6

Chemical reactions can be grouped according to the characteristics of their reactants and products.

The colourful patterns on these sails are the result of a dye process that relies on chemical reactions.

Skills You Will Use

In this chapter, you will:

- use appropriate terminology related to chemical reactions
- investigate simple chemical reactions, including synthesis, decomposition, and displacement reactions, and represent them using a variety of formats

Concepts You Will Learn

In this chapter, you will:

- write word equations and balanced chemical equations for simple chemical reactions
- describe, on the basis of observation, the reactants in and products of a variety of chemical reactions, including synthesis, decomposition, and displacement reactions

Why It Is Important

The products you buy and use every day are made using chemical reactions. As a consumer, you have a responsibility to use these products safely and choose products that do the least harm to the environment. Knowing about the types of chemical reactions can help you do this. Many careers also require some knowledge of the types of chemical reactions.

Before Writing

Thinking Literacy

Making Precise Observations

Scientists try to be very precise in describing what they see. They use adjectives to describe the colour, shape, size, quantity, and quality of substances and reactions. As you read "The Chemistry of Steel," note the adjectives that help you to see and understand the substances and the process.

Key Terms

- combustion reaction • decomposition reaction
- displacement reaction • synthesis reaction

6.1 Synthesis Reactions and Decomposition Reactions

Here is a summary of what you will learn in this section:

- Chemical reactions can be classified into types.
- You can identify the type of chemical reaction by considering the reactants and products.
- In synthesis reactions, two or more elements combine to produce at least one new pure substance.
- In decomposition reactions, a single compound is broken down into its elements.

Figure 6.1 The updated architecture of the Art Gallery of Ontario depends on the strength and malleability of steel.

Figure 6.2 The extraction of iron metal from iron ore is performed in this enormous tower called a blast furnace.

The Chemistry of Steel

Steel is the most widely used metal and most recycled material on Earth. Steel manufacturing is a major industry in Ontario, and steel has been used in some of the most impressive architectural designs of our time, including the Art Gallery of Ontario (Figure 6.1). Steel is found in our homes, vehicles, appliances, tools, computers, and even in the zippers and clasps of our clothing. According to the Canadian Steel Producers Association, every Canadian owns an average of over 900 kg of steel!

Steel is made from highly purified iron and a small amount of carbon. The carbon in steel makes it much stronger than pure iron. Steel is produced from four materials: iron ore (mainly iron(III) oxide), coke, oxygen, and calcium carbonate (limestone). Coke is pure carbon, formed by heating coal in the absence of air.

The process of making steel begins in a smelter. A smelter contains a blast furnace, which is a chimney-like structure in which iron metal is extracted from iron ore in a process called "smelting" (Figure 6.2). During smelting, iron ore, coke, and limestone are loaded into the top of the blast furnace, while air is blown in from below. Smelting of the iron ore produces an impure liquid metal called "hot metal." When hot metal solidifies, it is called "pig iron."

The first chemical reaction in the smelting process is between carbon (C) and oxygen (O_2). The carbon monoxide (CO) that is produced then reacts with the iron(III) oxide (Fe_2O_3) to give molten iron metal:

$$2C(s) + O_2(g) \rightarrow 2CO(g)$$

$$3CO(g) + Fe_2O_3(s) \rightarrow 2Fe(l) + 3CO_2(g)$$

Limestone (calcium carbonate, $CaCO_3$) is then added to the hot metal, $Fe(l)$, to remove impurities and refine the iron. The initial chemical reaction breaks down the calcium carbonate, forming calcium oxide (CaO) and carbon dioxide (CO_2). Next, the calcium oxide reacts with the impurities and produces molten calcium silicate ($CaSiO_3$), commonly called slag.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

$$CaO(s) + SiO_2(s) \rightarrow CaSiO_3(l)$$

Calcium silicate is less dense than molten iron, so it can be poured off separately, leaving behind the purified iron. Iron is converted to steel by adding small amounts of carbon and, in some cases, elements such as manganese, silicon, nickel, molybdenum, and chromium (Figure 6.3). This process produces the steel that you use and employs thousands of Canadians.

Figure 6.3 Stainless steel contains iron, carbon, and at least 11 percent chromium.

B20 *Quick Lab*

Simulating Chemical Reactions

Purpose

To use tennis balls to model chemical reactions

Procedure

1. Suppose you have two tennis balls, A and B, that are apart. One way that they can interact is to join (Figure 6.4), forming the pair AB. If balls A and B were already joined, the only interaction would be for them to separate (Figure 6.5).

Questions

2. What kinds of interactions are possible among three tennis balls? Draw, label, and colour the possible interactions for three tennis balls, A, B, and C.
3. Repeat the exercise using four tennis balls, A, B, C, and D.
4. Share the interactions you find with one or more of your classmates.

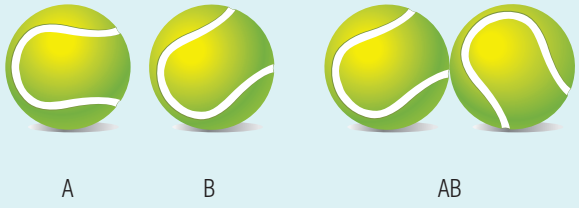

Figure 6.4 The two tennis balls can interact by forming a pair.

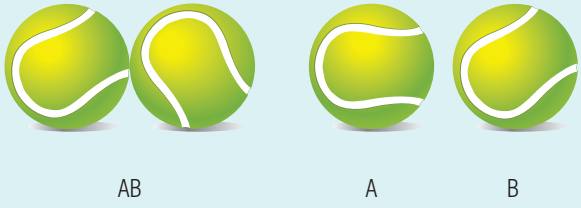

Figure 6.5 Here, the two tennis balls can interact by coming apart.

Figure 6.6 New plastics are developed using chemical reactions that are predicted to give products with different properties.

Types of Chemical Reactions

There are many possible ways that elements and compounds may interact. In other words, there are many types of chemical reactions. When you can identify a reaction type from the reactants, you can predict the products of the reaction. Predicting products is important in the manufacture of many of the consumer goods we use, such as plastics (Figure 6.6). When chemists develop new plastics, they predict the products of the chemical reactions they use.

Each type of chemical reaction can be represented by a general chemical equation. A **general chemical equation** (**GCE**) is an equation that uses letters of the alphabet (A, B, C, D) in place of the symbols for elements. A GCE can help you understand and remember a type of chemical reaction more easily. Table 6.1 shows how letters are used when writing a GCE.

Table 6.1 Symbols and Formulas Used in General Chemical Equations

Symbol or Formula	Meaning
a single letter (e.g., A, B, X)	a metallic element (e.g., Li or Mg) or a non-metallic element (e.g., H or F)
H	hydrogen ion (in an acid), on the left of the formula (e.g., HCl)
OH	hydroxide ion (in a base), on the right of the formula (e.g., NaOH)
AB or CD	an ionic compound with a metallic ion and a non-metallic ion, such as Li_2O or $MgBr_2$
AB or CD	a molecular compound of two non-metals, such as H_2O or CO
H_2O	water (compound)
CO_2	carbon dioxide (compound)

For example, in chapter 5, you explored neutralization reactions between acids and bases. The GCE for a neutralization reaction is:

General chemical equation: $HB + XOH \rightarrow XB + H_2O$

Word equation: sulphuric acid + sodium hydroxide → sodium sulphate + water

Skeleton equation: $H_2SO_4(aq) + NaOH(s) \rightarrow Na_2SO_4(aq) + H_2O(l)$

Balanced chemical equation: $H_2SO_4(aq) + 2NaOH(s) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

Synthesis Reactions

In the simplest type of **synthesis reaction**, two elements combine to form a compound. Either a metallic element combines with a non-metallic element or a non-metallic element combines with a second non-metallic element to produce one compound. A general statement for a synthesis reaction is:

element + element → compound

The general chemical equation for a synthesis reaction is:

A + B → AB

Whenever the reactants of a chemical reaction are two elements and the product is a single compound, you know that the chemical reaction is a synthesis reaction. For example, when the metallic element magnesium burns in the presence of oxygen gas, magnesium oxide is formed (Figure 6.7). Oxygen is a non-metallic element that forms diatomic molecules. The formulas and states of matter at room temperature of some common molecular elements and compounds are shown in Table 6.2.

Skeleton equation: $Mg(s) + O_2(g) \rightarrow MgO(s)$

Balanced chemical equation: $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

Magnesium oxide has a number of commercial uses, including making reflective coatings for optical instruments and lining metal and glass furnaces.

Sulphur and oxygen can also undergo a synthesis reaction, producing a poisonous gas called sulphur dioxide. In this case, both reactants are non-metallic elements.

Skeleton equation: $S_8(g) + O_2(g) \rightarrow SO_2(g)$

Balanced chemical equation: $S_8(g) + 8O_2(g) \rightarrow 8SO_2(g)$

As you saw in chapter 5, sulphur dioxide can combine with water in the air to form acid rain. That is why as much sulphur as possible is removed from gasoline during production.

Another synthesis reaction involving only non-metals is the synthesis of ammonia from its elements. The formula of ammonia is NH_3, so the reactants must be the elements hydrogen and nitrogen. Both of these elements form diatomic molecules.

