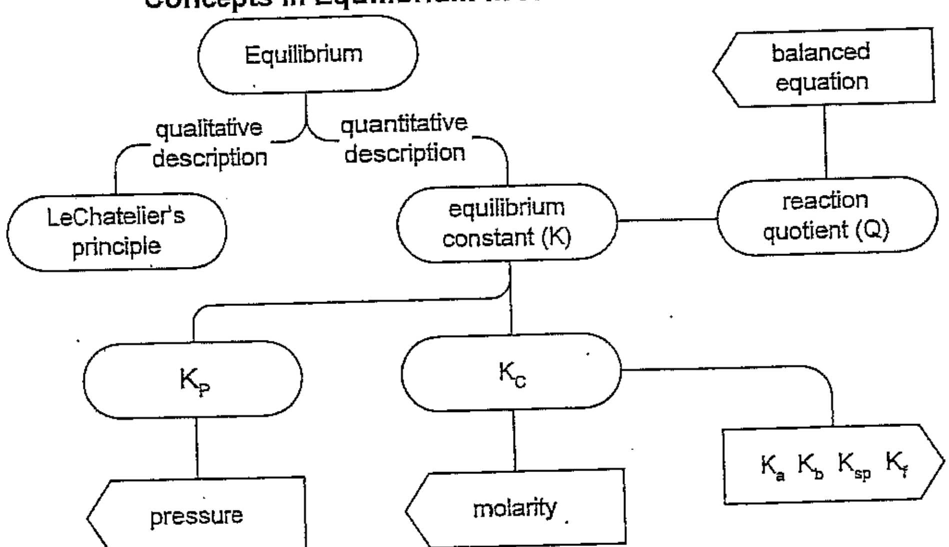
CHEMICAL EQUILIBRIUM IN REACTIONS OF GASES

This lesson deals with:

1. Writing the equilibrium constant expression for a given reaction.
2. Calculating the value of the equilibrium constant from the number of moles of reactants and products at equilibrium.
3. Calculating the value of K_P for an equilibrium system given the value of its K_C.
4. Calculating the amounts of substances present at equilibrium, given the initial conditions and the value of the equilibrium constant.
5. Calculating the effect on equilibrium concentrations of adding additional material involved in the reaction.
6. Using Le Chatelier's principle to predict the direction an equilibrium will shift in response to a change in its conditions.

Concepts in Equilibrium in Reactions of Gases



THE REACTION QUOTIENT

For every chemical reaction, there is an expression that indicates the completeness of the reaction. This is called the **reaction quotient.**

For a reaction represented by the generalized chemical equation

$$p\,A(g) + q\,B(g) \longrightarrow x\,C(g) + y\,D(g)$$

the reaction quotient has the form

$$Q = \frac{[C]^x[D]^y}{[A]^p[B]^q}$$

In this expression, the square brackets represent concentrations in moles per liter (molarity).

The value of the reaction quotient expresses quantitatively the extent of the reaction. For a reaction that has gone almost to completion, there will be very little reactant and much product. In this case, Q will be very large. For a reaction that has produced very little product and in which most of the reactants remain unreacted, Q will be very small. The value of Q increases as a reaction proceeds.

A **chemical equilibrium** exists when a chemical reaction and its reverse reaction occur simultaneously at the same rate, so that the molar concentrations of reactants and products do not change with time.

$$\mathrm{p\,A(g) + q\,B(g) \rightleftharpoons x\,C(g) + y\,D(g)}$$

When the concentrations of reactants and products do not change, the value of the reaction quotient does not change. This value of Q, when the reaction is at equilibrium, is called the equilibrium constant for the reaction, and is represented by K. For a reaction at equilibrium,

$$K = \frac{[\mathrm{C}]^x [\mathrm{D}]^y}{[\mathrm{A}]^p [\mathrm{B}]^q}$$

where [C], [D], [A], and [B] are the concentrations of the products and reactants when the reaction is at equilibrium.

For reactions that involve liquids and solids, these are not included in the reaction quotient or equilibrium constant expression.

$$\mathrm{p\,E(s) + q\,F(g) \rightleftharpoons x\,G(l) + y\,H(g)}$$

$$K = \frac{[\mathrm{H}]^y}{[\mathrm{F}]^q}$$

The concentrations of solids and liquids are constant and do change during a reaction. To simplify calculations involving equilibrium, these factors that do not change are omitted.

In writing an equilibrium constant expression (or reaction quotient):

1. Balance the chemical equation.
2. Write the concentration of each product in the numerator of K. Use the coefficient of each product in the balanced equation as the exponent of its concentration.
3. Write the concentration of each reactant in the denominator of K. Use the coefficient of each reactant in the balanced equation as the exponent of its concentration.
4. Delete all pure solids and pure liquids from the equilibrium constant expression.

The equilibrium constants for specific types of reactions are given special names, such as acid ionization constant (K_a) or solubility product (K_{sp}). However, no matter what the name, the process for writing the equilibrium constant expression is always the same.

Example 1

Write an equilibrium constant expression for each of the following reactions.

A. $NO_2(g) + SO_2(g) \rightleftharpoons NO(g) + SO_3(g)$

1. The equation is balanced.
2. $K = \frac{[NO]\,[SO_3]}{\quad}$
3. $K = \frac{[NO]\,[SO_3]}{[NO_2]\,[SO_2]}$
4. There are no solids or liquids in the reaction.

$$K = \frac{[NO]\,[SO_3]}{[NO_2]\,[SO_2]}$$

B. $C_2H_4(g) + O_2(g) \rightleftharpoons CO_2(g) + H_2O(g)$

1. Balance the equation: $C_2H_4(g) + 3\,O_2(g) \rightleftharpoons 2\,CO_2(g) + 2\,H_2O(g)$
2. $K = \frac{[CO_2]^2\,[H_2O]^2}{\quad}$
3. $K = \frac{[CO_2]^2\,[H_2O]^2}{[C_2H_4]\,[O_2]^3}$
4. There are no solids or liquids in the reaction.

$$K = \frac{[CO_2]^2\,[H_2O]^2}{[C_2H_4]\,[O_2]^3}$$

C. $Ca(OH)_2(s) + C_2H_2(g) \rightleftharpoons CaC_2(s) + 2\,H_2O(l)$

1. The equation is balanced.
2. $K = \frac{[CaC_2]\,[H_2O]^2}{\quad}$
3. $K = \frac{[CaC_2]\,[H_2O]^2}{[Ca(OH)_2]\,[C_2H_2]}$
4. Delete $Ca(OH)_2$ from denominator, CaC_2 and H_2O from numerator.

$$K = \frac{1}{[C_2H_2]}$$