CHAPTER 15: CHEMICAL EQUILIBRIUM

Equilibrium - a condition which exists when the rates of two opposing processes (chemical or physical) are equal
**reversible reaction** - a reaction which proceeds in both forward and reverse directions

**Equilibrium Constant, $K$ ($K_c$ or $K_p$)** - a number obtained for the general reaction as follows:

\[ aA + bB + cC \rightarrow \rightarrow \rightarrow \rightarrow xX + yY + zZ \]

\[
K_c = \frac{[X]^{x}_{eq}[Y]^{y}_{eq}[Z]^{z}_{eq}}{[A]^{a}_{eq}[B]^{b}_{eq}[C]^{c}_{eq}}
\]
Solids and solvents (liquids) are ignored in equilibrium expressions.

Units of $K$ (treat as a pure number)
The position of equilibrium is the same regardless of direction of approach (from reactants or from products).

The value of $K_{eq}$ depends only on temperature.

- $K_{eq}$ varies with $T$; not with $[M]$
- $K_{eq}$ indicates the relative
position of equilibrium

$K_{eq} \ll 1$ reactant favored

$K_{eq} \gg 1$ product favored

- Algebraic properties of $K_{eq}$

reversing a reaction

The $K$ for the reverse Rx is the
 reciprocal of the forward Rx
adding two reactions
The K for the sum of two reactions is the product of the individual Ks

-\(K_p - K_c\) relationship
\[K_p = K_c (RT)^{\Delta n_g}\]

\(\Delta n_g = \text{# mol gas prod} - \text{# mol gas react}\)

Calculate the \(K_c\) and \(K_p\) for the following reaction at 298 K:
CO(g) + Cl_2(g) → COCl_2(g)

if at equilibrium the [CO] = .228M, [Cl_2] = .228M, and [COCl_2] = .208M.

Calculate the [COCl_2]_{eq} if the eq. values of CO and Cl_2 are .100 and .500 M respect.

What is the value of Q if all concentrations are 2.00M. Which direction will the reaction shift?

**Reaction Quotient, Q** an expression having the same
form as $K_{eq}$ but using non-equilibrium values.

$Q>K$ Rx proceeds to left  
$Q<K$ Rx proceeds to right  
$Q=K$ at equilibrium
What you should be able to do

-Write $K_{eq}$ ($K_c$ or $K_p$) expression for any Rx
-Calculate $K_{eq}$ given $[\_]_{eq}$ or $P_{eq}$; or determine missing $[\_]_{eq}$ or $P_{eq}$
-Calculate $Q$; make predictions as to direction of reaction

-DETERMINE $[\_]_{eq}$ or $P_{eq}$ FROM $K_{eq}$ and INITIAL $[\_]$ or $P$
Give an algebraic expression for the equilibrium constant for the following reactions assuming the initial [ ] of all reactants is 1.000 M.

\[ \text{H}_2(g) + \text{I}_2(g) \rightarrow 2\text{HI}(g) \]
\[ \text{CO}(g) + \text{Cl}_2(g) \rightarrow \text{COCl}_2(g) \]
\[ \text{N}_2 + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) \]

Solve for the [ ]_{eq} of all species if \( K_{eq} = 45.2 \) for HI Rx
if \( K_{eq} = 4.00 \) for COCl\(_2\) Rx
if \( K_{eq} = .16 \) for NH\(_3\) Rx

**Le Chatelier's Principle** - when
a stress (change in [ ], P(V) (gas), or T) is applied to a system at equilibrium the system will shift to adjust to the stress.

\[
\begin{align*}
\text{stress} & \quad \text{shift} \\
\text{inc [reactant]} & \quad \rightarrow \\
\text{dec [product]} & \\
\text{dec [product]} & \quad \leftarrow \\
\text{inc P(dec V)} & \quad \text{favor side with fewer gas mol.}
\end{align*}
\]
dec $P(inc \, V)$  favor side with more gas mol.

inc $T$  \quad \rightarrow \quad Endo \, Rx
\quad \leftarrow \quad Exo \, Rx

dec $T$  \quad \rightarrow \quad Exo \, Rx
\quad \leftarrow \quad Endo \, Rx

do ex of Ni/CO and $N_2/H_2$
The position of equilibrium is the same regardless of direction of approach (from reactants or from products). The value of $K$ depends only on temperature.
\[ \text{O}_2\text{Hb(aq)} + \text{CO(g)} \rightarrow \text{COHb(aq)} + \text{O}_2\text{(g)} \quad \text{K}=200. \]

What pressure of CO is fatal if death results when \([\text{COHb}]/[\text{O}_2\text{Hb}]\) is 1.00

What can be done to save a victim using Le Chatelier's Principle

At equilibrium the \([\text{HBr}]=0.644\text{M}, [\text{H}_2]=[\text{Br}_2]=0.0279\text{M}. \) Determine \(K_c\)
Determine the final [ ] of all species if the [HBr] increased to .744M by the addition of extra HBr.

Calculate the pressures of H$_2$S and NH$_3$ at equilibrium from the decomposition of NH$_4$HS if $K_P=0.11$ at 298K. Also calculate $K_c$.

Calculate the $P_{eq}$ of CO and CO$_2$ if $P_T$ at equilibrium is 11.8ATM. $K_P=37.5$
ZnO(s)+CO(g) → Zn(s)+CO₂(g)