N13 - Equilibrium

K – Equilibrium Constant

(Capitalized!)

Link to YouTube Presentation: https://youtu.be/JbbaquQpHsw

N13 - Equilibrium

K – Equilibrium Constant
(Capitalized!)

Target: I can calculate K, convert K when changes to a reaction are made, and can use the size of K to determine product or reactant favored.

Equilibrium Constant

Even though the concentrations of reactants and products are not equal at equilibrium, there is a relationship between them.

Law of Mass Action or also **Equilibrium Expression**
The relationship between the chemical equation and the concentrations of reactants and products.

Equilibrium Constant

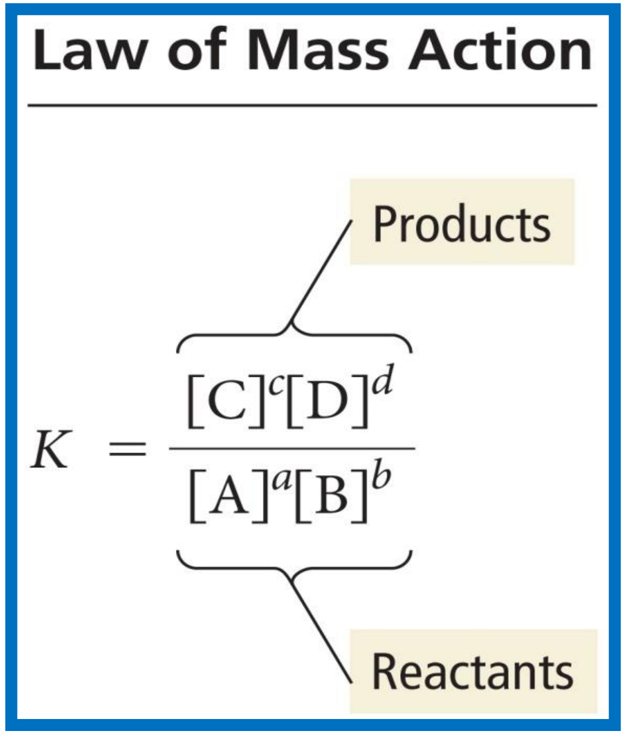
For the general equation ***a*A + *b*B → *c*C + *d*D**

The law of mass action gives the relationship below.

- The lowercase letters represent the coefficients of the balanced chemical equation.
- Always products over reactants

K is called the **equilibrium constant**.

- Unitless



Writing Equilibrium Constant Expressions

$$2\ N_2O_{5(g)} \Leftrightarrow 4\ NO_{2(g)} + O_{2(g)}$$

The equilibrium constant expression is:

$$K = \frac{[NO_2]^4[O_2]}{[N_2O_5]^2}$$

Heterogeneous Equilibria

- [ ]s of pure solids and pure liquids do not change during the course of a reaction.

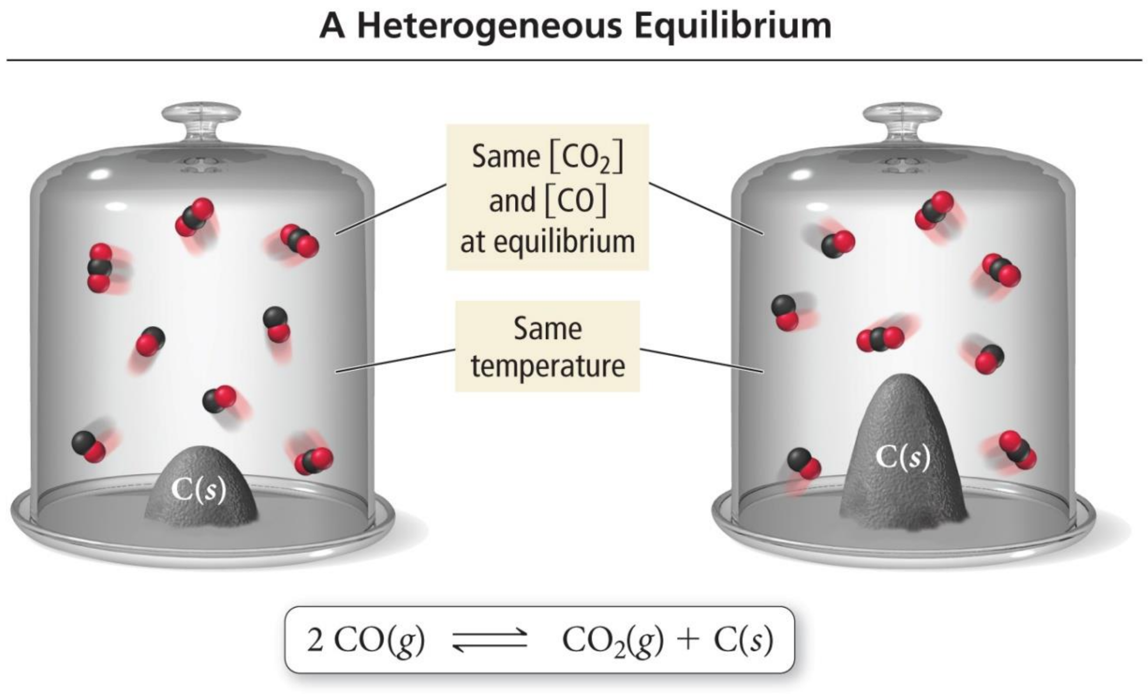
- Because their [ ]s don't change, solids and liquids are not included in the equilibrium constant expression.

