Stoichiometry and Equilibrium

In grade 11 chemistry, you learned how to carry out stoichiometric calculations involving reactions that proceed to completion.

Example 1
Determine the mass of sodium chloride or table salt ($NaCl$) produced when 1.25 *mol* of chlorine gas reacts vigorously with sodium.

When a reversible reaction achieves equilibrium, instead of proceeding to completion, the stoichiometry requires a little more thought.

ICE Tables

An **ICE table** is a useful way to organize the information needed to solve a stoichiometric problem involving an equilibrium system. ICE stands for *Initial*, *Change*, and *Equilibrium*.

For systems composed of aqueous solutions or gases, *I* means *initial* concentrations of reactants and products, *C* stands for *change* in the concentrations of reactants and products between the start and the point at which equilibrium is achieved, and *E* stands for the concentration of reactants and products at *equilibrium*.

In the following example, we will use an ICE table to calculate equilibrium concentrations.

Example 2
Consider the following equation for the formation of hydrogen fluoride from its elements at STP.

$$H_2(g) + F_2(g) \Leftrightarrow 2HF(g)$$

If the reaction begins with 1.00 mol/L concentrations of H_2 and F_2 and no HF, calculate the equilibrium concentrations of H_2 and HF if the equilibrium concentration of F_2 is measured to be $0.24\ mol/L$.

Example 3

When ammonia is heated, it decomposes into nitrogen gas and hydrogen gas according to the following equation.

$$2NH_3(g) \Leftrightarrow N_2(g) + 3H_2(g)$$

$4.0\ mol$ of NH_3 is introduced into a $2.0\ L$ container and heated to a particular temperature. The amount of ammonia decreases until equilibrium is achieved. If there is found to be $2.0\ mol\ NH_3$ at equilibrium, determine the equilibrium concentrations of the other two entities.

Example 4

In a gaseous system, 0.20 mol of H_2 is added to 0.20 mol of I_2 in a 2.0 L container at $448°C$. At equilibrium the system contains 0.04 mol of H_2. Determine the equilibrium concentrations of H_2 and HI.

$$H_2(g) + I_2(g) \Leftrightarrow 2HI(g)$$

Worksheet

1. When carbon dioxide is heated in a closed container, it decomposes into carbon monoxide and oxygen according to the following equation.

$$2CO_2(g) \Leftrightarrow 2CO(g) + O_2(g)$$

When 2.0 mol of CO_2 is placed in a 5.0 L container and heated to a particular temperature, the equilibrium concentration of CO_2 is measured to be 0.39 mol/L. Use an ICE table to determine the equilibrium concentrations of CO and O_2.

2. At $35°C$, 2.0 mol of pure $NOCl$ is introduced into a 2.0 L flask. The $NOCl$ partially decomposes according to the following equation.

$$2NOCl(g) \Leftrightarrow 2NO(g) + Cl_2(g)$$

At equilibrium, the concentration of NO is 0.032 mol/L. Use an ICE table to determine equilibrium concentrations of $NOCl$ and Cl_2 at this temperature.

3. After 4.0 mol of C_2H_4 and 2.5 mol of Br_2 are placed in a sealed 1.0 L container, the reaction

$$C_2H_4(g) + Br_2(g) \Leftrightarrow C_2H_4Br_2(g)$$

reaches equilibrium. If the equilibrium concentration of C_2H_4 is 2.5 mol/L, determine the equilibrium concentrations of Br_2 and $C_2H_4Br_2$.

4. A 2.0 mol sample of phosphorous pentachloride (PCl_5) is placed into a 2.0 L flask at $160°C$. The reaction produces 0.20 mol of phosphorous trichloride (PCl_3) and some chlorine (Cl_2) at equilibrium.

$$PCl_5(g) \Leftrightarrow PCl_3(g) + Cl_2(g)$$

Calculate the concentration of PCl_5 and Cl_2 at equilibrium.

5. Methanol (CH_3OH) is manufactured from carbon monoxide (CO) and hydrogen (H_2) according to the following equation:

$$CO(g) + 2H_2(g) \Leftrightarrow CH_3OH(g)$$

A 1.0 L container is filled with 0.10 mol CO and 0.20 mol H_2. The reaction is allowed to proceed at $200°C$. At equilibrium, there is 0.12 mol H_2. What are the equilibrium concentrations of CO and CH_3OH?