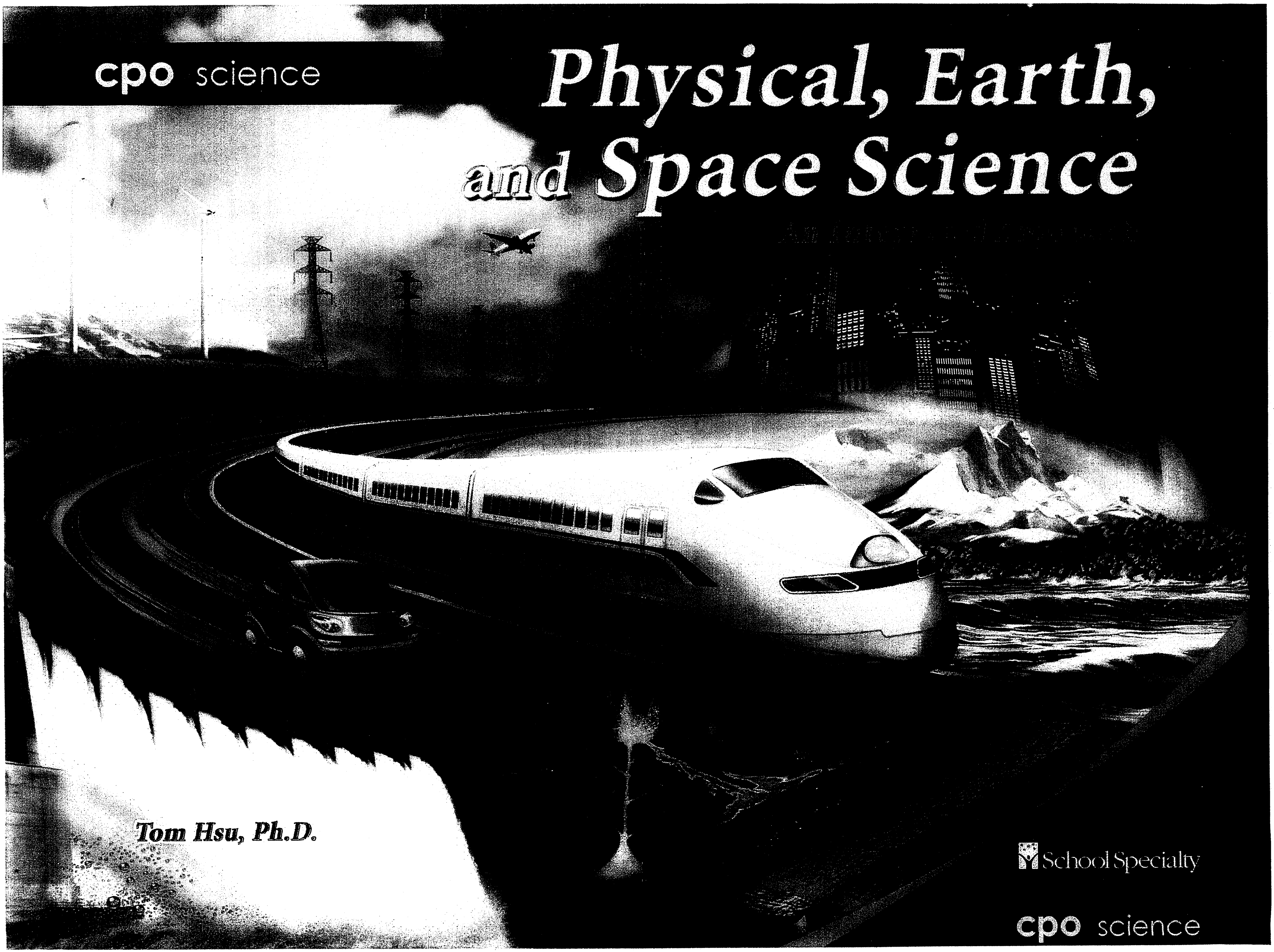
cpo science

Physical, Earth, and Space Science



Tom Hsu, Ph.D.

School Specialty

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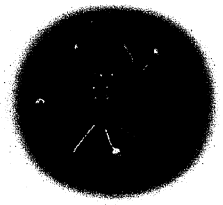
Chapter 14

