SECTION 3.2 Synthesis Reactions and Decomposition Reactions

Key Terms

synthesis reaction
decomposition reaction
electrolysis

The bullsnake (*Pituophis melanoleucus*), shown in **Figure 3.7**, is a non-venomous snake that is found in much of North America, including southern Canada. People often mistake it for a venomous rattlesnake because it may have similar colours and markings. In addition, when a bullsnake is threatened, it imitates a rattlesnake by hissing and rapidly beating its tail against plants or leaves on the ground to make noise. Another animal mimic, the hoverfly (subfamily Syrphidae), is also found in Ontario. Many species of hoverfly have yellow and black markings. Therefore, they strongly resemble bees or wasps. Hoverflies, however, do not sting or bite. People who understand how to classify these animals understand their different characteristics and can predict where they are likely to be encountered.

Like these animals, chemical reactions can be classified. By understanding how to classify chemical reactions, you can better understand them, recognize patterns in them, and make predictions about their products.

Figure 3.7 When disturbed, this bullsnake may imitate the aggressive posture of a rattlesnake and shake its tail. Unlike a rattlesnake, however, a bullsnake produces no poisonous venom. Understanding how to classify these two animals is very important to biologists. Likewise, chemists need to understand how to classify chemical reactions.

Classifying Chemical Reactions

Chemical reactions can be classified by type, including

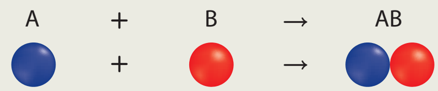
- synthesis reactions
- decomposition reactions
- combustion reactions
- single displacement reactions
- double displacement reactions

In this chapter, you will learn how to recognize and predict the products of synthesis reactions, decomposition reactions, and combustion reactions. In Chapter 4, you will study single displacement reactions and double displacement reactions.

Characteristics of Synthesis Reactions

In a **synthesis reaction**, two or more substances react to produce a single compound. A synthesis reaction can be represented by the following general form:

synthesis reaction a chemical reaction in which two or more reactants combine to produce a single compound



In a synthesis reaction, the reactants can be any combination of elements and compounds. The product, however, is always a single compound. Therefore, the determining factor in classifying a chemical reaction as a synthesis reaction is the formation of a single compound. An example of a synthesis reaction that occurs in the environment is the formation of acid precipitation. **Figure 3.8** models one step in this process.

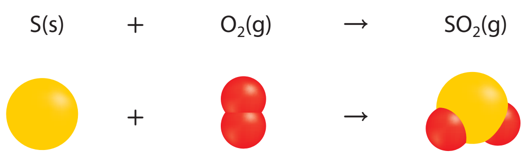


Figure 3.8 In a synthesis reaction, a single compound forms from two or more reactants. This model shows sulfur dioxide forming from the elements sulfur and oxygen.

***Explain** the relationship between the general form of a synthesis reaction and the reaction shown here.*

Synthesis Reactions and Acid Precipitation

Normally, precipitation such as, snow, and fog is slightly acidic because carbon dioxide dissolves in water in the atmosphere and reacts with the water according to the following synthesis equation:

$$\text{carbon dioxide} + \text{water} \rightarrow \text{carbonic acid}$$
$$CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq)$$

Other natural processes contribute to the acidity of atmospheric precipitation. For example, lightning strikes produce nitrogen compounds that form nitric acid, $HNO_3(aq)$. Volcanic gases add sulfur compounds that form sulfuric acid, $H_2SO_4(aq)$. But the major sources of acid-forming compounds are coal-burning and oil-burning power plants. These power plants produce sulfur compounds, which can be carried many hundreds of kilometres by winds. In the atmosphere, sulfur compounds combine with atmospheric moisture to cause rain, snow, and fog with increased acidity.

There are three key reactions in the formation of acid precipitation involving sulfur. These reactions are all synthesis reactions. In the first reaction in the sequence, sulfur and oxygen (two elements) combine to form sulfur dioxide, as shown in **Figure 3.8**. Note that diatomic molecules, such as oxygen, are molecular elements and not compounds, because they consist of two atoms of one element. In the second reaction, sulfur dioxide (a compound) combines with additional oxygen (an element) to form sulfur trioxide. In the third reaction, sulfur trioxide and water (two compounds) combine to form sulfuric acid (another compound).

$$S(s) + O_2(g) \rightarrow SO_2(g)$$
$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$
$$SO_3(g) + H_2O(\ell) \rightarrow H_2SO_4(aq)$$

Notice how, in each equation, a single product is formed from the reactants.

