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.

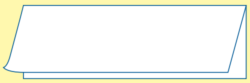
Skills You Will Use

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

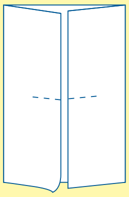
FOLDABLES™ Reading & Study Skills

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

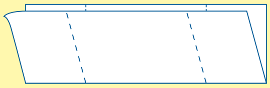
STEP 1 **Hold** a sheet of 28 cm by 43 cm paper with the long edge held horizontally and fold, but instead of creasing the paper, pinch it to show the midpoint.



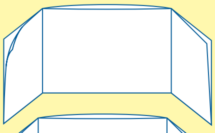
STEP 2 **Fold** the outer edges of the paper to meet at the pinch, or midpoint, forming a shutterfold. **Crease** the folds well, and then **open** the shutterfold.



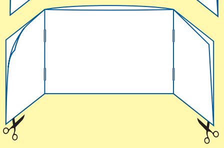
STEP 3 **Fold** the paper upward, so that the two horizontal edges meet.



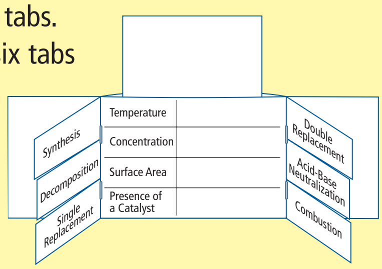
STEP 4 Use the left and right creases to **fold** the edges inward, which will create a large central pocket. **Glue** or **staple** the left and right creases to reinforce the pocket.



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



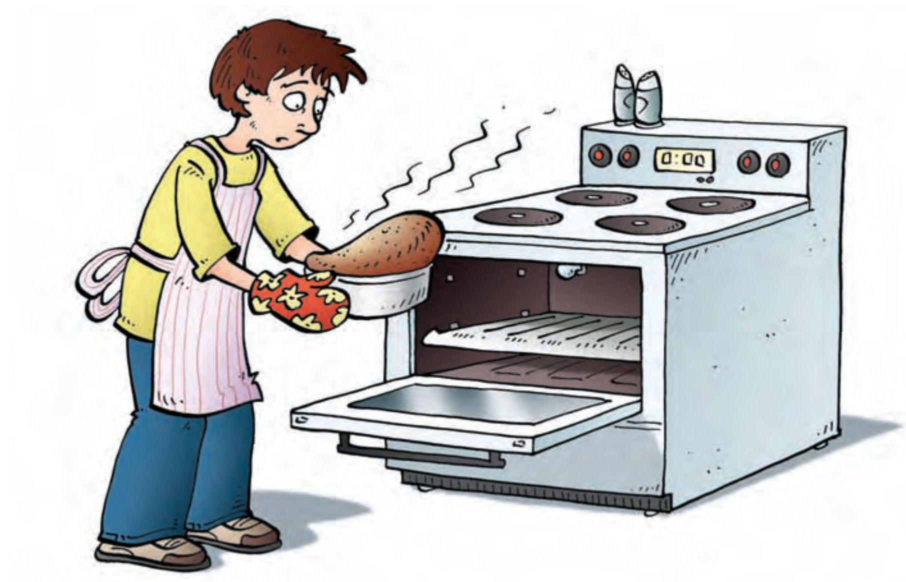
STEP 6 **Cut** the side tabs of the top layer into thirds to make six tabs. **Label** the six tabs with the six different types of chemical reactions.



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.

Did You Know?

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

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.

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.

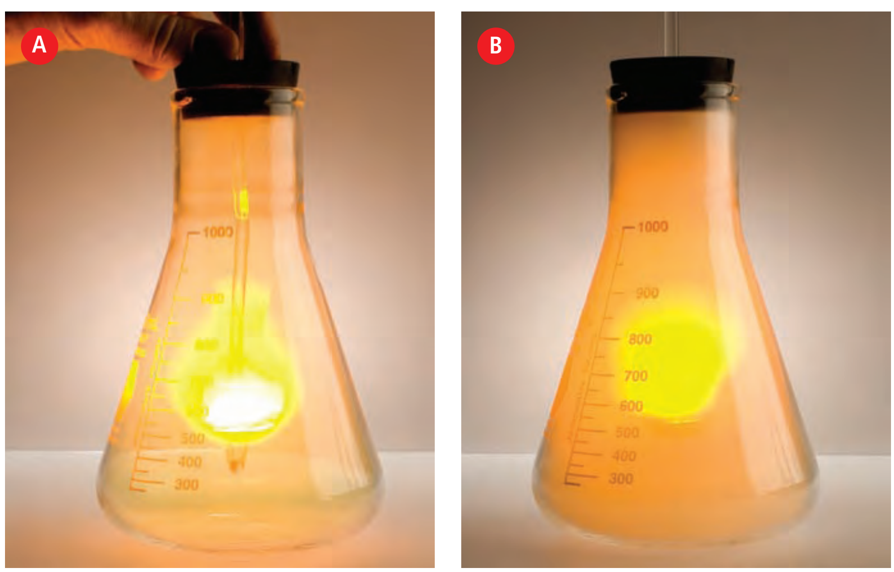


Figure 6.2 Sodium is added to a flask of chlorine gas (A). This synthesis reaction continues until all the sodium has combined with chlorine, producing NaCl (B).

