Chapter 6

Chemical reactions occur in predictable ways.

Chemical reactions, like the one shown here between the elements aluminum and bromine, can look unpredictable. However, the way in which these elements react follows a pattern that can be used to predict the products that will be formed during the reaction. There are also patterns that help us predict if a reaction will occur quickly or slowly. In this chapter, you will learn about these patterns.

What You Will Learn

In this chapter, you will
- **classify** reactions as one of six different types
- **predict** the identity of the products of a chemical reaction
- **identify** factors that affect the rate of a chemical reaction
- **define** the rate of a chemical reaction
- **explain** the role of catalysts in a chemical reaction

Why It Is Important

We live in a chemical world. Millions of chemical reactions in you and around you transform reactants into products. Some chemical reactions provide energy, to keep you warm and to process the food you eat to live and grow. By studying the types of reactions and the factors that affect reaction rates, you will be able to predict the outcome of reactions you have never seen.

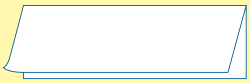
Skills You Will Use

In this chapter, you will
- **measure** the rate of chemical reactions safely in a laboratory setting
- **identify** situations where the rate of reaction needs to be controlled
- **use** models to understand types of chemical reactions
- **work co-operatively and safely** in a laboratory setting

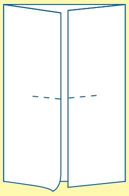
FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 6.

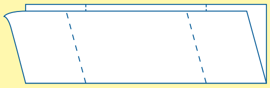
STEP 1 **Hold** a sheet of 28 cm by 43 cm paper with the long edge held horizontally and fold, but instead of creasing the paper, pinch it to show the midpoint.



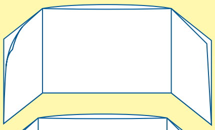
STEP 2 **Fold** the outer edges of the paper to meet at the pinch, or midpoint, forming a shutterfold. **Crease** the folds well, and then **open** the shutterfold.

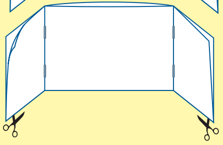


STEP 3 **Fold** the paper upward, so that the two horizontal edges meet.



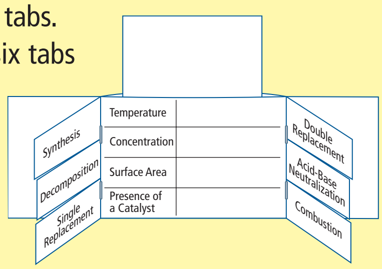
STEP 4 Use the left and right creases to **fold** the edges inward, which will create a large central pocket. **Glue** or **staple** the left and right creases to reinforce the pocket.





STEP 5 **Cut** along the bottom fold line of the right and left tabs, allowing them to open and close.

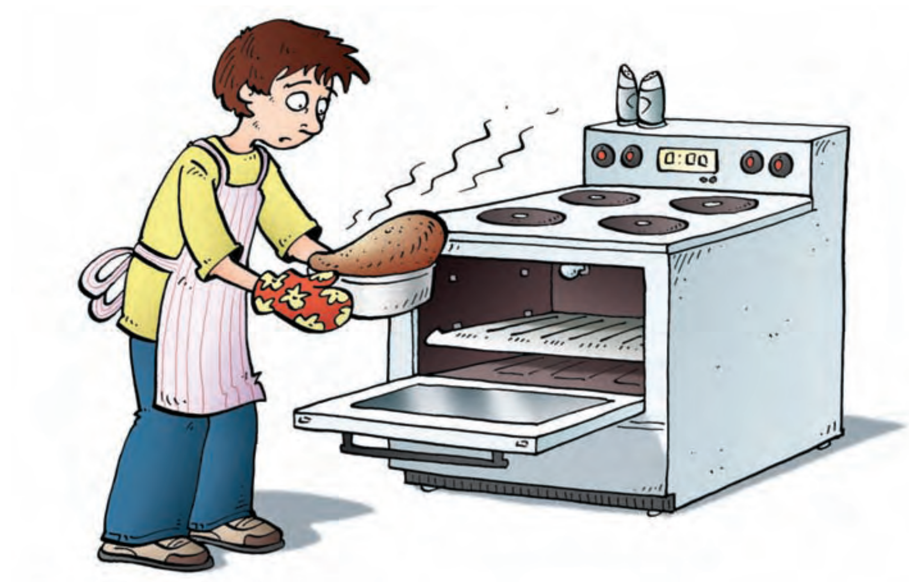
STEP 6 **Cut** the side tabs of the top layer into thirds to make six tabs. **Label** the six tabs with the six different types of chemical reactions.



Define the reactions and provide examples beneath the tabs. **Divide** the centre panel into a four-column chart and label with the four factors affecting chemical reactions. Use the top pocket to store notes and work.

6.1 Types of Chemical Reactions

Chemical reactions can be classified as one of six main types: synthesis, decomposition, single replacement, double replacement, neutralization (acid-base), and combustion. You can identify each type of reaction by examining the reactants. This makes it possible to classify a reaction and then predict the identity of the products.



Words to Know

combustion
decomposition
double replacement
neutralization (acid-base)
precipitate
single replacement
synthesis

Did You Know?

All known chemical reactions require energy to break the chemical bonds in the reactants. Energy is often released when new bonds form in the products.

