In a **balanced chemical equation**, the total number of atoms of each element present is the same on both sides of the equation. **Stoichiometric coefficients** are the coefficients required to balance a chemical equation. These are important because they relate the amounts of reactants used and products formed. The coefficients relate to the **equilibrium constants** because they are used to calculate them. For this reason, it is important to understand how to balance an equation before using the equation to calculate equilibrium constants.

### Introduction

There are several important rules for balancing an equation:

1. An equation can be balanced only by adjusting the coefficients.
2. The equation must include only the reactants and products that participate in the reaction.
3. Never change the equation in order to balance it.
4. If an element occurs in only one compound on each side of the equation, try balancing this element first.
5. When one element exists as a free element, balance this element last.

Example 1:

\[
H_2(g) + O_2(g) \rightleftharpoons H_2O(l)
\]

Because both reactants are in their elemental forms, they can be balanced in either order. Consider oxygen first. There are two atoms on the left and one on the right. Multiply the right by 2.

\[
H_2(g) + 2O_2(g) \rightleftharpoons 2H_2O(l)
\]

Next, balance hydrogen. There are 4 atoms on the right, and only 2 atoms on the left. Multiply the hydrogen on the left by 2.

\[
2H_2(g) + O_2(g) \rightleftharpoons 2H_2O(l)
\]

Check the stoichiometry. Hydrogen: on the left, 2 \times 2 = 4; on right 2 \times 2 = 4. Oxygen: on the left: 1 \times 2 = 2; on the right 2 \times 1 = 2. All atoms balance, so the equation is properly balanced.

Example 2:

\[
Al(s) + MnSO_4(aq) \rightleftharpoons Al_2(SO_4)_3 + Mn(s)
\]

First, consider the SO\(_4^{2-}\) ions. There is one on the left side of the equation, and three on the right side. Add a coefficient of three to the left side.

\[
Al(s) + 3MnSO_4(aq) \rightleftharpoons Al_2(SO_4)_3 + 3Mn(s)
\]

Next, check the Mn atoms. There is one on the right side, but now there are three on the left side from the previous adjustment. Add a coefficient of three on the right side.

\[
Al(s) + 3MnSO_4(aq) \rightleftharpoons 3Al_2(SO_4)_3 + 3Mn(s)
\]
Consider Al. There is one atom on the left side and two on the right side. Add a coefficient of two on the left side. Make sure there are equal numbers of each atom on each side.

\[2Al(s) + 3\text{MnSO}_4(aq) \rightleftharpoons Al_2(\text{SO}_4)_3 + 3\text{Mn(s)}\]

Example (PageIndex{3}):

\[\text{P}_4\text{S}_3 + \text{KClO}_3 \rightleftharpoons \text{P}_2\text{O}_5 + \text{KCl} + \text{SO}_2\]

This problem is more difficult. First, look at the P atoms. There are four on the reactant side and two on the product side. Add a coefficient of two to the product side.

\[\text{P}_4\text{S}_3 + 2\text{KClO}_3 \rightleftharpoons 2\text{P}_2\text{O}_5 + \text{KCl} + 2\text{SO}_2\]

Next, consider the sulfur atoms. There are three on the left and one on the right. Add a coefficient of three to the right side.

\[\text{P}_4\text{S}_3 + 3\text{KClO}_3 \rightleftharpoons 2\text{P}_2\text{O}_5 + \text{KCl} + 3\text{SO}_2\]

Now look at the oxygen atoms. There are three on the left and 16 on the right. Adding a coefficient of 16 to the KClO$_3$ on the left and the KCl on the right preserves equal numbers of K and Cl atoms, but increases the oxygen.

\[3\text{P}_4\text{S}_3 + 16\text{KClO}_3 \rightleftharpoons 2(3)\text{P}_2\text{O}_5 + 16\text{KCl} + 9\text{SO}_2\]

Tripling the other three species (P$_4$S$_3$, P$_2$O$_5$, and SO$_2$) balances the rest of the atoms.

Simplify and check.

---

**Chemical Equilibrium**

Balanced chemical equations can now be applied to the concept of chemical equilibrium, the state in which the reactants and products experience no net change over time. This occurs when the forward and reverse reactions occur at equal rates. The equilibrium constant is used to determine the amount of each compound that present at equilibrium. Consider a chemical reaction of the following form:

\[a\text{A} + b\text{B} \rightleftharpoons c\text{C} + d\text{D}\]

For this equation, the equilibrium constant is defined as:

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

The activities of the products are in the numerator, and those of the reactants are in the denominator. For $K_c$, the activities are defined as the molar concentrations of the reactants and products ([A], [B] etc.). The lower case letters are the stoichiometric coefficients that balance the equation.

