SECTION 1

READING WARM-UP

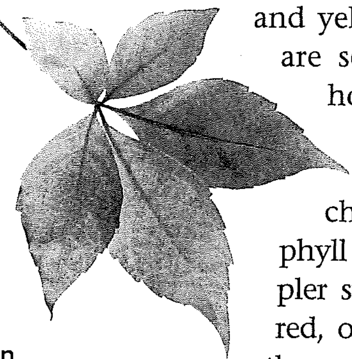
# Forming New Substances

### *Terms to Learn*

chemical reaction
chemical formula
chemical equation
reactants
products
law of conservation of mass

### *What You'll Do*

- Identify the clues that indicate a chemical reaction might be taking place.
- Interpret and write simple chemical formulas.
- Interpret and write simple balanced chemical equations.
- Explain how a balanced equation illustrates the law of conservation of mass.



Each fall, an amazing transformation takes place. Leaves change color, as shown in **Figure 1.** Vibrant reds, oranges, and yellows that had been hidden by green all year are seen as the temperatures get cooler and the hours of sunlight become fewer. What is happening to cause this change? Leaves have a green color as a result of a compound called chlorophyll (KLOR uh FIL). Each fall, the chlorophyll undergoes a chemical change and forms simpler substances that have no color. You can see the red, orange, and yellow colors in the leaves because the green color of the chlorophyll no longer hides them.

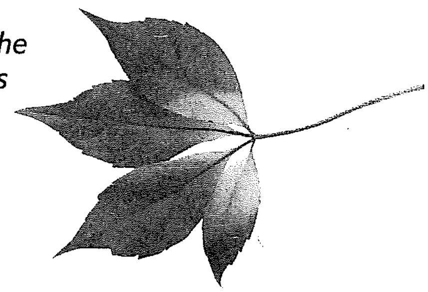
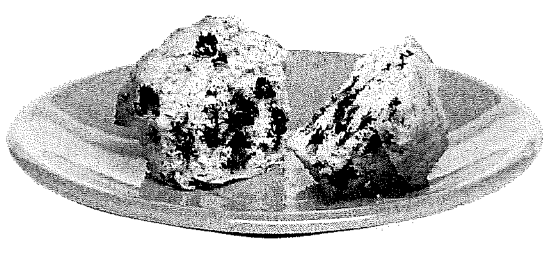


**Figure 1** *The change of color in the fall is a result of chemical changes in the leaves.*

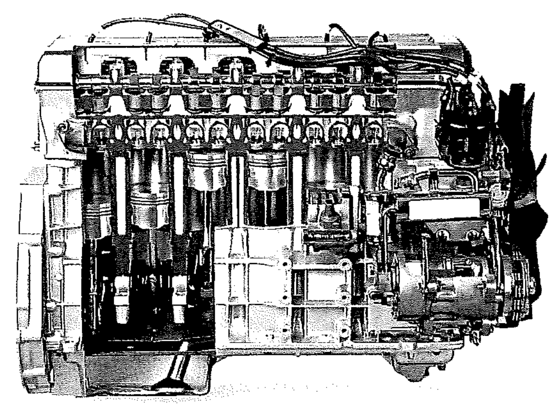
## Chemical Reactions

The chemical change that occurs as chlorophyll breaks down into simpler substances is one example of a chemical reaction. A **chemical reaction** is the process by which one or more substances undergo change to produce one or more different substances. These new substances have different chemical and physical properties from the original substances. Many of the changes you are familiar with are chemical reactions, including the ones shown in **Figure 2.**

**Figure 2 Examples of Chemical Reactions**



The substances that make up baking powder undergo a chemical reaction when mixed with water. One new substance that forms is carbon dioxide gas, which causes the bubbles in this muffin.



