Production of plastic film for use in containers such as soft drink bottles (*left*). Nylon being drawn from the boundary between two solutions containing different reactants (*right*).

6.1 Evidence for a Chemical Reaction

Test Item File: 1

AIM: To learn the signals that show a chemical reaction has occurred.

The *Chemistry in Motion* videodisc and videotape show several reactions. For example, demo 4 shows the reaction between zinc and iodine and demo 11 is the thermite reaction.

4.2, 4.18, 4.19

Energy and chemical reactions will be discussed in more detail in Chapter 8.

How do we know when a chemical reaction has occurred? That is, what are the clues that a chemical change has taken place? A glance back at the processes in the introduction suggests that *chemical reactions often give a visual signal.* Steel changes from a smooth, shiny material to a reddish brown, flaky substance when it rusts. Hair changes color when it is bleached. Solid nylon is formed when two particular liquid solutions are brought into contact. A blue flame appears when natural gas reacts with oxygen. Chemical reactions, then, often give *visual* clues: a color changes, a solid forms, bubbles are produced (see Figure 6.1), a flame occurs, and so on. However, reactions are not always visible. Sometimes the only signal that a reaction is occurring is a change in temperature as heat is produced or absorbed (see Figure 6.2).

Table 6.1 summarizes common clues to the occurrence of a chemical reaction, and Figure 6.3 gives some examples of reactions that show these clues.

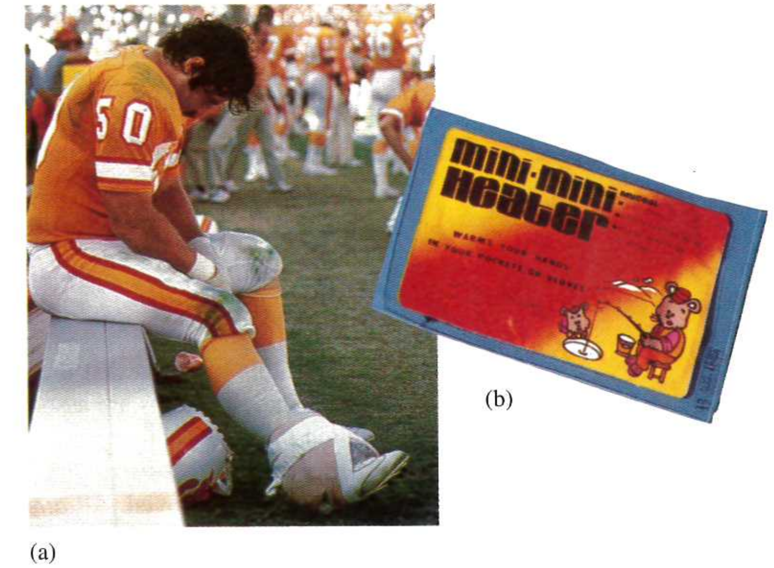
FIGURE 6.1
Bubbles of hydrogen and oxygen gas form when an electric current is used to decompose water.

TABLE 6.1
Some Clues That a Chemical Reaction Has Occurred

1. The color changes.
2. A solid forms.
3. Bubbles form.
4. Heat and/or a flame is produced, or heat is absorbed.

FIGURE 6.2
(a) An athlete wears a cold pack to help prevent swelling of an injury. The pack is activated by breaking an ampule; this initiates a chemical reaction that absorbs heat rapidly, lowering the temperature of the area to which the pack is applied. (b) A hot pack used to warm hands and feet in winter. When the package is opened, oxygen from the air penetrates a bag containing solid chemicals. The resulting reaction produces heat for several hours.

The cold packs and hand warmers mentioned in the textbook are interesting and practical examples of the production and absorption of heat. Hand warmers can often be purchased at outdoor shops and cold packs at large drugstores.