Skeleton equation: $H_2(g) + N_2(g) \rightarrow NH_3(g)$

Balanced chemical equation: $3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$

Since ammonia is used in the production of fertilizers and other useful compounds, synthesizing ammonia is an important industrial reaction.

WORDS MATTER

The word "synthesis" comes from two Greek words: *syn* meaning "together" and *tithenai*, meaning "put." Synthesis therefore literally means put together.

Figure 6.7 Magnesium oxide is the ashy, white solid below the flame.

Table 6.2 Common Molecular Elements and Compounds, with States at Room Temperature

Formula (State)	Name
Molecular Elements	
$H_2(g)$	hydrogen
$N_2(g)$	nitrogen
$O_2(g)$	oxygen
$F_2(g)$	fluorine
$Cl_2(g)$	chlorine
$Br_2(l)$	bromine
$I_2(s)$	iodine
$P_4(s)$	phosphorus
$S_8(s)$	sulphur
Molecular Compounds	
$CH_4(g)$	methane
$H_2O(l)$	water
$NH_3(g)$	ammonia

Practice Problems

1. Lithium and chlorine combine to produce lithium chloride. Identify the type of chemical reaction, and then write the balanced chemical equation.
2. Calcium oxide is produced from calcium and oxygen. Identify the type of chemical reaction, and then write the balanced chemical equation.
3. Carbon dioxide gas can be formed from two non-metals, solid carbon and oxygen gas. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

Example Problem 6.1

Sodium sulphide is a yellow-red solid that is used in making dyes and in processing wood pulp. Although sodium sulphide is not produced commercially this way, a chemical reaction between solid sodium and solid sulphur will produce solid sodium sulphide. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

1. Write the word equation for the reaction.
   sodium + sulphur → sodium sulphide
2. Identify the type of chemical reaction from the nature of the reactants and products.
   - Sodium is a metallic element, sulphur is a non-metallic element, and sodium sulphide is a compound. Therefore, the chemical reaction is a synthesis reaction.
3. Use the word equation to write the skeleton equation, including states.
   - Sulphur is a molecular element with the formula S_8. This information must be read from a chart or memorized.
     $Na(s) + S_8(s) \rightarrow Na_2S(s)$
4. Write the balanced chemical equation for the reaction.
   $16Na(s) + S_8(s) \rightarrow 8Na_2S(s)$

Decomposition Reactions

During a **decomposition reaction**, a compound is broken apart into two or more elements and/or simpler compounds. A decomposition reaction is the reverse of a synthesis reaction. The elements that are produced may be a metallic element and a non-metallic element or two non-metallic elements.

Suggested Activity •
B21 Inquiry Activity on page 228

compound → element + element

The GCE for a decomposition reaction is:

AB → A + B

Whenever the reactant of a chemical reaction is a single compound and the products are elements or simpler compounds, you can identify the chemical reaction as a decomposition reaction.

For example, chemists in the 18th century prepared oxygen gas by heating solid mercury(II) oxide, leaving globules of mercury metal.

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

Balanced chemical equation: $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$

Take It Further

Synthesis and decomposition reactions are more common and important than you might think. Prepare a script for a short newscast or documentary on one or both of these types of chemical reactions using information and images. Begin your research at *ScienceSource*.

The breakdown of water into hydrogen and oxygen is another example of a decomposition reaction. Figure 6.8 shows an apparatus that is used to decompose water in a laboratory. This apparatus is called the Hoffman apparatus, and it decomposes water by passing electricity through it.

Skeleton equation: $H_2O(l) \rightarrow H_2(g) + O_2(g)$

Balanced chemical equation: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

Some vehicles now use hydrogen gas as fuel for at least part of their energy needs. However, it is not practical to use electricity to produce the amounts of hydrogen gas needed by hydrogen-fuelled vehicles.

Large volumes of hydrogen are produced by the decomposition of methane (CH_4, natural gas). A device called a reformer or a fuel processor splits the hydrogen atoms from the carbon atoms in the methane. This method of producing hydrogen gas has two main disadvantages. First, it depends on methane gas, which is a non-renewable energy source. Secondly, it also produces carbon dioxide, a greenhouse gas that contributes to global warming.

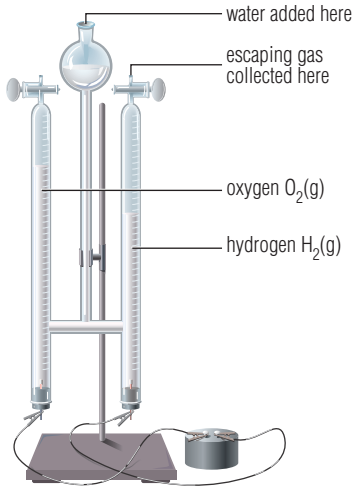

Figure 6.8 A Hoffman apparatus breaks water down into oxygen and hydrogen using electricity. This process is called electrolysis.

Example Problem 6.2

Solid calcium chloride is used to reduce dust on roads and in mines. When calcium chloride is heated to a sufficiently high temperature, it undergoes a chemical reaction that produces solid calcium and chlorine gas. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

1. Write the word equation for the reaction.
   calcium chloride → calcium + chlorine
2. Identify the type of chemical reaction from the nature of the reactants and products.
   - Calcium chloride is a compound, and calcium and chlorine are elements. Therefore, this is a decomposition reaction.
3. Use the word equation to write the skeleton equation.
   $CaCl_2(s) \rightarrow Ca(s) + Cl_2(g)$
4. Write the balanced chemical equation for the reaction.
   $CaCl_2(s) \rightarrow Ca(s) + Cl_2(g)$

Practice Problems

1. During a chemical reaction, magnesium and sulphur are produced from magnesium sulphide. Identify the type of chemical reaction, and then write the balanced chemical equation.
2. When heated, sodium iodide may be broken down into sodium and iodine. Identify the type of chemical reaction, and then write the balanced chemical equation.
3. Chlorine gas is used to disinfect water in drinking supplies and pools, and in making plastics, pharmaceuticals, and fertilizers. In the lab, chlorine gas and sodium metal can be produced by passing an electric current through hot, molten sodium chloride, which is a liquid. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

B21 Inquiry Activity

Skills References 1, 2, 9

SKILLS YOU WILL USE

- Using equipment, materials, and technology accurately and safely
- Interpreting data/information to identify patterns or relationships

Synthesis of Iron(III) Oxide

Question

What changes will you observe during a synthesis reaction between iron and oxygen-rich air?

Materials & Equipment

- Bunsen burner
- matches or flint striker
- long tweezers or tongs
- 2 pieces of steel wool
- 25-mL graduated cylinder
- scoopula
- paper towels
- potassium iodide (KI) powder
- 125-mL Erlenmeyer flask
- 3% hydrogen peroxide solution ($H_2O_2(aq)$)

CAUTION: Tie back long hair and fasten any loose clothing.

Procedure

1. Light the Bunsen burner with matches or a flint striker.
2. Using long tweezers or tongs, pick up a piece of steel wool. Hold the steel wool in the flame until it begins to burn.
3. Remove the steel wool from the flame, and allow it to finish burning. Observe the burnt steel wool. Record your observations.
4. Using a 25-mL graduated cylinder, measure 20 mL of 3% hydrogen peroxide solution. Pour this hydrogen peroxide into the 125-mL Erlenmeyer flask.
5. Using a clean scoopula, measure a pea-sized amount (about 1 mL) of potassium iodide powder into the Erlenmeyer flask.
6. Gently swirl the contents of the flask for a few seconds. Observe the formation of bubbles. These are bubbles of pure $O_2(g)$.

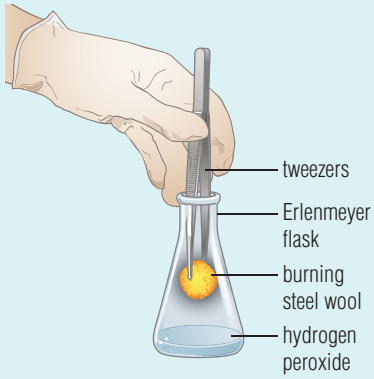

Figure 6.9 The burning steel wool does not need to contact the liquid in the Erlenmeyer flask. Do not get the steel wool wet.

7. Using the tweezers or tongs, pick up the second piece of steel wool. Hold the steel wool in the flame until it begins to burn.
8. Plunge the burning steel wool into the Erlenmeyer flask (Figure 6.9).
9. Put out the Bunsen burner, and then record your observations of the steel wool.
10. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Analyzing and Interpreting

11. Describe the differences between burning steel wool (a source of iron) in air and burning it in air that is rich in oxygen (from hydrogen peroxide).
12. Rewrite the following sentence as a balanced chemical equation (include the state symbols): "Solid iron reacts with oxygen gas to form solid iron(III) oxide."

Skill Practice

13. In point form, outline all the safety precautions that you used while you conducted this lab.

Forming Conclusions

14. Describe the observations you made that provided evidence that a chemical reaction had occurred.

6.1 CHECK and REFLECT

Key Concept Review

1. Name the two types of chemical reactions discussed in this section.

2. You learned about neutralization reactions in chapter 5 and reviewed them in this section. What are the products of a neutralization reaction?