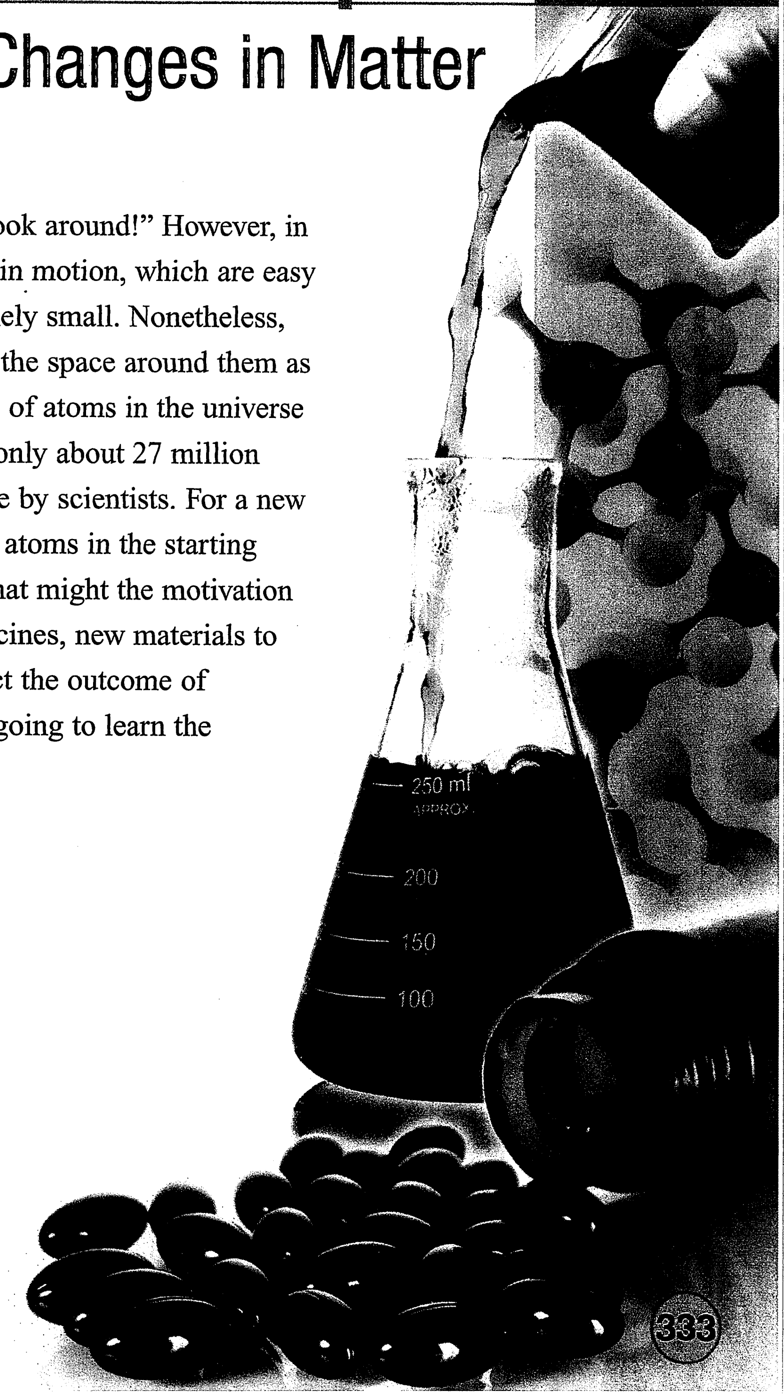
Changes in Matter



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.

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.

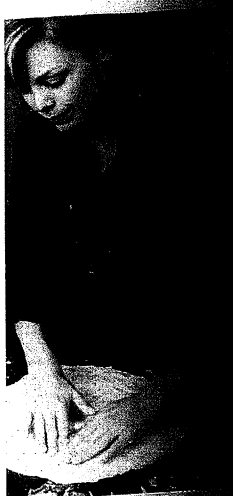
Figure 14.1: *This woman is ma[...] pizza from scratch. Here, she is preparing the dough. What part of making a pizza involves physical changes? What part of the process involves chemical changes?*

JOURNAL

Science in Your Mouth

Place a saltine cracker in your m[...] How does it taste? Hold it there [...] about 3 to 5 minutes. Now how d[...] taste? Is this evidence of a chem[...] or a physical change? Write do[...] what you observe and think.

t is a chemical reaction?



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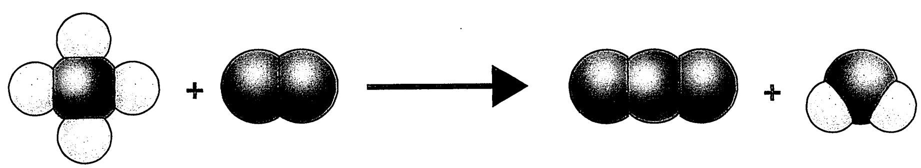
Chemical tion defined

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.

Substances that Change | **Substances that Are Formed**



$CH_4 + O_2 \rightarrow CO_2 + H_2O$

Methane (gas) + Oxygen (gas) → Carbon dioxide (gas) + Water (gas)

vidence 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.

JRNAL

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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.

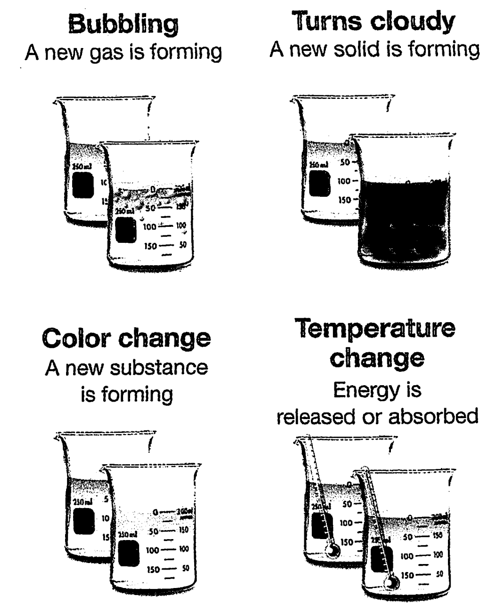


Figure 14.2: *These are all different kinds of evidence that a chemical reaction is occurring.*

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.

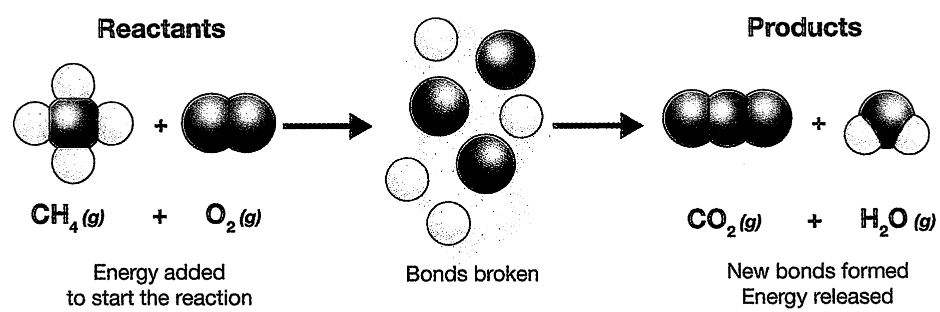
Reactants are chemically changed to form products

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.

Chemical Reaction



VOCABULARY

reactant - a starting ingredie... chemical reaction.

product - a new substance fo... in a chemical reaction.

Symbol	Meaning
(*s*)	substance is a so...
(*l*)	substance is a li...
(*g*)	substance is a g...
(*aq*)	substance is diss... in water (aqueo...

