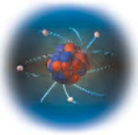
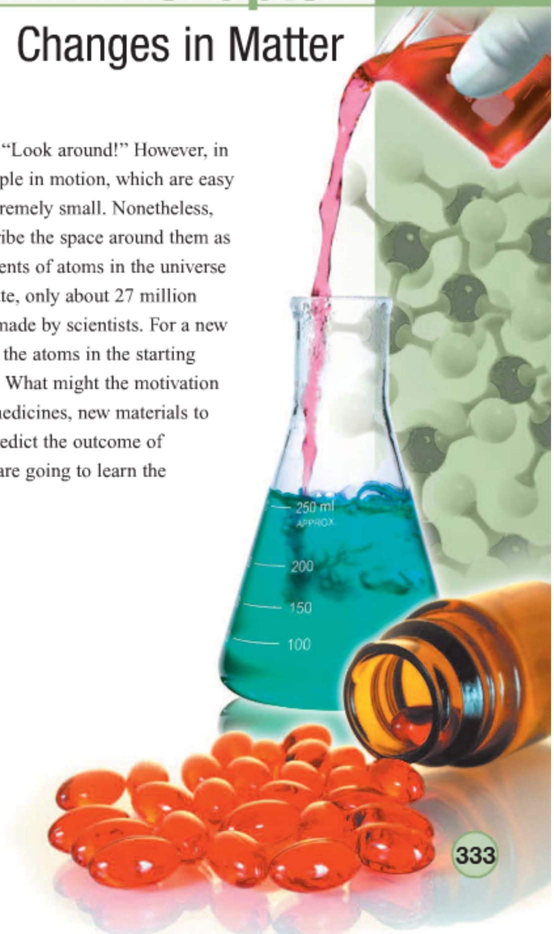
Chapter 14

Changes in Matter



When studying science, it is common to be told, "Look around!" However, in chemistry, the objects of study aren't cars or people in motion, which are easy to see. The objects of study are atoms and molecules, which are extremely small. Nonetheless, these tiny particles are all around you. In fact, some scientists describe the space around them as "chemical space." They think that the number of possible arrangements of atoms in the universe might be as many as 10^{60} compounds. That is a huge number! To date, only about 27 million compounds are known to occur naturally on Earth or to have been made by scientists. For a new compound to be made, a chemical change has to occur. This means the atoms in the starting materials are rearranged to make different or even new compounds. What might the motivation be for making a new compound? New compounds can mean new medicines, new materials to make lighter cars or airplanes, and even new fuels. Being able to predict the outcome of chemical changes is important when making new compounds. You are going to learn the basics of doing that in this chapter.



Key Questions

- ✔ What is a chemical reaction and how do you show what happens during one?
- ✔ How are chemical reactions classified?
- ✔ What does energy have to do with chemical reactions?
- ✔ What is a nuclear reaction and how is it different from a chemical reaction?

14.1 Chemical Reactions

Atoms and molecules are all around us and so are chemical reactions. How do you know a chemical reaction is occurring? When you make pizza, for example, some of your work involves physical changes and some involves chemical changes (Figure 14.1). You know a chemical reaction has occurred if a chemical change has occurred as well. In this section, you will learn about chemical reactions.

Figure 14.1: *This woman is making pizza from scratch. Here, she is preparing the dough. What part of making a pizza involves physical changes? What part of the process involves chemical changes?*

Chemical reactions involve chemical changes

A review of changes Earlier, you learned that matter undergoes chemical changes and physical changes. Recall that a physical change is a change that affects only the physical properties of a substance. Examples of physical changes include chopping pizza toppings (such as vegetables) into smaller pieces and melting an ice cube into liquid water. Both of these changes involve a change in size, shape, or state of matter. A chemical change is a change in a substance that involves the breaking and reforming of chemical bonds to make one or more different substances.

Physical and chemical changes in making pizza The process of making pizza involves some physical changes (such as chopping vegetables) and chemical changes. Pizza dough is made of flour, oil, salt, and yeast (a type of fungus). As pizza dough is made, the yeast produces carbon dioxide gas in a process called cellular respiration. The carbon dioxide causes the dough to rise. This gas, the result of a chemical change, is responsible for the small holes you see in any kind of bread made with yeast. The action of the yeast and heat from an oven cause chemical changes that transform the sticky pizza dough into a tasty crust.

