Chemical Reactions

The process by which the atoms of one or more substances are rearranged to form different substances is called a **chemical reaction**. For example, when the methane in natural gas combines with oxygen in the air and burns, carbon dioxide and water are formed. This process is represented by a **chemical equation** with the **reactants** (methane and oxygen) on the left side of an arrow and the **products** (carbon dioxide and water) on the right side:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

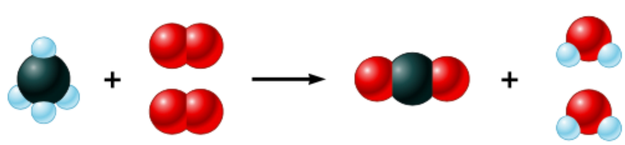
Reactants Products

Notice that the atoms have been reorganized. *Bonds have been broken, and new ones have been formed.*

It is important to recognize that **in a chemical reaction, all atoms present in the reactants must be accounted for in the products**. Making sure that this rule is obeyed is called **balancing a chemical equation** for a reaction.

The equation for the combustion of methane (above) is not balanced. We can see this from the following representation of the reaction:

There are 2 oxygen atoms and 4 hydrogen atoms on the left of the arrow, but 3 oxygen atoms and 2 hydrogen atoms on the right. According to the rule above, the number of atoms of each element must be the same on both sides of the arrow. Through simple trial and error we can determine that the needed numbers of molecules are:



We can represent this situation by the following chemical equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

We can verify that the equation is balanced by counting the number of atoms of each element on both sides.

Reactants		Products
	C	
	H	
	O	

The Meaning of a Chemical Equation

The chemical equation for a reaction gives two important types of information: the nature of the reactants and products, and the relative numbers of each.

Besides specifying the compounds involved in the reaction, the equation often gives the **physical states** of the reactants and products:

State	**Symbol**
Solid	(s)
Liquid	(l)
Gas	(g)
Dissolved in water (in aqueous solution)	(aq)

For example:

$$HCl(aq) + NaHCO_3(s) \rightarrow CO_2(g) + H_2O(l) + NaCl(aq)$$

The relative numbers of reactants and products in a reaction are indicated by the **coefficients** in the balanced equation. For example, the balanced equation

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

can be interpreted in several equivalent ways, as shown below.

Reactants		**Products**
$CH_4(g) + 2O_2(g)$	$\rightarrow$	$CO_2(g) + 2H_2O(g)$
$1\ molecule\ CH_4 + 2\ molecules\ O_2$	$\rightarrow$	$1\ molecule\ CO_2 + 2\ molecules\ H_2O$
$1\ mole\ CH_4 + 2\ moles\ O_2$	$\rightarrow$	$1\ mole\ CO_2 + 2\ moles\ H_2O$
$6.02 \times 10^{23}\ molecules\ CH_4$ $+ 2(6.02 \times 10^{23})\ molecules\ O_2$	$\rightarrow$	$6.02 \times 10^{23}\ molecules\ CO_2$ $+ 2(6.02 \times 10^{23})\ molecules\ H_2O$
$16\ g\ CH_4 + 2(32\ g)\ O_2$	$\rightarrow$	$44\ g\ CO_2 + 2(18\ g)\ H_2O$
$80\ g\ reactants$	$\rightarrow$	$80\ g\ products$

Note that the total mass is 80 g for both reactants and products. Per the law of conservation of mass, the mass remains constant throughout the reaction.

Balancing Chemical Equations

The principle that is the heart of balancing is that the same number of each type of atom must be found among the reactants and the products. It is also important to remember that **the formulas of the compounds must never be changed in balancing a chemical equation**. In other words, the subscripts in a formula cannot be changed.

Most chemical equations can be balanced by following the steps given below.