3. Write the general chemical equation for each of the following types of chemical reactions.

(a) a synthesis chemical reaction

(b) a decomposition chemical reaction

(c) a neutralization reaction

4. Classify each of the following chemical reactions.

(a) $CaCl_2(s) \rightarrow Ca(s) + Cl_2(g)$

(b) $NaN_2(s) \rightarrow Na(s) + N_2(g)$

(c) $2Rb(s) + Cl_2(g) \rightarrow 2RbCl(s)$

(d) $4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$

(e) $2NaCl(s) \rightarrow 2Na(s) + Cl_2(s)$

(f) $2NI_3(aq) \rightarrow N_2(g) + 3I_2(s)$

Connect Your Understanding

5. (a) Identify the following chemical reaction as either a synthesis or a decomposition. Explain how you know.

$2Fe(s) + O_2(g) \rightarrow 2FeO(s)$

(b) In the chemical reaction in (a), which of the possible ions of iron is in the compound FeO(s)? (Hint: Use the periodic table to check.)

(c) Explain how you answered 5(b).

6. If you heat solid potassium chlorate ($KClO_3$), it decomposes into solid potassium chloride and oxygen gas. For the decomposition of potassium chlorate, write:

(a) the word equation

(b) the skeleton equation, including states

(c) the balanced chemical equation, including states

7. Water can be decomposed by passing a large electrical current through it. Write the balanced chemical equation for the decomposition reaction for water. Include states.

8. Zinc nitride is a solid chemical used in electronics. Write the balanced chemical equation for the synthesis of solid zinc nitride from solid zinc and nitrogen gas. Start with the word equation. Follow the steps shown earlier in this chapter, including states.

9. Magnesium chloride powder is sprinkled on roads and sidewalks to reduce ice formation. Write the word equation, skeleton equation, and balanced chemical equation, including states, for the synthesis of solid magnesium chloride from solid magnesium metal and chlorine gas.

10. Iron and oxygen can combine to produce iron(III) oxide (rust), as shown in the photograph below. Explain why knowledge of this synthesis reaction is important in daily life.

Question 10

Reflection

11. Using a poster, a Web page, or another creative method of your choosing, describe at least two things that you found to be the most interesting in this section.

For more questions, go to ***ScienceSource***.

6.2 Combustion Reactions and Displacement Reactions

Here is a summary of what you will learn in this section:

- In combustion chemical reactions, an element or a compound reacts rapidly with oxygen.
- In single displacement reactions, a reactive element reacts with a compound.
- Double displacement reactions occur between two ionic compounds.

Figure 6.10 An oxyacetylene torch burns acetylene gas in a stream of oxygen gas, producing a flame that is hot enough to melt metal.

Figure 6.11 Thomas L. Willson was born in Princeton, Ontario, in 1860. He accidentally found a way to produce acetylene gas.

The Hottest Flame

When we need two pieces of metal to be joined together, a common way of doing so is to weld them. Welding involves melting the edges of the pieces to be joined, which then form a seam when they cool. Melting metal requires high temperatures. During welding, only specific parts of a metal piece must be melted and not the whole piece. One way of getting such precise melting is to use an oxyacetylene torch (Figure 6.10).

Oxyacetylene torches work by burning acetylene gas. The balanced chemical equation for this reaction is:

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

An oxyacetylene torch contains a cylinder of acetylene and a cylinder of oxygen. In this type of torch, the acetylene burns in a stream of pure oxygen gas. The flame of an oxyacetylene torch has a temperature of about 3000°C. When acetylene burns in air, the flame will reach a maximum temperature of only about 538°C. Burning the acetylene in pure oxygen enables the flame temperature to become hot enough to melt steel.

As well as producing heat for welding, acetylene gas is used in the synthesis of many other products. However, its usefulness was recognized only when an experiment failed. Thomas L. Willson was the first to make acetylene and to find ways to use it (Figure 6.11).

He was trying to produce aluminum metal by reacting aluminum oxide with carbon. The reaction produced only a few small globules of aluminum. Willson next tried reacting calcium oxide with carbon to produce calcium. This time, a solid formed.

When solid calcium reacts with water, aqueous calcium hydroxide and hydrogen gas are produced. Therefore, to see if the solid that had formed was calcium, Willson mixed it with water. A gas was produced. Willson next tested to see if the gas was, in fact, hydrogen. To his surprise, it was not. Instead, the solid product was calcium carbide, CaC_2, and the gas product was acetylene, C_2H_2. The initial reaction had been:

calcium oxide + carbon → calcium carbide + carbon monoxide

$$CaO(s) + 3C(g) \rightarrow CaC_2(s) + CO(g)$$

The calcium carbide had then reacted with water as follows:

calcium carbide + water → calcium hydroxide + acetylene

$$CaC_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + C_2H_2(g)$$

B22 Quick Lab

Observing Reactions in Solution

Purpose

To combine solutions of ionic compounds and observe what happens

Materials & Equipment

- 6 medium test tubes
- sodium hydroxide solution
- test-tube rack
- iron(III) chloride solution
- copper(II) chloride solution
- nickel(II) nitrate solution
- paper towel
- stirring rod

Procedure

1. Fill three test tubes about 2 cm with sodium hydroxide solution. Place them in the test-tube rack.
2. Fill one of the remaining test tubes to a depth of about 2 cm with iron(III) chloride solution.
3. Repeat step 2 with copper(II) chloride solution and nickel(II) nitrate solution.
4. Into each of the test tubes from steps 2 and 3, pour the sodium hydroxide solution from one of the test tubes from step 1. Observe.
5. Without spilling or allowing the liquid to touch your skin, shake each test tube to promote mixing. Observe.
6. Using a stirring rod, remove some of the solid that has formed in each test tube and examine it.
7. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Questions

8. What evidence was there that chemical reactions occurred with each mixing?
9. Each reaction had two reactants and two products. By looking at the names of each reactant, you may be able to predict the names of each product. (Hint: one of the products is sodium chloride.)
10. Write a word equation and balanced formula equation for each reaction.

Combustion Reactions of Hydrocarbons

WORDS MATTER

The word "combustion" comes from the Latin word *comburere* which means to burn up.

A **combustion** reaction is a chemical reaction in which a compound or element rapidly combines with oxygen gas. These reactions usually give off a large amount of heat and light. A **hydrocarbon** is a compound made of only carbon and hydrogen. Hydrocarbons have the formula C_xH_y where the letters "x" and "y" stand for the number of atoms (i.e., 2, 3, or higher). The simplest example of this kind of compound is methane (CH_4) (Figure 6.12). Some of these compounds are fossil fuels, such as methane and petroleum. **Fossil fuels** are hydrocarbons formed underground over millions of years from the remains of once-living organisms. The general chemical equation for the combustion reaction of a hydrocarbon is:

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

(where C_xH_y stands for a hydrocarbon molecule).

Figure 6.12 The combustion of methane (natural gas) is commonly used to produce heat for cooking and for heating.

We write C_xH_y in the general chemical equation because there are many different compounds made up of only carbon and hydrogen atoms. The products of a hydrocarbon combustion reaction are always carbon dioxide and water.

For example, the combustion reaction of methane gas can be written this way:

Skeleton equation: $CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$

Balanced chemical equation: $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

Impact on the Environment

When combustion reactions of hydrocarbons release carbon dioxide gas into the atmosphere, they play a role in global warming. Atmospheric carbon dioxide gas prevents thermal energy from escaping into space. As the levels of carbon dioxide gas have increased over the last century, the average temperature on Earth has also increased.

Combustion reactions can be used to help the environment. When oil is spilled on land, the oil spill may first be set on fire. The contaminated soil is then removed for additional treatment. The combustion of an oil spill can produce toxic smoke, and so this method is unlikely to be used on a spill near human populations. Combustion may also be used to clean up oil spills on water (Figure 6.13).

Figure 6.13 Intentionally burning off spilled oil on water is still mainly experimental. Combustion of spilled oil is mainly used for oil spills on land.

More commonly, oil spills on water are absorbed by enclosing the oil slick with large, floating sponges. The sponges are then collected and treated elsewhere. When an oil spill has reached the shore, micro-organisms may be used in the clean-up efforts. Fertilizers, such as phosphorus and nitrogen, are spread over the affected area of the shoreline. The fertilizers promote the growth of the micro-organisms, which break down the oil into harmless or less-toxic substances.

Single Displacement Reactions

In a **single displacement reaction**, an element reacts with an ionic compound. During the reaction, the element becomes part of the ionic compound, while one of the elements in the ionic compound becomes an element by itself. The elements that switch places may be either two metals or two non-metals.

In the first type of displacement reaction, a metallic atom trades places with a metallic ion in a compound. The general chemical equation for this single displacement reaction is:

$$AB + C \rightarrow CB + A$$

(where the metallic element A is replaced by another metal, C).

Suggested Activity •
B25 Design a Lab on page 239

In this type of single displacement reaction, the reactants will always be a compound and a metallic element, and the products also will always be a compound and a metallic element.

For example, a single displacement reaction can take place between copper(II) chloride and aluminum. This reaction is written as:

Skeleton equation: $CuCl_2(aq) + Al(s) \rightarrow AlCl_2(aq) + Cu(s)$

Balanced chemical equation: $3CuCl_2(aq) + 2Al(s) \rightarrow 2AlCl_2(aq) + 3Cu(s)$

Example Problem 6.3

When solid magnesium reacts with aqueous silver nitrate, silver and aqueous magnesium nitrate are produced. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction, including states.