Energy and changes Both physical and chemical changes involve energy. For example, you need energy to chop a green pepper into smaller pieces. Energy is also required for a substance to change its state from a solid to a liquid to a gas. Because chemical changes involve breaking and forming bonds, energy is also involved in these changes. Heat or light—forms of energy—are produced or used during a chemical change. The chemical changes in making pizza require the yeast to use and release energy and the heat of an oven to cook the pizza.

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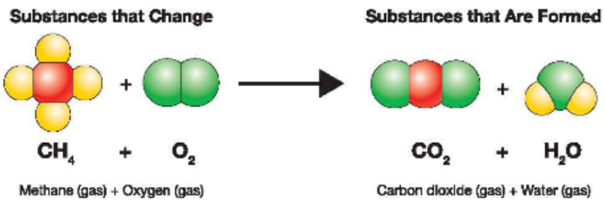
Science in Your Mouth

Place a saltine cracker in your mouth. How does it taste? Hold it there for about 3 to 5 minutes. Now how does it taste? Is this evidence of a chemical or a physical change? Write down what you observe and think.

What is a chemical reaction?

Chemical reaction defined

You have just learned something about the physical and chemical changes involved in making pizza. Any time there is a chemical change, a chemical reaction has occurred. A **chemical reaction** is the process of breaking chemical bonds in one or more substances and re-forming new bonds to create new substances. The process of cellular respiration performed by yeast in making pizza dough is a chemical reaction. The process used to generate heat in a gas stove to bake the pizza is also a chemical reaction and is illustrated below. When methane gas (a fuel) and oxygen react, the bonds in these molecules are broken to form the compounds carbon dioxide and water.



Evidence of a chemical reaction

When you combine two or more compounds, how do you know whether or not a chemical reaction has occurred? You can't see atoms and molecules actually breaking and forming bonds, but you can observe other events that indicate a chemical reaction. Figure 14.2 illustrates the type of evidence you can expect. For example, if you see a newly formed substance, such as a gas or a solid, you can suspect a chemical reaction. If a gas is a product in the reaction, you might see bubbles. If a new solid is produced, you might see powder forming in the reaction mixture so that it turns cloudy. A solid that forms and does not dissolve in the reaction mixture is called a **precipitate**. Similarly, if you see a color change in the reaction mixture, a new substance might have been formed. Finally, evidence of a chemical reaction includes a temperature change. Keep in mind that any heat added to the reaction to get it started is not part of the evidence of a chemical reaction.

VOCABULARY

chemical reaction - the process of breaking chemical bonds in one or more substances and the reforming of new bonds to create new substances.

precipitate - a solid that forms and does not dissolve in a reaction mixture.

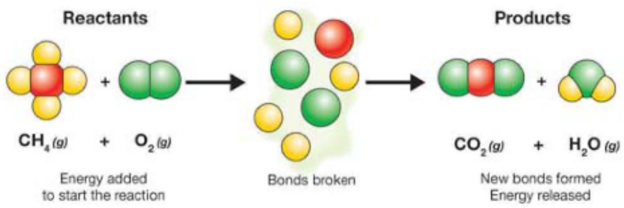
Figure 14.2: *These are all different kinds of evidence that a chemical reaction is occurring.*

Reactants and products

Parts of a chemical reaction You can think of a chemical reaction as a kind of recipe. A recipe calls for specific amounts of ingredients to make a food—such as a cake. A **reactant** is a starting ingredient in a chemical reaction. The resulting substances formed in a chemical reaction are called the products. A **product** is a compound that results from new chemical bonds formed when a chemical reaction occurs.

Reactants are chemically changed to form products On the previous page, you saw a reaction involving methane and oxygen. Below is that reaction presented again so that you can see what happens when reactants are chemically changed to become products. In the reaction, methane (a natural gas) is burned, or combusted. Some energy is added to get the reaction started. Once this happens, a carbon atom from the methane molecule reacts with oxygen in the air to form carbon dioxide. Single oxygen atoms and hydrogen atoms also combine to form water. This reaction is particularly useful in making gas stoves work because it releases a large amount of heat.

States of matter in chemical reactions You know that the reactants in the reaction below are gases because of the symbol (*g*) listed next to the molecules (Figure 14.3). Likewise, you know that the products are gases—carbon dioxide gas and water vapor.



VOCABULARY

reactant - a starting ingredient in a chemical reaction.

product - a new substance formed in a chemical reaction.

Symbol	Meaning
(*s*)	substance is a solid
(*l*)	substance is a liquid
(*g*)	substance is a gas
(*aq*)	substance is dissolved in water (aqueous)

Figure 14.3: *Symbols used for states of matter.*

SOLVE IT!