Dark, mysterious mixtures react and create new substances. Gas bubbles up and expands. Powerful aromas waft through the air. Are you in a chemical laboratory carrying out a complex experiment? No, you are in the kitchen baking a chocolate cake. Many chemical reactions take place in the kitchen.

One way to predict the outcome of a specific reaction is by recognizing that chemical reactions follow patterns. By understanding these patterns, you can be successful in cooking food and in understanding the chemistry of the world around you.

You have already written and balanced many chemical equations. Each equation represents a chemical reaction—the production of pure substances (elements and/or compounds). Although every kind of chemical reaction involves a unique combination of substances, there are many patterns in the way substances react. Chemists classify chemical reactions to make it easier to predict the products of reactions and recognize new reactions (Figure 6.1 on the next page).

Figure 6.1 A synthetic chemist formulates new compounds (A). Then, an analytical chemist analyzes the compounds to verify their structure and percent composition (B).

6-1A Comparing Chemical Reactions

Find Out ACTIVITY

In this activity, you will observe and compare three similar chemical reactions.

Safety

- Avoid touching all reactants and products.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.
- Follow your teacher's directions for safety in the science room.

Materials

- copper(II) chloride solution
- four medium-sized test tubes
- test tube rack or four small beakers
- strip of magnesium
- iron nail
- zinc metal (mossy)
- copper wire
- paper towel

What to Do

1. Place copper(II) chloride solution into four medium–sized test tubes to a depth of about 1 cm. Set the test tubes in a test tube rack or small individual beakers so that you can easily see the bottom of the test tubes.
2. Place each metal (magnesium strip, iron nail, zinc, copper wire) into a different test tube. Tilt each test tube to allow the metal to be in contact with the solution.
3. Observe each chemical reaction. Record what happens to the metals and any colour changes in the solution.
4. Design a table of observations. Organize your observations in the table. Give your table a title.
5. After a few minutes, carefully pour off the copper(II) chloride solution from each test tube into a waste container, as directed by your teacher. Leave the solid products in the test tubes. Do not pour the copper(II) chloride down the sink as it can harm the environment.
6. Pour the products out onto a paper towel. Compare the products, but do not handle them.
7. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

What Did You Find Out?

1. What metal do you think was produced in the following chemical reactions?
   (a) magnesium plus copper(II) chloride
   (b) iron plus copper(II) chloride
   (c) zinc plus copper(II) chloride
2. (a) Describe what you observed in the test tube containing the copper wire.
   (b) Suggest a reason for your observations.
3. List at least one way in which the reactions involving Mg, Fe, and Zn appeared to be different from each other.

Classifying Chemical Reactions

Chemists have identified six common types of reactions: synthesis, decomposition, single replacement, double replacement, neutralization (acid-base), and combustion. These six general types represent thousands of reactions.

Did You Know?

There are two correct ways to classify sulfur burning in oxygen to produce sulfur dioxide: synthesis and combustion.

Synthesis (Combination) Reactions

In a **synthesis** (combination) reaction, two or more reactants (A and B) combine to produce a single product (AB).

element + element ➔ compound

A + B ➔ AB

(The letters A and B represent elements.)

Example 1: To make table salt in a synthesis reaction, two atoms of sodium metal (Na) and one molecule of chlorine gas (Cl_2) react to form sodium chloride, NaCl (Figure 6.2).

$2Na + Cl_2 \rightarrow 2NaCl$

Notice that chlorine is written as a diatomic molecule, Cl_2. Chlorine occurs as a diatomic molecule when it is a pure element. You may recall from Chapter 4 that there are seven common diatomic elements: H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2. When diatomic elements are not combined into a compound, they exist as molecules containing two atoms.

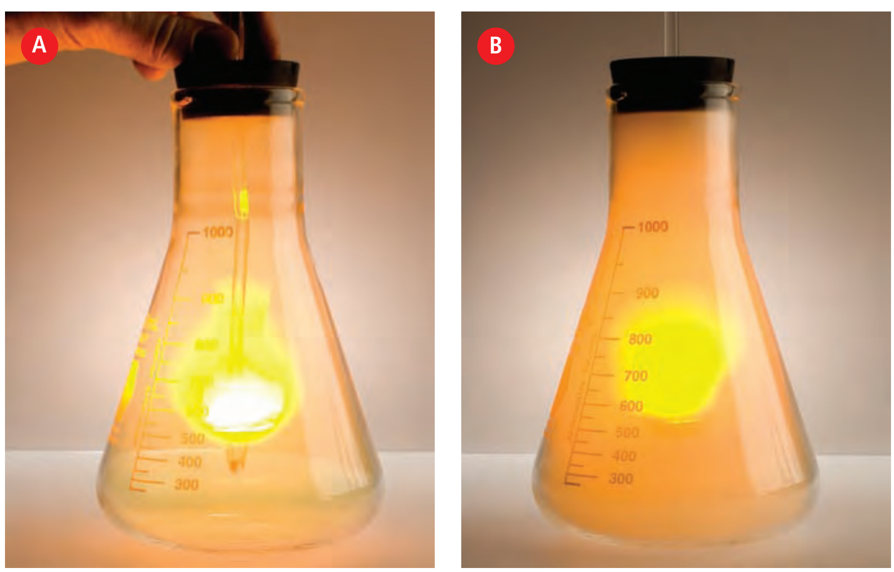


Figure 6.2 Sodium is added to a flask of chlorine gas (A). This synthesis reaction continues until all the sodium has combined with chlorine, producing NaCl (B).

