7.3: Chemical Equations

Learning Objectives

- Identify the reactants and products in any chemical reaction.
- Convert word equations into chemical equations.
- Use the common symbols, such as (s), (l), (g), (aq), and $\rightarrow$ appropriately when writing a chemical reaction.

In a chemical change, new substances are formed. In order for this to occur, the chemical bonds of the initial substances break, and the atoms that compose them separate and rearrange themselves into new substances with new chemical bonds. When this process occurs, we call it a chemical reaction. A **chemical reaction** is the process in which one or more substances are changed into one or more new substances.

Reactants and Products

To describe a chemical reaction, we need to indicate what substances are present at the beginning and what substances are present at the end. The substances that are present at the beginning are called **reactants** and the substances present at the end are called **products**.

Sometimes when reactants are put into a reaction vessel, a reaction will take place to produce products. Reactants are the starting materials, that is, whatever we have as our initial ingredients. The products are just that – what is produced – or the result of what happens to the reactants when we put them together in the reaction vessel. If we think about making tacos, our reactants would be tortillas, meat, cheese, lettuce, tomatoes, sour cream, and salsa. What would be the products? Tacos! The reaction vessel would be our plate or countertop.

$$\underbrace{\text{tortillas} + \text{meat} + \text{cheese} + \text{lettuce} + \text{tomatoes} + \text{sour cream} + \text{salsa}}_{\text{Ingredients} = \text{Reactants}} \rightarrow \underbrace{\text{tacos}}_{\text{Product}}$$

Writing Chemical Equations

Let's consider the explosive reaction between hydrogen and oxygen gases (see Figure 7.3.1 below). One might describe this reaction using words like this:

- Hydrogen gas reacts with oxygen gas to yield water in the gaseous phase.

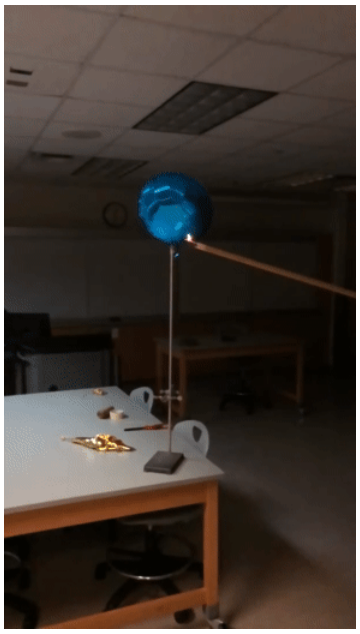

Figure 7.3.1: Slow-motion capture of a Mylar balloon filled with hydrogen and oxygen gas exploding upon ignition during a test conducted by Anoka-Ramsey Community College chemistry faculty.

Word descriptions are typically simplified by writing out chemical reactions in the form of a chemical equation using chemical formulas to represent the substances that are reacting. The reaction between hydrogen and oxygen may be simplified by the chemical equation:

$$H_2\,(g) + O_2\,(g) \rightarrow H_2O\,(g)$$

Hydrogen and oxygen are the reactants and water is the product.

$$\underbrace{H_2\,(g) + O_2\,(g)}_{\text{Reactants}} \rightarrow \underbrace{H_2O\,(g)}_{\text{Product}}$$

In chemical reactions, reactants are shown to the left of the arrow ($\rightarrow$) and products are shown after the arrow. The general equation for a chemical reaction is:

$$\text{Reactants} \rightarrow \text{Products}$$

As to why water is produced as a gas, it may be observed that the water is produced as a result of an explosion as shown in Figure 7.3.1. At the elevated temperature of the explosion, water exists as a gas and not as a liquid. This leads to a few special symbols that we need to know in order to "talk" in chemical shorthand. Table 7.3.1 provides a summary of the major symbols used in chemical equations.

Table 7.3.1: Symbols Used in Chemical Equations

Symbol	Description	Symbol	Description
$+$	used to separate multiple reactants or products	(s)	reactant or product in the solid state
$\rightarrow$	yield sign; separates reactants from products	(l)	reactant or product in the liquid state
$\rightleftharpoons$	replaces the yield sign for reversible reactions that reach equilibrium	(g)	reactant or product in the gas state
$\xrightarrow{\text{Pt}}$	formula written above the arrow is used as a catalyst in the reaction	(aq)	reactant or product in an aqueous solution (dissolved in water)
$\xrightarrow{\Delta}$	triangle indicates that the reaction is being heated		

The symbols (*s*), (*l*), (*g*), and (*aq*) are called phase labels. Phase labels aren't always necessary. However, they add clarity when the physical states of each substance involved are unclear or when they add important context.