Figure 14.3: *Symbols used fo... of matter.*

SOLVE IT!

For the methane reaction, does t... number of atoms of the reactan... equal the number of atoms of th... products? Count and see. How ... you make the numbers match? ... In the next section, you'll find ou...

Law of conservation of mass

Burning wood is a chemical reaction

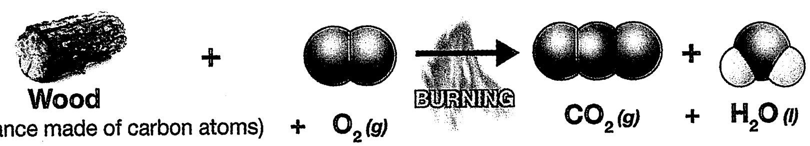
Have you ever wondered what happens to wood in a fireplace or campfire as it is burned? The burning of wood is a chemical reaction. By writing this reaction as a chemical equation, you can figure out what happened to the wood. It doesn't just disappear!

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?*

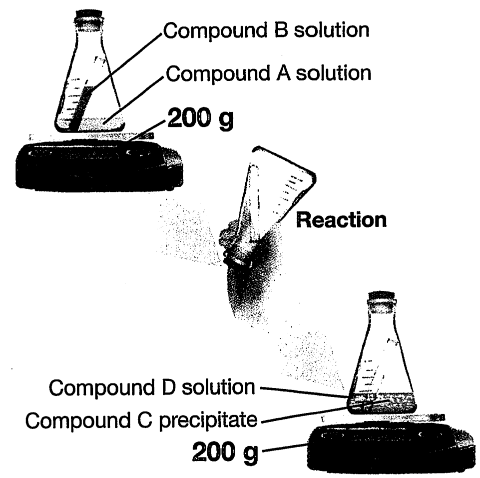


Figure 14.5: *A closed system illustrates the law of conservation of mass.*

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 reactio[n] using chemical formulas and symbols.

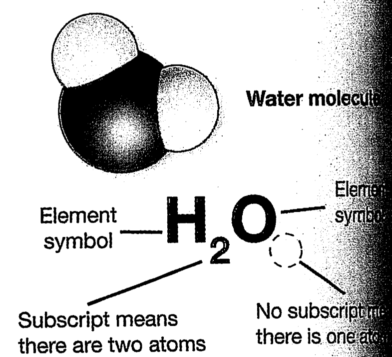


Figure 14.6: *The parts of a che[mical] formula.*

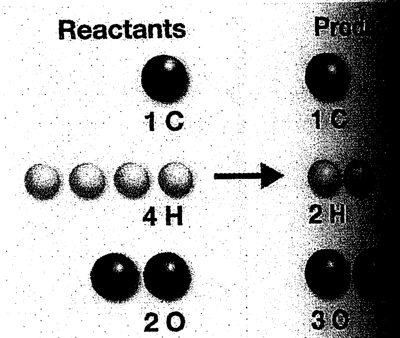


Figure 14.7: *This graphic illu[strates] that the number of oxygen and hy[drogen] atoms are not balanced for the m[ethane] reaction.*

…cing 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.

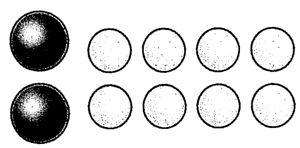
Adding coefficients

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.

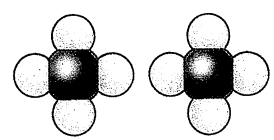
A coefficient of **2** in front of methane CH_4 gives you:

$2 \times CH_4$

$2 \times 1C = 2C$
$2 \times 4H = 8H$



2 carbon atoms and 8 hydrogen atoms



Enough carbon and hydrogen to make 2 molecules of methane

VOCABULARY

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

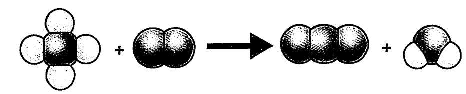


Figure 14.8: *Graphic of the unbalanced methane reaction.*

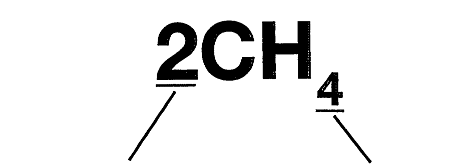
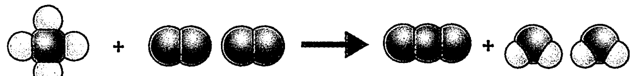


Figure 14.9: *What do coefficients and subscripts mean?*

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.



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

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 du… the process of balancing the equ… Changing the subscripts will cha… the chemical makeup of the compounds.
3. Numbers called **coefficients** are placed in front of the formulas to make the number of atoms on ea… 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 L…

a. balanced

b. balanced

c. unbalanced

d. unbalanced

e. balanced

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Key points for
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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): $Cu_2S + O_2 \rightarrow Cu_2O + SO_2$.

king for: Coefficients that will balance the chemical equation.

n: 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

tionships: 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.

tion: 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:

$Cu_2S + 2O_2 \rightarrow 2Cu_2O + SO_2$

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

Second try:

$2Cu_2S + 2O_2 \rightarrow 2Cu_2O + SO_2$

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:

$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$

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

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 Everywhe

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

Here are some simple examples

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

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

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

(4) Read the ingredients on labe Can you write the chemical form for any of the ingredients?

Types of Reactions

the products you use every day are the result of one or more chemical reactions. As you imagine, there are many possible chemical reactions. This section provides you with ation on how to classify the different types of chemical reactions.

hesis reactions

Making compounds In a **synthesis reaction**, two or more substances combine to form a new compound. A good example of a synthesis reaction is the formation of rust.

$$Fe\,(s) + O_2\,(g) \longrightarrow Fe_2O_3\,(s)$$

From this example, how might you describe the reaction in general terms? The answer to this question is below. In this general equation for a synthesis reaction and the other reactions in this section, A and B represent ions, atoms, or molecules.

$$A + B \longrightarrow AB$$

ymerization Recall that a *polymer* is a large molecule made up of repeating segments. **Polymerization**, or the formation of polymers, is a series of synthesis reactions taking place to produce a very large molecule. Polymers are made by joining smaller molecules called *monomers*.