Example 2: Magnesium metal (Mg) reacts with oxygen gas (O_2) to form magnesium oxide, MgO, (Figure 6.3 on the next page). The balanced chemical equation for this reaction is:

$2Mg + O_2 \rightarrow 2MgO$

In both examples on the previous page, two elements combined to form an ionic compound. When synthesis reactions occur between a metal and non-metal, electrons are transferred from the metal to the non-metal, producing ions. For ionic compounds, you can use the ion charges to predict the product and write the equation. For covalent compounds or when a multivalent metal, such as copper or iron, is involved, it is more difficult to predict the product. In these cases, you will need extra information to complete the chemical equation.

Figure 6.3 The synthesis reaction between magnesium and oxygen can be one of the reactions that provides the light in an emergency flare.

Example 3: Nitrogen gas (N_2) can react with oxygen gas (O_2) to form dinitrogen monoxide (N_2O), also called nitrous oxide. The balanced equation for this reaction is:

$$2N_2 + O_2 \rightarrow 2N_2O$$

Nitrous oxide is sometimes administered to dental patients during treatment to manage pain and is also sometimes added to the fuel lines of race cars to give more power to the engine.

Nitrous oxide is an example of an oxide (a combination of oxygen with another element). In Chapter 5, you learned that metals and non-metals react with oxygen to form oxides. Reactions that produce oxides can all be classified as synthesis reactions but sometimes may also be classified as other types of reactions. Some fast reactions with oxygen are more frequently classified as combustion, such as the combustion of gasoline in a car's engine or hydrogen with oxygen in a rocket.

Practice Problems

1. Complete and balance the following synthesis (combination) reactions. Remember to consider the chemical formulas of the products carefully before you begin to balance.
   (a) $Mg + N_2 \rightarrow$
   (b) $Al + F_2 \rightarrow$
   (c) $K + O_2 \rightarrow$
   (d) $Cd + I_2 \rightarrow$
   (e) $Cs + P_4 \rightarrow$

2. Identify whether or not each of the following chemical equations is a synthesis (combination) reaction.
   (a) $2H_2 + O_2 \rightarrow 2H_2O$
   (b) $2Al + 3CuCl_2 \rightarrow 2AlCl_3 + 3Cu$
   (c) $2KClO_3 \rightarrow 2KCl + 3O_2$
   (d) $S_8 + 12O_2 \rightarrow 8SO_3$
   (e) $2Ti + 3\ Cl_2 \rightarrow 2TiCl_3$

Answers provided on page 592

Did You Know?

Some rockets launch into space fuelled by liquid oxygen and liquid hydrogen, which combine in a synthesis reaction. The reaction is

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

Did You Know?

Not all decompositions produce elements. The fizz from a carbonated soft drink comes from the production of carbon dioxide gas, a compound, released in the following decomposition:

$H_2CO_3 \rightarrow H_2O + CO_2$

Figure 6.4 Producing hydrogen through the decomposition of water may increase in importance if hydrogen becomes a major fuel for automobiles.

Decomposition Reactions

A **decomposition** reaction is the breaking down of a compound into smaller compounds or separate elements. A decomposition reaction is the reverse of a synthesis reaction.

compound → element + element
AB → A + B

Example 1: Table salt can be decomposed into sodium metal and chlorine gas by melting it at 800°C and passing an electric current through the liquid salt. This is one way to produce sodium metal.

$$2NaCl \rightarrow 2Na + Cl_2$$

Example 2: Water decomposes when an electric current is passed through it (Figure 6.4). About 4 percent of the hydrogen gas used in the world is produced by decomposition. Decomposing water by passing an electric current through water is called electrolysis.

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

In both decomposition examples above, a compound consisting of two elements is decomposed into the original elements. During decomposition of an ionic compound, electrons transfer back to the atoms of the metal and each element becomes electrically neutral. As a result, neither of the products is an ion.

Practice Problems

1. Complete and balance the following decomposition reactions. Remember to check for diatomic elements as you write the formulas of the products.
   (a) $AuCl_3 \rightarrow$
   (b) $K_2O \rightarrow$
   (c) $MgF_2 \rightarrow$
   (d) $Ca_3N_2 \rightarrow$
   (e) $CsI \rightarrow$

2. Identify each reaction as synthesis, decomposition, or neither.
   (a) $CO_2 \rightarrow C + O_2$
   (b) $2AgCl + Cu \rightarrow CuCl_2 + 2Ag$
   (c) $2Cr + 3F_2 \rightarrow 2CrF_3$
   (d) $CaI_2 + Na_2CO_3 \rightarrow 2NaCl + CaCO_3$
   (e) $2NaClO_3 \rightarrow 2NaCl + 3O_2$

Answers provided on page 592

Single Replacement Reactions

In a **single replacement** reaction, a reactive element (a metal or a non-metal) and a compound react to produce another element and another compound. In other words, one of the elements in the compound is replaced by another element. The element that is replaced could be a metal or a non-metal.

element + compound ➔ element + compound
A + BC ➔ B + AC where A is a metal OR
A + BC ➔ C + BA where A is a non-metal