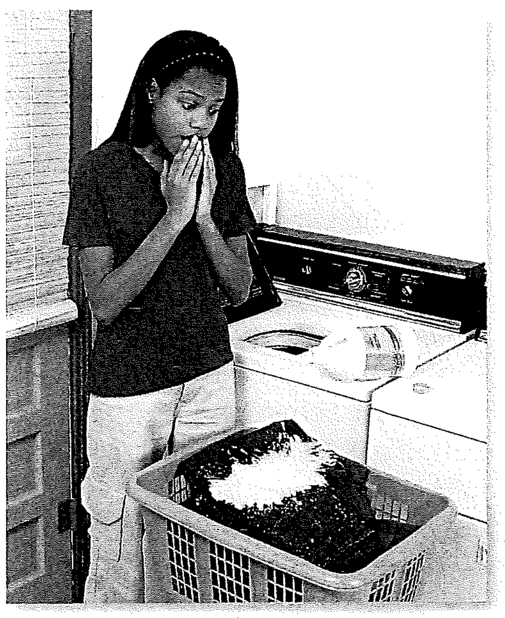
Once ignited, gasoline reacts with oxygen gas in the air. The new substances that form, carbon dioxide and water, push against the pistons in the engine to keep the car moving.

**Clues to Chemical Reactions** How can you tell when a chemical reaction is taking place? There are several clues that indicate when a reaction might be occurring. The more of these clues you observe, the more likely it is that the change is a chemical reaction. Several of these clues are described below.

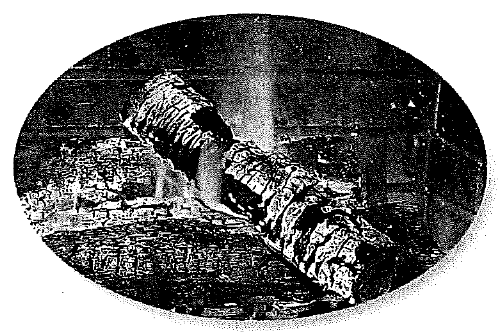
## Some Clues to Chemical Reactions

**Gas Formation**
The formation of gas bubbles is a clue that a chemical reaction might be taking place. For example, bubbles of carbon dioxide are produced when hydrochloric acid is placed on a piece of limestone.

**Solid Formation**
A solid formed in a solution as a result of a chemical reaction is called a *precipitate* (pruh SIP uh TAYT). Here you see potassium chromate solution being added to a silver nitrate solution. The dark red solid is a precipitate of silver chromate.



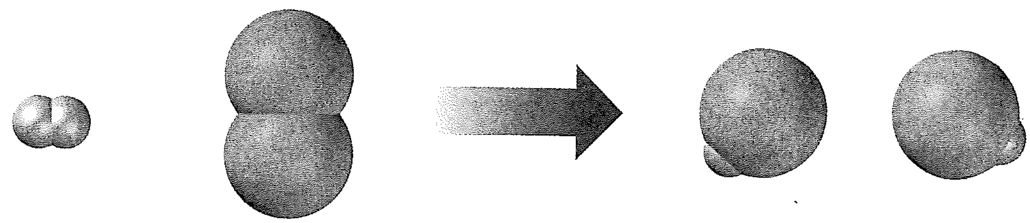
**Color Change**
Chlorine bleach is great for removing the color from stains on white clothes. But don't spill it on your jeans. The bleach reacts with the blue dye on the fabric, causing the color of the material to change.



**Energy Change**
Energy is released during some chemical reactions. A fire heats a room and provides light. Electrical energy is released when chemicals in a battery react. During some other chemical reactions, energy is absorbed. Chemicals on photographic film react when they absorb energy from light shining on the film.

**Breaking and Making Bonds** New substances are formed in a chemical reaction because chemical bonds in the starting substances break, atoms rearrange, and new bonds form to make the new substances. Look at the model in **Figure 3** to understand how this process occurs.