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.

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.

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

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

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

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.

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.

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.

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

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.

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

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)	$A + B \rightarrow AB$	• Two elements combine (Figure 6.9).
Decomposition	$AB \rightarrow A + B$	• One reactant only (Figure 6.9)
Single replacement		
If A is a metal	$A + BC \rightarrow B + AC$	• One element and one compound
If A is a non-metal	$A + BC \rightarrow C + BA$	
Double replacement	$AB + CD \rightarrow AD + CB$	• 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 ➔

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 ➔ Fe + O_2
balanced equation: $2Fe_2O_3$ ➔ 4Fe + $3O_2$

2. Al + $NiBr_3$ ➔

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 + $NiBr_2$ ➔ Ni + $AlBr_3$
balanced equation: 2Al + $3NiBr_2$ ➔ 3Ni + $2AlBr_3$

3. Cl_2 + $NiBr_2$ ➔

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 + $NiBr_2$ ➔ Br_2 + $NiCl_2$
balanced equation: Cl_2 + $NiBr_2$ ➔ Br_2 + $NiCl_2$ (already balanced)

4. HCl + $Mg(OH)_2$ ➔

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 + $Mg(OH)_2$ ➔ $MgCl_2$ + H_2O
balanced equation: 2HCl + $Mg(OH)_2$ ➔ $MgCl_2$ + $2H_2O$

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).

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: $6Li + N_2 \rightarrow 2Li_3N$

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: $2AgNO_3 + Na_2CrO_4 \rightarrow 2NaNO_3 + Ag_2CrO_4$

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

Suggested Activity

Conduct an Investigation 6-1B on page 268

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

SkillCheck

- 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 × 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?

6.2 Factors Affecting the Rate of Chemical Reactions

Understanding the factors that affect reaction rates helps chemists speed up or slow down chemical reactions. Four main factors affect the rate of chemical reactions: temperature (hotter is faster), surface area (the more surface contact between reactants, the faster the reaction), concentration (the greater the concentration, the faster the reaction rate), and the presence of a catalyst (the catalyst helps the reaction go more quickly but is still present in the same amount at the end of the reaction).

Words to Know

catalyst
catalytic converter
rate of reaction
surface area

Many chemical reactions happen quickly, sometimes at tremendous rates. For example, chemicals that burn slowly under usual conditions can react explosively in their powder form. The increased contact between air and powder can be enough to blow up an entire grain silo. This is a real concern for people who work in or live close to granaries, coal mines, and other industrial operations, such as flour mills, where powders are manufactured, used, or packaged.

Other chemical reactions occur much more slowly and can take many hundreds or even thousands of years to complete. You may have observed evidence of the slow rusting of a bicycle chain (Figure 6.12). Unless a bicycle chain is protected with a coating of oil, it will eventually become too rusted to use, but this can take years.

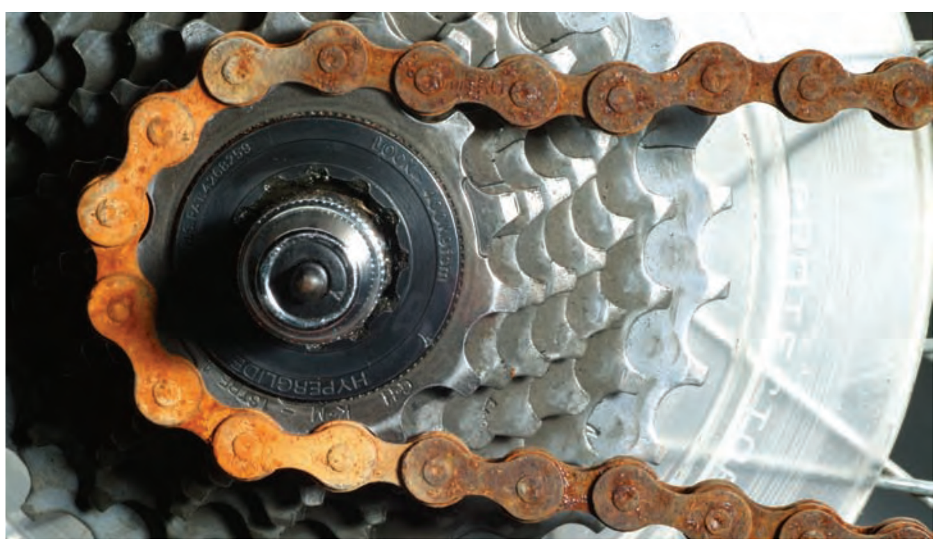


Figure 6.12 Rusting can seriously damage the parts of a bicycle.