Example 1: When aluminum foil is placed into a solution of copper(II) chloride, electrons transfer from the aluminum atoms to the copper(II) ions. This single replacement reaction releases copper atoms (Cu) and aluminum ions (Al^{3+}). The aluminum ions form a compound with the chloride ions.

$$2Al + 3CuCl_2 \rightarrow 3Cu + 2AlCl_3$$

Example 2: Another example of a single replacement reaction involving copper occurs when copper is placed into a solution of silver nitrate (Figure 6.5).

$$Cu + 2AgNO_3 \rightarrow 2Ag + Cu(NO_3)_2$$

Example 3: When a non-metal element is combined with a compound, the non-metal will replace the other non-metal. For example, fluorine replaces iodine in sodium iodide.

$$F_2 + 2NaI \rightarrow I_2 + 2NaF$$

Figure 6.5A Silver crystals and a blue-green solution of copper nitrate are formed when copper metal is dipped in a solution of silver nitrate.

Figure 6.5B The pattern of silver crystals grown in this solution is an irregular pattern called a fractal. Fractal shapes appear everywhere in nature. Notice how this image resembles a shoreline.

Practice Problems

1. Complete and balance the following single replacement reactions.
   (a) $PbCl_4 + Al \rightarrow$
   (b) $Na + Cu_2O \rightarrow$
   (c) $CuF_2 + Mg \rightarrow$
   (d) $Cl_2 + CsBr \rightarrow$
   (e) $Be + Fe(NO_3)_2 \rightarrow$
2. Classify each reaction as synthesis, decomposition, or single replacement.
   (a) $2N_2O \rightarrow 2N_2 + O_2$
   (b) $Au(NO_3)_3 + 3Ag \rightarrow Au + 3AgNO_3$
   (c) $CH_4 \rightarrow C + 2H_2$
   (d) $2NH_4Br + Cl_2 \rightarrow 2NH_4Cl + Br_2$
   (e) $Br_2 + I_2 \rightarrow 2IBr$

Answers provided on page 592

Word Connect

You can use a memory device to help you notice when a precipitate forms. The (s) in the equation stands for solid, but "s" also stands for settles and sinks, which is what a precipitate does.

Figure 6.6A When potassium chromate, K_2CrO_4, is added to silver nitrate, $AgNO_3$, the precipitate formed is silver chromate, Ag_2CrO_4.

Figure 6.6B Yellow lead(II) iodide was used in the 18th century as a pigment in paints. Due to its toxicity, it is no longer used in paints.

Double Replacement Reactions

A **double replacement** reaction usually involves two ionic solutions that react to produce two other ionic compounds. One of the compounds forms a **precipitate**, which is an insoluble solid that forms from a solution (Figure 6.6A). A precipitate floats in the solution, then settles and sinks to the bottom. The other compound may also form a precipitate, or it may remain dissolved in solution.

ionic solution + ionic solution ➔ ionic solution + ionic solid

$AB(aq) + CD(aq) \rightarrow AD(aq) + CB(s)$

Example 1: If lead(II) nitrate solution is mixed with sodium iodide solution, two new compounds form consisting of sodium nitrate solution and solid lead(II) iodide (Figure 6.6B). Yellow lead(II) iodide is used in the construction of detectors of high-energy radiation, such as X rays and gamma rays.

$Pb(NO_3)_2 + 2NaI \rightarrow 2NaNO_3 + PbI_2$

Example 2: When sodium hydroxide solution is mixed with iron(III) chloride, a precipitate occurs involving the iron(III) ion. To find the products, simply trade the parts of the names around. One product is iron(III) hydroxide, and the other is sodium chloride. The equation for this double replacement reaction is:

$3NaOH + FeCl_3 \rightarrow 3NaCl + Fe(OH)_3$

In later science courses, you can learn how to determine which product or products form a precipitate.

Practice Problems

1. Complete and balance the following double replacement reactions. You do not need to decide which product(s) form a precipitate or to show states in the balanced equation.
   (a) $CaS + NaOH \rightarrow$
   (b) $K_3PO_4 + MgI_2 \rightarrow$
   (c) $SrCl_2 + Pb(NO_3)_2 \rightarrow$
   (d) $AlCl_3 + CuNO_3 \rightarrow$
   (e) $AgNO_3 + Na_2CrO_4 \rightarrow$

2. Classify each reaction as synthesis, decomposition, single replacement, or double replacement.
   (a) $2FeBr_3 + 3Zn \rightarrow 3ZnBr_2 + 2Fe$
   (b) $FeBr_2 + ZnSO_4 \rightarrow ZnBr_2 + FeSO_4$
   (c) $2Al + Fe_2O_3 \rightarrow 2Fe + Al_2O_3$
   (d) $2Fe + O_2 \rightarrow 2FeO$
   (e) $2FeBr_3 \rightarrow 2Fe + 3Br_2$

Answers provided on page 592

Neutralization (Acid-Base) Reactions

You may recall from Chapter 5 that acids are compounds that produce H^+ ions in solution. Acidic solutions have a pH less than 7. The formula of an acid usually has an H on the left side. For example, solutions of HCl, H_2SO_4, and HNO_3 are all acidic. An exception to this general trend is water (H_2O): pure water is neutral.