1. Write the word equation for the reaction.
   silver nitrate + magnesium → magnesium nitrate + silver
2. Identify the type of chemical reaction from the nature of the reactants and products.
   - Magnesium and silver are metallic elements. Silver nitrate and magnesium nitrate are compounds. Therefore, this is a single displacement reaction.
3. Use the word equation to write the skeleton equation, including states.
   $AgNO_3(aq) + Mg(s) \rightarrow Mg(NO_3)_2(aq) + Ag(s)$
4. Write the balanced chemical equation.
   $2AgNO_3(aq) + Mg(s) \rightarrow Mg(NO_3)_2(aq) + 2Ag(s)$

Practice Problems

1. When magnesium metal and zinc nitrate react, they form zinc and magnesium nitrate. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction.
2. Iron metal is placed into a solution of silver nitrate and allowed to sit. This produces aqueous iron(II) nitrate and solid silver metal. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction, including states.

In the second kind of displacement reaction, a non-metal in a compound is displaced by another non-metal. The general chemical equation for this single displacement reaction is:

$$AB + C \rightarrow AC + B$$

(where the non-metallic element B is replaced by another non-metal, C).

Suggested Activity •
B26 Inquiry Activity on page 239

In this form of single displacement reaction, the reactants will always be a compound and a non-metallic element, and the products will also always be a compound and a non-metallic element.

For example, a single displacement reaction can take place between potassium iodide and bromine. This reaction is written as:

Skeleton equation: $KI(aq) + Br_2(l) \rightarrow KBr(aq) + I_2(aq)$

Balanced chemical equation: $2KI(aq) + Br_2(l) \rightarrow 2KBr(aq) + I_2(aq)$

Example Problem 6.4

When they are both in an aqueous solution, chlorine gas and calcium bromide react to produce bromine liquid and aqueous calcium chloride. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction, including states.

1. Write the word equation for the reaction.
   chlorine + calcium bromide → bromine + calcium chloride
2. Identify the type of chemical reaction from the nature of the reactants and products.
   - Chlorine and bromine are non-metallic elements. Calcium bromide and calcium chloride are compounds. Therefore, this is a single displacement reaction. Both chlorine and bromine are diatomic in their pure element form.
3. Use the word equation to write the skeleton equation, including states.
   $CaBr_2(aq) + Cl_2(aq) \rightarrow CaCl_2(aq) + Br_2(l)$
4. Write the balanced chemical equation for the reaction.
   $CaBr_2(aq) + Cl_2(aq) \rightarrow CaCl_2(aq) + Br_2(l)$

Practice Problems

1. Fluorine and aluminum bromide undergo a chemical reaction to produce bromine and aluminum fluoride. Identify the type of chemical reaction, and then write a balanced chemical equation.
2. Bromine and silver chloride are produced when chlorine and silver bromide undergo a chemical reaction. Identify the type of chemical reaction, and then write a balanced chemical equation.
3. Chlorine gas reacts with a solution of aqueous nickel(III) bromide and produces aqueous nickel(III) chloride and liquid bromine. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction, including states.

Double Displacement Reactions

In a **double displacement reaction**, the positive or negative ions in two dissolved ionic compounds switch places. The general chemical equation for a double displacement reaction is:

$$AB + CD \rightarrow AD + CB$$

In a double displacement reaction, the reactants will always be compounds. Therefore, a positive ion will only switch places with a positive ion, and a negative ion will only switch places with a negative ion. Two positive ions will never pair up to form a new compound, because their charges will repel one another. Two negative ions will never pair up to form a new compound for the same reason. Double displacement reactions may result in the formation of a precipitate.

For example, when aqueous magnesium hydroxide combines with aqueous silver nitrate, the products are aqueous magnesium nitrate and silver hydroxide.

Skeleton equation: $Mg(OH)_2(aq) + AgNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + AgOH(s)$

Balanced chemical equation: $Mg(OH)_2(aq) + 2AgNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + 2AgOH(s)$

You are not expected to be able to predict the states of the products in a double displacement reaction.

Take It Further

The combustion of hydrocarbons provides energy for many human activities. Prepare a poster or another form of display for your classroom using information and images. Begin your research at ***ScienceSource***.

Example Problem 6.5

When aqueous lead(II) nitrate and aqueous sodium iodide are mixed, solid lead(II) iodide and aqueous sodium nitrate are formed. Identify the type of chemical reaction, and then write a balanced chemical equation for the reaction.

1. Write the word equation for the reaction.

lead(II) nitrate + sodium iodide → lead(II) iodide + sodium nitrate

2. Identify the type of chemical reaction from the nature of the reactants and products.
   - The reactants and products are all ionic compounds. Therefore, this is a double displacement reaction.
3. Use the word equation to write the skeleton equation, including states.
   $Pb(NO_3)_2(aq) + NaI(aq) \rightarrow PbI_2(s) + NaNO_3(aq)$
4. Write the balanced chemical equation for the reaction.
   $Pb(NO_3)_2(aq) + 2NaI(aq) \rightarrow PbI_2(s) + 2NaNO_3(aq)$

Practice Problems

1. When aqueous aluminum chloride and aqueous sodium hydroxide react, solid aluminum hydroxide and aqueous sodium chloride form. Identify the type of chemical reaction, and then write a balanced chemical equation, including states.
2. When aqueous copper(I) nitrate and aqueous potassium bromide react, solid copper(I) bromide and aqueous potassium nitrate are produced. Identify the type of chemical reaction, and then write a balanced chemical equation, including states.

During Writing Thinking Literacy

Keep Your Emotions in Check

Scientists try to be objective rather than emotional. They base their arguments on research — their conclusions are drawn from observations and experiments. As you prepare arguments for a debate, remember to keep emotions in check and to base your points on scientific research.

Neutralization and Double Displacement

A neutralization reaction between an acid and a base also follows the same general pattern as a double-displacement reaction. Recall that in a neutralization reaction, an acid reacts with a base to form an ionic salt and water. The general chemical equation for this reaction is:

$$HB + XOH \rightarrow XB + H_2O$$

(where HB is an acid, XOH is a base, and XB is an ionic salt).

Another way of looking at this reaction is that the H^+ ion in the acid switches places with the positive ion (X) in the base, or the OH^- ion in the base switches places with the negative ion (B) in the acid. Since neutralization reactions are so common and so important, they are classified on their own and are not usually called double displacement reactions.

Summary: Types of Chemical Reactions

Table 6.3 summarizes the types of chemical reactions you explored in this chapter and in chapter 5. The general chemical equation and an example of a matching balanced chemical equation are shown for each.

Table 6.3 Summary Chart for Types of Chemical Reactions

Type of Chemical Reaction	Type of Reactant(s) (R) and Product(s) (P)	General Chemical Equation (GCE)	Balanced Chemical Equation of Example Reactions
Synthesis	R: two elements P: a single compound	$A + B \rightarrow AB$	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
Decomposition	R: a single compound P: elements and/or simpler compounds	$AB \rightarrow A + B$	$CaCl_2(s) \rightarrow Ca(s) + Cl_2(g)$
Combustion of hydrocarbons	R: a hydrocarbon and oxygen P: carbon dioxide and water	$C_xH_y + O_2 \rightarrow CO_2 + H_2O$	$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$
Single displacement	R: a compound and a metal element P: a compound and a metal element OR R: a compound and a non-metal element P: a compound and a non-metal element	$AB + C \rightarrow CB + A$ $DB + C \rightarrow DC + B$	$2FeCl_3(aq) + 3Mg(s) \rightarrow 3MgCl_2(aq) + 2Fe(s)$ $2KI(aq) + Br_2(l) \rightarrow 2KBr(aq) + I_2(aq)$
Double displacement	R: two aqueous ionic compounds P: two ionic compounds	$AB + CD \rightarrow AD + CB$	$Ca(OH)_2(aq) + 2AgNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + 2AgOH(s)$
Neutralization	R: an acid and a base P: a salt and water	$HB + XOH \rightarrow XB + H_2O$	$H_2SO_4(aq) + 2NaOH(s) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

B23 STSE Science, Technology, Society, and the Environment

A New Fertilizer Plant: Beneficial or Harmful?

A fertilizer manufacturing company would like to build a large factory in your community. The factory would bring jobs and more tax revenue to the community. However, chemicals will need to be transported in and out of the factory. The plant will also use a lot of water, electricity, and other energy sources, such as hydrocarbons (for combustion reactions).

1. Your teacher will place you in a group that represents one of the following stakeholders:
   - an investor in the fertilizer plant
   - an unemployed worker
   - a city government official
   - a homeowner in the area of the proposed plant
   - an environmentalist
2. In your group, decide if you will support the construction of the proposed fertilizer factory. Consider positive and negative effects. If you need to do additional research, you can start at ***ScienceSource***.
3. When you have come to a consensus, write down your decision and the reasons for your decision.
4. Hold a town hall meeting between the various groups of stakeholders. Debate the pros and cons of having the fertilizer factory in your community. At the end of the debate, take a vote to accept or reject the proposed factory.

B24 Skill Builder Activity

Keeping Safe by Using MSDS

In Activity B26, you will write a procedure. Whenever you write a procedure, you must ensure that it includes appropriate safety precautions. In this activity, you will practise writing safety precautions when planning a procedure for an inquiry lab.