**Figure 3**
**Reaction of Hydrogen and Chlorine**



**Breaking Bonds** The elements hydrogen and chlorine are diatomic, meaning they are composed of molecules that consist of two atoms bonded together. For these molecules to react, the bonds joining the atoms must break.

**Making Bonds** Molecules of the new substance, hydrogen chloride, are formed as new bonds are made between hydrogen atoms and chlorine atoms.

## Chemical Formulas

Remember that a chemical symbol is a shorthand method of identifying an element. A **chemical formula** is a shorthand notation for a compound or a diatomic element using chemical symbols and numbers. A chemical formula indicates the chemical makeup by showing how many of each kind of atom is present in a molecule.

The chemical formula for water, $H_2O$, tells you that a water molecule is composed of two atoms of hydrogen and one atom of oxygen. The small number *2* in the formula is a subscript. A *subscript* is a number written below and to the right of a chemical symbol in a formula. When no subscript is written after a symbol, as with the oxygen in water's formula, only one atom of that element is present. **Figure 4** shows two more chemical formulas and what they mean.

**Figure 4** *A chemical formula shows the number of atoms of each element present.*

$$O_2$$

**Oxygen** is a diatomic element. Each molecule of oxygen gas is composed of two atoms of oxygen bonded together.

$$C_6H_{12}O_6$$

Every molecule of **glucose** (the sugar formed by plants during photosynthesis) is composed of six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen.

### MATH BREAK

**Counting Atoms**

Some chemical formulas contain two or more chemical symbols enclosed by parentheses. When counting atoms in these formulas, multiply everything inside the parentheses by the subscript as though they were part of a mathematical equation. For example, $Ca(NO_3)_2$ contains:

- 1 calcium atom
- 2 nitrogen atoms (2 × 1)
- 6 oxygen atoms (2 × 3)

**Now It's Your Turn**

Determine the number of atoms of each element in the formulas $Mg(OH)_2$ and $Al_2(SO_4)_3$.

**Writing Formulas for Covalent Compounds** You can often write a chemical formula if you know the name of the substance. Remember that covalent compounds are usually composed of two nonmetals. The names of covalent compounds use prefixes to tell you how many atoms of each element are in the formula. A *prefix* is a syllable or syllables joined to the beginning of a word. Each prefix used in a chemical name represents a number, as shown in the table at right. **Figure 5** demonstrates how to write a chemical formula from the name of a covalent compound.

**Prefixes Used in Chemical Names**

| | | | |
|---|---|---|---|
| *mono-* | 1 | *hexa-* | 6 |
| *di-* | 2 | *hepta-* | 7 |
| *tri-* | 3 | *octa-* | 8 |
| *tetra-* | 4 | *nona-* | 9 |
| *penta-* | 5 | *deca-* | 10 |

**Carbon dioxide**

$$CO_2$$

The ***lack of a prefix*** indicates 1 carbon atom.

The prefix ***di-*** indicates 2 oxygen atoms.

**Dinitrogen monoxide**

$$N_2O$$

The prefix ***di-*** indicates 2 nitrogen atoms.

The prefix ***mono-*** indicates 1 oxygen atom.

**Figure 5** *The formulas of these covalent compounds can be written using the prefixes in their names.*

## Self-Check

How many atoms of each element make up $Na_2SO_4$?
*(See page 136 to check your answer.)*

**Writing Formulas for Ionic Compounds** If the name of a compound contains the name of a metal and a nonmetal, the compound is probably ionic. To write the formula for an ionic compound, you must make sure the compound's overall charge is zero. In other words, the formula must have subscripts that cause the charges of the ions to cancel out. (Remember that the charge of many ions can be determined by looking at the periodic table.) **Figure 6** demonstrates how to write a chemical formula from the name of an ionic compound.

