Part 2 - Kc - the Equilibrium Constant - pgs 684-687

- From repeating experiments on a chemical system, chemists discovered that there always exists a mathematical relationship between the amount concentrations (mol/L) of the products and the reactants at equilibrium

- This relationship always provides a **constant** value for a specific chemical system

- This constant value is called the ***equilibrium constant***, **K_c**

For the reaction $a\text{A} + b\text{B} \rightleftarrows c\text{C} + d\text{D}$,

the equilibrium law expression is $K_c = \dfrac{[\text{C}]^c[\text{D}]^d}{[\text{A}]^a[\text{B}]^b}$

**Note that this is $\dfrac{\text{products}}{\text{reactants}}$

$H_2 + I_2 \rightleftharpoons 2HI$

Table 1 The Hydrogen–Iodine System at 448 °C

System	Initial system concentrations (mmol/L)			Equilibrium system concentrations (mmol/L)			k_c
	H_2(g)	I_2(g)	HI(g)	H_2(g)	I_2(g)	HI(g)	
1	5.00	5.00	0	1.10	1.10	7.80	50.3
2	0.50	0.50	1.70	0.30	0.30	2.10	49.0
3	0	0	3.20	0.35	0.35	2.5	51.0

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

Example: Write the equilibrium law expression for the reaction of nitrogen monoxide gas with oxygen gas to form nitrogen dioxide gas.

$$2\,NO_{(g)} + 1\,O_{2(g)} \rightarrow 2\,NO_{2(g)}$$

$$k_c = \frac{[NO_2]^2}{[NO_{(g)}]^2[O_{2(g)}]}$$

- Experiments have shown that the value of the equilibrium constant depends on **temp**.

- The equilibrium constant provides only a measure of the equilibrium position of the reaction; it does not provide any information on the **rate** of the reaction
Speed

- Substances in a gaseous or dissolved (aqueous) state have *variable* concentrations, and must *always* be shown in an equilibrium law expression

- Substances in liquid or solid state have fixed concentrations and are not shown in an equilibrium law expression

Example: Write the equilibrium law expression for the decomposition of solid ammonium chloride to gaseous ammonia and gaseous hydrogen chloride.

$$NH_4Cl_{(s)} \rightarrow NH_{3(g)} + HCl_{(g)}$$

$$k_c = [NH_{3(g)}][HCl_{(g)}]$$

Calculating K_c and Using K_c to calculate equilibrium concentrations

Example:

Phosphorus pentachloride gas can be decomposed into phosphorus trichloride gas and chlorine gas.

$PCl_{5(g)} \rightarrow PCl_{3(g)} + Cl_{2(g)}$

a) Write the equilibrium law expression for this reaction.

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]}$$

b) If the $[PCl_{5(g)}] = 4.3 \times 10^{-4}$ mol/L, the $[PCl_{3(g)}] = 0.014$ mol/L and the $[Cl_{2(g)}] = 0.014$ mol/L then calculate K_c.

$$K_c = \frac{(0.014 \text{ mol/L})(0.014 \text{ mol/L})}{(4.3 \times 10^{-4} \text{ mol/L})} = \boxed{0.46}$$

Example

Find the $[SO_{3(g)}]$ for the following reaction if $K_c = 85.0$ at 25.0°C. The concentrations given are the concentrations at equilibrium.

$2\ SO_{2(g)}$	+	$O_{2(g)}$	-->	$2\ SO_{3(g)}$
0.500 mol/L		0.500 mol/L		???

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

$$85.0 = \frac{[SO_3]^2}{(0.500 \text{ mol/L})^2(0.500)}$$

$$\boxed{[SO_3] = 3.26 \text{ mol/L}}$$

Using ICE table to calculate equilibrium concentrations

- An ICE table is used when we are missing one or more equilibrium concentrations

    -We can't calculate K_c without equilibrium concentrations

- ICE stands for

    Initial – the initial conditions we started with in the system

    Change – the change in concentration between initial and equilibrium conditions

    Equilibrium – the concentrations at equilibrium

Example

In the decomposition of hydrogen iodide, we start with 2.00 mol/L of $HI_{(g)}$. At equilibrium $[H_{2(g)}] = [I_{2(g)}] = 0.214$ mol/L. Find the value for Kc

$$2\,HI_{(g)} \rightleftharpoons 1\,H_{2(g)} + I_{2(g)}$$

	$2\,HI_{(g)}$	$1\,H_{2(g)}$	$I_{2(g)}$
I	2.00 mol/L	0	0
C	−0.428	+0.214	+0.214
E	1.572M	0.214M	0.214 M

$$K_c = \frac{[H_2][I_2]}{[HI]^2} = \frac{(0.214\,M)^2}{(1.572\,M)^2} = \boxed{0.0185}$$

Example:

Phosphorus pentachloride gas decomposes into phosphorus trichloride gas and chlorine gas. If the $[PCl_{5(g)}]_i = 8.1 \times 10^{-3}$ mol/L and the $[PCl_{3(g)}]_i = 0.298$ mol/L, and the $[Cl_{2(g)}]_{eq} = 2.00 \times 10^{-3}$ mol/L. Calculate the unknown equilibrium [ ] and the K_c.

$$PCl_{5(g)} \rightarrow PCl_{3(g)} + Cl_{2(g)}$$

	$PCl_{5(g)}$	$PCl_{3(g)}$	$Cl_{2(g)}$
I	0.0081	0.298	0
C	- 0.002	+ 0.002	+ 0.002
E	0.0061	0.300	0.002

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{(0.300)(0.002)}{(0.0061)} = \boxed{0.098}$$

<u>What do K_c values tell us??</u>

- A K_c value is essentially a ratio of products:reactants @ equilibrium

- So this tells us where the equilibrium lies (reactants favored or products favored)

>1, then this means that the products are favored

< 1, then this means that the reactants are favored