1. Obtain a copy of the Material Safety Data Sheet (MSDS) for each of the following substances:

   copper(II) sulphate ($CuSO_4$)

   hydrochloric acid (HCl)

   hydrogen peroxide (H_2O_2)
2. For each substance, make a point-form list of the most important safety precautions.
3. Describe how you would handle each substance safely. For example, for potassium iodide, you might write "Use gloves when handling potassium iodide and do not get any on your eyes, skin, or clothing."
4. Why is it important to read the MSDS before writing a procedure?
5. In an investigation, copper(II) sulphate is provided in aqueous solution. Are there any safety precautions for solid copper(II) sulphate that do not apply to an aqueous solution of copper(II) sulphate? Explain.

B25 Design a Lab

Skills References 1, 2, 6, 9

SKILLS YOU WILL USE

- Identifying variables
- Selecting instruments and materials

Iron and Copper(II) Chloride

In a single displacement reaction, one element in a compound replaces another element. Displacement reactions are used by some industries to recover metals from solutions. For example, industries such as mining and smelting use a displacement reaction to recover copper metal from waste solutions. Copper is a valuable metal and also causes heavy-metal pollution if it is released into the environment.

In this activity, you will cover an iron nail with water and an aqueous solution of copper(II) chloride.

Question

Will a displacement reaction occur when an iron nail is suspended in an aqueous copper(II) chloride solution?

Materials & Equipment

- iron nail (Fe)
- 1 M copper(II) chloride ($CuCl_2$) solution
- other materials and equipment as determined by the student

Figure 6.14 This is one way that you might set up your experiment.

Design and Conduct Your Investigation

1. Consider the question, and write a prediction.
2. Write a procedure to test your prediction. Your procedure should have numbered steps. When writing the procedure, ensure you do the following:
   (a) Identify the independent, dependent, and controlled variables.
   (b) Describe how the variables will be controlled.
   (c) Include all the materials and equipment you will use. You could use a set-up similar to that shown in Figure 6.14.
   (d) Identify any safety precautions and describe how you will work safely.
   (e) Describe what evidence you will look for and how you will record your observations. You will need to make observations over a period of several days.
3. Submit your procedure to your teacher. Once your teacher has approved your procedure, carry out your investigation.
4. When you have completed your investigation, clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.
5. Analyze your results. Did you make an accurate prediction? Explain.
6. Compare your procedure with those of your classmates. How might you adapt or improve your experimental procedure?
7. Identify any new questions that arose from your experiment that you would like to explore.

B26 *Inquiry Activity*

Skills References 1, 2, 9

SKILLS YOU WILL USE

- Using equipment, materials, and technology accurately and safely
- Processing and synthesizing data

Single Displacement Reactions

Question

What will you observe that indicates a chemical reaction is occurring during single displacement reactions?

Materials & Equipment

- 1-cm^2 pieces of magnesium and copper metal
- dropper
- 0.1 M silver nitrate solution
- 0.1 M copper(II) chloride solution
- microscope slides
- microscope (preferred), hand lens, or magnifying glass

Procedure

1. Use a microscope or magnifying glass to make your observations during this procedure.
2. Put a piece of magnesium on a clean slide. Place the slide under the microscope lens or magnifying glass. Focus on the edge of the magnesium.
3. Using a dropper, place a drop of silver nitrate solution on the magnesium (Figure 6.15). Look for evidence that a chemical reaction is occurring. If you are using a microscope, look for the growth of metallic crystals.

Figure 6.15 The experimental set-up

4. Record your observations.
5. Repeat steps 2 to 4 using the copper metal and the silver nitrate solution.
6. Repeat steps 2 to 4 using the magnesium metal and the copper(II) chloride solution.
7. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Analyzing and Interpreting

8. Did the combinations of metals and solutions appear to react the same way? In your answer, describe and compare the speed at which any reactions occurred and the shape of any crystals that formed.
9. Write a word equation, skeleton equation, and balanced chemical equation, including states, for each of the following:
   (a) Solid magnesium metal reacts with aqueous silver nitrate to produce solid silver metal and aqueous magnesium nitrate.
   (b) Aqueous copper(II) chloride reacts with solid magnesium metal to produce aqueous magnesium chloride and solid copper metal.
   (c) Aqueous silver nitrate reacts with solid copper metal to produce solid silver metal and aqueous copper(II) nitrate solution.

Skill Practice

10. Why is it preferable to use a microscope to make observations in this investigation?

Forming Conclusions

11. For each of the metals and solutions tested, state whether a chemical reaction occurred. Provide evidence to justify your conclusion.

6.2 CHECK and REFLECT

Key Concept Review

1. Write the general chemical equation for the combustion reactions of hydrocarbons.

2. Suppose that a friend tells you that there is only one type of single displacement reaction. Do you agree with this statement? Explain why you agree or disagree.

3. Describe the similarities and differences between a single displacement reaction and a double displacement reaction.

4. What type of chemical reaction is described by each of the following general chemical equations?

   (a) $AB + CD \rightarrow AD + BC$

   (b) $HB + XOH \rightarrow XB + H_2O$

   (c) $C_xH_y + O_2 \rightarrow CO_2 + H_2O$

   (d) $A + BC \rightarrow B + AC$

   (e) $AB \rightarrow A + B$

   (f) $A + B \rightarrow AB$

5. Of the general chemical equations in the previous question, only two include the formulas for specific compounds. Suggest a reason why these are the only types of reactions that include specific compounds in the general chemical equation.

Connect Your Understanding

6. Why are two kinds of single displacement reactions listed in Table 6.3 on page 236?

7. Classify each of the following chemical reactions.

   (a) $K_2SO_4(aq) + Al(s) \rightarrow Al_2(SO_4)_3(aq) + 2K(s)$

   (b) $KI(aq) + Pb(NO_3)_2(aq) \rightarrow PbI_2(aq) + KNO_3(aq)$

   (c) $C_4H_{10}(aq) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$

   (d) $AgNO_3(aq) + KCl(aq) \rightarrow KNO_3(aq) + AgCl(aq)$

8. Write a balanced chemical equation for each of the chemical reactions in the previous question.

9. When lithium metal and oxygen gas react, solid lithium oxide is produced. Identify the type of chemical reaction, and then write the balanced chemical equation.

10. When aqueous chlorine reacts with aqueous potassium bromide, aqueous potassium chloride and liquid bromine are produced. Identify the type of chemical reaction, and then write the balanced chemical equation, including states.

11. When a log burns in a fireplace, as shown in the photograph below, the hydrocarbons in the log combine with oxygen gas in the air, producing ashes and gases.

    (a) What two gases are produced?

    (b) The ashes weigh much less than the log that was burned. Does this mean that this combustion reaction does not follow the law of conservation of mass? Explain.

Question 11

12. Write the balanced chemical equation for the single displacement reactions between each of the following reactants:

    (a) magnesium and zinc nitrate

    (b) fluorine and calcium bromide

    (c) lithium and potassium chlorate

Reflection

13. Did anything you learned in this section surprise you? Why?

For more questions, go to *ScienceSource*.

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The Bombardier Beetle

Some insects bite when attacked. Some run for their lives or fly away. Then there are others that use chemistry to protect themselves. One in particular has been called a "champion chemist" — the bombardier beetle. This insect repels attackers with a foul chemical spray (Figure 6.16).

Here is how the beetle produces its spray. The beetle has two internal tanks near the tip of its abdomen. The tanks contain the chemicals hydrogen peroxide (H_2O_2) and hydroquinone ($C_6H_4(OH)_2$). Normally, these two chemicals just sit inside the beetle, isolated from one another. However, when the beetle feels threatened, it squeezes the walls of the tanks. This forces the hydrogen peroxide and hydroquinone into a second chamber where additional chemicals are stored. When all these chemicals combine, a series of chemical reactions occur.

One reaction releases oxygen (O_2) from the hydrogen peroxide. The hydroquinone reacts with the oxygen, which produces an evil-smelling and noxious chemical called benzoquinone ($C_6H_4O_2$). The benzoquinone then explodes out the rear end of the beetle with a loud popping sound!

Close inspection reveals that the popping sound is not a single explosion. The beetle produces a rapid series of explosions — 500 to 1000 every second, similar to the firing of a machine gun. The chemical reaction also generates heat, so the chemical spray emerges from the beetle at about the temperature of boiling water.

The beetle is incredibly accurate when it releases its spray, thanks to special nozzles in the beetle's body. These nozzles allow the beetle to spray whatever is attacking it. Since the spray is hot and toxic, the beetle itself would be damaged if the chemicals combined and did not leave its body.

Most insects or frogs will drop the beetle when it sprays them. However, one species of toad, *Bufo marinus*, swallows the beetle in a quick gulp, before the beetle can fire (Figure 6.17). If you listen closely, you can hear the popping coming from inside the toad's stomach!

Question

1. Summarize this reading. Include a main idea and two points that support it.

Figure 6.16 The bombardier beetle emits a toxic spray that is produced by a series of chemical reactions inside its body.

Figure 6.17 This species of toad, *Bufo marinus*, is able to eat the bombardier beetle before it sprays.