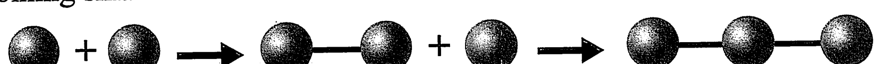


Table 14.1: Polymers

Common Polymers	Polymer Products
polystyrene	foam containers
polyethylene	food packaging
polyester	clothing
polyvinyl chloride	plumbing (PVC pipes)
polyvinyl acetate	chewing gum

VOCABULARY

synthesis reaction - a chemical reaction in which two or more substances combine to form a new compound.

polymerization - the formation of polymers by a series of synthesis reactions.

SCIENCE FACT

Synthesis Reactions and Acid Rain

Some fossil fuels, such as coal, contain sulfur. When these fuels are burned, the sulfur reacts with oxygen in the air to form sulfur dioxide in the following synthesis reaction:

$S\,(s) + O_2\,(g) \rightarrow SO_2\,(g)$

In air polluted with sulfur dioxide, acid rain is produced in the reaction below:

$SO_2\,(g) + H_2O_2\,(g) \rightarrow H_2SO_4\,(aq)$

H_2O_2 is hydrogen peroxide, a substance that is produced in clouds in a reaction between oxygen and water. H_2SO_4 is sulfuric acid.

Decomposition reactions

Breaking down compounds As you might suspect, chemical reactions are used to make compounds. However, a chemical reaction is also used to break down compounds. A chemical reaction in which a single compound is broken down to produce two or more smaller compounds is called a **decomposition reaction**. The general equation for decomposition is:

$$AB \xrightarrow{Energy} A + B$$

Energy is required In most cases, energy is required to get a decomposition reaction going. The most common form of energy used in these chemical reactions is heat. For example, the reaction below was involved in the discovery of oxygen. Heat was used in the decomposition of mercury (II) oxide.

$$2HgO\,(s) \xrightarrow{Heat} 2Hg\,(l) + O_2\,(g)$$

For the decomposition of water into hydrogen and oxygen, the energy source is electricity. In fact, this particular reaction, illustrated in Figure 14.13, is called *electrolysis*.

$$2H_2O\,(l) \xrightarrow{Electricity} 2H_2\,(g) + O_2\,(g)$$

The number of products formed The simplest kind of decomposition is the breakdown of a binary compound into its elements. However, larger compounds can also decompose to produce other compounds. The number of compounds that form as products in a decomposition reaction depends on the number of elements in the reactant compound. For example, baking soda ($NaHCO_3$) has four elements. When it undergoes a decomposition reaction with heat, three products form.

$$2NaHCO_3\,(s) \xrightarrow{Heat} 2CO_2\,(g) + H_2O\,(g) + Na_2O\,(s)$$

VOCABULARY

decomposition reaction - a chemical reaction in which a compound is broken down into two or more smaller substances.

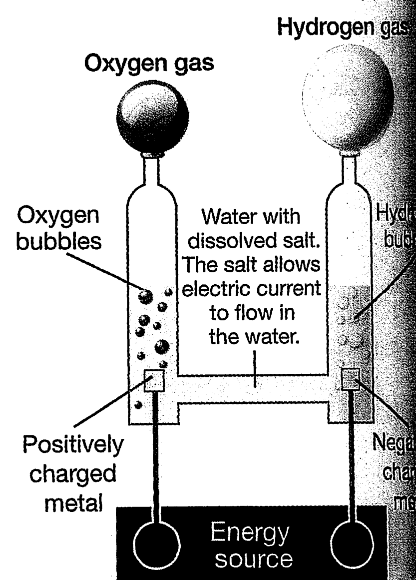


Figure 14.13: *A diagram of the experimental setup for performing the electrolysis of water. Why do you think the balloon for hydrogen gas is twice as big as the one for oxygen gas?*

lacement reactions

Single-displacement reactions

In a **single-displacement reaction**, one element replaces a similar element in a compound. For example, if you place an iron nail into a beaker of copper (II) chloride, you will begin to see reddish copper forming on the iron nail. In this reaction, iron replaces copper in the solution and the copper falls out of the solution onto the nail as a metal.

$$Fe_{(s)} + CuCl_2{}_{(aq)} \longrightarrow FeCl_2{}_{(aq)} + Cu_{(s)}$$

The general equation for a single-displacement reaction is:

$$A + BX \longrightarrow AX + B$$

In this equation, A and B are elements, and AX and BX are compounds.

Double-displacement reactions

In a **double-displacement reaction**, ions from two compounds in a solution exchange places to produce two new compounds. One of the compounds formed is usually a precipitate that settles out of the solution, a gas that bubbles out of the solution, or a molecular compound such as water. The other compound formed often remains dissolved in the solution. Precipitates are first recognizable by the cloudy appearance they give to a solution. A precipitate is the result of one of the products in a double-displacement reaction being insoluble in water (Figure 14.14). The term *insoluble* means that it does not dissolve. Depending on the compound formed, the precipitate can be many different colors from white to fluorescent yellow, as in the reaction between lead (II) nitrate and potassium iodide.

$$Pb(NO)_3{}_{(aq)} + 2KI_{(aq)} \longrightarrow PbI_2{}_{(s)} + 2KNO_3{}_{(aq)}$$

The general formula for a double-displacement reaction is give below. Each pairing of letters—AB and CD, and AD and CB—are ionic compounds in a solution.

$$AB + CD \longrightarrow AD + CB$$

VOCABULARY

single-displacement reaction - a chemical reaction in which one element replaces a similar element in a compound.

double-displacement reaction - a chemical reaction in which ions from two compounds in solution exchange places to produce two new compounds.