$$CO_2(g) + H_2O(\ell) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

the equilibrium constant expression is as follows:

$$K_c = \frac{[H^+][HCO_3^-]}{[CO_2]}$$

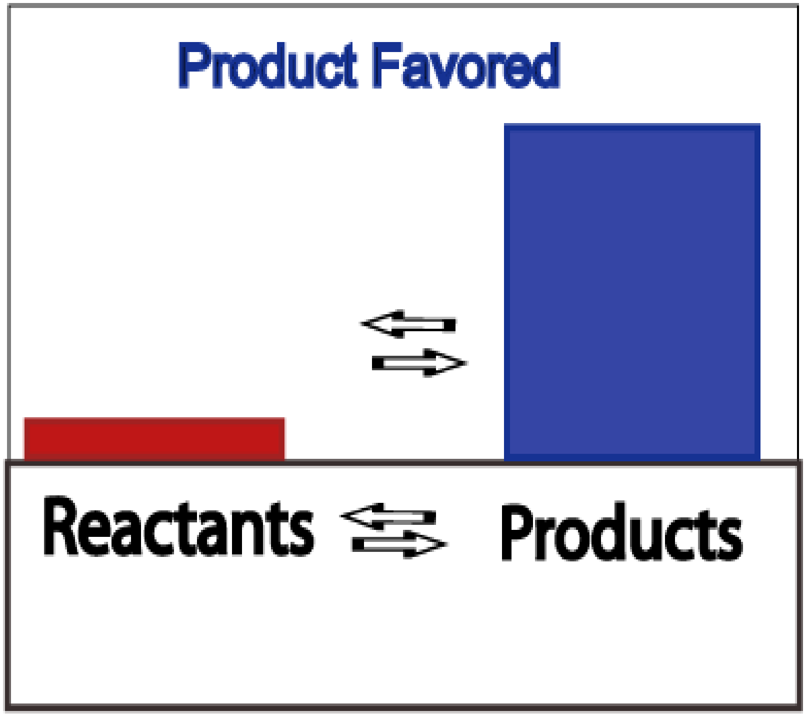
Heterogeneous Equilibria



The *amount* of C is different, but the concentrations of CO and CO_2 remain the same. Therefore, the amount of C has no effect on the position of equilibrium.

Product Favored Equilibrium

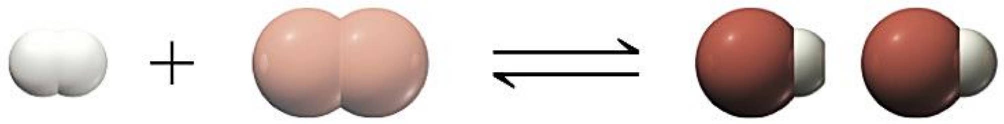
Large values for *K* signify the reaction is **product favored**

