2$ and 0.200 atm of $H_2$. What is the partial pressure of $NH_3$ in this mixture?

b) A second equilibrium mixture contains 830 torr of $H_2$ and 42 torr of $NH_3$. What is the partial pressure of $N_2$ in this mixture?

c) A third equilibrium mixture contains 0.0100 mol/L of $N_2$ and 0.0300 mol/L of $NH_3$. What is the concentration of $H_2$ in this mixture?

d) A fourth equilibrium mixture contains equal concentrations of all three chemicals. What is the pressure of each substance in this mixture?

12) 1.00 g of $N_2O_4$ is put into a 5.00 L container and heated to 50˚C. At this temperature, the following reaction occurs and reaches equilibrium:

$$N_2O_4(g) \rightleftarrows 2\ NO_2(g)$$

The concentration of $NO_2$ in the equilibrium mixture is found to be $6.68 \times 10^{-4}$ M. Calculate $K_c$ and $K_p$ for this reaction at 50˚C.

13) When 0.100 mol of gaseous $N_2$ and 0.100 mol of gaseous $H_2$ are put into a 5.00 L container at 300ºC, the following reaction occurs and reaches equilibrium.

$$N_2(g) + 3\ H_2(g) \rightleftarrows 2\ NH_3(g)$$

The partial pressure of ammonia in the equilibrium mixture is 0.0506 atm. Calculate $K_p$ and $K_c$ for this reaction at 300˚C.

14) For the reaction below, $K_c = 0.0168$ at 250˚C:

$$PCl_5(g) \rightleftarrows PCl_3(g) + Cl_2(g)$$

a) A flask contains 0.100 mol/L of $PCl_5$. What will be the concentrations of all three gases when the above reaction reaches equilibrium?

b) A different flask contains 0.100 mol/L of $PCl_5$, 0.200 mol/L of $PCl_3$, and 0.300 mol/L of $Cl_2$. What will be the concentrations of all three gases when the above reaction reaches equilibrium?

15) For the reaction below, $K_p = 0.513$ at a certain temperature.

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

a) A flask holds some gaseous HI at this temperature and a pressure of 3.00 atm. What will be the partial pressures of all three gases when the above reaction reaches equilibrium?

b) A second flask contains a mixture of the three gases with the following partial pressures: $H_2 = 0.433$ atm, $I_2 = 0.0471$ atm, HI = 0.0310 atm. What will be the partial pressures of all three gases when the above reaction reaches equilibrium?

16) Parts a through d of this problem relate to the reaction below:

$$O_2(g) + 2\ F_2(g) \rightleftarrows 2\ OF_2(g)$$

a) If you add some gaseous $F_2$ to an equilibrium mixture of these three chemicals, which way will the reaction proceed?

b) If you add some gaseous $O_2$ to an equilibrium mixture of these three chemicals, what will happen to the partial pressure of $F_2$ in the mixture (i.e. will it go up, go down, or remain the same)?

c) If you increase the volume of the container, which way will the reaction proceed?

d) If you decrease the volume of the container, what will happen to the mass of $OF_2$ in the mixture?

e) If you increase the temperature, which way will the reaction proceed? You will need to look up the bond energy values to answer this question.

17) Will the value of the equilibrium constant K change in any of the parts of problem 16? If so, which parts?

18) Consider an equilibrium mixture of ammonium chloride, ammonia, and hydrogen chloride:

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

a) If you add a little solid $NH_4Cl$ to the mixture, what will happen to the mass of $NH_3$?

b) If you add a little gaseous $NH_3$ to the mixture, what will happen to the mass of HCl?

c) If you add a little gaseous HCl to the mixture, what will happen to the mass of $NH_4Cl$?

19) The reaction below is allowed to reach equilibrium:

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

a) If you add a little 1 M HCl to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.

b) If you add a little 1 M $MgCl_2$ to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.

c) If you add a little 1 M $NH_4NO_3$ to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.