In a chemical reaction, how quickly or slowly reactants turn into products is called **rate of reaction**. A reaction that takes a long time has a low reaction rate. A reaction that occurs quickly has a high reaction rate. A *rate* describes how quickly or slowly a change occurs. Every chemical reaction proceeds at a definite rate. However, you can speed up or slow down the rate of a chemical reaction.

Did You Know?

The conversion of graphite into diamond, both of which are made of pure carbon, happens faster when the graphite is compressed at high temperatures and pressures.

6-2A Increasing Reaction Rate

Find Out ACTIVITY

Teacher Demonstration

In this activity, your teacher will demonstrate three ways to increase the rate of a reaction. See if you can identify which factors might be involved in the rate increase.

Safety

- Avoid touching all reactants and products.
- Follow your teacher's directions regarding using open flames.
- Do not remove any materials from the science room.

Materials

- three 100 mL beakers
- hydrochloric acid solutions (3 M, 1 M, and 0.1 M)
- magnesium ribbon
- 50 cm sheet of aluminum foil
- masking tape
- sifted flour
- small plastic bowl
- candle
- matches or flame striker
- sifter
- 200 mL graduated cylinder
- plastic pan
- dish soap
- food colouring
- potassium iodide powder
- hydrogen peroxide solution
- wooden splint

What to Do

Demonstration 1 Single Replacement Reaction between Magnesium and Hydrochloric Acid

1. Fill each of three 100 mL beakers with about 75 mL of a different concentration of hydrochloric acid solution. Label them 3 M, 1 M, and 0.1 M. (The concentration unit, M, stands for molar. A 1 M solution is 10 times more concentrated than a 0.1 M solution.)
2. Cut three 5 cm strips of magnesium ribbon.
3. Drop one magnesium strip into each beaker, and observe. Record your observations.
4. Clean up and put away the equipment you have used.

Demonstration 2 Combustion of Flour

5. Roll a sheet of aluminum foil into a tube, and tape the edges together.
6. Measure about 30 mL of sifted flour into a small plastic bowl.
7. Light a candle and hold the aluminum tube above it. Drop the flour into the tube from the top by pouring it through a sifter held above the tub. Observe. Record your observations.
8. Clean up and put away the equipment you have used.

Demonstration 3 Decomposition of Hydrogen Peroxide

9. Place a 200 mL graduated cylinder into a plastic pan (to catch any spills).
10. Add about 1 mL of soap and a few drops of food colouring to a 200 mL graduated cylinder.
11. Add about 1 mL of potassium iodide (KI) powder to the mixture.
12. Add 50 mL of hydrogen peroxide solution ($H_2O_2(aq)$) to the mixture. Observe. Record your observations.
13. Light a wooden splint. Extinguish the flame, then plunge the glowing splint into the soap bubbles that have been produced. Observe. Record your observations.
14. Clean up and put away the equipment you have used.

What Did You Find Out?

Discuss the following as a class.

1. What is the connection between the concentration of a reactant and the rate of the chemical reaction?
2. (a) What factor was responsible for increasing the rate of combustion of flour?
   (b) What are several real world situations where this factor might apply to reactions?
3. (a) What factor was responsible for speeding up the decomposition of hydrogen peroxide?
   (b) Most chemical reactions in your body are sped up in this fashion. What is the biological term for the kind of substance that speeds up reactions in living things?

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In this activity, your teacher will demonstrate three ways to increase the rate of a reaction. See if you can identify which factors might be involved in the rate increase.

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3. Drop one magnesium strip into each beaker, and observe. Record your observations.
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10. Add about 1 mL of soap and a few drops of food colouring to a 200 mL graduated cylinder.
11. Add about 1 mL of potassium iodide (KI) powder to the mixture.
12. Add 20 mL of hydrogen peroxide solution ($H_2O_2(aq)$) to the mixture. Observe. Record your observations.
13. Light a wooden splint. Extinguish the flame, then plunge the glowing splint into the soap bubbles that have been produced. Observe. Record your observations.
14. Clean up and put away the equipment you have used.

What Did You Find Out?

Discuss the following as a class.

1. What is the connection between the concentration of a reactant and the rate of the chemical reaction?
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   (b) Most chemical reactions in your body are sped up in this fashion. What is the biological term for the kind of substance that speeds up reactions in living things?

Did You Know?

The tusks, some hair, and some skin of this Siberian woolly mammoth were preserved by cold temperatures and dry air for 23 000 years before being discovered in 1997.

Temperature

One way chemists control the rate of a chemical reaction is by controlling the temperature. For example, when you cook food, you use heat to increase the rate of reactions that cause the breakdown of food into simple components. When you refrigerate food, you remove heat and lower the rate of reactions that cause food to spoil.

You can see the effect of a change in temperature on reaction rate in the operation of light sticks. The light produced by light sticks is the result of a chemical reaction that begins when you bend the light stick and crack open a container inside it. This allows the reactants to mix and begin generating light. As you can see in Figure 6.13, temperature affects the rate of reaction and the brightness of the light. When placed in hot water, light sticks glow more brightly, but they also glow for a shorter period of time because the reactants are used up more quickly than at a cooler temperature.