A reaction between aqueous solutions of calcium nitrate and sodium hydroxide to produce solid calcium hydroxide and an aqueous solution of sodium nitrate may be written as:

$$Ca(NO_3)_2\,(aq) + NaOH\,(aq) \rightarrow Ca(OH)_2\,(s) + NaNO_3\,(aq)$$

Many would agree that the chemical equation is much easier to read.

We should also be able to read a chemical equation and put into words a description for a chemical reaction. Consider,

$$Cu\,(s) + AgNO_3\,(aq) \rightarrow Cu(NO_3)_2\,(aq) + Ag\,(s)$$

This equation may be described something like

- Solid copper reacts with an aqueous solution of silver nitrate to produce an aqueous solution of copper(II) nitrate and solid silver metal.

To turn word equations into chemical equations, it may be helpful to think of the process something like this:

1. Identify the reactants and products. This will help you know which symbols go on each side of the arrow and where the + signs belong.
2. Write the correct formulas for all compounds. You will need to use the rules you learned in Chapter 5 (making sure all ionic compounds are charge balanced).
3. Write the correct formulas for all elements, remembering that that there are seven diatomic elements (H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2), meaning that they are always found in pairs in nature. Diatomic elements were discussed in Section 5.3.

✅ Example 7.3.1

Convert the chemical equations into word equations and the word equations into chemical equations.

A. $\mathrm{HCl}(aq) + \mathrm{NaOH}(aq) \rightarrow \mathrm{NaCl}(aq) + \mathrm{H_2O}(l)$
B. Gaseous propane, C_3H_8, burns in oxygen gas to produce gaseous carbon dioxide and liquid water.
C. Hydrogen fluoride gas reacts with an aqueous solution of potassium carbonate to produce an aqueous solution of potassium fluoride, liquid water, and gaseous carbon dioxide.

Solution

A. An aqueous solution of hydrochloric acid reacts with an aqueous solution of sodium hydroxide to produce an aqueous solution of sodium chloride and liquid water.

B. Reactants: propane (C_3H_8) and oxygen (O_2)

Product: carbon dioxide (CO_2) and water (H_2O)

$$\boxed{\mathrm{C_3H_8\ (g)\ +\ O_2\ (g)\ \rightarrow\ CO_2\ (g)\ +\ H_2O\ (l)}}$$

C. Reactants: hydrogen fluoride (HF) and potassium carbonate (K_2CO_3)

Products: potassium fluoride (KF), water (H_2O), and carbon dioxide (CO_2)

$$\boxed{\mathrm{HF\ (g)\ +\ K_2CO_3\ (aq)\ \rightarrow\ KF\ (aq)\ +\ H_2O\ (l)\ +\ CO_2\ (g)}}$$

✏️ Exercise 7.3.1

Convert the chemical equations into word equations and the word equations into chemical equations.

A. Hydrogen gas reacts with nitrogen gas to produce gaseous ammonia.
B. $\mathrm{HCl}(aq) + \mathrm{LiOH}(aq) \rightarrow \mathrm{LiCl}(aq) + \mathrm{H_2O}(l)$
C. Copper metal is heated with oxygen gas to produce solid copper(II) oxide.

Answer A

$\mathrm{H_2\ (g) + N_2\ (g) \rightarrow NH_3\ (g)}$

Answer B

An aqueous solution of hydrochloric acid reacts with an aqueous solution of lithium hydroxide to produce an aqueous solution of lithium chloride and liquid water.

Answer C

$\mathrm{Cu\ (s) + O_2\ (g) \rightarrow CuO\ (s)}$

Summary

- A chemical reaction is the process by which one or more substances are changed into one or more new substances.
- Chemical reactions are represented by chemical equations.
- Chemical equations have reactants on the left, an arrow that is read as "yields", and the products on the right.