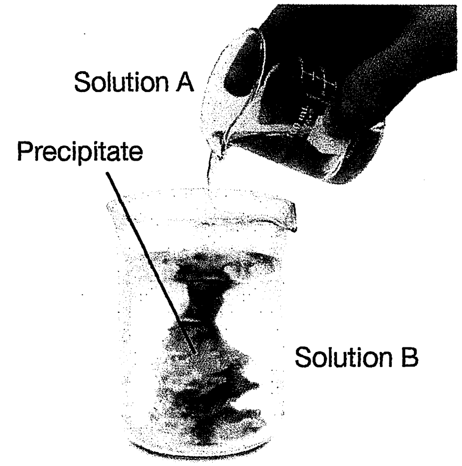


Figure 14.14: *The formation of a cloudy precipitate is evidence that a double-displacement reaction has occurred. If left undisturbed in a beaker, a precipitate will settle to the bottom. The precipitate in the image is potassium iodide.*

Combustion reactions

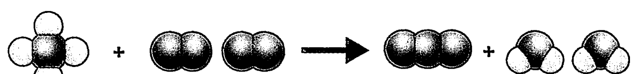
In a combustion reaction, energy is released

A **combustion reaction**, also called burning, occurs when a substance, such as wood, natural gas, or propane combines with oxygen and releases a large amount of energy in the form of light and heat. The products of this kind of combustion reaction are carbon dioxide and water. What do reactants such as wood, natural gas, and propane have in common? The answer is that they are all carbon compounds. Following is the general equation for a combustion reaction.

$$\text{Carbon Compound} + O_2(g) \longrightarrow CO_2(g) + H_2O(g)$$

Carbon compounds

The methane reaction, which you have seen before, is a good example of a combustion reaction. As you can see, a carbon compound is a mixture of carbon and hydrogen atoms. The general formula for a carbon compound is C_xH_y where x and y represent different subscripts. Examples of carbon compounds can be found in Figure 14.15.



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

Another kind of combustion reaction

Not all combustion reactions use carbon compounds as a reactant. These types of combustion reactions do not produce carbon dioxide. For example, when hydrogen gas is burned in oxygen, water is the only product.

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$$

The value of an alternative combustion reaction

Perhaps in the future some of our cars will run by the reaction above. Instead of using gasoline, which is a mixture of carbon compounds, cars might run on hydrogen. Currently, automobile manufacturers are developing technologies that utilize hydrogen combustion in the internal combustion engines of cars. Another way hydrogen can be used to power cars is in an electrochemical process that uses a fuel cell. In either case, the use of hydrogen fuel could help reduce the amount of carbon dioxide emissions related to transportation. However, it would still take energy, sometimes in the form of fossil fuels, to make the hydrogen fuel. What do you think? Should hydrogen technologies be developed for cars?

VOCABULARY

combustion reaction - a chemical reaction that results in a large amount of energy being released when a carbon compound combines with oxygen.

Carbon Compound	Chemical Formula
methane	CH_4
ethane	C_2H_6
propane	C_3H_8
butane	C_4H_{10}
pentane	C_5H_{12}
hexane	C_6H_{14}
heptane	C_7H_{16}
octane	C_8H_{18}

Figure 14.15: *Examples of carbon compounds.*

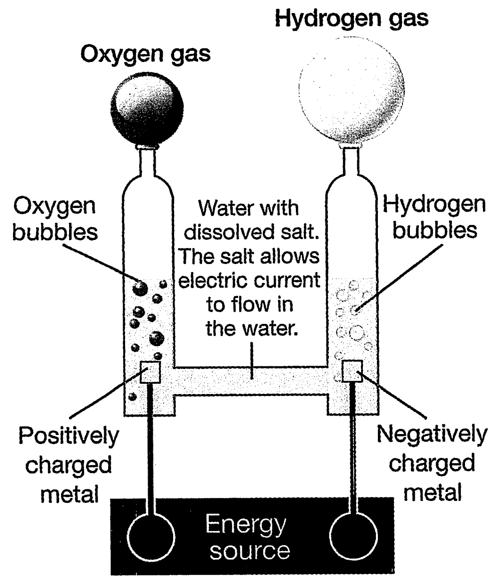
CHALLENGE

Hydrogen Technology

In the text, you learned about two forms of hydrogen technology used in running an automobile. Find out more about each one. Is hydrogen fuel a viable alternative to fossil fuels?

Section 14.2 Review

1. Why is polymerization a type of synthesis reaction?
2. You have learned about the different kinds of chemical reactions. Come up with a set of simple rules that you can use to help you identify each kind of chemical reaction. There are no right or wrong answers. Write rules that make sense to you.
3. The graphic at the right shows the electrolysis of water.
   a. Come up with an explanation for why oxygen forms near the positively charged metal and hydrogen forms near the negatively charged metal.
   b. Why is a greater amount of hydrogen gas collected in this reaction?
   c. Is this reaction occurring in a closed container? Justify your answer.



4. How does the involvement of energy in a decomposition reaction compare to how energy is involved in a combustion reaction?
5. Compare and contrast single-displacement and double-displacement reactions.
6. Identify the following reactions as synthesis, decomposition, single or double displacement, or combustion.
   a. $N_2\,(g) + 3H_2\,(g) \rightarrow 2NH_3\,(g)$
   b. $NH_4NO_3\,(s) \rightarrow N_2O\,(g) + 2H_2O\,(g)$
   c. $AgNO_3\,(aq) + NaCl\,(aq) \rightarrow AgCl\,(s) + NaNO_3\,(aq)$
   d. $Fe\,(s) + H_2SO_4\,(aq) \rightarrow H_2\,(g) + FeSO_4\,(aq)$

BIOGRAPHY

George Washington Carver

Tuskegee University Archives/Museum

George Washington Carver was born around 1864 in Missouri toward the end of the Civil War. George and his mother, a slave for Moses and Susan Carver, were kidnapped when he was an infant. Only George was found and returned to the Carvers who then raised him. Due to frail health, he spent a lot of time exploring nature and developed his talent for studying plants. He pursued plant studies in school and earned an agricultural degree from Iowa State College. He became the first African-American faculty member at the college and earned his master's degree two years later. Soon afterward, Booker T. Washington, founder of Tuskegee Institute in Alabama, recruited Carver to lead the agricultural department. There, Carver taught students and local farmers to rotate crops annually to enrich the soil. Benefits included improving the cotton crop and adding new cash crops such as peanuts and sweet potatoes. Carver is especially known for compiling a list of products and recipes that utilized the peanut plant. His many achievements include conducting research on soy as a possible biofuel, displaying artwork at the 1893 World's Fair, and meeting with three American presidents.