6 CHAPTER REVIEW

ACHIEVEMENT CHART CATEGORIES

- (k) Knowledge and understanding
- (t) Thinking and investigation
- (c) Communication
- (a) Application

Key Concept Review

1. What is the opposite of a decomposition chemical reaction? (k)
2. The prefix "syn-" means "together." Explain why this is a suitable prefix for describing a synthesis chemical reaction. (t)
3. What are the two types of displacement chemical reactions? (k)
4. What is the general formula for a hydrocarbon compound? (k)
5. From what are fossil fuels formed? (k)
6. Name the six different types of chemical reactions discussed in chapter 6. (k)
7. In which two types of chemical reactions is water always produced? (k)
8. Which type of chemical reaction is described by each of the following general chemical equations? (k)

   (a) $AB + CD \rightarrow AD + BC$

   (b) $HB + XOH \rightarrow XB + H_2O$

Connect Your Understanding

9. Suggest two or more reasons why it is important for chemists to study many examples of the different types of chemical reactions you learned about in this chapter. (a)
10. Name the product in each of the following reactions: (a)

    (a) potassium and iodine →

    (b) cesium and chlorine →

11. What two compounds are always produced by the combustion of hydrocarbons and carbohydrates? (a)
12. Magnesium chloride can undergo a decomposition reaction to produce magnesium metal and chlorine gas. Write the word equation, skeleton equation, and balanced chemical equation for this reaction. (a)
13. The gas rising from the beaker in the photograph below is carbon dioxide. Combustion reactions produce carbon dioxide gas, CO_2. Why are these reactions of concern to people who care about changes in Earth's atmosphere? (a)

Question 13

14. The types of chemical reactions discussed in chapter 6 can be classified by the nature of the reactants. Identify the type of chemical reaction that would occur between the following reactants: (a)

    (a) $Li(s) + O_2(g) \rightarrow$

    (b) $NaCl(s) \rightarrow$

    (c) $K_2SO_4(aq) + Al(s) \rightarrow$

    (d) $CaBr_2(aq) + Ba(NO_3)_2(aq) \rightarrow$

    (e) $C_4H_{10}(aq) + O_2(g) \rightarrow$

    (f) $AgNO_3(aq) + KCl(aq) \rightarrow$

    (g) $NI_3(aq) \rightarrow$

15. Identify the type of chemical reaction described by the skeleton equation below. Then, write the balanced equation. (a)
    $FeCl_2(aq) + K_2S(aq) \rightarrow FeS(s) + KCl(aq)$

16. In the previous question, the reaction takes place in water. Which substance would you be able to see in the container? Explain how you know. (a)

17. Classify each of the following reactions, and balance the equations. (a)

(a) $CaCl_2(g) \rightarrow Ca(s) + Cl_2(g)$

(b) $NaN_3(s) \rightarrow Na(s) + N_2(g)$

(c) $Pb(NO_3)_2(aq) + Cu_2SO_4(aq) \rightarrow PbSO_4(s) + CuNO_3(aq)$

(d) $Ni_2O_3(s) \rightarrow Ni(s) + O_2(g)$

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

(f) $NaI(aq) + AlCl_3(aq) \rightarrow NaCl(aq) + AlI_3(s)$

18. Classify each of the following reactions, and write a balanced chemical equation for each. (a)

(a) sodium sulphate + calcium chloride → sodium chloride + calcium sulphate

(b) magnesium + nitrogen → magnesium nitride

(c) strontium hydroxide + lead(II) bromide → strontium bromide + lead(II) hydroxide

(d) sodium + oxygen → sodium oxide

(e) nitrogen + hydrogen → ammonia (NH_3)

(f) hydrogen chloride → hydrogen + chlorine

(g) aluminum iodide + bromine → aluminum bromide + iodine

(h) hydrochloric acid + sodium hydroxide → sodium chloride + water

19. Calcium metal reacts with iodine to produce calcium iodide. Identify the type of chemical reaction. Then, write a balanced chemical equation for this reaction. (a)

20. When zinc metal is mixed with aqueous copper(II) sulphate, copper metal and aqueous zinc sulphate are produced. Identify the type of chemical reaction and then write the balanced chemical equation. (a)

21. Several compounds made up of a metallic element combined with bromine are used in water treatment facilities, including magnesium bromide. Write the balanced chemical equation, including states, for the formation of solid magnesium bromide from magnesium and bromine. (a)

22. When aqueous zinc bromide and aqueous silver nitrate react, solid silver bromide and aqueous zinc nitrate are produced. Identify the type of chemical reaction, and then write a word equation, skeleton equation, and balanced chemical equation for the reaction. Include states. (a)

23. Suppose that a classmate tells you "In a neutralization reaction, you always have to start with two compounds." Is your classmate correct? Support your answer. (t)

Reflection

24. Of the six types of chemical reactions that you learned about in this chapter, which do you think is most important to society? Give reasons for your answer. (c)

After Writing

Thinking Literacy

The Scientist's Approach to Writing

Make a list of what you learned about important features of scientific writing. Write a paragraph reflecting on how writing for science class is different from writing that you might do in English or history class. Share your thoughts with a partner.

Unit Task Link

Apply your knowledge of types of reactions to classify and predict the outcome of these reactions, all of which are part of the Unit Task:

$Mg + HCl \rightarrow ?$

$MgSO_4 + Na_2CO_3 \rightarrow ?$

$Mg + CuCl_2 \rightarrow ?$

In the Unit Task, you will have an opportunity to carry out these reactions and observe them in the laboratory.

UNIT B Summary

KEY CONCEPTS	CHAPTER SUMMARY
4 Chemical change occurs during chemical reactions.	
• Chemical change • Ions and molecules • Ionic and molecular compounds • Law of conservation of mass • Balanced chemical equations	• During a chemical reaction, new substances are formed that have different properties from the reactants. (4.1) • Metallic atoms form positive ions; non-metallic atoms form negative ions. (4.2) • Polyatomic ions are charged groups of atoms. (4.2) • Ionic compounds form between metals and non-metals. (4.2) • Molecular compounds form between non-metals and non-metals. (4.2) • The reactant(s) in a chemical reaction undergo chemical change(s). The product(s) of a chemical reaction have different properties than the reactant(s). (4.3) • The law of conservation of mass states that mass will remain constant during any chemical reaction. (4.3) • A word equation describes a chemical reaction using words. (4.3)
5 Acids and bases are important to our health, industries, and environment.	
• Properties of acids and bases • pH scale • Measuring pH • Neutralization	• The pH of liquids can be determined using pH indicators. (5.1) • An acid has a pH less than 7, a base has a pH greater than 7, and a neutral liquid has a pH equal to 7. (5.1) • Neutralization is a chemical reaction between an acid and a base that produces water and a salt. (5.2) • Neutralization reactions can be used to help solve chemical contamination problems in the environment. (5.2)
6 Chemical reactions can be grouped according to the characteristics of their	

• General chemical equations
• Types of chemical equations:
  • Synthesis
  • Decomposition
  • Combustion
  • Single displacement
  • Double displacement
	• A general chemical equation (GCE) is an equation that uses letters of the alphabet (A, B, C, D, X), as well as some element symbols, to represent different chemical reactions. (6.1)
	• In a synthesis reaction, two or more elements combine to produce at least one new substance. (6.1)
	• In a decomposition reaction, a single compound is broken down into its elements. (6.1)
	• A combustion reaction always involves oxygen as a reactant and carbon dioxide and water as products. (6.2)
	• In a single displacement reaction, a reactive metallic element can replace a less reactive metallic element in a compound. (6.2)
	• In a double displacement reaction between two ionic compounds, the positive or negative ions switch places. (6.2)

VOCABULARY

- alkali metal (p. 148)
- alkaline earth metal (p. 148)
- atom (p. 144)
- atomic mass (p. 149)
- atomic number (p. 149)
- atomic theory (p. 144)
- Bohr diagram (p. 145)
- chemical change (p. 174)
- chemical equation (p. 175)
- chemical property (p. 142)
- chemical reaction (p. 174)
- compound (p. 143)
- covalent bond (p. 164)
- diatomic molecule (p. 164)
- electron (p. 144)
- element (p. 143)
- family (p. 146)
- halogen (p. 146)
- heterogeneous mixture (p. 143)
- homogeneous mixture (p. 143)
- ion (p. 149)
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- matter (p. 142)
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- physical property (p. 142)
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- product (p. 174)
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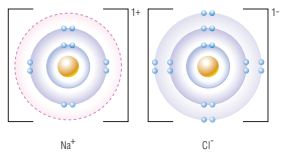
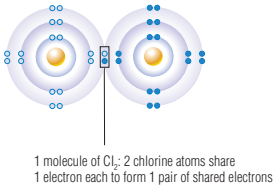
- skeleton equation (p. 178)
- state (p. 142)
- suspension (p. 143)
- valence electron (p. 145)
- valence shell (p. 145

KEY VISUALS

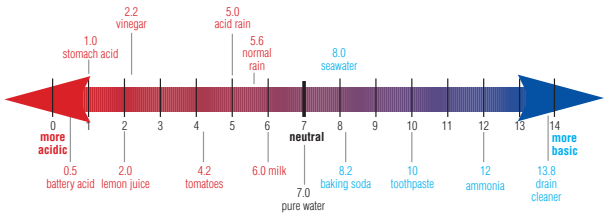


An ionic compound



A molecular compound

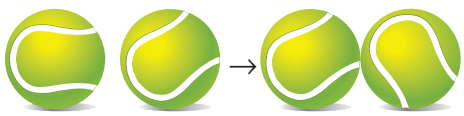
- acid (p. 196)
- acid leaching (p. 211)
- acid precipitation (p. 208)
- acid-base indicator (p. 197)
- base (p. 197)
- neutral (p. 196)
- neutralization (p. 206)
- pH scale (p. 196)
- precipitate (p. 206)
- universal indicator (p. 197)



ph scale

reactants and products.