Types of Synthesis Reactions

On the next few pages, you will learn about the following types of synthesis reactions:

- two elements forming a binary compound
- an element and a compound forming a new compound
- two compounds forming a new compound

Two Elements Forming a Binary Compound

A common type of synthesis reaction occurs when two elements react. These reactions include those listed below. Note that a *univalent* metal is a metal that can form ions with only one charge, while a *multivalent* metal is a metal that can form ions with more than one charge.

- a univalent metal reacting with a non-metal to form an ionic compound
- a multivalent metal reacting with a non-metal to form various compounds
- two non-metals combining to form a molecular compound

The product of the reaction of two elements is a binary compound composed of the elements. The types of elements that react are related to the type of compound that forms.

A Univalent Metal Reacting with a Non-metal to Form an Ionic Compound

When a metal reacts with a non-metal, an ionic compound forms. Recall that the electronegativity difference between a metal and a non-metal tends to be large, so electrons are transferred from the metal atoms to the non-metal atoms. The charges of the resulting ions determine the chemical formula for the compound. **Figure 3.9** shows the reaction between sodium and chlorine. Through the transfer of electrons, sodium ions and chloride ions are formed. Sodium is a member of the alkali metals and forms only one ion, Na^+. Chlorine is a halogen and forms the chloride ion, Cl^-. You can predict the formula for the product that forms, NaCl. When predicting the formula for the product that forms from the synthesis reaction of a metal and a non-metal, remember to balance the charges so that the net charge of the compound is zero.

Go to **scienceontario** to find out more

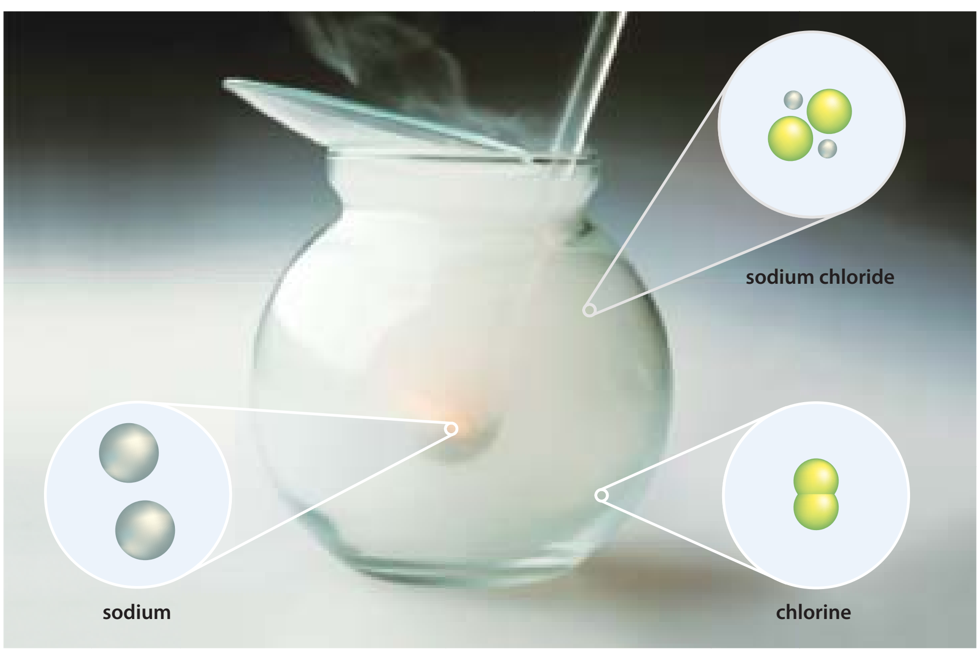


Figure 3.9 When sodium reacts with chlorine, the two elements undergo a synthesis reaction in which a binary ionic compound, sodium chloride, is produced.