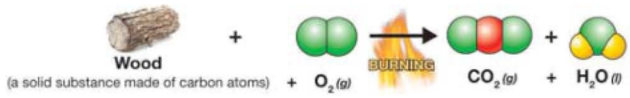
For the methane reaction, does the number of atoms of the reactants equal the number of atoms of the products? Count and see. How could you make the numbers match? (Note: In the next section, you'll find out!)

The law of conservation of mass

Burning wood is a chemical reaction Have you ever wondered what happens to wood in a fireplace or campfire as it is burned? The burning of wood is a chemical reaction. By writing this reaction as a chemical equation, you can figure out what happened to the wood. It doesn't just disappear!

The law of conservation of mass In the eighteenth century, chemical reactions were still a mystery. A French scientist, Antoine Laurent Lavoisier, established an important principal based on his experiments with chemical reactions. He stated that the total mass of the reactants of a reaction is equal to the total mass of the products. This statement, which relates reactants and products, is known as the **law of conservation of mass**.

Investigating a reaction To understand the law of conservation of mass, let's look at the reaction of burning wood. It is easy to find the mass of a piece of wood you want to burn. But, what happens to the mass of the wood after it burns (Figure 14.4)? To find out, look at the reaction below. The combined mass of the burning wood and oxygen is converted into carbon dioxide and water.



Using a closed system to study a reaction How can you prove that the mass of the reactants is equal to the mass of the products in the reaction of burning wood? Lavoisier showed that a closed system must be used when studying chemical reactions. When chemicals are reacted in a closed container, you can show that the mass before and after the reaction is the same (Figure 14.5).

For a chemical reaction, the total mass of reactants always equals the total mass of the products.

VOCABULARY

law of conservation of mass - a principle that states that the total mass of the reactants equals the total mass of the products in a chemical reaction.

Figure 14.4: *What happens to wood when it is burned?*

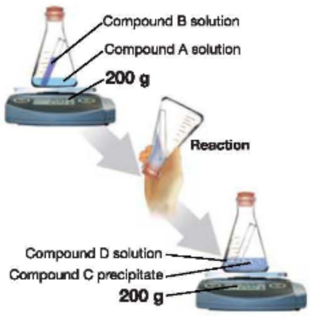


Figure 14.5: *A closed system illustrates the law of conservation of mass.*

How are chemical reactions written?

The chemical equation So far you have seen how a chemical reaction—such as the methane reaction below—is written. When a chemical reaction is written using chemical formulas and symbols, it is called a **chemical equation**. Chemical equations are a convenient way to describe chemical reactions. Here you see the methane reaction written as a chemical equation and as a sentence. What advantages do you see for writing the reaction as an equation?

$$CH_4\,(g) + O_2\,(g) \longrightarrow CO_2\,(g) + H_2O\,(g)$$

Methane gas reacts with oxygen gas to produce carbon dioxide gas and water vapor.

Parts of a chemical equation In Chapter 13, you learned how to write chemical formulas (Figure 14.6). Recall that the symbols for elements are used along with subscripts. Additional parts of a chemical equation are symbols that indicate the state of matter for each reactant and product. An arrow is always included between reactants and products. The arrow means "to produce" or "to yield."

Accounting for the atoms You know that a chemical reaction involves breaking and reforming chemical bonds. See if you can account for how atoms are distributed on the reactant side versus the product side in the methane reaction above. What's wrong? Notice that there are only two oxygen atoms on the reactant side, but there are three on the product side. You might also notice that you have four hydrogen atoms on the reactant side and only two on the product side (Figure 14.7). This means that the chemical equation above is not completely correct.

Numbers and types of atoms must balance The law of conservation of mass is always applied to chemical equations. The law is applied by balancing the number and type of atoms on either side of the equation. When balancing a chemical equation, you consider whole atoms rather than fractions of an atom because only whole atoms react. Also, you are not allowed to change the chemical composition of any of the compounds on the reactant or product side. To learn how to balance chemical equations, let's take another look at the methane reaction.

VOCABULARY

chemical equation - an expression of a chemical reaction using chemical formulas and symbols.