**Figure 6** *The formula of an ionic compound is written by using enough of each ion so the overall charge is zero.*

**Sodium chloride**

$$NaCl$$

A sodium ion has a **1+ charge.**

A chloride ion has a **1− charge.**

One sodium ion and one chloride ion have an overall **charge of $(1+) + (1-) = 0$**

**Magnesium chloride**

$$MgCl_2$$

A magnesium ion has a **2+ charge.**

A chloride ion has a **1− charge.**

One magnesium ion and two chloride ions have an overall **charge of $(2+) + 2(1-) = 0$**

## Chemical Equations

A composer writing a piece of music, like the one in **Figure 7,** must communicate to the musician what notes to play, how long to play each note, and in what style each note should be played. The composer does not use words to describe what must happen. Instead, he or she uses musical symbols to communicate in a way that can be easily understood by anyone in the world who can read music.

Similarly, people who work with chemical reactions need to communicate information about reactions clearly to other people throughout the world. Describing reactions using long descriptive sentences would require translations into other languages. Chemists have developed a method of describing reactions that is short and easily understood by anyone in the world who understands chemical formulas. A **chemical equation** is a shorthand description of a chemical reaction using chemical formulas and symbols. Because each element's chemical symbol is understood around the world, a chemical equation needs no translation.

**Figure 7** *The symbols on this music are understood around the world—just like chemical symbols!*

**Reactants Yield Products** Consider the example of carbon reacting with oxygen to yield carbon dioxide, as shown in **Figure 8.** The starting materials in a chemical reaction are **reactants** (ree AKT uhnts). The substances formed from a reaction are **products.** In this example, carbon and oxygen are reactants, and carbon dioxide is the product formed. The parts of the chemical equation for this reaction are described in **Figure 9.**

**Figure 8** *Charcoal is used to cook food on a barbecue. When carbon in charcoal reacts with oxygen in the air, the primary product is carbon dioxide.*

**Figure 9 The Parts of a Chemical Equation**

The formulas of the **reactants** are written before the arrow.

The formulas of the **products** are written after the arrow.

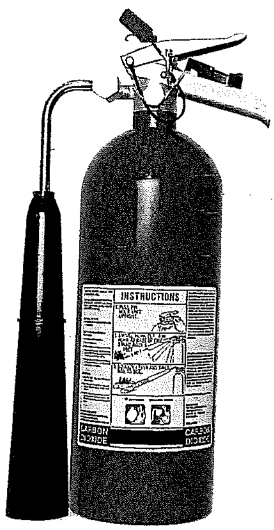
$$C + O_2 \rightarrow CO_2$$

A **plus sign** separates the formulas of two or more reactants or products from one another.

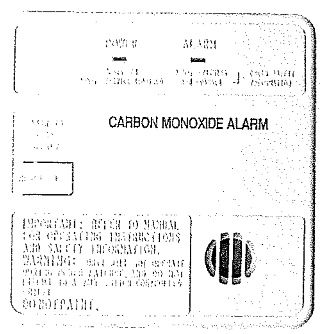
The **arrow,** also called the yields sign, separates the formulas of the reactants from the formulas of the products.

**Accuracy Is Important** The symbol or formula for each substance in the reaction must be written correctly. For a compound, determine if it is covalent or ionic, and write the appropriate formula. For an element, use the proper chemical symbol, and be sure to use a subscript of 2 for the diatomic elements. (The seven diatomic elements are hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine.) An equation with an incorrect chemical symbol or formula will not accurately describe the reaction. In fact, even a simple mistake can make a huge difference, as shown in **Figure 10.**

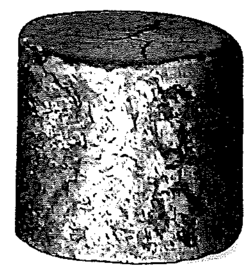
**Figure 10** *The symbols and formulas shown here are similar, but don't confuse them while writing an equation!*




The chemical formula for the compound carbon dioxide is **$CO_2$.** Carbon dioxide is a colorless, odorless gas that you exhale.