Learning Check

7. What is the general form of a synthesis reaction?
8. When a metal reacts with a non-metal during a synthesis reaction, what type of compound forms?
9. **Figure 3.9** shows a synthesis reaction between solid sodium and chlorine gas.
   a. What main characteristic of this chemical reaction causes it to be classified as a synthesis reaction?
   b. Write a balanced chemical equation for this reaction.
10. Solid calcium and chlorine gas can produce a solid product in a synthesis reaction.
    a. Predict the product of this reaction.
    b. Write a balanced chemical equation for this reaction.
11. As you have learned, three chemical reactions involving sulfur are associated with the formation of acid precipitation. Create a graphic organizer to compare the types of reactants in these reactions.
12. A product of the chemical reaction of ethane, $C_2H_6(g)$, with oxygen is carbon dioxide. Could this reaction be a synthesis reaction? Explain.

A Multivalent Metal Reacting with a Non-metal to Form Various Compounds

The periodic table provides the charges that metal ions can have. Thus, the periodic table is an important tool for predicting the formulas of the compounds that are formed in synthesis reactions.

If a metal has more than one possible ion charge, you cannot accurately predict the product of a synthesis reaction that involves this metal. For example, copper can have a charge of 1+ or 2+. For the reaction of copper with a non-metal, you need to consider each charge when predicting the possible product. Thus, for the reaction of copper with chlorine, you need to consider the following reactions:

Formation of Copper(I) Chloride

copper + chlorine → copper(I) chloride

$$2Cu(s) + Cl_2(g) \rightarrow 2CuCl(s)$$

Formation of Copper(II) Chloride

copper + chlorine → copper(II) chloride

$$Cu(s) + Cl_2(g) \rightarrow CuCl_2(s)$$

As these chemical equations indicate, the reaction might produce copper(I) chloride or copper(II) chloride. Both compounds are shown in **Figure 3.10**.

Figure 3.10 Because copper is a multivalent metal, it can form two different binary compounds with chlorine.

Analyze *Manganese can form the oxides $MnO(s)$, $MnO_2(s)$, $Mn_2O_3(s)$, and $Mn_2O_7(s)$. How are these manganese oxides similar to the copper compounds shown here?*

Two Non-metals Combining to Form a Molecular Compound

When two non-metals react, the electronegativity difference between the elements tends to be too low for the transfer of electrons to occur. Instead, the non-metal atoms share electrons, and the elements combine to form a molecular compound. Because electrons are shared, the non-metal atoms do not form ions, so there are no charges to help you determine the chemical formula for the product. In addition, many non-metals can combine in several different ratios. For example, carbon and oxygen can react to form either carbon dioxide or carbon monoxide, as shown below.

Formation of Carbon Dioxide

$$\text{carbon} + \text{oxygen} \rightarrow \text{carbon dioxide}$$
$$C(s) + O_2(g) \rightarrow CO_2(g)$$

Formation of Carbon Monoxide

$$\text{carbon} + \text{oxygen} \rightarrow \text{carbon monoxide}$$
$$2C(s) + O_2(g) \rightarrow 2CO(g)$$

If you only know that the reactants are carbon and oxygen, you cannot predict with certainty which compound will form without additional information. This information can be determined by collecting and analyzing the products formed during the reaction.

Sample Problem

Predicting Synthesis Products

Problem

Write balanced chemical equations that show the likely products of the synthesis reactions of chromium with sulfur.

What Is Required?

The chemical formulas of the likely products of the synthesis reactions are required. Balanced chemical equations for the reactions are also required.

What Is Given?

You are given the reactants: chromium and sulfur.
You know the type of reaction: synthesis.

Plan Your Strategy	Act on Your Strategy
Identify the types of elements involved. Determine the type of compound they will form.	Chromium, Cr: metal Sulfur, S: non-metal They will react to form an ionic compound.
If there is a metal, determine whether it is multivalent. If so, determine its possible charges. If there is no metal, examine the information about the products given in the problem.	Chromium is a multivalent metal. Cr^{3+}, Cr^{2+}
Use the appropriate method to write the formulas of the products.	Cr_2S_3 CrS
Write a balanced chemical equation for each reaction.	$2Cr(s) + 3S(s) \rightarrow Cr_2S_3(s)$ $Cr(s) + S(s) \rightarrow CrS(s)$

Check Your Solution

The overall charge of each formula is zero. The chemical equations are balanced.