Bases are compounds that produce OH^- ions in solution. Bases form solutions with a pH greater than 7. The formula of a base has a metal or NH_4^+ on the left and OH^- on the right side. For example, NaOH, $Mg(OH)_2$, and NH_4OH are all bases.

When an acid and a base are combined, they will neutralize each other (Figure 6.7). In a neutralization (acid-base) reaction, an acid and a base react to form a salt and water.

acid + base ➔ salt + water
$HX + MOH \rightarrow MX + H_2O$
(X represents a negative ion. M represents a positive ion.)

Example 1: Sulfuric acid (H_2SO_4) is the most widely used industrial chemical in the world. It is frequently used for neutralization in industry because it is easier to use than many other acids, and it can be produced in highly concentrated forms (up to 98 percent acid and 2 percent water). The reaction of sulfuric acid and lime ($Ca(OH)_2$) is:

$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + 2H_2O$$

Example 2: Phosphoric acid (H_3PO_4) is a main ingredient in rust remover solutions. Rust is a mixture of iron compounds, one of which is iron(II) hydroxide ($Fe(OH)_2$). Iron(II) hydroxide dissolves when it reacts with phosphoric acid.

$$2H_3PO_4 + 3Fe(OH)_2 \rightarrow Fe_3(PO_4)_2 + 6H_2O$$

Practice Problems

1. Complete and balance the following neutralization (acid-base) reactions.
   (a) $HBr + NaOH \rightarrow$
   (b) $H_3PO_4 + Mg(OH)_2 \rightarrow$
   (c) $HCl + Pb(OH)_2 \rightarrow$
   (d) $Al(OH)_3 + HClO_4 \rightarrow$

2. Classify each reaction as synthesis, decomposition, single replacement, double replacement, or neutralization.
   (a) $2HCl + Zn \rightarrow ZnCl_2 + H_2$
   (b) $2HCl \rightarrow H_2 + Cl_2$
   (c) $2HCl + Sr(OH)_2 \rightarrow SrCl_2 + 2H_2O$
   (d) $2HCl + Pb(NO_2)_2 \rightarrow 2HNO_2 + PbCl_2$

Answers provided on page 592

Figure 6.7A This equipment allows precise amounts of an acid to be added to a base.

Figure 6.7B Zinc metal reacts with hydrochloric acid to produce zinc chloride and hydrogen. The bubbles shown here are hydrogen bubbles.

Combustion Reactions

Combustion is the rapid reaction of a compound or element with oxygen to form an oxide and to produce heat. For example, organic compounds, such as methane, combust with oxygen to form carbon dioxide (the oxide of carbon) and water (the oxide of hydrogen). Compounds that contain oxygen, such as carbohydrates, also react with oxygen to form carbon dioxide and water.

hydrocarbon + oxygen → carbon dioxide + water
$C_XH_Y + O_2 \rightarrow CO_2 + H_2O$
(The subscripts $_X$ and $_Y$ represent integers.)

Example 1: Natural gas (methane) is used as a heating fuel. The main reaction in the combustion of natural gas is the following.

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

Example 2: An oxyacetylene torch used for welding metals has acetylene gas as the fuel (Figure 6.8).

Figure 6.8 Acetylene is a gas used for welding because of the high-temperature flame produced when it is burned with oxygen. Welding with oxyacetylene produces carbon dioxide and water.

$2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O$
acetylene

Example 3: Glucose is a simple sugar as well as a carbohydrate. When burned in air, glucose reacts as follows.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
glucose

Practice Problems

1. Complete and balance the following combustion reactions.
   (a) $C_3H_8 + O_2 \rightarrow$
   (b) $C_4H_{10} + O_2 \rightarrow$
   (c) $C_2H_4 + O_2 \rightarrow$
   (d) $C_6H_{12}O_6 + O_2 \rightarrow$
   (e) $C_{12}H_{22}O_{11} + O_2 \rightarrow$

2. Classify each reaction as synthesis, decomposition, single replacement, double replacement, neutralization, or combustion.
   (a) $3Ca(NO_3)_2 + 2Na_3PO_4 \rightarrow 6NaNO_3 + Ca_3(PO_4)_2$
   (b) $Ca(OH)_2 + H_2SO_4 + \rightarrow 2H_2O + CaSO_4$
   (c) $2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$
   (d) $6Mg + P_4 \rightarrow 2Mg_3P_2$
   (e) $C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Answers provided on page 592

Summary of Chemical Reaction Types

The summary chart below compares the six types of chemical reactions that you have studied. Each type of reaction has a unique pattern. You can examine the reactants to determine what kind of reaction each one is. This makes it possible to predict the products of each reaction.

Table 6.1 Summary of Chemical Reactions

Reaction Type	Reactants and Products	Notes on the Reactants
Synthesis (combination)	A + B ➔ AB	• Two elements combine (Figure 6.9).
Decomposition	AB ➔ A + B	• One reactant only (Figure 6.9)
Single replacement		
If A is a metal	A + BC ➔ B + AC	• One element and one compound
If A is a non-metal	A + BC ➔ C + BA	
Double replacement	AB + CD ➔ AD + CB	• Two compounds react.
Neutralization (acid-base)	$HX + MOH \rightarrow MX + H_2O$	• Acid plus base
Combustion	$C_XH_Y + O_2 \rightarrow CO_2 + H_2O$	• Organic compound with oxygen

Figure 6.9 An energy source, such as a battery or photocell, can be used to produce hydrogen gas through a decomposition reaction:

$2H_2O \rightarrow 2H_2 + O_2$

Later, the hydrogen and oxygen can be recombined in a synthesis reaction to release energy that can be used to run an electric motor.