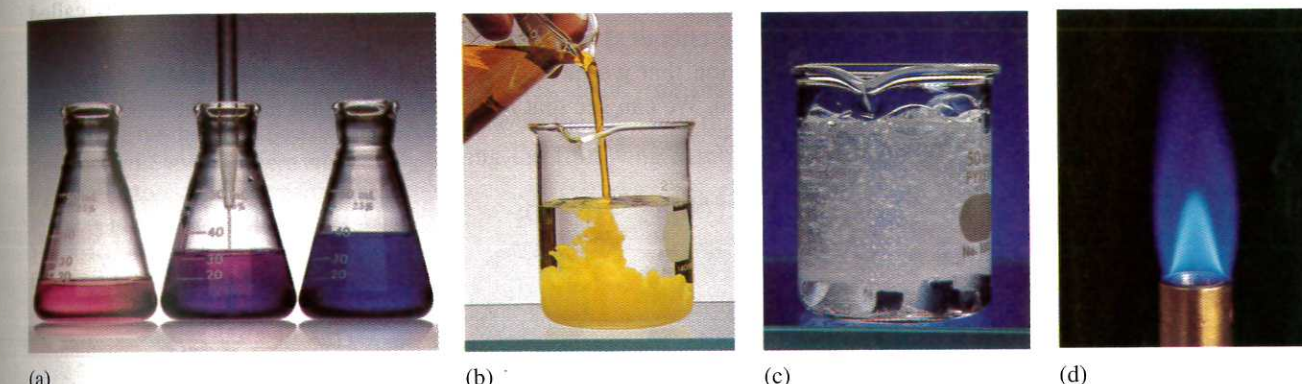


FIGURE 6.3
(a) When colorless hydrochloric acid is added to a red solution of cobalt(II) nitrate, the solution turns blue, a sign that a chemical reaction has taken place. (b) A solid forms when a solution of sodium dichromate is added to a solution of lead nitrate. (c) Bubbles of hydrogen gas form when calcium metal reacts with water. (d) Methane gas reacts with oxygen to produce a flame in a bunsen burner.

6.2 Chemical Equations

Test Item File: 2, 3

AIM: To learn to identify the characteristics of a chemical reaction and the information given by a chemical equation.

This section shows how elements rearrange to form new compounds during a chemical reaction. Ball-and-stick models can be very beneficial when introducing reactions. You can show that there are no balls left over after the reaction has occurred. All the atoms in the reactants are found in the products.

Chemists have learned that a chemical change always involves a rearrangement of the ways in which the atoms are grouped. For example, when the methane, CH_4, in natural gas combines with oxygen, O_2, in the air and burns, carbon dioxide, CO_2, and water, H_2O, are formed. A chemical change such as this is called a **chemical reaction.** We represent a chemical reaction by writing a **chemical equation** in which the chemicals present before the reaction (the **reactants**) are shown to the left of an arrow and the chemicals formed by the reaction (the **products**) are shown to the right of an arrow.

This is a good place to point out that conditions under which a reaction will occur are sometimes printed above or below the arrow.

The arrow indicates the direction of the change and is read as "yields" or "produces":

Reactants → Products

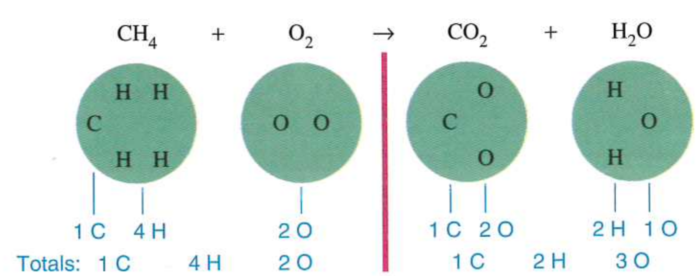
For the reaction of methane with oxygen, we have

Methane		Oxygen		Carbon dioxide		Water
CH_4	+	O_2	→	CO_2	+	H_2O
Reactants				Products		

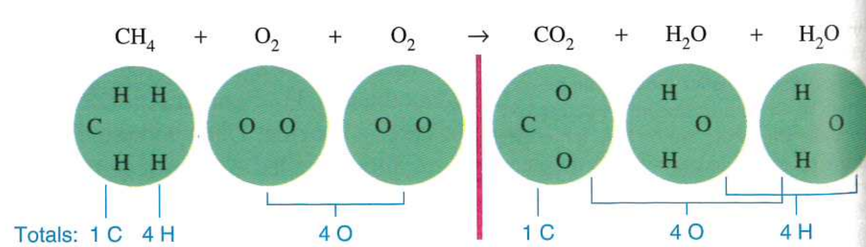
Note from this equation that the products contain the same atoms as the reactants but that the atoms are associated in different ways. That is, a *chemical reaction involves changing the ways the atoms are grouped.*

It is important to recognize that **in a chemical reaction, atoms are neither created nor destroyed.** *All atoms present in the reactants must be accounted for among the products.* In other words, there must be the same number of each type of atom on the product side as on the reactant side of the arrow. Making sure that the equation for a reaction obeys this rule is called **balancing the chemical equation** for a reaction.

The equation that we have shown for the reaction between CH_4 and O_2 is not balanced. We can see that it is not balanced by taking the reactants and products apart.