Practice Problems

Predict the product that is likely to form in each reaction, and write a balanced chemical equation for the reaction.

21. lithium and oxygen
22. strontium and fluorine
23. iron and bromine
24. phosphorus and hydrogen, forming gaseous phosphorus trihydride
25. calcium and iodine
26. tin and oxygen
27. bismuth and sulfur
28. aluminum and iodine
29. silver and oxygen
30. nitrogen and oxygen, forming nitrogen dioxide

An Element and a Compound Forming a New Compound

In some synthesis reactions, an element and a compound are the reactants. Earlier in this section, you saw one such reaction, which is involved in the formation of acid precipitation:

$$\text{sulfur dioxide} + \text{oxygen} \rightarrow \text{sulfur trioxide}$$
$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

Another reaction that occurs between an element and a compound is the formation of phosphorus pentachloride from phosphorus trichloride and chlorine. This is a reversible reaction, as shown below.

$$\text{phosphorus trichloride} + \text{chlorine} \rightleftharpoons \text{phosphorus pentachloride}$$
$$PCl_3(\ell) + Cl_2(g) \rightleftharpoons PCl_5(s)$$

Phosphorus pentachloride is used as a source of chlorine in various industrial chemical reactions, including the production of flame-retardant products, such as the fabric shown in **Figure 3.11**. Another use of phosphorus pentachloride is in lithium-based batteries.

Figure 3.11 This hot-air balloon is made from a flame-resistant fabric. The same type of fabric is also used for such applications as making protective clothing for firefighters.

Two Compounds Forming a New Compound

The final combination of reactants that can undergo a synthesis reaction is two compounds. Because a synthesis reaction has a single compound as the product, the reacting compounds tend to be small, simple compounds, such as oxides and water. An oxide is a compound that is composed of oxygen and another element.

A Non-metal Oxide Reacting with Water

Earlier in this section, you saw how carbonic acid forms in the reaction between carbon dioxide and water, and how sulfuric acid forms in the reaction between sulfur trioxide and water. In both of these reactions, a non-metal oxide combines with water to form an acid:

$$CO_2(g) + H_2O(\ell) \rightarrow H_2CO_3(aq)$$
$$SO_3(g) + H_2O(\ell) \rightarrow H_2SO_4(aq)$$

Suggested Investigation

Plan Your Own Investigation 3-A, Testing the Acidity of Oxides

Reactions involving carbon dioxide and sulfur trioxide contribute to acid precipitation. Acid precipitation formed in the reaction between non-metal oxides and water can damage structures, such as buildings and bridges, and plants, as shown in **Figure 3.12**. Acid precipitation can also cause bodies of water to become too acidic to support fish and other aquatic life. To help reduce the harm done by acid precipitation, governments have passed laws that limit emissions of oxides from industrial plants.

Figure 3.12 These trees have died due to acid precipitation.

A Metal Oxide Reacting with Water

As you have learned, a non-metal oxide can react with water to form an acid. Similarly, a metal oxide can react with water to form a metal hydroxide (or base). For example, the formation of sodium hydroxide can be represented by the following equation:

$$\text{sodium oxide} + \text{water} \rightarrow \text{sodium hydroxide}$$
$$Na_2O(s) + H_2O(\ell) \rightarrow 2NaOH(aq)$$

Sodium hydroxide has a wide variety of industrial uses, including the production of paper, soaps, and detergents.

Metal hydroxides are ionic compounds. You can use the charge of the metal ion in the oxide to predict the formula for the metal hydroxide that is formed during the synthesis reaction between a metal oxide and water.

Characteristics of Decomposition Reactions

A **decomposition reaction** is a reaction in which a compound breaks down into two or more elements or simpler compounds. It is often the reverse of a synthesis reaction. A decomposition reaction can be represented by the following general form:

decomposition reaction a chemical reaction in which a compound breaks down into elements or simpler compounds

$$AB \rightarrow A + B$$

In a decomposition reaction, a single reactant, which is always a compound, is changed into more than one product. These products can be elements, elements and compounds, or multiple compounds.