1. Write the *unbalanced* equation for the reaction.
    - show the physical states of all reactants and products whenever possible

2. Count the atoms of the elements in the reactants.
    - if a reaction involves identical polyatomic ions in the reactants and products, count the ions as if they were elements

3. Count the atoms of the elements in the products.

4. Change the coefficients to make the number of atoms of each element equal on both sides of the equation.
    - never change a subscript of a formula, since doing so changes the identity of the substance
    - change coefficients one at a time, and recount the elements after every change

5. Write the coefficients in their lowest possible ratio.
    - think of this like reducing a fraction

6. Check your work.
    - make sure the chemical formulas are written correctly
    - check that the number of atoms of each element is equal on both sides of the equation

Example 1

Write the balanced chemical equation for the reaction in which hydrogen gas and chlorine gas react to produce hydrogen chloride.

Example 2

Write the balanced chemical equation for the reaction in which sodium hydroxide and calcium bromide react to produce solid calcium hydroxide and sodium bromide. The reaction occurs in water.

Example 3

Write the balanced chemical equation for the reaction in which methane gas reacts with oxygen gas to produce carbon dioxide gas and water vapor.

Example 4

Write the balanced chemical equation for the reaction in which solid magnesium reacts with nitric acid (HNO_3) to produce hydrogen gas and magnesium nitrate. The reaction occurs in water.

Worksheet

1. What is the purpose of writing a word equation?

2. Examine the following word equation:

$$\text{propane} + \text{oxygen gas} \rightarrow \text{carbon dioxide} + \text{water}$$

   a) List all the reactants in this reaction.

   b) List all the products in this reaction.

   c) What is the purpose of the arrow in the word equation?

3. Write word equations for the following reactions:

   a) $CaCl_2$ and Na_2SO_4 react to form $CaSO_4$ and $NaCl$.

   b) $BaCO_3$ reacts when heated to produce BaO and CO_2.

   c) $AgNO_3$ reacts with KCl to produce $AgCl$ and KNO_3.

4. Write word equations to represent the following chemical reactions:

   a) Carbon dioxide and water are produced in human cell respiration. The reactants are sugar and an important gas that humans need to survive.

   b) Stalactites form in caves when calcium bicarbonate reacts to form calcium carbonate, water, and carbon dioxide gas.

5. Write your own word equation for the production of a peanut butter sandwich.

6.
   a) Why is the following equation not balanced?

$$N_2 + H_2 \rightarrow NH_3$$

   b) The following is an attempt to balance the above equation. What is wrong with the way that the equation is balanced?

$$N_2 + H_3 \rightarrow N_2H_3$$

7. Copy the following skeleton equation into your notebook. Then balance the equations.

a) $Na + Cl_2 \rightarrow NaCl$

b) $K + O_2 \rightarrow K_2O$

c) $H_2 + O_2 \rightarrow H_2O$

d) $H_2 + Cl_2 \rightarrow HCl$

e) $N_2 + H_2 \rightarrow NH_3$

f) $CO + O_2 \rightarrow CO_2$

g) $Al + Br_2 \rightarrow AlBr_3$

h) $N_2H_4 + O_2 \rightarrow H_2O + N_2$

i) $CH_4 + O_2 \rightarrow CO_2 + H_2O$

8. For each of the following, write the correct skeleton equation, and then balance it to form a chemical equation.

a) copper(II) oxide + hydrogen → copper + water

b) lead(II) nitrate + potassium iodide → lead(II) iodide + potassium nitrate

c) calcium + water → calcium hydroxide + hydrogen gas

d) lead(II) sulfide + oxygen → lead + sulfur dioxide

e) hydrogen sulfide → hydrogen + sulfur

9. Imagine that you are an engineer trying to determine how much air had to be supplied to burn gasoline in a car engine. Assuming that gasoline is heptane (C_7H_{16}), the word equation is:

heptane + oxygen → carbon dioxide + water vapor

a) Write the skeleton equation for the reaction.

b) Balance the equation by adding coefficients as necessary.

c) How many molecules of oxygen are required for every molecule of heptane that burns?