The chemical formula for the compound carbon monoxide is **CO.** Carbon monoxide is a colorless, odorless, poisonous gas.



The chemical symbol for the element cobalt is **Co.** Cobalt is a hard, bluish gray metal.

## Self-Check

When calcium bromide reacts with chlorine, bromine and calcium chloride are produced. Write an equation to describe this reaction. Identify each substance as either a reactant or a product. *(See page 136 to check your answers.)*

**An Equation Must Be Balanced** In a chemical reaction, every atom in the reactants becomes part of the products. Atoms are never lost or gained in a chemical reaction. When writing a chemical equation, you must show that the number of atoms of each element in the reactants equals the number of atoms of those elements in the products by writing a balanced equation.

## BRAIN FOOD

Hydrogen gas, $H_2$, is an important fuel that may help reduce air pollution. Because water is the only product formed as hydrogen burns, there is little air pollution from vehicles that use hydrogen as fuel.

## MATH BREAK

### Balancing Act

When balancing a chemical equation, you must place coefficients in front of an entire chemical formula, never in the middle of a formula. Notice where the coefficients are in the balanced equation below:

$$F_2 + 2KCl \rightarrow 2KF + Cl_2$$

### Now It's Your Turn

Write balanced equations for the following:

$$HCl + Na_2S \rightarrow H_2S + NaCl$$
$$Al + Cl_2 \rightarrow AlCl_3$$

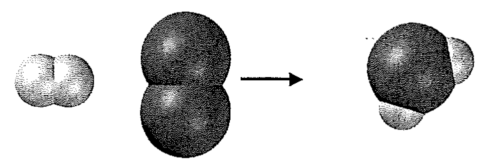
**How to Balance an Equation** Writing a balanced equation requires the use of coefficients (KOH uh FISH uhnts). A *coefficient* is a number placed in front of a chemical symbol or formula. When counting atoms, you multiply a coefficient by the subscript of each of the elements in the formula that follows it. Thus, $2CO_2$ represents 2 carbon dioxide molecules. Together the two molecules contain a total of 2 carbon atoms and 4 oxygen atoms. Coefficients are used when balancing equations because the subscripts in the formulas cannot be changed. Changing a subscript changes the formula so that it no longer represents the correct substance. Study **Figure 11** to see how to use coefficients to balance an equation. Then you can practice balancing equations by doing the MathBreak at left.

**Figure 11** *Follow these steps to write a balanced equation for $H_2 + O_2 \rightarrow H_2O$.*

**1** **Count the atoms** of each element in the reactants and in the products. You can see that there are fewer oxygen atoms in the products than in the reactants.

$H_2 + O_2 \rightarrow H_2O$

**Reactants** **Products**

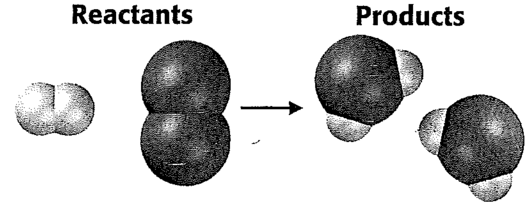


H = 2 O = 2 → H = 2, O = 1

**2** **To balance the oxygen atoms,** place the coefficient *2* in front of water's formula. This gives you 2 oxygen atoms in both the reactants and the products. But now there are too few hydrogen atoms in the reactants.

$H_2 + O_2 \rightarrow 2H_2O$

**Reactants** **Products**

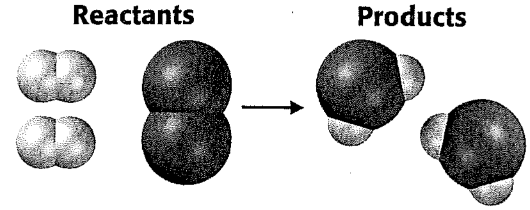


H = 2 O = 2 → H = 4, O = 2

**3** **To balance the hydrogen atoms,** place the coefficient *2* in front of hydrogen's formula. But just to be sure your answer is correct, always double-check your work!