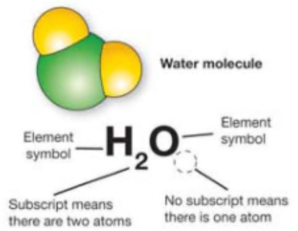


Figure 14.6: *The parts of a chemical formula.*

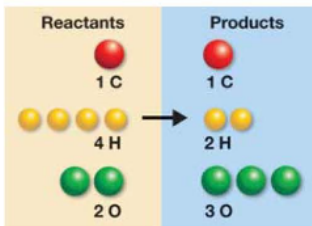


Figure 14.7: *This graphic illustrates that the number of oxygen and hydrogen atoms are not balanced for the methane reaction.*

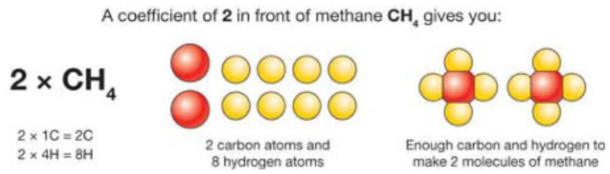
Balancing a chemical equation

Begin by counting the number of atoms The first step in balancing a chemical equation involves counting the number of each type of atom on both sides of the reaction. Recall that the subscripts in a chemical formula tell you the number of each type of atom. The table below summarizes this information for the methane reaction (Figure 14.8).

Type of Atom in Methane Reaction	Total on Reactant Side	Total on Product Side	Balanced?
C	1	1	yes
H	4	2	no
O	2	3	no

When an equation is unbalanced As you can see, the chemical equation for the methane reaction is not balanced. The number of hydrogen and oxygen atoms is different on each side of the equation. To make the number of atoms equal and balance the equation, you must figure out what number to multiply each compound by in order to make the numbers add up. Remember: You cannot change the number of individual atoms in a compound. That would change its chemical formula and you would have a different compound.

Adding coefficients To change the number of molecules of a compound, you can write a whole number **coefficient** in front of the chemical formula (Figure 14.9). When you do this, *all* of the types of atoms in that formula are multiplied by that number. When there is no coefficient in front of a chemical formula, you assume that one molecule of that compound is sufficient.



VOCABULARY

coefficient - a whole number placed in front of a chemical formula in a chemical equation.

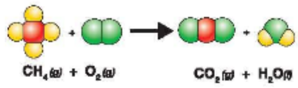


Figure 14.8: *Graphic of the unbalanced methane reaction.*

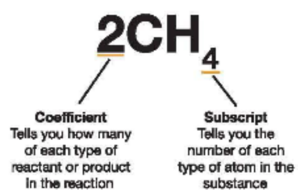
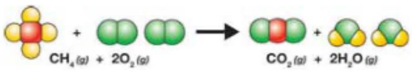


Figure 14.9: *What do coefficients and subscripts mean?*

Checking your work

Figuring out where to place coefficients to multiply the numbers of atoms in a chemical formula is largely a process of trial and error. Let's look at the methane reaction after the correct coefficients have been added.



Counting the atoms on both sides again, we see that the equation is balanced.

Type of Atom in Methane Reaction	Total on Reactant Side	Total on Product Side	Balanced?
C	1	1	yes
H	4	2(× 2) = **4**	yes
O	2(× 2) = **4**	2 + 1(× 2) = **4**	yes

Reading a balanced equation

Now that the equation is balanced, it can be read as follows: "One molecule of methane reacts with two molecules of oxygen to produce one molecule of carbon dioxide and two molecules of water." Figure 14.10 reviews key points to remember when balancing chemical equations.

When Balancing a Chemical Equation...
1. Make sure you have written the correct chemical formula for each reactant and product.
2. The subscripts in the chemical formulas of the reactants and products cannot be changed during the process of balancing the equation. Changing the subscripts will change the chemical makeup of the compounds.
3. Numbers called **coefficients** are placed in front of the formulas to make the number of atoms on each side of the equation equal.

Figure 14.10: *Key points for balancing a chemical equation.*

Your turn... balanced or unbalanced?

Identify which of the following equations are balanced. Count the number of each type of atom on both sides.

a. $2H_2 + O_2 \rightarrow 2H_2O$

b. $MgO + H_2O \rightarrow Mg(OH)_2$

c. $Ca + O_2 \rightarrow CaO$

d. $Na_2O + H_2O \rightarrow NaOH$

e. $2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$

SOLVE FIRST LOOK LATER

a. balanced
b. balanced
c. unbalanced
d. unbalanced
e. balanced

Next

Solving Problems: Balancing Equations

In this reaction, chalcocite (a mineral) reacts with oxygen in the presence of heat. The products are a type of copper oxide and sulfur dioxide. Balance this equation (Figure 14.11): $Cu_2S + O_2 \rightarrow Cu_2O + SO_2$.