14.3 Energy and Chemical Reactions

All chemical reactions involve energy. If you have ever sat near a campfire, you have experienced this energy as heat and light. In addition to producing energy, chemical reactions also *use* energy. For example, plants perform photosynthesis, which is a chemical reaction that uses energy from sunlight.

VOCABULARY

exothermic - describes a chemical reaction that releases more energy than it uses.

endothermic - describes a chemical reaction that uses more energy than it releases.

Exothermic and endothermic reactions

Energy is involved in two ways

Energy is involved in chemical reactions in two ways: (1) At the start of a chemical reaction, energy is used to break some (or all) bonds between atoms in the reactants so that the atoms are available to form new bonds; and (2) Energy is released when new bonds form as the atoms recombine into the new compounds of the products. We classify chemical reactions based on how the energy used in (1) compares to the energy released in (2).

Exothermic reactions

If forming new bonds releases *more* energy than it takes to break the old bonds, the reaction is **exothermic** (Figure 14.16, top). Once started, exothermic reactions tend to keep going because each reaction releases enough energy to start the reaction in neighboring molecules. A good example is the reaction of hydrogen with oxygen. If we include energy, the balanced reaction looks like this:

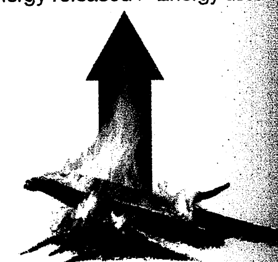
$$\underset{\text{Oxygen}}{O_2(g)} + \underset{\text{Hydrogen}}{2H_2(g)} \longrightarrow \underset{\text{Water}}{2H_2O(l)} + \textit{Energy}$$

Endothermic reactions

If forming new bonds in the products releases *less* energy than it took to break the original bonds in the reactants, the reaction is **endothermic** (Figure 14.16, bottom). Endothermic reactions absorb energy. In fact, endothermic reactions need more energy to keep going. An example of an important endothermic reaction is *photosynthesis*. In photosynthesis, plants use energy from sunlight to make glucose and oxygen from carbon dioxide and water. If we include energy, the balance formula looks like this:

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} + \textit{Energy} \longrightarrow \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Exothermic
Energy released > Energy used



Endothermic
Energy used > Energy released

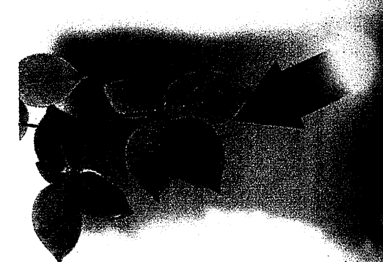


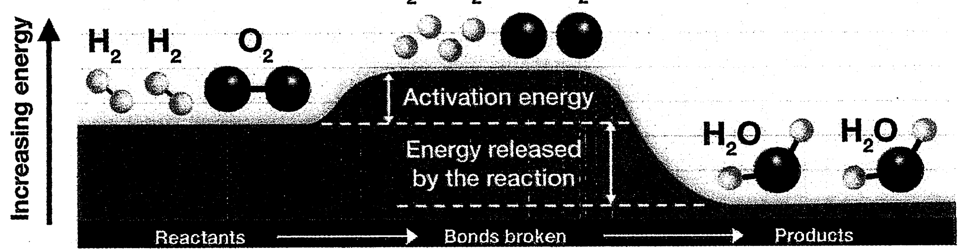
Figure 14.16: *Exothermic and endothermic reactions.*

Activation energy

An interesting question Exothermic reactions occur because the atoms arranged as compounds of the products have lower energy and are more stable than they are when arranged as compounds of the reactants. Chemical reactions—like other systems—move toward more stable circumstances. If this is true, why don't all the elements combine into the molecules that have the lowest possible energy?

Activation energy The answer has to do with **activation energy**, which is the energy needed to begin a reaction and break chemical bonds in the reactants. Without enough activation energy, a reaction will not happen even if it is exothermic. That is why a flammable material such as gasoline does not burn without a spark or flame. The spark supplies the activation energy to start the reaction.

Reaction: $2H_2 + O_2 \rightarrow 2H_2O$ + *energy*



An example of a reaction The diagram above shows how the energy flows in the reaction of hydrogen and oxygen. The activation energy must be supplied to break the molecules of hydrogen and oxygen apart. Energy is then released when the four free hydrogen and two free oxygen atoms combine to form two water molecules. The reaction is exothermic because the energy released by forming water is greater than the activation energy. Once the reaction starts, it supplies its own activation energy and quickly grows (Figure 14.17).

Reactions occur only when conditions are right A reaction begins by itself when thermal energy is greater than the activation energy. However, any reaction that could start by itself probably already has! The compounds and molecules in substances around you need more activation energy to change into anything else. For example, table salt in a dish will remain table salt for a long time unless the conditions change to cause a chemical reaction between the salt and another compound.

VOCABULARY

activation energy - energy needed to break chemical bonds in the reactants to start a reaction.