$2H_2 + O_2 \rightarrow 2H_2O$

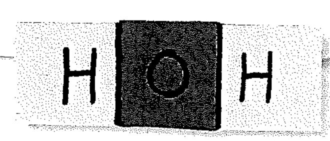
**Reactants** **Products**



H = 4 O = 2 → H = 4, O = 2

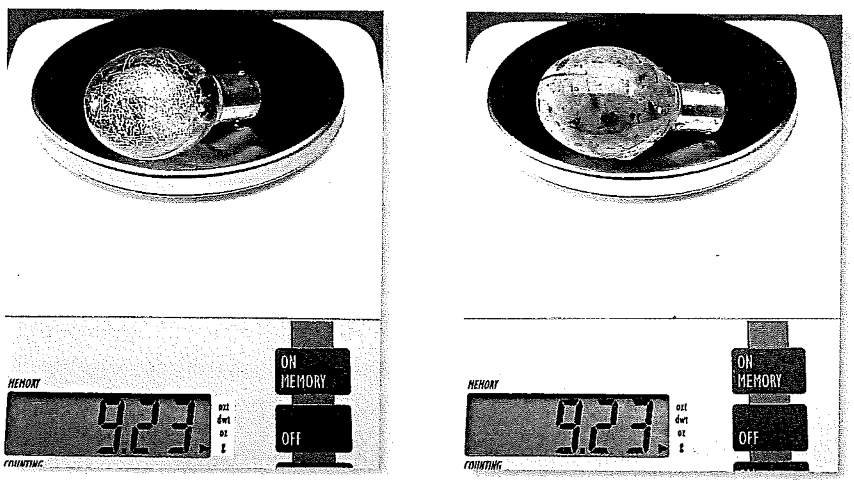
**LabBook**

Become a better balancer of chemical equations on page 106 of the LabBook.



**Mass Is Conserved—It's a Law!** The practice of balancing equations is a result of the work of a French chemist, Antoine Lavoisier (luh vwa ZYAY). In the 1700s, Lavoisier performed experiments in which he carefully measured and compared the masses of the substances involved in chemical reactions. He determined that the total mass of the reactants equaled the total mass of the products. Lavoisier's work led to the **law of conservation of mass,** which states that mass is neither created nor destroyed in ordinary chemical and physical changes. Thus, a chemical equation must show the same number and kind of atom on both sides of the arrow. The law of conservation of mass is demonstrated in **Figure 12.** You can explore this law for yourself in the QuickLab at right.

**Figure 12** *In this demonstration, magnesium in the flashbulb of a camera reacts with oxygen. Notice that the mass is the same before and after the reaction takes place.*




## SECTION REVIEW

1. List four clues that a chemical reaction is occurring.
2. How many atoms of each element make up $2Na_3PO_4$?
3. Write the chemical formulas for carbon tetrachloride and calcium bromide.
4. Explain how a balanced chemical equation illustrates that mass is never lost or gained in a chemical reaction.
5. **Applying Concepts** Write the balanced chemical equation for methane, $CH_4$, reacting with oxygen gas to produce water and carbon dioxide.

## QuickLab

**Mass Conservation**

1. Place 5 g (1 tsp) of **baking soda** into a **sealable plastic bag.**
2. Place 5 mL (1 tsp) of **vinegar** into a **plastic film canister.** Close the lid.
3. Use a **balance** to determine the masses of the bag with baking soda and the canister with vinegar, and record both values in your ScienceLog.
4. Place the canister into the bag. Squeeze the air out of the bag, and tightly seal it.
5. Open the canister in the bag. Mix the vinegar with the baking soda.
6. When the reaction has stopped, measure the total mass of the bag and its contents.
7. Compare the mass of the materials before and after the reaction.

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