Decomposition Reactions and Rocket Thrusters

The chapter opener showed how the Phoenix Mars Lander used decomposition reactions within its thruster rockets to fire pulses of gases, which controlled its final descent to the Martian surface. One of the thruster rockets is shown in **Figure 3.13**.

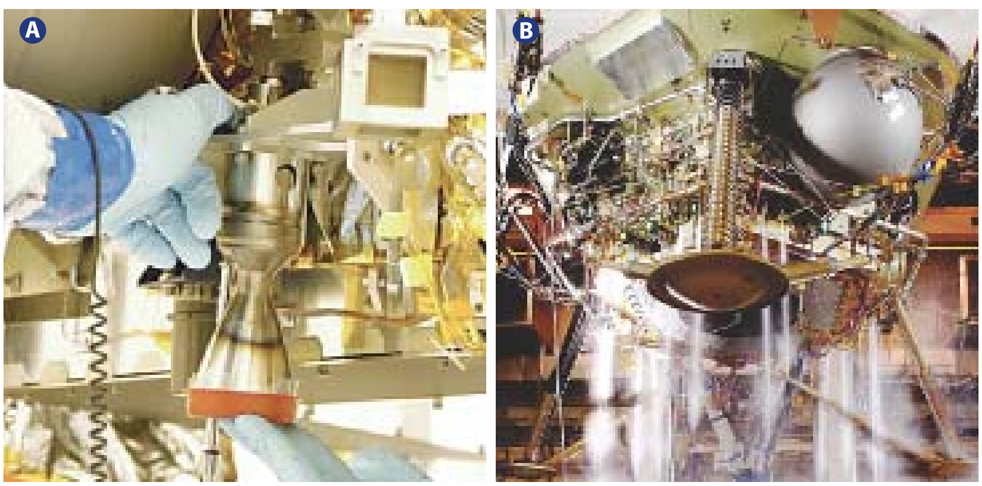


Figure 3.13 The Phoenix Mars Lander has twelve thruster rockets **(A)**. The thruster-rocket system in the partial model of the Phoenix Mars Lander **(B)** is being tested for its ability to withstand the stresses related to the decomposition of rocket fuel.

The reactions in the thruster rockets of the Phoenix Mars Lander broke down liquid hydrazine, $N_2H_4(\ell)$, according to the following decomposition reactions:

$$3N_2H_4(\ell) \rightarrow 4NH_3(g) + N_2(g)$$
$$N_2H_4(\ell) \rightarrow N_2(g) + 2H_2(g)$$

Hydrazine is an effective fuel for thruster rockets because its decomposition very quickly produces a large volume of hot gases from a small amount of fuel. The amount of hydrazine being released controls the volume of hot gases being produced, and therefore the degree of thrust being provided. The final descent of the Phoenix Mars Lander could be controlled very precisely by varying the amount of hydrazine being burned in each of the lander's twelve thruster rockets. Hydrazine is also effective for use in thruster rockets because it does not need to be combined with another chemical for a decomposition reaction to occur. Therefore, it does not require a complex storage or mixing system.

Decomposition Reactions and Automobile Safety

When a vehicle with air bags is in a collision, a decomposition reaction causes the air bags to inflate within thousandths of a second. The air bags cushion the people inside the vehicle, preventing impact with hard surfaces.

How does an air bag work? During a crash, the abrupt slowing of the vehicle triggers a sensor in the air bag. The sensor generates an electrical impulse that ignites a pellet of sodium azide, $NaN_3(s)$. The sodium azide undergoes a very rapid decomposition reaction into sodium and nitrogen as represented in **Figure 3.14**. The nitrogen gas inflates the air bag. The sodium is a very reactive metal and is hazardous. Other chemical reactions take place within the air bag to convert the sodium into compounds that are harmless and stable.

Sodium azide is a toxic chemical. It is changed into harmless substances by the reactions that occur when an air bag inflates. However, most vehicles are never involved in crashes that cause their air bags to inflate. When the vehicles are no longer useful, they are often recycled by being crushed flat and shredded into small pieces. Various metals and plastics can then be separated and used again. Before the recycling begins, the air bags are removed or caused to inflate to prevent the release of sodium azide.