- combustion (p. 232)
- decomposition reaction (p. 226)
- double displacement reaction (p. 235)
- fossil fuel (p. 232)
- general chemical equation (GCE) (p. 224)
- hydrocarbon (p. 232)
- single displacement reaction (p. 233)
- synthesis reaction (p. 225)

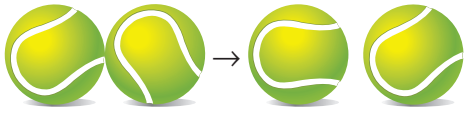


Synthesis

$$AB + C \rightarrow CB + A$$

$$AB + C \rightarrow AC + B$$

Single displacement



Decomposition

$$AB + CD \rightarrow AD + CB$$

Double displacement

Classifying Chemical Reactions Involving Magnesium

Getting Started

In this unit, you have learned how to identify substances from their names and formulas, how to write word equations and balanced chemical equations, and how to identify six types of chemical reactions. In this Unit Task, you will apply this knowledge in carrying out a procedure to observe chemical reactions involving magnesium.

Magnesium is the eighth most abundant element in Earth's crust. It is not usually found in its elemental form.

Your Goals

You will carry out several chemical reactions involving magnesium and classify each type of reaction. You will then write word equations and balanced chemical equations for each chemical reaction.

Criteria for Success

- You must identify whether each reactant is an element, an ionic compound, a molecular compound, an acid, or a base.
- You must predict the products of each reaction.
- You must provide written observations, as well as word equations and balanced chemical equations showing states, for each reaction.

What You Need to Know

The six types of chemical reactions that you learned about in this unit are neutralization reactions, synthesis reactions, decomposition reactions, combustion reactions, single-displacement reactions, and double-displacement reactions.

What You Need

- 10-mL graduated cylinder
- 1 M hydrochloric acid solution, HCl(aq)
- 3 test tubes
- 3-cm strips of Mg metal ribbon
- balance
- 3 scoopulas
- magnesium sulphate, $MgSO_4(s)$
- water, $H_2O(l)$
- 3 test-tube stoppers
- test-tube rack
- sodium carbonate, $Na_2CO_3(s)$
- copper(II) chloride, $CuCl_2(s)$

CAUTION

- Follow your teacher's safety instructions for each chemical reaction.
- Avoid touching all reactants and products.
- Tie back long hair and secure any loose clothing before working around an open flame.

Procedure

1. For each of the substances listed in the What You Need, identify whether each is an element, an ionic compound, a molecular compound, an acid, or a base. If a substance is an ionic compound, state whether it contains a polyatomic ion.
2. Read over the remaining steps of the procedure. Write a prediction of the type of reaction that will occur for each chemical reaction you will carry out.

Part 1 — Reaction 1

3. Using the graduated cylinder, measure 5 mL of the hydrochloric acid and then pour it into a test tube. Drop in a piece of magnesium ribbon. Add a second piece so you can see the reaction again. Record your observations.

Part 2 — Reaction 2

4. Using the balance and a clean scoopula, weigh out 1 g of magnesium sulphate and then place it in a test tube. Using the graduated cylinder, measure 10 mL of water and add it to the test tube. Stopper the test tube, and shake it to dissolve the magnesium sulphate. Place the test tube in the test-tube rack.
5. Using the balance and a clean scoopula, weigh out 1 g of sodium carbonate and place it in a test tube. Using the graduated cylinder, measure 10 mL of water and add it to the test tube. Stopper the test tube, and shake it in order to dissolve the sodium carbonate. Place the test tube in the test-tube rack.
6. Mix the magnesium sulphate solution and sodium carbonate solution together by pouring the contents of one test tube into the other. Record your observations.

In step 6, mix the two solutions by pouring the contents of one test tube into the other.

Part 3 — Reaction 3

7. Using the balance and a clean scoopula, weigh out a 1 g quantity of copper(II) chloride crystals and place it in a test tube. Using the graduated cylinder, measure 10 mL of water and add it to the test tube. Stopper the test tube, and shake it in order to dissolve the copper(II) chloride.
8. Drop in a piece of magnesium ribbon. Record your observations.
9. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Assessing Your Work

10. In reaction 1, the hydrogen in the hydrochloric acid behaves chemically like a metal. What type of reaction is this? Write the word equation and the balanced chemical equation for this reaction.
11. In reaction 2, a white precipitate was observed. What is the identity of this precipitate? What type of reaction is this? Write the word equation and the balanced chemical equation for this reaction.
12. In reaction 3, one of the products is copper metal. The other is magnesium chloride. What type of reaction is this? Write the word equation and the balanced chemical equation for this reaction.
13. Write a summary report. Your report should include the type of substance for each reactant, your initial predictions, and whether each prediction was correct. It should also include your observations and the word and balanced chemical equations for each reaction.

UNIT B Review

ACHIEVEMENT CHART CATEGORIES

- (k) Knowledge and understanding
- (t) Thinking and investigation
- (c) Communication
- (a) Application

Key Terms Review

1. Create a mind map that illustrates your understanding of the following terms and how they relate to chemical reactions. (c)

acid
acid-base indicator
atom
balanced chemical equation
base
binary compound
chemical formula
chemical reaction
combustion reaction
compound
decomposition reaction
double displacement reaction
element
ion
ionic compound
law of conservation of mass
matter
metals
molecular compound
neutralization
non-metals
pH
polyatomic ion
product
pure substance
reactant
salt
single displacement reaction
synthesis reaction
valence shell
word equation

Key Concept Review

4 Chemical change occurs during chemical reactions.

2. Write the symbols for the following ions. (k)

(a) cesium
(b) oxide
(c) tin(II)
(d) nickel(III)
(e) titanium(IV)

3. Write the name of the following ions. (k)

(a) Mg^{2+}
(b) F^-
(c) Au^+
(d) Ag^+
(e) N^{3-}

4. (a) What kind of electric charge do metallic ions possess? (k)

(b) What kind of electric charge do non-metallic ions possess? (k)

5. What is a molecule? (k)

6. (a) What is a valence shell? (k)

(b) What are valence electrons? (k)

7. What is the difference between a molecule that is an element and a molecule that is a compound? (k)

8. How many occupied shells are there in a neon atom? (k)

9. What kinds of elements combine to form ionic compounds? (k)

10. What kinds of elements combine to form molecular compounds? (k)

11. State the law of conservation of mass. (k)

12. What information does a word equation contain? (k)

13. Where are the reactants and the products located in a chemical equation? (k)

14. How do the properties of ionic and molecular compounds differ? (t)

5 Acids and bases are important to our health, industries, and environment.

15. What is the typical range of numbers on the pH scale? (k)

16. What is the pH range of bases? (k)

17. What is the pH range of acids? (k)

18. What kinds of substances are the reactants in a neutralization reaction? (k)

19. In which type of chemical reaction is an ionic compound called a salt always produced? (k)

20. How can you identify an acid and a base from their chemical formulas? (Two answers are required.)

21. What is acid precipitation? (k)

22. What would the pH of a neutral liquid be? (k)

23. (a) What are scrubbers? (k)

(b) Where would they be used? (k)

6 Chemical reactions can be grouped according to the characteristics of their reactants and products.

24. What is a general chemical equation?

25. What type of chemical reaction is the opposite of a synthesis reaction? (k)

26. What type of chemical reaction is represented by these general chemical equations? (k)

(a) $A + B \rightarrow AB$

(b) $C_xH_y + O_2 \rightarrow CO_2 + H_2O$

27. Complete and balance each equation below. The products are all solid ionic compounds. (a)

(a) $Na + Br_2 \rightarrow$

(b) $Mg + F_2 \rightarrow$

(c) $Al + Cl_2 \rightarrow$

(d) $K + N_2 \rightarrow$

(e) $Ca + P_4 \rightarrow$

28. Suppose the reactants of a chemical reaction include a compound and a metallic element. What type of chemical reaction will occur? (k)

29. Suppose the products of a chemical reaction are carbon dioxide and water. What kind of chemical reaction occurred? (k)

Connect Your Understanding

30. Name three elements that form positively charged ions. (a)

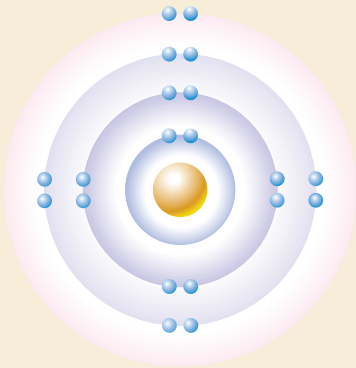
31. Name three elements that form negatively charged ions. (a)

32. The figure below shows a Bohr diagram of a calcium atom.

(a) How many electron shells are shown? (k)