The reaction cannot happen this way because, as it stands, this equation states that one oxygen atom is created and two hydrogen atoms are destroyed. A reaction is only rearrangement of the way the atoms are grouped; atoms are not created or destroyed. The total number of each type of atom must be the same on both sides of the arrow. We can fix the imbalance in this equation by involving one more O_2 molecule on the left and by showing the production of one more H_2O molecule on the right.



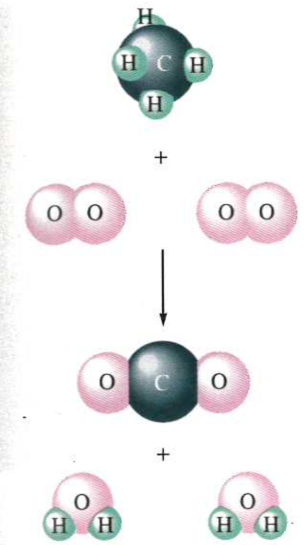
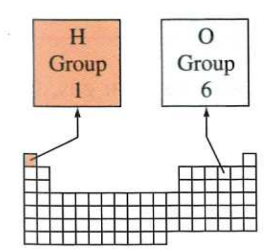


FIGURE 6.4
The reaction between methane and oxygen to give water and carbon dioxide. Note that there are four oxygen atoms in the products *and* in the reactants; none has been gained or lost in the reaction. Similarly, there are four hydrogen atoms and one carbon atom in the reactants *and* in the products. The reaction simply changes the way the atoms are grouped.

Students often have trouble distinguishing between liquid water and an aqueous solution. This is especially troublesome when water is a product of the reaction.



This *balanced chemical equation* shows the actual numbers of molecules involved in this reaction (see Figure 6.4).

When we write the balanced equation for a reaction, we group like molecules together. Thus

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

is written

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

The chemical equation for a reaction provides us with two important types of information:

1. The identities of the reactants and products
2. The relative numbers of each

Physical States

Besides specifying the compounds involved in the reaction, we often indicate in the equation the *physical states* of the reactants and products by using the following symbols:

Symbol	*State*
(*s*)	solid
(*l*)	liquid
(*g*)	gas
(*aq*)	dissolved in water (in aqueous solution)

For example, when solid potassium reacts with liquid water, the products are hydrogen gas and potassium hydroxide; the latter remains dissolved in the water. From this information about the reactants and products, we can write the equation for the reaction. Solid potassium is represented by $K(s)$; liquid water is written as $H_2O(l)$; hydrogen gas contains diatomic molecules and is represented as $H_2(g)$; potassium hydroxide dissolved in water is written as $KOH(aq)$. So the *unbalanced* equation for the reaction is

Solid potassium		Water		Hydrogen gas		Potassium hydroxide dissolved in water
$K(s)$	+	$H_2O(l)$	→	$H_2(g)$	+	$KOH(aq)$

This reaction is shown in Figure 6.5.

The hydrogen gas produced in this reaction then reacts with the oxygen gas in the air, producing gaseous water and a flame. The *unbalanced* equation for this second reaction is

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

Both of these reactions produce a great deal of heat. In Example 6.1 we will practice writing the unbalanced equations for reactions. Then, in the next section, we will discuss systematic procedures for balancing equations.

(a) (b) (c)

FIGURE 6.5
The reactants (a) potassium metal (stored in mineral oil to prevent oxidation) and (b) water. (c) The reaction of potassium with water. The flame occurs because the hydrogen gas, $H_2(g)$ produced by the reaction burns in air (reacts with $O_2(g)$)at the high temperatures caused by the reaction.

EXAMPLE 6.1 *Chemical Equations: Recognizing Reactants and Products*

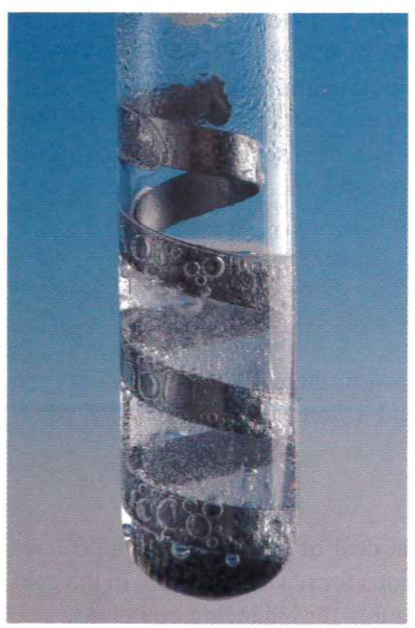
Write the *unbalanced* chemical equation for each of the following reactions.

a. Solid mercury(II) oxide decomposes to produce liquid mercury metal and gaseous oxygen.

b. Solid carbon reacts with gaseous oxygen to form gaseous carbon dioxide.

c. Solid zinc is added to an aqueous solution containing dissolved hydrogen chloride to produce gaseous hydrogen that bubbles out of the solution and zinc(II) chloride that remains dissolved in the water.

