Equilibrium Constant and Expression

- There is a mathematical relationship between the concentration of the reactants and products once equilibrium is reached that is *independent of the initial concentration of the chemicals*
- For any general reaction:

$$aA + bB \rightleftharpoons cC + dD$$

An **equilibrium expression** can be written as $K_c = \frac{[C]^c \times [D]^d}{[A]^a \times [B]^b}$ = $\frac{\text{products}}{\text{reactants}}$

where [ ] represents the concentrations of each chemical at *equilibrium*

- This mathematical relationship exists for all equilibrium systems and produces a constant ratio called the **equilibrium constant, K_c**
  - **The Law of Chemical Equilibrium** states that in a chemical system at equilibrium, there is a constant ratio (K_c) between the concentration of the products and the concentration of the reactants.
- The equilibrium constant (K_c) does not depend on the initial concentrations used to reach the point of equilibrium
- The equilibrium constant has *no units* and is constant for any particular reaction

EXAMPLES:

1. Consider the reaction between hydrogen and iodine gas to produce hydrogen iodide; $H_{2\,(g)} + I_{2\,(g)} \rightleftharpoons 2\,HI_{(g)}$.

   a. Write out the equilibrium expression.

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

* remember coefficients as exponents *

   b. At equilibrium, the concentration of hydrogen gas and iodine gas was 0.022mol/L and the concentration of hydrogen iodide gas was 0.156mol/L. Calculate the equilibrium constant (K_c).

$$K_c = \frac{(0.156)^2}{(0.022)(0.022)} = \boxed{50.3}$$

2. Consider the following equilibrium system at 487 °C:

$$2\ SO_{2(g)} + O_{2(g)} \leftrightarrow 2\ SO_{3(g)} \qquad K_c = 35$$

If the equilibrium concentrations of the $SO_{2(g)}$ and $O_{2(g)}$ are 0.15 mol/L and 0.18mol/L, respectively, what is the concentration of the $SO_{3(g)}$ at equilibrium?

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]} \Rightarrow [SO_3] = \sqrt{K_c[SO_2]^2[O_2]}$$

$$[SO_3] = \sqrt{(35)(0.15)^2(0.18)}$$

$$[SO_3] = 0.37649\ldots\ mol/L$$

$$\boxed{[SO_3] = 0.38\ mol/L}$$

- The equilibrium constant (K_c) is a ratio that relates the concentration of products to reactants at equilibrium
  - The concentration of both aqueous solutions and gases can change during a chemical reaction, therefore should be included in the equilibrium expression
  - ✳ In a chemical reaction, the amounts of solids or pure liquids will change, but their *concentrations* will NOT change, therefore solids and pure liquids are not included in the equilibrium expression
  - For example, write out the equilibrium expression for the following reactions.

    a. $CaO_{(s)} + CO_{2\,(g)} \rightleftharpoons CaCO_{3\,(s)}$
    b. $CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$

a.) $K_c = \frac{1}{[CO_2]}$

b.) $K_c = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]}$

  - Mixtures of liquids must be included since the concentration can be varied by changing the relative amounts of the mixed liquids. For example, write out the equilibrium expression for the following reaction.

$$C_6H_{6(l)} + Br_{2(l)} \rightleftharpoons C_6H_5Br_{(l)} + HBr_{(l)}$$

$$K_c = \frac{[HBr][C_6H_5Br]}{[C_6H_6][Br_2]}$$

- Equilibrium constants (K_c) can be used to determine which side the reaction will favour. Technically, this is valid only if reaction has the same number of reactant and product molecules in the balanced chemical equation.
    - If the equilibrium constant is very large, the concentrations of the products is much greater than the concentration of the reactants (products are favoured)
    - If the equilibrium constant is very small, the concentration of the reactants is much greater than the concentration of the products (reactants are favoured)
    - When the equilibrium constant has an value of approximately 1 (value with an exponent of 1 or -1), the concentration of the reactants and products are approximately equal

3. State whether the reactants or products are favoured.

    a. $N_{2(g)} + O_{2(g)} \leftrightarrow 2\ NO_{(g)}$ $K_c = 1.0 \times 10^{-25}$

    b. $CO_{(g)} + H_2O_{(g)} \leftrightarrow CO_{2(g)} + H_{2(g)}$ $K_c = 5.09$

a.) reactants favoured

b.) approximately equal

*****Now try Practice Problems, pg. 644 #7-10 & pg. 649 #12-14*****

Practice Problems

1. Write out the equilibrium expression for the following equilibriums.

   a. $N_{2(g)} + O_{2(g)} \leftrightarrow 2\ NO_{(g)}$

   b. $2\ H_{2(g)} + O_{2(g)} \leftrightarrow 2\ H_2O_{(l)}$

   c. $H_2O_{(g)} + C_{(s)} \leftrightarrow H_{2(g)} + CO_{(g)}$

   d. $Cu_{(s)} + 2\ Ag^+_{(aq)} \leftrightarrow Cu^{2+}_{(aq)} + 2\ Ag_{(s)}$

2. Write out the equilibrium reaction based off the equilibrium law.

   a. $K_c = \dfrac{[NO]^4[H_2O]^6}{[NH_3]^4[O_2]^5}$

   b. $K_c = \dfrac{[NCl_3]^2}{[Cl_2]^3[N_2]}$

Solutions for "Equilibrium Constant & Expression" Practice Problems

1.) a.) $K_c = \frac{[NO]^2}{[O_2][N_2]}$

b.) $K_c = \frac{1}{[H_2]^2[O_2]}$

c.) $K_c = \frac{[H_2][CO]}{[H_2O]}$

d.) $K_c = \frac{[Cu^{2+}]}{[Ag^+]^2}$

2.) a.) $4\,NH_3 + 5\,O_2 \rightleftharpoons 4NO + 6\,H_2O$

b.) $3\,Cl_2 + N_2 \rightleftharpoons 2\,NCl_3$