Decomposition of Sodium Azide

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

Figure 3.14 In a decomposition reaction, a single compound breaks down. The decomposition of sodium azide is used to inflate air bags.

Analyze *Which product of the decomposition of sodium azide causes an air bag to inflate?*

Types of Decomposition Reactions

Just as there are different types of synthesis reactions, there are different types of decomposition reactions. On the following pages, you will learn more about these decomposition reactions:

- a binary compound decomposing into its elements
- a metal nitrate decomposing into a metal nitrite and oxygen gas
- a metal carbonate decomposing into a metal oxide and carbon dioxide
- a metal hydroxide decomposing into a metal oxide and water

Depending on the type of compound that breaks down, you might be able to predict the products that are likely to form because of patterns in the ways that the substances react. The general rules presented in this section reflect a small number of decomposition reactions but include examples of some common reactions you might encounter.

A Binary Compound Decomposing into Its Elements

A compound that is composed of only two elements will usually decompose into those elements. High temperature or an electric current is often used to break a compound into its elements. **Electrolysis** is a process that uses electrical energy to cause a chemical reaction.

electrolysis a process that uses electrical energy to cause a chemical reaction

Electrolysis was used by early chemists to isolate and identify elements, and it is used by modern industries to produce elements for commercial use. For example, one method of generating hydrogen gas for hydrogen-fuelled vehicles is through the decomposition of water, as shown in **Figure 3.15**. An electric current is used to break down the water molecules into hydrogen molecules and oxygen molecules.

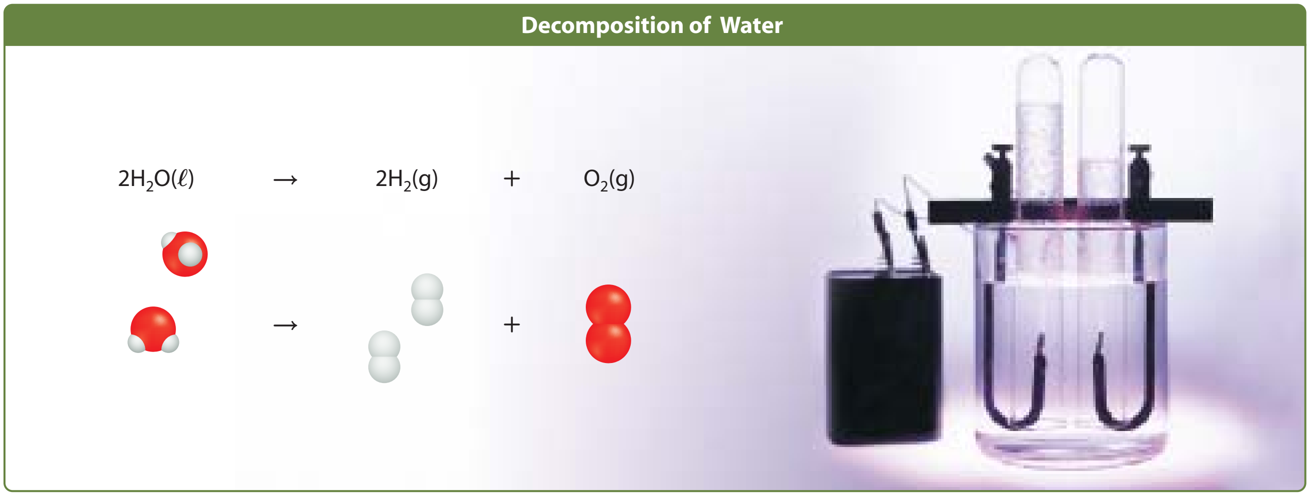


Figure 3.15 The electrolysis of water uses electrical energy to break down water into the elements hydrogen and oxygen. On an industrial scale, hydrogen-generating plants can use the electrolysis of water to produce hydrogen for use as a fuel.

Another important application of electrolysis is the decomposition of sodium chloride, according to the following chemical equation:

$$\text{sodium chloride} \rightarrow \text{sodium} + \text{chlorine}$$
$$2NaCl(\ell) \rightarrow 2Na(\ell) + Cl_2(g)$$

Notice that the reactant must be in the liquid state. This is because an ionic compound, such as sodium chloride, is a good electrical conductor only when its ions are free to move.