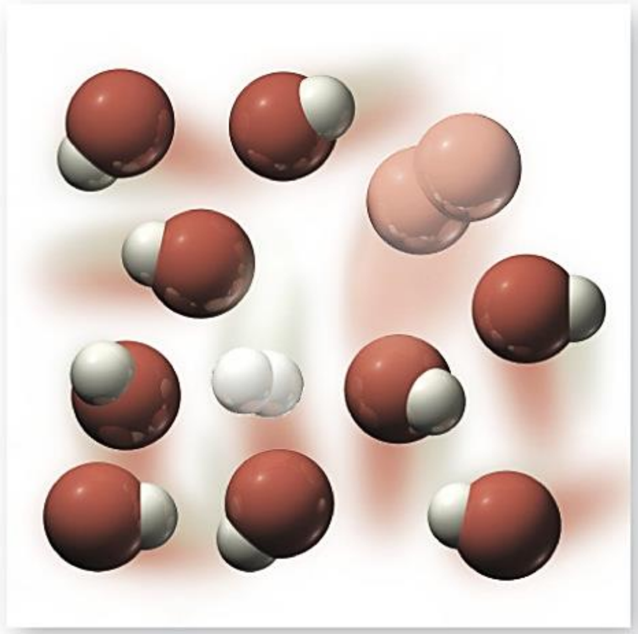


When equilibrium is achieved, most reactant has been converted to product

A Large Equilibrium Constant

$$H_2(g) + Br_2(g) \rightleftharpoons 2\,HBr(g)$$





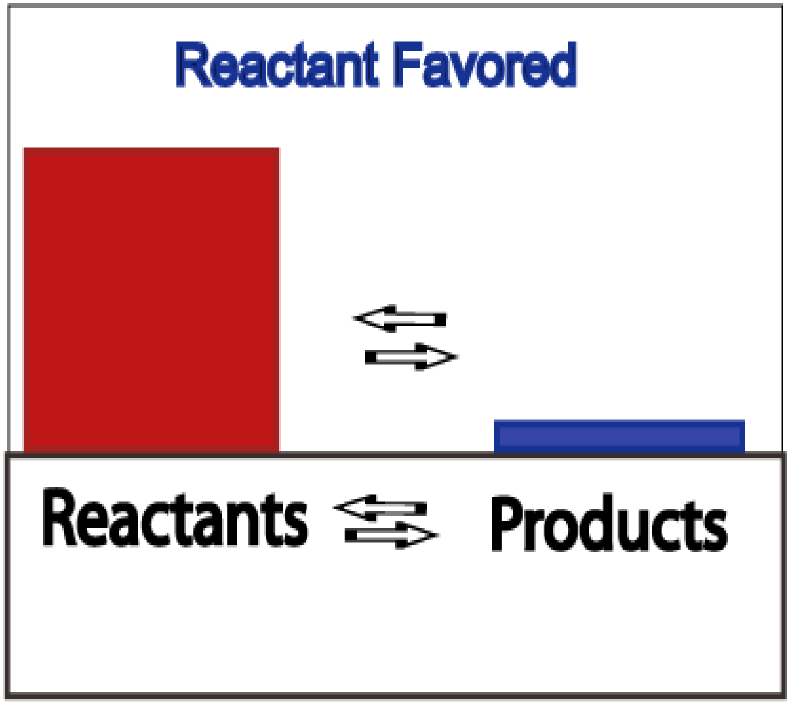
$$K = \frac{[HBr]^2}{[H_2][Br_2]} = \text{large number}$$

PRODUCT FAVORED

Lots of products = Large numerator = Large K value

Reactant Favored Equilibrium

Small values for *K* signify the reaction is **reactant favored**



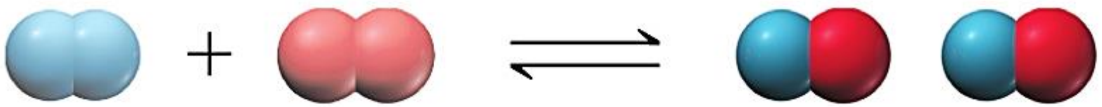
When equilibrium is achieved, very little reactant has been converted to product

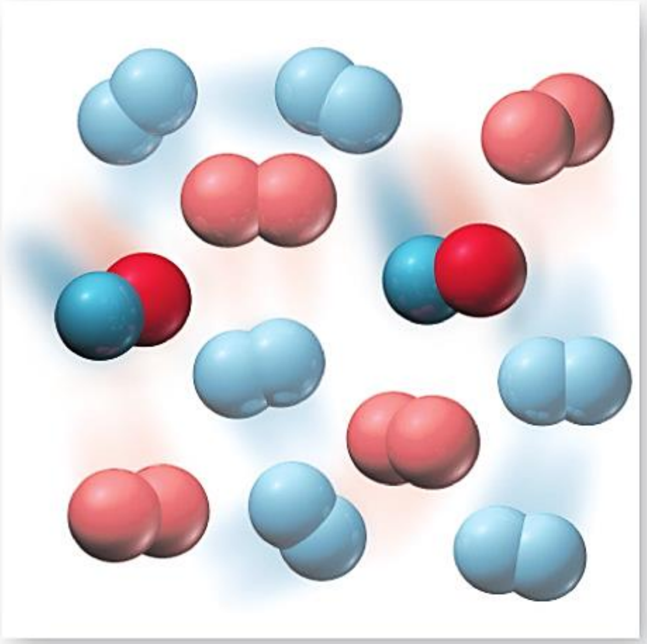
A Small Equilibrium Constant

Reactant FAVORED

Lots of reactants =
Large denomenator =
Small K value

$$N_2(g) + O_2(g) \rightleftharpoons 2\,NO(g)$$





$$K = \frac{[NO]^2}{[N_2][O_2]} = \text{small number}$$

Relationships between *K* and Chemical Equations

- When the reaction is **written backward**, the equilibrium constant is **inverted.**