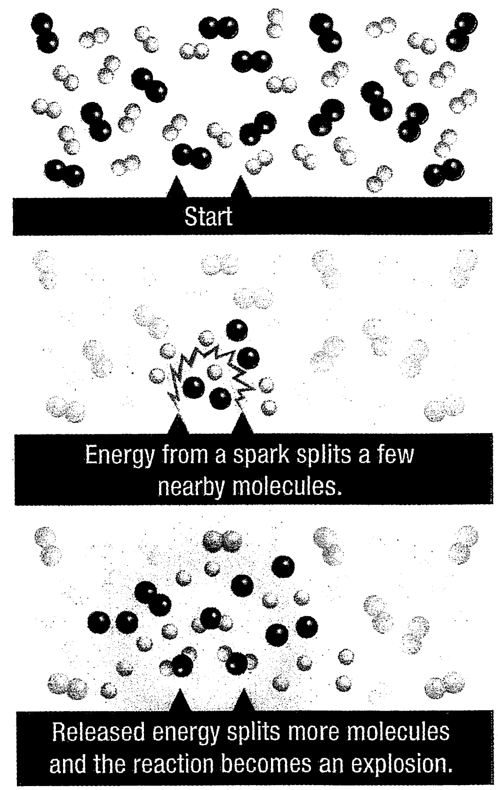


Figure 14.17: *Because energy released by one reaction supplies activation energy for new reactions, exothermic reactions can grow quickly once activation energy has been supplied.*

Examples of endothermic reactions

Endothermic reactions in industry

It's certainly useful when chemical reactions *produce* more energy than they use. But how do we benefit from reactions that *use* more energy than they produce? It turns out that most of the reactions used in industry to produce useful materials require more energy than they produce. This is one of the reasons sources of energy are so important to industry. In other words, exothermic reactions are needed to cause endothermic reactions to run. One example of an industry process that frequently uses endothermic reactions is the refining of ores to produce useful metals. Here is a specific example, the refinement of aluminum ore from aluminum oxide.

$$2Al_2O_3(s) + \textit{Energy} \longrightarrow 4Al(s) + 3O_2(g)$$

This reaction requires the input of energy because it takes more energy to break the bonds in the aluminum oxide than is released when the products are formed.

Cold packs

Have you ever used an instant cold pack as a treatment for a twisted ankle or a bruise? These products, found in your local drugstore, work by using an endothermic chemical reaction. The fact that more energy is used than produced is what makes the cold pack cold. The reaction, shown below, works as follows. The product usually comes in a plastic bag. Inside of the bag is a sealed packet of water surrounded by crystals of ammonium nitrate. To activate the cold pack, you squeeze the plastic bag to break the packet of water. When the water contacts the ammonium nitrate crystals, a reaction occurs and the pack becomes icy cold (Figure 14.18).

$$NH_4NO_3(s) + H_2O(l) + \textit{Energy} \longrightarrow NH_4^+(aq) + NO_3^-(aq)$$

Dissolution reactions

The ice pack gets very cold because it takes energy to dissolve the ionic bonds in the ammonium nitrate. Besides being endothermic, this reaction is also a dissolution reaction. A **dissolution reaction** occurs when an ionic compound, such as ammonium nitrate, dissolves in water to make an ionic solution. In the cold pack reaction, the ions are ammonium (NH_4^+) and nitrate (NO_3^-).

VOCABULARY

dissolution reaction - an endothermic reaction that occurs when an ionic compound dissolve water to make an ionic solution.

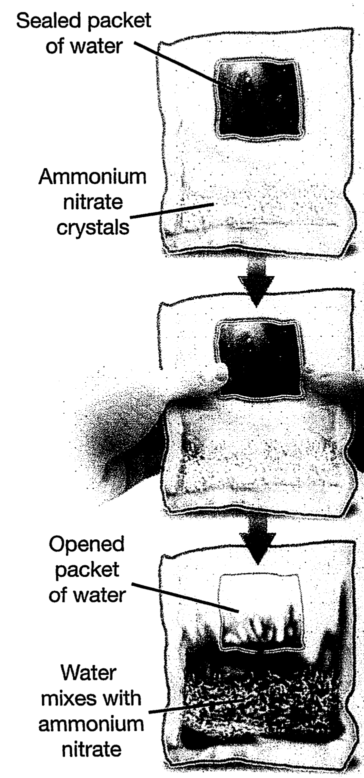


Figure 14.18: *A cold pack works because of an endothermic reaction*

ction rate

Kinetic molecular theory

at is reaction rate?

Increasing collisions

Increasing entration of reactants

alysts and inhibitors

ULARY

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ion that occu
ıpound disso
ionic solution

A cold pack wor
othermic reaction

ion rate

Kinetic molecular theory In all phases of matter, atoms and molecules exhibit random motion. This concept is part of the kinetic molecular theory. The speed at which atoms or molecules move depends on the state of matter and the temperature. As you know, gas molecules move faster than molecules in a solid, and warmer substances have greater molecular motion than cold ones.

at is reaction rate? The **reaction rate** for a chemical reaction is the change in concentration of reactants or products over time. For a reaction involving two or more reactants, the reaction only works if the molecules collide. If we want the reaction to go faster, what kinds of things could we do to increase the motion and number of collisions among the reactants?

Increasing collisions For starters, you can add heat to a reaction to increase molecular motion. For example, to dissolve salt faster in water in a dissolution reaction, you increase the temperature of the water. Other ways to increase collisions include stirring the reaction mixture and using powdered reactants. Fine particles in powders have more available surface area for reacting.

Increasing entration of reactants Another way to increase collisions among atoms or molecules is to increase the concentration of the reactants. When you increase the concentration of a reactant, it is like adding an extra team member to complete a project. If the project involved many calculations, the team could complete them more quickly with six people than with five. As you know, doing calculations by hand takes a while. What if the team had a computer or calculator?

atalysts and inhibitors A **catalyst** is a molecule that can be added to a reaction to speed it up, but it doesn't get used up. A catalyst is a little like using a computer or a calculator to help you speed up the job of making calculations. Catalysts work by increasing the chances that two molecules will be positioned in the right way for a reaction to occur. Because a catalyst ensures the correct orientation of colliding molecules, less energy is needed in the collision for the reaction to occur. In effect, a catalyst provides a "shortcut" because a lower activation energy is needed for a reaction to proceed (Figure 14.19). Reactions can also be slowed down by molecules called **inhibitors**. Inhibitors bind with reactant molecules and effectively block them from combining to form products.