$2H_2 + O_2 \rightarrow 2H_2O$

Practice Problems

For each of the following reactions, classify the reaction type and then predict what the products will be. Then write the skeleton equation and balance it. After you have answered all the questions, turn the page to review the solutions and the steps for solving each equation.

1. $Fe_2O_3 \rightarrow$
2. $Al + NiBr_3 \rightarrow$
3. $Cl_2 + NiBr_2 \rightarrow$
4. $HCl + Mg(OH)_2 \rightarrow$
5. $C_{18}H_{38} + O_2 \rightarrow$
6. $Li + N_2 \rightarrow$
7. $AgNO_3 + Na_2CrO_4 \rightarrow$

Answers provided on page 592

Solutions to Practice Problems

1. $Fe_2O_3 \rightarrow$

This reaction has only one reactant. Therefore, this reaction is a decomposition reaction. The two products will be the separate elements iron and oxygen. As a pure element, iron is written as Fe (it has no charge as a pure element) and oxygen is diatomic, so it is O_2.

skeleton equation: $Fe_2O_3 \rightarrow Fe + O_2$
balanced equation: $2Fe_2O_3 \rightarrow 4Fe + 3O_2$

2. $Al + NiBr_3 \rightarrow$

This reaction has two reactants: one reactant is an element, and one reactant is a compound. Therefore, this reaction is a single replacement reaction. Since aluminum is a metal, it will replace the other metal, nickel, in the compound. As the aluminum forms the new compound, it generates an aluminum ion (Al^{3+}). The bromide ion (Br^-) remains unchanged but is now combined with the aluminum to make $AlBr_3$. The other product is simply nickel metal. As a pure element, nickel is written as Ni. Nickel has no charge as a pure element.

skeleton equation: $Al + NiBr_2 \rightarrow Ni + AlBr_3$
balanced equation: $2Al + 3NiBr_2 \rightarrow 3Ni + 2AlBr_3$

3. $Cl_2 + NiBr_2 \rightarrow$

Figure 6.10 $MgCl_2$ is used to produce magnesium and to manufacture paper, fabrics, and cements. It is also used to prepare tofu from soy milk (shown in the photograph) and as an ingredient in baby formula milk.

This reaction has two reactants: one reactant is an element, and one reactant is a compound. Therefore, this reaction is a single replacement reaction. Since chlorine is a non-metal, it will replace the other non-metal, bromine, in the compound. The nickel, which is already an ion (Ni^{2+}), stays as an ion but is now combined with the chloride ion (Cl^-) to make $NiCl_2$. The element produced is bromine, which is diatomic, so it is written as Br_2. Notice that sometimes the skeletal equation is the same as the balanced equation.

skeleton equation: $Cl_2 + NiBr_2 \rightarrow Br_2 + NiCl_2$
balanced equation: $Cl_2 + NiBr_2 \rightarrow Br_2 + NiCl_2$ (already balanced)

4. $HCl + Mg(OH)_2 \rightarrow$

This reaction has two reactants. The presence of an acid (HCl) and a base ($Mg(OH)_2$) means that it is neutralization and will produce a salt and water. The salt will be formed from the metal ion in the base (Mg^{2+}) and the non-metal ion in the acid (Cl^-), forming $MgCl_2$ (Figure 6.10).

skeleton equation: $HCl + Mg(OH)_2 \rightarrow MgCl_2 + H_2O$
balanced equation: $2HCl + Mg(OH)_2 \rightarrow MgCl_2 + 2H_2O$

5. $C_{18}H_{38} + O_2 \rightarrow$

This reaction has two reactants: one reactant is a compound and one reactant is an element. Be careful: this reaction is not a single replacement reaction! Notice that the compound contains carbon. The element is oxygen, and it is reacting with an organic compound. Therefore, this reaction is a combustion reaction. Oxygen will be part of both products. Remember, the products are always the same for a combustion reaction: carbon dioxide and water (Figure 6.11).

Figure 6.11 The products of a burning candle are CO_2 and H_2O.

skeleton equation: $C_{18}H_{38} + O_2 \rightarrow CO_2 + H_2O$
balanced equation: $2C_{18}H_{38} + 55O_2 \rightarrow 36CO_2 + 38H_2O$

6. $Li + N_2 \rightarrow$

This reaction has two reactants, both are elements. Therefore, this reaction can only be a synthesis reaction. The single product will be an ionic compound because one of the reactants is a metal and the other is a non-metal. The lithium ion is Li^+, and the nitride ion is N^{3-}. Together they produce the compound Li_3N.

skeleton equation: $Li + N_2 \rightarrow Li_3N$
balanced equation: $6Li + N_2 \rightarrow 2Li_3N$

Suggested Activity

Conduct an Investigation 6-1B on page 268

7. $AgNO_3 + Na_2CrO_4 \rightarrow$

There are two reactants in this reaction. Both are ionic compounds. Therefore, this reaction is a double replacement reaction. It is not possible to tell from the question, but this reaction happens in solution. All the ions will mix in the water, and one new pair of ions will form a precipitate (a solid). You do not have to worry about which pair of ions forms the precipitate. Simply follow the pattern. The Ag^+ and NO_3^- ions from the first compound trade places with Na^+ and CrO_4^{2-} ions from the second compound. The new combinations are Ag^+ with CrO_4^{2-} to make Ag_2CrO_4, and Na^+ with NO_3^- to make $NaNO_3$.