An important aspect of this equation is that pure liquids and solids are not included. This is because their activities are defined as one, so plugging them into the equation has no impact. This is due to the fact that pure liquids and solids...
have no effect on the physical equilibrium; no matter how much is added, the system can only dissolve as much as the solubility allows. For example, if more sugar is added to a solution after the equilibrium has been reached, the extra sugar will not dissolve (assuming the solution is not heated, which would increase the solubility). Because adding more does not change the equilibrium, it is not accounted for in the expression.

K is related to to the Balanced Chemical Reaction

The following are concepts that apply when adjusting K in response to changes to the corresponding balanced equation:

- When the equation is reversed, the value of K is inverted.
- When the coefficients in a balanced equation are multiplied by a common factor, the equilibrium constant is raised to the power of the corresponding factor.
- When the coefficients in a balanced equation are divided by a common factor, the corresponding root of the equilibrium constant is taken.
- When individual equations are combined, their equilibrium constants are multiplied to obtain the equilibrium constant for the overall reaction.

A balanced equation is very important in using the constant because the coefficients become the powers of the concentrations of products and reactants. If the equation is not balanced, then the constant is incorrect.

K IS ALSO RELATED TO THE BALANCED CHEMICAL EQUATION OF GASES

For gas-phase equilibria, the equation is a function of the reactants’ and products’ partial pressures. The equilibrium constant is expressed as follows:

\[
K_p = \frac{P_C^c P_D^d}{P_A^a P_B^b}
\]

P represents partial pressure, usually in atmospheres. As before, pure solids and liquids are not accounted for in the equation. \(K_c\) and \(K_p\) are related by the following equation:

\[
K_p = K_c(RT)^{\Delta n}
\]

where

\[
\Delta n = (c+d) - (a+b)
\]

This represents the change in gas molecules. \(a,b,c\) and \(d\) are the stoichiometric coefficients of the gas molecules found in the balanced equation.

Neither \(K_c\) nor \(K_p\) have units. This is due to their formal definitions in terms of activities. Their units cancel in the calculation, preventing problems with units in further calculations.

Example: Using \(K_c\)

\[
PbI_2 \rightleftharpoons Pb^{\text{aq}} + I^{\text{aq}}
\]

First, balance the equation.
Check the Pb atoms. There is one on each side, so lead can be left alone for now. Next check the I atoms. There are two on the left side and one on the right side. To fix this, add a coefficient of two to the right side.

\[ \text{Pb}^2+ (aq) + 2\text{I}^-(aq) \rightleftharpoons \text{PbI}_2 \]

Check to make sure the numbers are equal.

Next, calculate find \( K_c \). Use these concentrations: \( \text{Pb}^+ \) 0.3 mol/L, \( \text{I}^- \) 0.2 mol/L, \( \text{PbI}_2^- \) 0.5 mol/L

\[ K_c = \dfrac{(0.3) \times (0.2)^2}{(0.5)} \]

\[ K_c = 0.024 \]

Note: If the equation had not been balanced when the equilibrium constant was calculated, the concentration of \( \text{I}^- \) would not have been squared. This would have given an incorrect answer.

utomatic number to work, you need to add the "AutoNum" template (preferably at the end) to the page.

Example \( \PageIndex{5} \)

\[ \text{SO}_2 \; (g) + \text{O}_2 \; (g) \rightleftharpoons \text{SO}_3 \; (g) \]

First, make sure the equation is balanced.

Check to make sure S is equal on both sides. There is one on each side. Next look at the O. There are four on the left side and three on the right. Adding a coefficient to the \( \text{O}_2 \) on the left is ineffective, as the S on right must also be increased. Instead, add a coefficient to the \( \text{SO}_2 \) on the left and the \( \text{SO}_3 \) on the right.

The equation is now balanced.

Calculate \( K_p \). The partial pressures are as follows: \( \text{SO}_2 \) 0.25 atm, \( \text{O}_2 \) 0.45 atm, \( \text{SO}_3 \) 0.3 atm

\[ K_p = \dfrac{(0.3)^2}{(0.25)^2 \times (0.45)} \]

\[ K_p = 3.2 \]

Contributors

- Charlotte Hutton, Sarah Reno, Curtis Kortemeier