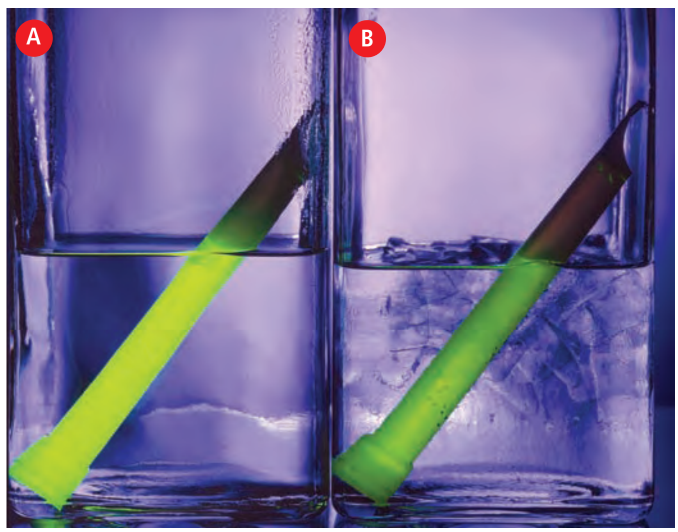

Figure 6.13 The chemical reaction rate is higher in the hot water than in the cold water. Therefore, the light stick in hot water (A) glows more brightly than the one in cold water (B).

Why does temperature affect reaction rate? Heating causes the particles (atoms or molecules) of the reactants to move more quickly, resulting in more collisions and more energy. Lowering the temperature slows down the particles of the reactants so that they collide with each other less frequently and with less energy.

Reading Check

1. Heating a light stick can make it glow brighter. Why?
2. What happens to the rate of a chemical reaction when the temperature is raised?
3. What does cooling do to the frequency at which particles of reactants can collide?
4. How does cooling affect the energy of the collisions between particles?

Concentration

Another way chemists can change the rate of a reaction is by changing the concentrations of the reactants. Concentration refers to how much solute is dissolved in a solution. We measure concentration by knowing the mass of a substance that is in 1 L of the solution. In order for new substances to be formed, the reactant atoms and molecules must be able to make contact with each other. If there is a greater concentration of reactant atoms and molecules present, there is a greater chance that collisions among them will occur. More collisions mean a higher reaction rate (Figure 6.14). Increasing the concentration of the reactants usually results in a higher reaction rate.

Figure 6.14 When you blow on a campfire, you are increasing the concentration of oxygen near the flames. Your exhaled breath has more oxygen than the air near the flames.

The concentration of a substance can change if it is in aqueous solution or in the gas state. For example, dilute hydrochloric acid will react more slowly with zinc than will concentrated hydrochloric acid (Figure 6.15). At lower concentrations, there is less chance for molecules of hydrochloric acid to make contact with the molecules of the zinc surface. Decreasing the concentrations of the reactants results in a lower reaction rate.

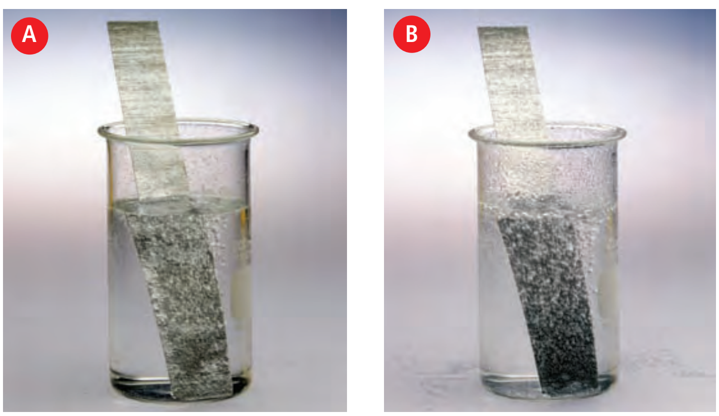

Figure 6.15 Hydrochloric acid reacts at a slower rate with zinc when the acid is less concentrated (A). The reaction rate is much faster when the acid is more concentrated (B).

We can identify oxygen gas by inserting a glowing wooden splint into a small container of the gas. If the splint bursts into flame, a high concentration of oxygen is present. In air, the splint only glows. The splint does not burst into flame because the concentration of oxygen in the air is only about 21 percent. There are not enough collisions among the oxygen molecules in air and the wooden splint to support a rapid combustion reaction. In a high concentration of oxygen, however, the increased number of collisions between oxygen molecules and the splint cause the flame to burn brightly. Figure 6.16 shows another example of the increased reaction rate when the concentration of a reactant is increased.