skeleton equation: $AgNO_3 + Na_2CrO_4 \rightarrow NaNO_3 + Ag_2CrO_4$
balanced equation: $2AgNO_3 + Na_2CrO_4 \rightarrow 2NaNO_3 + Ag_2CrO_4$

Explore More

Some reactions can be predicted but are difficult to make happen. For example, sodium nitride (Na_3N) was not synthesized from sodium and nitrogen until 2002 by chemist Martin Jansen. Find out what special techniques he used to make this reaction work. Start your search at **www.bcscience10.ca**.

6-1B Predicting the Products in Chemical Reactions

Skill Check

- Observing
- Predicting
- Classifying
- Communicating

Safety

- Report any spills to your teacher immediately.
- Wear proper eye protection
- Handle chemicals safely. Avoid touching all reactants and products.
- Tie back long hair.
- Follow your teacher's directions regarding using open flames.
- Do not remove any materials from the science room.
- Many of these chemicals are toxic. Do not place your fingers near food or your mouth during this activity.
- Follow your teacher's directions for safety in the science room.
- Wash your hands and equipment thoroughly after completing this activity.

In this activity, you will observe three types of chemical reactions. Use your understanding of reaction types to predict the products in each reaction.

Question

What are the products in the single replacement, double replacement, and decomposition reactions?

Materials

Part 1

- copper(II) chloride solution ($CuCl_2$)
- graduated cylinder
- small beaker (about 100 mL)
- strips of aluminum foil
- water
- Bunsen burner
- matches or flame striker
- wooden splint

Part 2

- calcium chloride solution ($CaCl_2$)
- small graduated cylinder (about 50 mL)
- small beaker (about 100 mL)
- water
- sodium carbonate solution (Na_2CO_3)
- glass stirring rod
- dilute hydrochloric acid (HCl)

Part 3

- potassium iodide solution (KI)
- petri dish
- 9.0 V battery
- wire leads with graphite electrodes

Procedure

These may be set up in stations. Do Parts 1 to 3 in any order. Read each part carefully before beginning.

Part 1 Single Replacement: $Al + CuCl_2$

1. Measure about 50 mL of copper(II) chloride solution using a graduated cylinder, and pour it into a small beaker. Roll up a 5 cm $\times$ 5 cm piece of aluminum foil and place it into the $CuCl_2$ solution. Observe. Record colour changes, temperature changes, changes in the aluminum foil, and appearance of a new substance.
2. After the reaction, decant the liquid portion into the designated waste container. (Decant means to carefully pour off the liquid but leave the precipitate behind.) Wash the brown product at the bottom of the beaker with water. Repeat several times to purify the product.
3. Light a Bunsen burner. Use a wooden splint to pick up the brown product and hold it in the flame. Note the flame colour. This may help you to determine the identity of the brown product.
4. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Part 2 Double Replacement: $CaCl_2 + Na_2CO_3$

5. Measure about 20 mL of calcium chloride solution using a graduated cylinder and pour it into a small beaker. Rinse the graduated cylinder with water and then measure about 20 mL of sodium carbonate solution into the graduated cylinder. Pour this into the beaker containing calcium chloride. Observe. Record any colour changes and the appearance of any new substance.
6. Add about 40 mL of water, and stir using a glass stirring rod. Wait about 2 min. Decant most of the solution, which will still look very milky, into a designated waste container.
7. Add more water to the white precipitate, stir it up again, and let it settle for another 2 min. Decant as much of the liquid as possible. It does not matter if you lose some white precipitate. Your objective is simply to have some wet but otherwise pure precipitate remaining at the bottom of the beaker.
8. Predict what compound the white precipitate might be. If it is a carbonate, then acid will cause it to decompose, releasing bubbles of carbon dioxide. If it is a chloride, there will be no bubbles.
9. Add 10 mL of dilute hydrochloric acid to the white precipitate and note any changes. This may help you to determine the identity of the white precipitate.
10. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Part 3 Decomposition: KI

11. Pour enough potassium iodide solution into a petri dish to make it about half full.
12. Connect wire leads to a 9.0 V battery. Make sure the leads do not touch each other, which would cause a short circuit and discharge the battery. The wire leads should have graphite electrodes, which are made from carbon and will not react.
13. Place the graphite electrodes into the solution at opposite sides of the petri dish. Observe. You are looking for evidence of iodine (I_2) at the graphite electrode that is attached to the positive side of the battery. The solution should turn purple at this electrode. (Potassium metal will not form at the other electrode because of the presence of water.) Record your observations.
14. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Analyze

1. Complete the following reactions by deciding which products will be produced. Then, write word equations representing the complete reactions.
   (a) $Al + CuCl_2 \rightarrow$
   (b) $CaCl_2 + Na_2CO_3 \rightarrow$
   (c) $KI \rightarrow$
2. Translate each of the word equations you have just written into balanced formula equations.
3. Classify each of the chemical reactions.