VOCABULARY

reaction rate - the change in concentration of reactants or products in a chemical reaction over time.

catalyst - a molecule added to a chemical reaction that increases the reaction rate without getting used up in the process.

inhibitor - a molecule that slows down a chemical reaction.

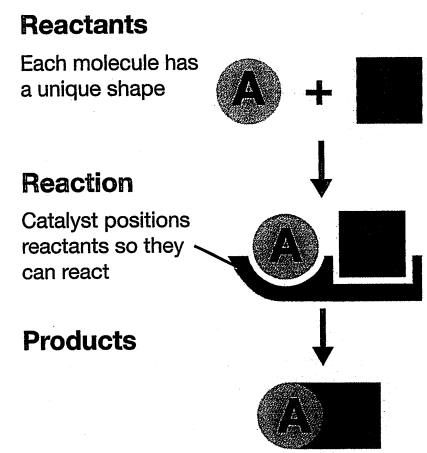

Figure 14.19: *By bringing together reactants, a catalyst lowers the activation energy needed.*

Chemical equilibrium

The direction of a chemical reaction Up until now, we have thought about chemical reactions as going in only one direction. Reactants react to make products. This has been shown in chemical equations with a right-pointing arrow that points toward the products of the reaction. Therefore, chemical reactions are commonly described as proceeding to the right. In some cases, once a reaction goes to the right, the reaction reverses and goes to the left. The products become reactants and the reactants become products (Figure 14.20).

Chemical equilibrium Eventually, a reaction might reach **chemical equilibrium**, the state in which the rate of the forward reaction equals the rate of the reverse reaction. When we talk about chemical equilibrium, we acknowledge that the reaction can go left and right simultaneously. Chemical equilibrium is represented by arrows going both ways, or a double-headed arrow (Figure 14.20).

Characteristics of chemical equilibrium Because chemical reactions are often open systems, the reactants and products can easily react with other compounds. If this happens, the products cannot revert back to reactants because they are unavailable. A gas that is a product, for example, easily leaves the reaction system. Therefore, for chemical equilibrium to be established, the chemical reaction has to occur in a closed system. When a chemical reaction occurs in a closed system at a constant temperature, the forward and reverse reactions occur at the same rate, and the amounts of reactants and products are constant.

An advanced topic: Le Chatelier's principle Let's say you have a chemical reaction at chemical equilibrium in a closed container in your laboratory. You leave the system alone but someone turns up the heat by accident and the room you are in gets hotter and hotter. What happens to the chemical reaction in the container? A change in temperature is considered to be a stress on the system. In response to this stress, the system reacts until chemical equilibrium is reestablished. This phenomenon is called *Le Chatelier's principle*. This principle states that a chemical reaction at chemical equilibrium reacts to any stress on the system until equilibrium is re-established. A stress could include increasing the concentration of a reactant or product, or changing the temperature or pressure conditions of the reaction.

VOCABULARY

chemical equilibrium - the state in a chemical reaction at which the rate of the forward reaction equals the rate of the reverse reaction.

A reaction going to the right

Reactants $\longrightarrow$ **Products**

A + B $\longrightarrow$ **AB**

A reaction going to the left

Products $\longleftarrow$ **Reactants**

A + B $\longleftarrow$ **AB**

Chemical equilibrium

Products $\longleftrightarrow$ **Reactants**

A + B $\longleftrightarrow$ **AB**

Figure 14.20: *The direction of a reaction is indicated with an arrow. When a reaction is in chemical equilibrium, a double-headed arrow is used.*

BULARY
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Section 14.3 Review

1. List the two ways that energy is involved in chemical reactions.
2. Identify the following statements as describing either an exothermic or an endothermic reaction.
   a. More energy is released than is used by the reaction.
   b. The chemical reaction involved in burning wood
   c. Less energy is released than is used by the reaction.
3. Why is a spark of energy required to begin the chemical reaction of burning a fossil fuel? What is another name for this spark of energy?
4. The reaction below is an exothermic reaction.
   $K_2O\ (s) + CO_2\ (g) \rightarrow K_2CO_3\ (s)$
   a. Rewrite this reaction and add "+ energy" in the correct location.
   b. Describe how the energy level of the reactants compares to the energy level of the products.
5. The reaction below is an endothermic reaction.
   $2HgO\ (s) \rightarrow 2Hg\ (l) + O_2\ (g)$
   a. Rewrite this reaction and add "+ energy" in the correct location.
   b. Describe how the energy level of the reactants compares to the energy level of the products.

14.2: *A Review of the Factors Affecting Reaction Rate*

Action	Do collisions increase?	Does the energy of the collisions increase?
Stirring	Yes	No
sing temperature	Yes	Yes
sing surface area	Yes	No
sing concentration	Yes	No
ding a catalyst	Improves the effectiveness of collisions so less energy is needed for a reaction	
ing an inhibitor	Prevents or diminishes the effectiveness of collisions so more energy is needed for a reaction	

SCIENCE FACT

Many reactions in the human body require enzymes, a kind of catalyst, to get reactions going. Not surprisingly, the temperature of the human body, 37°C or 98°F, is ideal for enzymes to work well.

Getting a mild fever indicates that you might be sick. However, you are dangerously ill if you have a high fever for too long. Based on the information above, what might be a consequence of having a high fever in terms of how your body works?

CHALLENGE

Table 14.2 organizes information related to the factors affecting reaction rate.

(1) List the two most effective factors in increasing reaction rate. Explain your choices.

(2) What is the most effective way to slow down a reaction rate? Explain your choice.

(3) Would stirring affect a chemical reaction that has chemical equilibrium? Explain your answer.