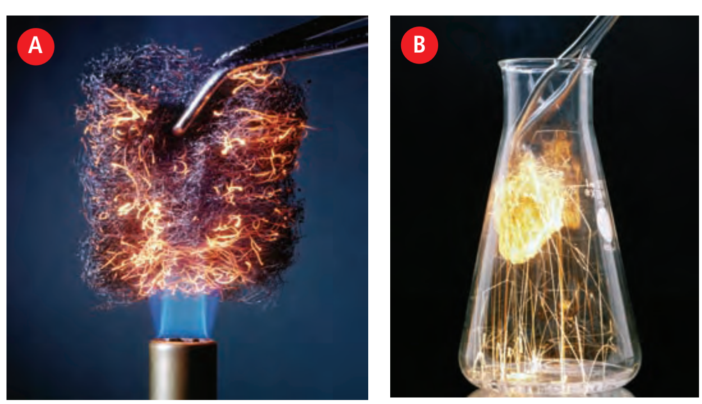

Figure 6.16 The concentration of oxygen in the air surrounding the steel wool is much less than that of the pure oxygen in the flask (A). The higher oxygen concentration in the flask accounts for the higher reaction (B).

Surface Area

Suppose you lowered a red-hot piece of steel into a flask of oxygen gas and the same mass of red-hot steel wool into another flask of oxygen gas. What might be different? The oxygen would react with the chunk of steel much more slowly than it would with the steel wool. Can you explain why? For the same mass of iron, steel wool has more surface area than the chunk of steel. **Surface area** is the measure of how much area of an object is exposed. The greater surface area of the steel wool allows oxygen molecules to collide with many more iron atoms per unit of time. For the same mass, many small particles have more total surface area than one large particle. Powders have much more surface area than solid blocks made of the same material. Powders may need to be stirred or blown into the air (as in a dust explosion) before the increase in reaction rate is noticed.

Figure 6.17 The rate at which the nylon is produced is controlled by limiting the surface area where the reactants in each layer can make contact.

Surface area can also be important if the reaction occurs between two liquids that cannot mix. In this case, the reaction can occur only at the boundary where the two liquids meet. For example, in order to make nylon, one component is dissolved in water and the other component is dissolved in an organic solvent such as tetrachloromethane. Because organic solvents and water do not mix very well, the two reactants only react at the surface where the solutions meet. This use of surface area to control the rate of the reaction allows a long thin fibre to form (Figure 6.17). Without this control, a solid block of nylon would form in the beaker. Not all reactions depend on surface area. If both reactants are gases or are liquids that mix together, then there is no surface, and surface area is not a factor.

Reading Check

1. How does increasing concentration result in an increase in reaction rate?
2. Can the concentration of a substance change if it is a gas?
3. Can the concentration of a solution change if it is an aqueous solution?
4. How does increasing the surface area of a reactant increase reaction rate?

Did You Know?

Substances called inhibitors are used to slow down a chemical reaction. For example, food preservatives such as BHT and BHA may provide chemical reactions for removing oxygen from the food. A decreased concentration of oxygen results in a slower reaction rate. Some inhibitors prevent a reaction from happening at all.

Presence of a Catalyst

The temperature and the concentration of reactants affect the rate of a reaction. However, increasing temperature or concentration is not always the best or most practical thing to do. For example, suppose that you want to increase the rate of the decomposition of glucose in a living cell. Increasing the temperature or the concentration of reactants is not an option because doing so might harm the cell. In this case, it may be helpful to use a catalyst. A **catalyst** is a substance that speeds up the rate of a chemical reaction without being used up in the reaction itself. A catalyst generally is not included directly when we write the chemical equation of a reaction.

Your body contains thousands of different biological catalysts, called enzymes (Figure 6.18). Enzymes are large organic molecules, usually proteins, which speed up reactions in living cells. Each enzyme in your body is specialized to perform its own function. For example, saliva contains an enzyme called amylase that breaks down only starch molecules. A large set of enzymes digests carbohydrates, fats, and protein molecules. Another complex set of enzymes makes new DNA. Still other enzymes convert extra nutrients into fat for storage. Many chemical reactions in living organisms would not occur quickly enough to sustain life at normal temperatures if it were not for the presence of enzymes. Like all catalysts, enzymes are not changed or used up by the reactions in which they are involved.

How do catalysts speed up reactions? Energy is needed to break bonds in any chemical reaction. One way to increase the rate of a reaction involves lowering the bond-breaking energy. Catalysts make it possible for reactions to occur with less energy than reactions would otherwise need to break old chemical bonds and form new ones. In the presence of a catalyst, molecules of reactants line up better so that when they collide with each other the reaction is more likely to take place.

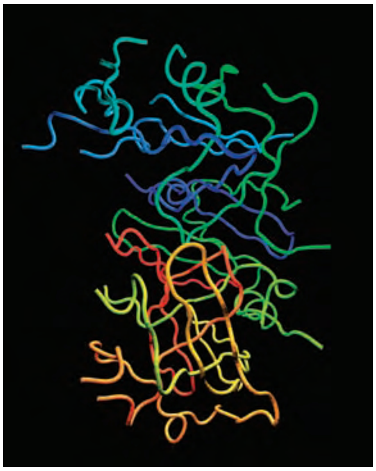

Figure 6.18 Enzymes are biological catalysts. The enzyme shown here, called TIM, helps convert glucose in your body into other kinds of molecules. During this process, energy is released for your body to use.