The products of the decomposition of sodium chloride are widely used. Sodium is used as a coolant in nuclear reactors. It is also used in sodium vapour lamps, as shown in **Figure 3.16**. Chlorine is used in water purification, and it is an important substance in the manufacture of an assortment of products, such as bleach, paper, paints, and plastics.

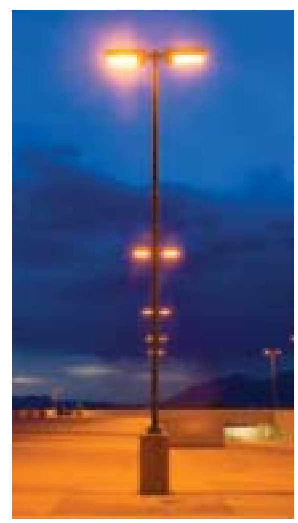


Figure 3.16 The sodium used in this street lamp was generated through the decomposition of sodium chloride. The yellow glow is characteristic of a sodium vapour lamp.

Heat can also be used to decompose a compound into its elements. In this process, which is called thermal decomposition, heat breaks chemical bonds in a compound. The *thermal decomposition* of mercury(II) oxide was important in the identification of oxygen as an element. Mercury(II) oxide decomposes into its elements according to the following chemical equation:

$$\text{mercury(II) oxide} \rightarrow \text{mercury} + \text{oxygen}$$
$$2HgO(s) \rightarrow 2Hg(\ell) + O_2(g)$$

Uses of mercury include the manufacture of thermometers and barometers. Mercury is mixed with other metals to make a material used to fill cavities in teeth. In nature, mercury is commonly found in combination with sulfur in the mineral cinnabar, $HgS(s)$. Powdered cinnabar is used as a pigment to make bright red paint. Mercury is also used in certain types of electrochemical batteries.

A Metal Nitrate Decomposing into a Metal Nitrite and Oxygen Gas

Compounds that are composed of more than two elements generally do not decompose into their individual elements. For example, sodium nitrate, $NaNO_3(s)$, will not decompose into sodium, nitrogen, and oxygen. You can often predict the products that are likely to form, however, based on the polyatomic ion in the compound. For example, compounds that are composed of the nitrate ion often decompose into a nitrite-containing compound and oxygen gas. Sodium nitrate, which can be used in explosives, decomposes as follows:

$$\text{sodium nitrate} \rightarrow \text{sodium nitrite} + \text{oxygen}$$
$$2NaNO_3(s) \rightarrow 2NaNO_2(s) + O_2(g)$$

Other decomposition reactions are also possible for nitrates, depending on the conditions in which the reactions occur.

Learning Check

13. What type of product forms when a metal oxide reacts with water?

14. Make a graphic organizer to compare the solutions formed when water reacts with a metal oxide and with a non-metal oxide.

15. Give the general form of a decomposition reaction. Describe the main characteristic of this type of reaction.

16. Is it possible for a decomposition reaction to have an element as a reactant? Explain.

17. In what state, other than the liquid state, is electrolysis possible? Explain your reasoning.

18. Describe the role of thermal decomposition in the isolation of elemental mercury, and give two examples of how mercury is used.

A Metal Carbonate Decomposing into a Metal Oxide and Carbon Dioxide

Quicklime, or calcium oxide, is a main component of cement. Cement is used to make concrete, such as the sidewalk shown in **Figure 3.17**. The decomposition of calcium carbonate in limestone is a major step in the production of cement. A metal carbonate generally decomposes to form a metal oxide compound, while giving off carbon dioxide gas. The following chemical equation shows the decomposition of calcium carbonate:

$$\text{calcium carbonate} \rightarrow \text{calcium oxide} + \text{carbon dioxide}$$
$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

Cement is mixed with water, sand, and gravel to make concrete. As the concrete dries, quicklime reacts to form compounds that bind the mixture together.

Figure 3.17 Quicklime, the main component of the cement in the concrete on which this mural was drawn, was produced in the decomposition of calcium carbonate. In addition, the main component of the chalk used to draw the mural is calcium carbonate.