(b) How many valence electrons are in the valence shell? (k)

(c) The charge on a calcium ion is 2+. Explain how this diagram might have been used to predict this charge. (a)



Ca atom
20 protons
20 electrons

Question 32

33. Do ionic compounds form molecules? Explain. (a)

34. What is the only common positively charged polyatomic ion? Provide its name and ion symbol. (a)

35. Draw and label a diagram to show electron transfer from the metallic atom to the non-metallic atom to form the compound lithium fluoride. (t)

36. Draw a Bohr diagram that shows how a pair of electrons is shared in a molecule of hydrogen fluoride (HF). (t)

37. Some sites on the Internet have a FAQ (frequently asked questions) page that contains several questions along with the answers. Design and create a FAQ page for balancing chemical equations. Be creative: add appropriate, relevant images so that your Web page is attractive and informative. (t)

38. Suppose that a student placed a small piece of lithium metal into a beaker of water. The student observed a chemical reaction, in which a hissing sound was produced along with bubbles. Decide if these changes could indicate a chemical reaction. Then, explain your thinking. (t)

39. Suppose you are given a formula equation and are told that it has been balanced. How can you determine whether it has been balanced correctly? (t)

40. Suggest how each of the following acids obtains its name, by providing the name of one or more elements in each: (a)

(a) sulphuric acid, H_2SO_4

(b) hydrochloric acid, HCl

(c) nitric acid, HNO_3

(d) phosphoric acid, H_3PO_4

41. A home gardener wants to raise the pH of some soil. What type of chemical might be used? Give at least one specific example. (a)

42. Predict how acid precipitation might cause changes that affect the organisms in a lake. (t)

43. Classify each of the following chemical reactions. (a)

(a) $NiCO_3(aq) + Fe(s) \rightarrow FeCO_3(aq) + Ni(s)$

(b) $C_5H_{10}(l) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$

(c) $Li_4C(s) + Ca(s) \rightarrow Li(s) + Ca_2C(s)$

(d) $C_6H_{14}(g) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$

(e) $CsF(aq) + AlBr_3(aq) \rightarrow CsBr(aq) + AlF_3(s)$

44. Write a word equation and a balanced chemical equation, including states, for the chemical reactions (a), (c), and (e) in the previous question. (a)

45. Calcium bromide is used in some medicines and as a food preservative. Write the word equation, skeleton equation, and balanced chemical equation for the synthesis reaction that produces calcium bromide. (t)

46. Contrast the two types of single displacement chemical reactions. (a)

47. What does a combustion reaction have in common with a neutralization reaction? (a)

48. Using a T-chart with two columns, list the similarities and differences between a synthesis reaction and a single displacement reaction. (c)

49. Write the names of the following ionic compounds. (a)

(a) BeO

(b) KCl

(c) $SrBr_2$

(d) Al_2S_3

(e) Ca_3P_2

(f) $MnCl_2$

(g) K_2SO_4

(h) Li_3PO_4

(i) $Cr(OH)_2$

(j) NH_4HCO_3

50. Write the formulas for the following ionic compounds. a

(a) sodium bromide

(b) beryllium phosphide

(c) copper(I) oxide

(d) palladium(IV) nitrate

(e) ammonium sulphate

(f) ammonium nitrate

51. Write the names of the following binary molecular compounds: a

(a) S_2O_3

(b) P_2S_5

(c) OF_2

(d) N_2O_3

(e) CO_2

52. Write the formulas of the following binary molecular compounds: a

(a) sulphur hexafluoride

(b) carbon disulphide

(c) dinitrogen monoxide

(d) carbon tetrachloride

(e) carbon monoxide

53. For each of the following word equations, identify the type of chemical reaction it represents. a

(a) methane (CH_4) + oxygen → carbon dioxide + water

(b) barium + oxygen → barium oxide

(c) aluminum bromide + fluorine → aluminum fluoride + bromine

(d) magnesium chloride → magnesium + chlorine

(e) lithium sulphate + barium chloride → lithium chloride + barium sulphate

(f) nitric acid + barium hydroxide → barium nitrate + water

54. Rewrite this balanced chemical equation. Fill in the missing salt compound (given by "?") on the products side. a

$HCl + KOH \rightarrow ? + H_2O$

55. Create an analogy by describing an event or activity in your daily life that is similar to a single displacement reaction. a

56. The following general chemical equations use picture symbols in place of chemical symbols. Identify the chemical reaction represented by each. a

(a) ■ + ▲○ → ■○ + ▲

(b) H□ + ▶OH → ▶□ + H_2O

(c) ●■ → ● + ■

(d) ▼ + ■● → ▼● + ■

(e) □ + ◀ → □◀

(f) ▲▼ + □○ → ▲○ + □▼

(g) ■OH + H□ → ■□ + H_2O

57. For each general chemical equation in the above question, find one example of a balanced chemical equation in this unit. a

58. When calcium metal undergoes a chemical reaction with oxygen gas, solid calcium oxide is produced. Identify the type of chemical reaction, and then write the balanced chemical equation. a

59. Write the skeleton equation and balanced chemical equation for each of the following chemical reactions. a

(a) carbon disulphide + oxygen → carbon dioxide + sulphur dioxide

(b) lead(II) nitrate + sodium sulphate → lead(II) sulphate + sodium nitrate

(c) potassium bromide + silver nitrate → silver bromide + potassium nitrate

60. Which of the chemical reactions in question 59 would be classified as a double-displacement reaction? t

61. A chemist carefully combines sulphuric acid (H_2SO_4) and ammonium hydroxide. Write the word equation, skeleton equation, and balanced chemical equation for this neutralization reaction. a

62. Benzene, C_6H_6, is a toxic liquid hydrocarbon that is used to produce plastics, adhesives, nylon, detergents, dyes, lubricants, explosives, and pesticides. Write the word equation, skeleton equation, and balanced chemical equation for the combustion of benzene. a

63. For each of the following, suggest one or more situations in which chemical reactions are important. a

(a) in your home

(b) at tourist resorts

(c) in restaurants in your community

(d) in another situation of your choice

64. Name several categories of consumer products that are produced through chemical reactions. a

65. Suggest several ways that you can keep informed about chemicals and chemical reactions. a

66. Pure substances are used to produce newspapers, paper towels, clothing, and many consumer products you use daily. What happens to these pure substances when you no longer need these products? Suggest several answers. a

67. Every Canadian province has emergency teams and procedures to deal with chemical spill situations. Why do you think it is important to have laws that cover an entire province? a

68. Suppose a train derailment spills sodium hydroxide into some soil. Use your knowledge of chemical reactions to suggest how an emergency response team could neutralize the effects of this chemical. a

69. Write an e-mail to a friend in which you describe two or more applications of chemical reactions in daily life a

70. Name five or more jobs or professions where it would be important to know about chemical reactions. a

71. The pulp and paper industry uses a number of different chemicals. The table below lists some of these chemicals and describes how they are used.

(a) Suggest several reasons why these chemicals are reused as often as possible. a

(b) Since the pulp and paper manufacturers reuse chemicals, if you reduce your use of paper products, will this affect the amount of chemicals that are used in making pulp and paper? Explain. a

Some Chemicals Used in the Pulp and Paper Industry

Substance	Formula	Use
barium sulphate	$BaSO_4$	provides white colour to paper
caustic lye (sodium hydroxide)	NaOH	maintains correct pH
chalk (calcium carbonate)	$CaCO_3$	makes paper look brighter

72. Suggest one or more reasons why a career in chemistry or chemical engineering can be rewarding. (a)

73. Suppose you are a member of the local government in your community. A company has indicated that it is interested in opening a chemical manufacturing facility in your community. The facility will offer year-round employment to many people. What additional information will you need in order to decide whether to allow the facility to be located in your community? (a)

Skills Practice

74. Write a brief procedure to test whether an unknown liquid is acidic, basic, or neutral. Include any safety precautions. (t)

75. Several groups of students performed the following investigation. Two beakers, each containing a colourless liquid, were weighed. The total mass was recorded. The two liquids were then combined, and a white solid was observed to form. The two beakers, one of which contained the solid product, were then reweighed and the total mass recorded. Each group then compared the total mass before and after the chemical reaction had occurred. Most found that the total mass had not changed. However, some groups found that the mass decreased slightly. Suggest possible reasons for these observations. (t)

Revisit the Big Ideas and Fundamental Concepts

76. Use the new terms and concepts you have learned in this unit to design and draw a mind map for the entire unit. You may use the titles of the chapters for the separate sections of your map. Add relevant details and information from activities and/or research you have completed. Add relevant images. Include your name and class to identify your map. (c)

STSE Science, Technology, Society, and the Environment

77. Consider the products of a combustion reaction. How could you and your family help to reduce global warming? Be specific. (a)

78. Why is acid rain less of a problem in Ontario in the 21st century than in the century before? Provide several answers, including a technology. (a)

79. Describe one or more aspects of your lifestyle that you could alter to reduce the number of chemical reactions your daily activities require. (a)

Reflection

80. In this unit, you have learned many things about how chemical reactions form. What is the most important thing you learned about chemical reactions? Why do you think it is the most important? (c)

81. Think back to your ideas about the effects of chemical reactions on the environment at the start of this chapter. How have your ideas changed? (c)