Catalytic converters

All automobiles built in North America since the 1980s have pollution control devices built into their exhaust systems (Figure 6.19). A **catalytic converter** is a stainless steel device, shaped like a muffler, located underneath the frame of the vehicle. Inside it is a ceramic or wire honeycomb-like structure that provides a large surface area for reactions to take place. The surface of the honeycomb is coated with a thin layer of metallic catalysts, involving platinum, rhodium, and palladium.

As exhaust passes through the catalytic converter, several reactions occur. Much of the poisonous carbon monoxide, which is produced from the combustion of gasoline, reacts with oxygen and is changed into carbon dioxide. Hydrocarbons react with oxygen to produce carbon dioxide and water. Finally, most of the poisonous nitrogen oxides are converted into nitrogen gas and oxygen gas in the following reaction.

$$2N_2O_3 \rightarrow 2N_2 + 3O_2$$

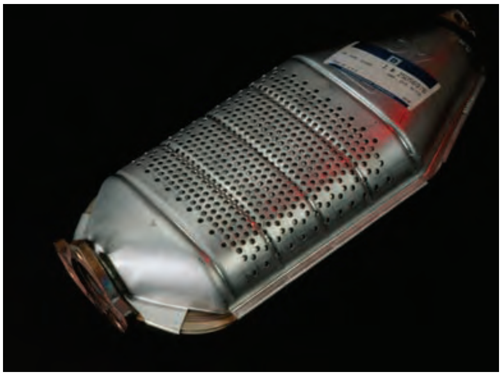

Figure 6.19 Most catalytic converters work best when the catalysts are warmed up. Studies show that 70 percent of all pollutants released from a car happen during the first 90 s while the car warms up. Very little pollution is produced after the first 90 s.

Suggested Activity

Conduct an Investigation 6-2B on page 278.

Explore More

Foods often spoil because they react with oxygen. Many methods of food preservation maintain product freshness by excluding oxygen. For example, crackers and popcorn are often packaged in an atmosphere of an unreactive gas such as nitrogen or argon. Find out more about chemical reactions and food preservation. Start your search at **www.bcscience10.ca.**

6-2B Factors Affecting Reaction Rate

SkillCheck

- Observing
- Predicting
- Measuring
- Controlling variables

Safety

- Wear safety goggles and protective clothing.
- Avoid touching all reactants and products.
- Do not remove any materials from the science room.
- Never taste or eat anything in the science room.
- 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 investigate temperature, surface area, and presence of a catalyst as factors affecting the rate of a reaction.

Question

How do temperature, surface area, and the presence of a catalyst affect the rate of a chemical reaction?

Materials

Part 1

- two 400 mL beakers
- ice water
- hot water
- thermometer
- 3 effervescent tablets
- stopwatch

Part 2

- 3 small test tubes
- test tube rack
- dish soap
- 6% hydrogen peroxide solution (H_2O_2)
- potassium iodide (KI)
- copper(II) chloride ($CuCl_2$)
- sodium chloride (NaCl)

Part 3

- mortar and pestle
- sodium carbonate
- 4 small test tubes
- test tube rack
- dilute hydrochloric acid solution (HCl)

Procedure

Part 1 Effect of Temperature

1. Fill one beaker with ice water. Fill the second beaker with very hot water. Use a thermometer to measure the temperature in each beaker. Record the temperatures.
2. Drop an effervescent tablet into each beaker at the same time. Observe. Use a stopwatch to measure how many seconds it takes for each tablet to finish dissolving. Record the times. Dispose of beaker contents down the sink.

3. Fill one of the beakers with a mixture of hot water and ice water. Adjust the temperature by adding more warm or cool water until the temperature is halfway between the temperatures recorded in step 1.
4. Make a prediction of the length of time it will take for an effervescent tablet to finish dissolving. Record your prediction.
5. Add a tablet to the water that is at a middle temperature. Observe and record the time it takes to dissolve. Dispose of beaker contents down the sink.

Part 2 Effect of Adding a Catalyst

6. Label three test tubes: KI, $CuCl_2$, NaCl. Place the test tubes in the test tube rack.
7. Place one drop of dish soap into each test tube.
8. Into each test tube, pour 6% hydrogen peroxide to a depth of about 2 cm.
9. Add a pea-sized amount of solid KI, $CuCl_2$, and NaCl to the appropriate test tube. Observe. Record your observations, including which reaction rate is the fastest and which is the slowest.
10. Dispose of test tube contents as your teacher directs.

Part 3 Effect of Surface Area

11. Use the pestle to grind some sodium carbonate lumps into a fine powder in the mortar. Place the four test tubes in the test tube rack.
12. Place lumps of sodium carbonate into one of the test tubes to a depth of about 1 cm. Place some finely ground sodium carbonate into a second test tube to a depth of about 1 cm.
13. Measure dilute hydrochloric acid solution into the two remaining test tubes to a depth of about 2 cm.
14. Simultaneously, pour the dilute HCl solution into each of the test tubes containing sodium carbonate. Observe. Note which reaction was faster.
15. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Analyze

1. What is the relationship between rate of reaction and change in temperature?
2. Compare your prediction in step 4 of the length of time it would take an effervescent table to dissolve at the middle temperature with how long it actually took.
3. (a) Which of the solutions that were added to the hydrogen peroxide solution may have acted as a catalyst?
   (b) Which catalyst sped up the reaction the most?
4. Which has more surface area, a 5 g lump of sodium carbonate or 5 g of sodium carbonate powder?
5. How did surface area affect the rate of sodium carbonate decomposition in step 14?