Conclude and Apply

1. Explain why it is helpful to have some method to test the product(s) you have made in a chemical reaction.
2. Apply your knowledge of chemical reactions to classify each of the reactions below. Then, write the balanced equations for these reactions.
   (a) $Cd + CuF_2 \rightarrow$
   (b) $CrBr_3 + K_2SO_4 \rightarrow$
   (c) $AuI_3 \rightarrow$

Stainless Steel

You probably use stainless steel many times every day. Many kitchen sinks are made of stainless steel, as are almost all knives, forks, spoons, and cookware. Large structures such as bridges are also made of stainless steel.

The Ironworkers Memorial Bridge, Vancouver

What is steel? Steel is a mixture of iron and carbon, and the combination of the two elements forms a material that is much harder than pure iron. Steel may be strong, but it is not resistant to rusting, which can be a big problem. Steel can rust when it is exposed to the weather or even to foods that contain acid, such as lemon juice.

Rust is really a term for a mixture of iron oxides and iron hydroxides. Rusting is responsible for millions of dollars' worth of damage to iron and steel every year. This is because iron oxide has no strength of its own. Iron oxide cracks and flakes off, exposing fresh iron below it to be a target for more rusting.

When iron reacts with oxygen, rust is produced. The process of rusting is also called corroding. The actual corrosion reaction occurs in the presence of oxygen dissolved in water and is aided by the presence of salt or acids. At very high temperatures, iron can react with oxygen directly in a synthesis reaction. One of the reactions that corrode steel is:

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

A close-up view of rust

How is steel made corrosion resistant, or "stainless"? Stainless steel is made of iron, carbon, and at least 11percent chromium and is very resistant to corrosion. Curiously, the reaction that prevents the corrosion of steel is remarkably similar to the reaction that causes corrosion. The reaction that makes steel stainless is the following.

$$4Cr + 3O_2 \rightarrow 2Cr_2O_3$$

Chromium oxides have very different properties than iron oxides. Chromium oxide forms a thin, invisible layer on the surface of steel. If you look at a piece of steel, you will not be able to see this layer, but it is there. The layer is only a few atoms thick, but this is enough to protect the steel from reacting with oxygen molecules and even mild acids. In fact, if the surface of the steel is scratched, a new layer of chromium oxide will form, sealing off the steel and preventing corrosion.

A stainless steel scalpel

Questions

1. How are iron, steel, and stainless steel different in terms of composition and properties?
2. (a) What is rust?
   (b) Why does the formation of rust damage iron or steel?
3. How does the presence of chromium in stainless steel give it special resistance to corrosion?

Check Your Understanding

Checking Concepts

1. Identify each of the following chemical reactions as synthesis, decomposition, single replacement, double replacement, neutralization (acid-base), or combustion.

(a) $HCl + KOH \rightarrow KCl + H_2O$
(b) $S_8 + 12O_2 \rightarrow 8SO_3$
(c) $(NH_4)_2CO_3 + Ca(NO_3)_2 \rightarrow 2NH_4NO_3 + CaCO_3$
(d) $N_2 + 3Zn \rightarrow Zn_3N_2$
(e) $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$
(f) $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$
(g) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
(h) $H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O$
(i) $2HF \rightarrow H_2 + F_2$
(j) $2Au(NO_3)_3 + 3Cu \rightarrow 2Au + 3Cu(NO_3)_2$

Understanding Key Ideas

2. Combustion and single replacement reactions both involve an element reacting with a compound. How can you tell the difference between these two reactions by looking only at the reactants?

3. No classification system is perfect. Find an example in this chapter of a chemical reaction that could be classified in more than one way.

4. Classify each of the following reactions, and write balanced formula equations for them.

(a) sodium + oxygen ➔ sodium oxide
(b) sodium sulfate + calcium chloride ➔ sodium chloride + calcium sulfate
(c) propane (C_3H_8) + oxygen ➔ carbon dioxide + water
(d) sulfuric acid + potassium hydroxide ➔ potassium sulfate + water
(e) aluminum chloride ➔ aluminum + chlorine
(f) cadmium + gold(III) nitrate ➔ cadmium nitrate + gold
(g) strontium hydroxide + lead(II) bromide ➔ strontium bromide + lead(II) hydroxide
(h) glucose ($C_6H_{12}O_6$) + oxygen ➔ carbon dioxide + water
(i) nitrogen + oxygen ➔ dinitrogen trioxide
(j) nitric acid + zinc ➔ zinc nitrate + hydrogen

5. Classify each reaction, and write the formula of each product or products. Balance the equation.

(a) $Na + N_2 \rightarrow$
(b) $AlF_3 \rightarrow$
(c) $CuSO_4 + Al \rightarrow$
(d) $CaI_2 + Pb(NO_3)_2 \rightarrow$
(e) $C_4H_{10} + O_2 \rightarrow$
(f) $AgNO_3 + NaBr \rightarrow$
(g) $CsI + Cl_2 \rightarrow$
(h) $HCl + NaOH \rightarrow$
(i) $K_2Cr_2O_7 + AgNO_3 \rightarrow$
(j) $C_5H_{10}O_5 + O_2 \rightarrow$

6. Write the balanced formula equation for the synthesis of iron(III) chloride (shown below) from its elements.

Pause and Reflect

When classifying a reaction, why might it *not* be helpful to consider whether the reaction produces water?