20) For the reaction $4\ HBr(aq) + O_2(g) \rightleftarrows 2\ Br_2(aq) + 2\ H_2O(l)$, $K_c = 6.7 \times 10^{10}$. Use this information to calculate the equilibrium constant for each of the following reactions.

a) $2\ HBr(aq) + \frac{1}{2}\ O_2(g) \rightleftarrows Br_2(aq) + H_2O(l)$

b) $4\ Br_2(aq) + 4\ H_2O(l) \rightleftarrows 8\ HBr(aq) + 2\ O_2(g)$

21) Consider the following reactions, where the equilibrium constants are represented by the variables *x* and *y*:

$2\ FeCl_3(aq) + Zn(s) \rightleftarrows 2\ FeCl_2(aq) + ZnCl_2(aq)$ $\quad K = x$

$FeCl_3(aq) + CrCl_2(aq) \rightleftarrows FeCl_2(aq) + CrCl_3(aq)$ $\quad K = y$

Write an expression for the equilibrium constant for the reaction below, in terms of *x* and *y*.

$2\ CrCl_3(aq) + Zn(s) \rightleftarrows 2\ CrCl_2(aq) + ZnCl_2(aq)$

22) Calculate the equilibrium constant for the following reaction:

$$3\ HClO_3(aq) \rightleftarrows 2\ HClO_4(aq) + HClO(aq)$$

Use the following equilibrium constants.

$Cl_2(aq) + H_2O(l) \rightleftarrows HCl(aq) + HClO(aq)$ $\quad K = 6.2 \times 10^{-2}$

$3\ HClO(aq) \rightleftarrows HClO_3(aq) + 2\ HCl(aq)$ $\quad K = 2.1 \times 10^{-6}$

$4\ Cl_2(aq) + 4\ H_2O(l) \rightleftarrows 7\ HCl(aq) + HClO_4(aq)$ $\quad K = 7.9 \times 10^{-8}$

23) The concentration of $H^+$ ions in a solution is 0.315 M.

a) Calculate the concentration of $OH^-$ ions in this solution.

b) Where did these $OH^-$ ions come from?

c) What is the pH of this solution?

24) The pH of an HCl solution is 2.88.

a) What is the concentration of $H^+$ ions in this solution?

b) What is the concentration of $OH^-$ ions in this solution?

c) What is the concentration of $Cl^-$ ions in this solution?

25) Calculate the pH of a $7.4 \times 10^{-4}$ M solution of $Ba(OH)_2$.

26) Write the $K_a$ expression and the corresponding chemical equation for each of the following weak acids.

a) HClO b) $H_2C_4H_4O_4$ c) $NH_4^+$ d) $H_2PO_4^-$

27) The pH of a 0.464 M solution of phosphorous acid ($H_3PO_3$) is 1.11. Using this information, calculate the $K_a$ of phosphorous acid. (You may assume that only one hydrogen ion dissociates from phosphorous acid.)

28) Calculate the pH of a 0.27 M solution of $HCO_2H$ (formic acid, $K_a = 1.8 \times 10^{-4}$)

29) Determine which solution from each of the following pairs has the higher pH. You may need top refer to the $K_a$ values in Table 12.4.2 of your textbook.

a) 0.1 M HCl or 0.1 M $HNO_2$ b) 0.1 M HF or 0.1 M HClO

c) 0.1 M HCN or 0.1 M NaCN

30) Each of the following species can function as an acid. Write the formula of its conjugate base.

a) $HC_3H_5O_3$ b) $N_2H_5^+$ c) $H_2O$ d) $HCO_3^-$ e) $H_2SO_4$

31) Each of the following species can function as a base. Write the formula of its conjugate acid.

a) $NH_3$ b) $HSO_3^-$ c) $H_2O$ d) $PO_4^{3-}$

32) Identify the acid and the base in each of the following reactions.

a) $HNO_2(aq) + H_2O(l) \rightarrow H_3O^+(aq) + NO_2^-(aq)$

b) $H_2PO_4^-(aq) + HSO_4^-(aq) \rightarrow H_3PO_4(aq) + SO_4^{2-}(aq)$

33) For each of the following reactions, tell whether the equilibrium will favor the reactants or the products. Use the $K_a$ values in Table 12.4.2 of your textbook.

a) $HC_3H_5O_3(aq) + CN^-(aq) \rightleftarrows C_3H_5O_3^-(aq) + HCN(aq)$

b) $HOCl(aq) + OH^-(aq) \rightleftarrows OCl^-(aq) + H_2O(l)$