Conclude and Apply

1. Suppose a reaction involved a finely ground powder reacting with a concentrated acid. Suggest three methods of decreasing the reaction rate.

Science Watch

Testing an air bag

Manufacturing air bags

Reaction Rate in Air Bags

Impact! Within 27 ms (0.027 s), a nylon air bag inflates. Another 23 ms later, the driver narrowly escapes serious injury, perhaps even death. Air bags are now a required feature of all new cars and trucks. Research shows that deaths among drivers using air bags and seatbelts are 26 percent lower than when using seatbelts alone.

Air bags dramatically illustrate the need for careful, precise control of chemical reactions. Vehicle air bags contain a compound called sodium azide, NaN_3, in the form of pellets. By carefully determining and controlling the surface area, a precise amount of gas is released at a highly specific rate. What might be the consequences if engineers could not control this reaction?

The air bag needs to inflate quickly enough to provide impact protection. But that is not all. The air bag needs to be partly deflated before the driver or passenger makes contact with it. Hitting the bag at maximum inflation would be just as dangerous as hitting an unprotected dashboard or steering wheel.

The shape of the sodium azide pellets allows engineers to determine the precise surface area needed for a reaction to occur within a very specific period of time, measured in milliseconds. If a front-end collision occurs, an electric signal ignites the sodium azide. The compound quickly decomposes, releasing 60 L of nitrogen gas to inflate the bag.

The chemical equation for the decomposition reaction of sodium azide is:

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

If the sodium that results from the reaction were to come in contact with moisture—for example, from a person's mouth or eyes—caustic sodium hydroxide would form. To prevent this, designers include other components, such as aluminum silicate, silicon dioxide, or alumina in the air bag. These components react with the sodium to form non-toxic sodium silicate, a form of sand, which is unreactive and safe.

Questions

1. What are the negative effects of an air bag inflating or deflating too slowly?
2. What does controlling the surface area of the sodium azide pellets have to do with the operation of air bags?
3. The decomposition of NaN_3 produces nitrogen gas, which inflates the air bag, as well as sodium metal.
   (a) What are the harmful effects of sodium metal?
   (b) How is sodium metal removed from the air bag during inflation?

Check Your Understanding

Checking Concepts

1. Give three examples where it is helpful to have a high reaction rate.
2. Give three examples where it is helpful to have a low reaction rate.
3. What is the function of enzymes?
4. What usually happens to the rate of a reaction when the concentration of one of the reactants is increased?
5. Which has a greater surface area, a single sugar cube or a spoonful of sugar? Explain your answer.
6. How does surface area affect the rate of a reaction?
7. Give an example of a reaction where surface area is not a factor.
8. How does a catalyst speed up a chemical reaction?

Understanding Key Ideas

9. The various factors that affect the rate of a reaction work in different ways at the molecular level. Raising temperature causes molecules to move more quickly, allowing them to hit each other harder and more often. Raising the concentration puts more molecules into the system than were present before. Adding a catalyst helps the molecules to hit with better alignment, making the formation of product more likely.
   (a) Which of these factors increase the reaction rate by increasing the number of collisions between reacting molecules?
   (b) Which of these factors work by making the collisions between the molecules happen in a more effective way?
   (c) Do any of these factors do both?
10. Explain how raising the temperature increases the rate of a chemical reaction.
11. Explain why increasing the surface area in a reaction will increase the rate of the reaction.
12. Explain why increasing the concentration of a reactant will increase the rate of a reaction.
13. Explain how using a catalyst makes it possible for the reaction to happen with less energy than without the catalyst.

Pause and Reflect

Suppose you have a box full of wrapped chocolates. Whenever you unwrap a chocolate to eat it, you throw the wrapper back into the box.

(a) What will happen to your rate of chocolate eating as time goes on?

(b) Why will it change?

(c) How might this analogy apply to the rate of a chemical reaction in terms of a catalyst (you) and concentration of reactants?

Chapter Review

Prepare Your Own Summary

In this chapter, you learned to classify reactions as one of six different types as well as predict the identity of the products of the reaction. You investigated the factors that affect the rate of chemical reaction and examined the role of catalysts in reaction rate. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with graphic organizers.) Use the following headings to organize your notes:

1. Six Types of Chemical Reactions
2. Classifying and Predicting Products of Reactions Based on the Reactants Only
3. Examples of Reactions Occurring at Different Rates
4. Four Factors Affecting the Rates of Reactions.