1. Looking for: Coefficients that will balance the chemical equation.

2. Given: The following information is based on the chemical equation.

Type of Atom	Reactants	Products	Balanced?
Cu	2	2	yes
S	1	1	yes
O	2	3	no

3. Relationships: Coefficients can be added in front of any chemical formula in a chemical equation. When a coefficient is added in front of a chemical formula, all atoms in that formula are multiplied by that number.

4. Solution: First try: Add a 2 in front of O_2 and in front of Cu_2O so that there are four O atoms on each side. However, this changes the number of Cu atoms.

Second try: Add a 2 in front of Cu_2S so that there are four Cu atoms on each side. However, this changes the number of S atoms.

Third try: Add a 2 in front of the SO_2. Change the 2 in front of O_2 to a 3. Now there are two S atoms and six O atoms on each side and the equation is balanced: $2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$

Your turn...

a. $KClO_3 \rightarrow KCl + O_2$

b. $Al_2S_3 + H_2O \rightarrow Al(OH)_3 + H_2S$

First try:

$Cu_2S + \mathbf{2}O_2 \rightarrow \mathbf{2}Cu_2O + SO_2$

Atom	Reactants	Products
Cu	2	2(× 2) = 4
S	1	1
O	2(× 2) = 4	1(× 2) + 2 = 4

Second try:

$\mathbf{2}Cu_2S + 2O_2 \rightarrow 2Cu_2O + SO_2$

Atom	Reactants	Products
Cu	2(× 2) = 4	2(× 2) = 4
S	1(× 2) = 2	1
O	2(× 2) = 4	1(× 2) + 2 = 4

Third try:

$2Cu_2S + \mathbf{3}O_2 \rightarrow 2Cu_2O + \mathbf{2}SO_2$

Atom	Reactants	Products
Cu	2(× 2) = 4	2(× 2) = 4
S	1(× 2) = 2	1(× 2) = 2
O	2(× 3) = 6	1(× 2) + 2(× 2) = 6

Figure 14.11: *Balancing the equation.*

SOLVE FIRST LOOK LATER

a. $2KClO_3 \rightarrow 2KCl + 3O_2$

b. $Al_2S_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2S$

Next

Section 14.1 Review

1. Is the formation of rust on an iron nail a chemical change or a physical change? Explain your answer.
2. List the kinds of evidence that indicate that a chemical reaction has occurred.
3. Identify the reactants and products in this chemical reaction. Identify each compound as a gas, a solid, a liquid, or a solution.

$$BaCO_3\,(s) + HBr\,(aq) \longrightarrow BaBr_2\,(aq) + H_2O\,(l) + CO_2\,(g)$$

4. What is the law of conservation of mass? How is it related to balancing chemical equations?
5. Why is it important to study chemical reactions in closed containers?
6. In one of his experiments, Lavoisier placed 10.0 grams of mercury (II) oxide into a sealed container and heated it. The mercury (II) oxide then reacted in the presence of heat to produce 9.3 grams of mercury. Oxygen gas was another product in the reaction. According to the law of conservation of mass, how much oxygen gas would have been produced?
7. What is the difference between a subscript and a coefficient in a chemical equation?
8. Are the following chemical equations balanced or unbalanced? Balance any unbalanced equations.
   a. $2KClO_3 \rightarrow KCl + 3O_2$
   b. $Fe + O_2 \rightarrow FeO$
   c. $2Li + Cl_2 \rightarrow 2LiCl$
   d. $NH_3 + HCl \rightarrow NH_4Cl$
9. $BaO_2\,(s) \rightarrow BaO\,(s) + O_2\,(g)$
   a. Balance the chemical equation above.
   b. Use the information in Figure 14.12 to write the equation in words. Be sure to describe the state of matter for each compound.

Some Chemical Formulas	
barium peroxide	BaO_2
barium oxide	BaO
oxygen	O_2

Figure 14.12: *Question 9.*

STUDY SKILLS

Look for Chemistry Everywhere

This chapter is all about chemistry. How can you improve your understanding? One way is to practice seeing objects and events in terms of chemistry.

Here are some simple examples.

(1) When you see a glass of water think of the chemical formula for water—H_2O.

(2) When you breathe, think about the oxygen (O_2) coming in and the carbon dioxide (CO_2) going out of your nose or mouth.

(3) Identify events as causing a physical change or a chemical change. For example, when you write with a pencil, you are causing a physical change in the pencil lead by wearing it down. If you cook food, you are probably causing chemical changes.

(4) Read the ingredients on labels. Can you write the chemical formula for any of the ingredients?