$aA + bB \rightarrow cC + dD$

the equilibrium constant expression is:

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

$cC + dD \rightarrow aA + bB$

the equilibrium constant expression is:

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

$$\boldsymbol{K_{backwards} = \frac{1}{K_{forward}}}$$

Relationships between *K* and Chemical Equations

- When the coefficients of an equation are **multiplied** by a factor, the equilibrium constant is **raised to that factor.**

$$aA + bB \Leftrightarrow cC$$

the equilibrium constant expression is:

$$K_{original} = \frac{[C]^c}{[A]^a \times [B]^b}$$

$$2aA + 2bB \Leftrightarrow 2cC$$

the equilibrium constant expression is:

$$K_{new} = \frac{[C]^{2c}}{[A]^{2a} \times [B]^{2b}} = \left(\frac{[C]^c}{[A]^a \times [B]^b}\right)^2$$

$$K_{new} = K_{original}^{n}$$

Relationships between K and Chemical Equations

- When you **add equations** to get a new equation, the equilibrium constant of the new equation is the **product** of the equilibrium constants of the old equations.

1) $aA \Leftrightarrow bB$
2) $bB \Leftrightarrow cC$

the equilibrium constant expressions are:

$$K_1 = \frac{[B]^b}{[A]^a} \qquad K_2 = \frac{[C]^c}{[B]^b}$$

$aA \Leftrightarrow cC$

the equilibrium constant is:

$$K_{new} = \frac{[C]^c}{[A]^a}$$

$$= \frac{\cancel{[B]^b}}{[A]^a} \times \frac{[C]^c}{\cancel{[B]^b}}$$

$$K_{new} = K_1 \, x \, K_2$$

Equilibrium Constants for Rxns Involving Gases

- The [ ]s of a gas in a mixture is proportional to its partial pressure.

- Therefore, K can be expressed as the ratio of the partial pressures of the gases.

$$aA(g) + bB(g) \Leftrightarrow cC(g) + dD(g)$$

the equilibrium constant expressions are:

$$K_c = \frac{[C]^c \times [D]^d}{[A]^a \times [B]^b} \qquad K_p = \frac{{P_C}^c \times {P_D}^d}{{P_A}^a \times {P_B}^b}$$

Kc and Kp

- K_p, the partial pressures are always in atm.

- K_p and K_c are not necessarily the same because of the difference in units.

  $K_p = K_c$ when $\Delta n = 0$

$$K_p = K_c \; x \; (RT)^{\Delta n}$$

Δn is the difference between the number of moles of reactants and moles of products.

Connecting K to k

At equilibrium $2A + B_2 \rightarrow 2C$

$$K_{eq} = \frac{[C]^2}{[A]^2[B_2]}$$

rate forward = rate backwards

$Rate_{forward} = k_f[A]^2[B_2]$ $Rate_{reverse} = k_r[C]^2$

$k_f [A]^2 [B_2] = k_r [C]^2$

Rearrange to look like this!

$$\frac{[C]^2}{[A]^2[B_2]} = \frac{k_f}{k_r}$$

Now you can find K_{eq} if you know k_f and k_r !

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Deriving the Relationship Between Kc and Kp

$$[\mathrm{A}] = \frac{n_\mathrm{A}}{V}, n_\mathrm{A} = \text{moles of A}, V = \text{volume of gas}$$

$$P_A V = n_\mathrm{A} RT, \text{ from the Ideal Gas Law}$$

$$\textit{substituting} \quad P_A = \frac{n_A}{V} RT = [A]RT$$

$$[A] = \frac{P_A}{RT}$$

Deriving the Relationship Between Kc and Kp

$$[X] = \frac{P_X}{RT}$$

***a*A(*g*) + *b*B(*g*) ⇔ *c*C(*g*) + *d*D(*g*)**

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

substituting

$$K_p = \frac{{P_C}^c \times {P_D}^d}{{P_A}^a \times {P_B}^b}$$

$$K_c = \frac{\left(\frac{P_C}{RT}\right)^c \times \left(\frac{P_D}{RT}\right)^d}{\left(\frac{P_A}{RT}\right)^a \times \left(\frac{P_B}{RT}\right)^b} = \frac{{P_C}^c {P_D}^d \left(\frac{1}{RT}\right)^{c+d}}{{P_A}^a {P_B}^b \left(\frac{1}{RT}\right)^{a+b}} = K_p \left(\frac{1}{RT}\right)^{(c+d)-(a+b)}$$

rearranging $K_p = K_c (RT)^{(c+d)-(a+b)} = K_c (RT)^{\Delta n}$