Zinc metal reacts with hydrochloric acid to produce bubbles of hydrogen gas.



Solution

a. In this case we have only one reactant, mercury(II) oxide. The name mercury(II) oxide means that the Hg^{2+} cation is present, so one O^{2-} ion is required for a zero net charge. Thus the formula is HgO, which is written HgO(s) in this case because it is given as a solid. The products are liquid mercury, written Hg(l), and gaseous oxygen, written $O_2(g)$. (Remember that oxygen exists as a diatomic molecule under normal conditions.) The unbalanced equation is

Reactant → Products

$$HgO(s) \rightarrow Hg(l) + O_2(g)$$

b. In this case, solid carbon, written C(s), reacts with oxygen gas, $O_2(g)$, to form gaseous carbon dioxide, which is written $CO_2(g)$. The equation (which happens to be balanced) is

Reactants → Product

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

c. In this reaction solid zinc, Zn(s), is added to an aqueous solution of hydrogen chloride, which is written HCl(aq) and called hydrochloric acid. These are the reactants. The products of the reaction are gaseous hydrogen, $H_2(g)$, and aqueous zinc(II) chloride. The name zinc(II) chloride means that the Zn^{2+} ion is present, so two Cl^- ions are needed to achieve a zero net charge. Thus zinc(II) chloride dissolved in water is written $ZnCl_2(aq)$. The unbalanced equation for the reaction is

Because Zn only forms the Zn^{2+} ion, a roman numeral is usually not used. Thus $ZnCl_2$ is commonly called zinc chloride.

Reactants → Products

$$Zn(s) + HCl(aq) \rightarrow H_2(g) + ZnCl_2(aq)$$

Self-Check Exercise 6.1

Identify the reactants and products and write the *unbalanced* equation (including symbols for states) for each of the following chemical reactions.

a. Solid magnesium metal reacts with liquid water to form solid magnesium hydroxide and hydrogen gas.

b. Solid ammonium dichromate (review Table 5.4 if this compound is unfamiliar) decomposes to solid chromium(III) oxide, gaseous nitrogen, and gaseous water.

c. Gaseous ammonia reacts with gaseous oxygen to form gaseous nitrogen monoxide and gaseous water.

See Problems 6.13 through 6.34.

6.3 Balancing Chemical Equations

Test Item File: 4–76

AIM: To learn how to write a balanced equation for a chemical reaction.

Now is a good time to remind students about the formulas of elements in their natural states. They should review Section 5.1 and memorize the list of elements that are found as diatomic molecules.

It can be hard to convince students that in order to balance an equation they cannot change the subscripts of products or reactants, but only the coefficients. An analogy to cooking may be helpful. If 1 cup of milk + 1 tbsp of cocoa + 1 tbsp of sugar make 1 cup of cocoa, then three cups of milk + 3 tbsp of cocoa + 3 tbsp of sugar make 3 cups of hot cocoa, not strawberry ice cream.

Trial and error is often useful for solving problems. It's okay to make a few wrong turns before you get to the right answer.

As we saw in the previous section, an unbalanced chemical equation is not an accurate representation of the reaction that occurs. Whenever you see an equation for a reaction, you should ask yourself whether it is balanced. The principle that lies at the heart of the balancing process is that **atoms are conserved in a chemical reaction.** That is, atoms are neither created nor destroyed. They are just grouped differently. The same number of each type of atom is found among the reactants and among the products.

Chemists determine the identity of the reactants and products of a reaction by experimental observation. For example, when methane (natural gas) is burned in the presence of sufficient oxygen gas, the products are always carbon dioxide and water. **The identities (formulas) of the compounds must never be changed in balancing a chemical equation.** In other words, the subscripts in a formula cannot be changed, nor can atoms be added to or subtracted from a formula.

Most chemical equations can be balanced by trial and error—that is, by inspection. Keep trying until you find the numbers of reactants and products that give the same number of each type of atom on both sides of the arrow. For example, consider the reaction of hydrogen gas and oxygen gas to form