LESSON 12

Chemical Equilibrium

Glossary: Acids and Bases

Chemical equilibrium	the state reached by a reaction mixture when the rate of forward reaction and that of the reverse reaction have become equal
Endothermic process	a chemical reaction or physical change in which heat is absorbed
Equilibrium constant K_c	the value obtained for the equilibrium-constant expression when equilibrium concentrations are substituted
Exothermic process	a chemical reaction or physical change in which heat is evolved
Le Chatelier's principle	a principle stating that when a system in equilibrium is disturbed by a change of temperature, pressure, or concentration variable, the system shifts in equilibrium composition in a way that tends to counteract this change of variable
Pressure	the force exerted per unit area of surface
Product	a substance that results from a chemical reaction
Reactant	a starting substance in a chemical reaction

Definition of Chemical Equilibrium

Helpful Links: Visit these links to view videos on chemical equilibrium.

http://www.khanacademy.org/science/chemistry/v/reactions-in-equilibrium

Chemical equilibrium applies to reactions that can occur in both directions. In a reaction such as:

$$CH_4(g) + H_2O(g) <--> CO(g) + 3H_2(g)$$

$\mathbf{K_c}$ and $\mathbf{K_p}$ are the equilibrium constants of gaseous mixtures. However, the difference between the two constants is that $\mathbf{K_c}$ is defined by molar concentrations, whereas $\mathbf{K_p}$ is defined by the partial pressures of the gasses inside a closed system. The equilibrium constants do not include the concentrations of single components such as liquids and solid, and they do not have any units.

The reaction can happen both ways. So after some of the products are created the products begin to react to form the reactants. At the beginning of the reaction, the rate that the reactants are changing into the products is higher than the rate that the products are changing into the reactants. Therefore, the net change is a higher number of products.

Even though the reactants are constantly forming products and vice-versa the amount of reactants and products does become steady. When the net change of the products and reactants is zero the reaction has reached equilibrium. The equilibrium is a dynamic equilibrium. The definition for a dynamic equilibrium is when the amount of products and reactants are constant. (They are not equal but constant. Also, both reactions are still occurring.)

Equilibrium Constant

Helpful Link: Visit this link to view a video on equilibrium concentrations.

http://www.khanacademy.org/science/chemistry/v/heterogenous-equilibrium

To determine the amount of each compound that will be present at equilibrium you must know the equilibrium constant. To determine the equilibrium constant you must consider the generic equation:

aA + bB <--> cC + dD

The upper case letters are the molar concentrations of the reactants and products. The lower case letters are the coefficients that balance the equation. Use the following equation to determine the equilibrium constant (K_c).

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

For example, determining the equilibrium constant of the following equation can be accomplished by using the K_c equation.

Using the following equation, calculate the equilibrium constant.

$N_2(g) + 3H_2(g)$ <--> $2NH_3(g)$

A one-liter vessel contains 1.60 moles NH_3, .800 moles N_2, and 1.20 moles of H_2. What is the equilibrium constant?

$$K_c = \frac{[1.60]^2}{[.800]\,[1.20]^3} = 29.6$$

Answer: 1.85

Le Chatelier's Principle

Helpful links: Visit this link to view a video on Le Chatelier's Principle.

http://www.khanacademy.org/video/le-chatelier-s-principle?topic=chemistry

Le Chatelier's principle states that when a system in chemical equilibrium is disturbed by a change of temperature, pressure, or a concentration, the system shifts in equilibrium composition in a way that tends to counteract this change of variable. The three ways that Le Chatelier's principle says you can affect the outcome of the equilibrium are as follows:

- Changing concentrations by adding or removing products or reactants to the reaction vessel.
- Changing partial pressure of gaseous reactants and products.
- Changing the temperature.

These actions change each equilibrium differently; therefore you must determine what needs to happen for the reaction to get back in equilibrium.

Example involving change of concentration:

In the equation

$$2NO_{(g)} + O_{2(g)} \text{<-->} 2NO_{2(g)}$$

If you add more $NO_{(g)}$ the equilibrium shifts to the right producing more $NO_{2(g)}$

If you add more $O_{2(g)}$ the equilibrium shifts to the right producing more $NO_{2(g)}$

If you add more $NO_{2(g)}$ the equilibrium shifts to the left producing more $NO_{(g)}$ and $O_{2(g)}$

Example involving pressure change:

In the equation

$$2SO_{2(g)} + O_{2(g)} \text{<-->} 2SO_{3(g)},$$

an increase in pressure will cause the reaction to shift in the direction that reduces pressure, that is the side with the fewer number of gas molecules. Therefore an increase in pressure will cause a shift to the right, producing more product. (A decrease in volume is one way of increasing pressure.)

Example involving temperature change:

In the equation

$$N_{2(g)} + 3H_{2(g)} \text{<-->} 2NH_3 + 91.8\ kJ,$$

an increase in temperature will cause a shift to the left because the reverse reaction uses the excess heat. An increase in forward reaction would produce even more heat since the forward reaction is exothermic. Therefore the shift caused by a change in temperature depends upon whether the reaction is exothermic or endothermic.

Lesson 12 Review

Le Châtlier's Principle

Predict the direction of the equilibrium shift for each of the following processes:

1) $H_{2(g)} + Cl_{2(g)} \rightleftarrows 2\ HCl_{(g)}$

What direction will the equilibrium shift when the partial pressure of hydrogen is increased?

2) $3\ H_{2(g)} + N_{2(g)} \rightleftarrows 2\ NH_{3(g)}$

Given that this reaction is exothermic, what direction will the equilibrium shift when the temperature of the reaction is decreased?

3) $2\ NO_{2(g)} \rightleftarrows N_2O_{4(g)}$

If a large quantity of argon is added to the container in which this equilibrium is taking place, in what direction will the equilibrium shift?

4) $NH_4OH_{(aq)} \rightleftarrows NH_{3(g)} + H_2O_{(l)}$

In what direction will the equilibrium shift if ammonia is removed from the container as soon as it is produced?

5) $2\ BH_{3(g)} \rightleftarrows B_2H_{6(g)}$

If this equilibrium is taking place in a piston with a volume of 1 L and I compress it so the final volume is 0.5 L, in what direction will the equilibrium shift?

6) The following system is at equilibrium. In which direction (right or left) will the equilibrium position shift with the following changes?
$3NO_{(g)}$ <--> $N_2O_{(g)} + NO_{2(g)} + 154.9$ kJ

(right, left, or no effect)

a. Lowering the temperature?

b. Raising the temperature?

c. Adding more N_2O?

d. Adding more NO?

e. Removing some N_2O?

f. Adding a catalyst?

g. Increasing the volume?

Submit your answers in the text box.