Checking Concepts

1. Identify each of the following reactions as synthesis, decomposition, single replacement, double replacement, neutralization (acid-base), or combustion.
   (a) $H_3PO_4 + 3NaOH \rightarrow Na_3PO_4 + 3H_2O$
   (b) $P_4 + 5O_2 \rightarrow P_4O_{10}$
   (c) $2Al + N_2 \rightarrow 2AlN$
   (d) $2HBr \rightarrow H_2 + Br_2$
   (e) $HF + KOH \rightarrow KF + H_2O$
   (f) $Au(NO_3)_3 + 3KI \rightarrow AuI_3 + 3KNO_3$
   (g) $Mg + 2\ HCl \rightarrow MgCl_2 + H_2$
   (h) $2Ti(NO_3)_3 + 3Cu \rightarrow 2Ti + 3Cu(NO_3)_2$
   (i) $(NH_4)_2CO_3 + Mn(NO_3)_2 \rightarrow 2NH_4NO_3 + MnCO_3$
   (j) $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$
2. Each reaction below has been identified by type. Use this information to help predict products. Copy and then complete each equation by writing the products of the reactions. **Hint:** Use the charges shown on the periodic table in Figure 4.3 on page 172. Remember to include subscripts and parentheses when required.
   (a) $Al + F_2 \rightarrow$ synthesis
   (b) $K + O_2 \rightarrow$ synthesis
   (c) $C_2H_6 + O_2 \rightarrow$ combustion
   (d) $C_6H_{12}O_4 + O_2 \rightarrow$ combustion
   (e) $Rb_2O \rightarrow$ decomposition
   (f) $SrF_2 \rightarrow$ decomposition
   (g) $BaCl_2 + Pb(NO_3)_2 \rightarrow$ double replacement
   (h) $AgNO_3 + K_2Cr_2O_7 \rightarrow$ double replacement
   (i) $Br_2 + NiI_3 \rightarrow$ single replacement, element is a non-metal
   (j) $Cl_2 + Mg_3N_2 \rightarrow$ single replacement, element is a non-metal
   (k) $HCl + Mo(OH)_2 \rightarrow$ neutralization (acid-base)
   (l) $Sn(OH)_2 + HClO_3 \rightarrow$ neutralization (acid-base)
   (m) $Al + CuI_2 \rightarrow$ single replacement, element is a metal
   (n) $Mg + FeF_2 \rightarrow$ single replacement, element is a metal
3. Which type(s) of reactions match the following descriptions?
   (a) There is only one reactant.
   (b) There is only one product.
   (c) The reactants are an acid and a base.
   (d) The products are an element and a compound.
   (e) The products are carbon dioxide and water.
   (f) Both reactants are compounds.
   (g) One reactant is an element. The other is a compound.

4. Which of the four factors affecting reaction rate is most important in each example below? Choose from among concentration, temperature, surface area, and catalyst.
   (a) Extra dish soap is added to help cut the grease when washing a frying pan.
   (b) Firewood is chopped up into kindling (small pieces) to help start a fire.
   (c) A lighted match is brought near a candlewick in order to light the candle.
   (d) Lemon juice is rubbed on an iron sink to help remove rust.
   (e) The accelerator pedal in a car is pressed, resulting in a faster consumption of fuel in the engine.
   (f) The reaction of oxygen with sucrose in human cells takes place in the presence of an enzyme.
   (g) In order to release the fragrance of garlic when frying it in oil, the garlic is crushed and ground.
   (h) A mild skin disinfectant containing hydrogen peroxide is prepared in a 1 percent solution, while a stronger formulation is prepared in a 3 percent solution.

Understanding Key Ideas

5. Classify each of the following reactions, and write a balanced formula equation for each.
   (a) lithium + oxygen ➔ lithium oxide
   (b) magnesium + aluminum chloride ➔ magnesium chloride + aluminum
   (c) butane (C_4H_{10}) + oxygen ➔ carbon dioxide + water
   (d) hydrochloric acid + lithium hydroxide ➔ lithium chloride + water
   (e) aluminum oxide ➔ aluminum + oxygen
   (f) tin + gold(III) nitrate ➔ tin(IV) nitrate + gold
   (g) barium hydroxide + lead((IV) bromide ➔ barium bromide + lead(IV) hydroxide
   (h) glycerine ($C_3H_8O_3$) + oxygen ➔ carbon dioxide + water
   (i) nitrogen + oxygen ➔ nitrogen dioxide
6. Some chemical reactions are affected by surface area, whereas others are not. Explain why this is so.

Applying Your Understanding

7. Suppose a chemist performed an experiment dissolving equal masses of marble in hydrochloric acid. The results of the three trials are shown in the table below.

Trial	Hydrochloric Acid	Marble	Temperature
1.	Dilute	Finely ground	20°C
2.	Concentrated	Lump	20°C
3.	Dilute	Lump	40°C

The marble dissolved fastest in Trial 1. and slowest in Trial 2. List concentration, surface area, and temperature in decreasing order of their importance in increasing the rate of this reaction.

Pause and Reflect

Many chemical reactions happen in your daily life. When might it be important for you to use your knowledge of speeding up or slowing down chemical reactions? How could you use your knowledge?