Activity 3.2 Thermal Decomposition of Calcium Carbonate

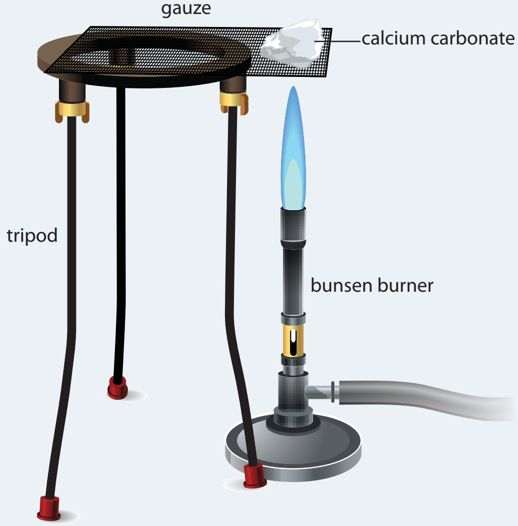
Calcium carbonate is the main component of limestone, marble, and seashells. In this activity, you will thermally decompose calcium carbonate. You will also cause a reaction between an aqueous solution of a product of the decomposition reaction and carbon dioxide that causes particles of calcium carbonate to form.

Safety Precautions

- Wear safety eyewear throughout this activity.
- Tie back loose hair and clothing.
- Use EXTREME CAUTION when you are near an open flame.
- Use clean a drinking straw in this activity. Get the straw from your teacher when it is needed. Do not let it touch the lab bench.

Materials

- small piece of calcium carbonate, $CaCO_3(s)$
- 15 mL of distilled water
- phenolphthalein indicator solution in a dropper bottle
- metal gauze
- tripod
- Bunsen burner secured to a utility stand
- igniter for Bunsen burner
- tongs
- 2 test tubes
- test tube stopper
- 10 mL graduated cylinder
- test-tube rack
- filter funnel
- filter
- clean drinking straw



Procedure

1. Place a piece of calcium carbonate on metal gauze supported on a tripod.
2. Ignite the Bunsen burner. Adjust the air vents to obtain a blue flame.
3. Heat the calcium carbonate with the Bunsen burner flame for 8 minutes. Allow the solid material to cool for 2 minutes. Record your observations.
4. Use the tongs to transfer the solid material to a test tube.
5. Use the graduated cylinder to add 10 mL of water to the test tube. Put the stopper in the test tube and then shake the test tube for about 15 seconds. Place the test tube in the test-tube rack. Record your observations.
6. Place the filter funnel into the opening of the second test tube. Put the filter paper into the funnel. Pour about half of the contents of the first test tube into the funnel and allow the liquid to pass through the filter.
7. Use a clean drinking straw to gently blow a stream of bubbles through the filtered liquid collected in the second test tube. Carefully observe the colour and cloudiness of the solution. Record your observations.
8. Add 3 drops of phenolphthalein indicator solution to the first test tube. Record your observations.

Questions

1. Write a balanced chemical equation for the thermal decomposition of calcium carbonate.
2. Explain why this is a decomposition reaction.
3. What is the material that remained after the calcium carbonate was heated? How did the solidity of this material compare to that of calcium carbonate? Explain your answer.
4. In step 5, calcium oxide and water reacted to produce an aqueous solution of calcium hydroxide. Write a balanced chemical equation for this reaction.
5. What type of reaction is the one for which you wrote a balanced equation in question 4? Explain your answer.
6. An aqueous solution of calcium hydroxide is commonly called limewater. Limewater reacts with carbon dioxide gas to form solid calcium carbonate, according to the following equation:
   $Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(\ell)$
   What was the source of carbon dioxide gas in step 7? How did the appearance of the solution change in step 7 to indicate the formation of calcium carbonate?
7. Is an aqueous solution of calcium hydroxide acidic or basic? Explain your answer.

A Metal Hydroxide Decomposing into a Metal Oxide and Water

A metal oxide is also produced in the decomposition of a metal hydroxide. When heated, a metal hydroxide will generally break down to form a metal oxide and water. For example, calcium oxide can be formed by the decomposition of calcium hydroxide according to the following chemical equation:

$$\text{calcium hydroxide} \rightarrow \text{calcium oxide} + \text{water}$$
$$Ca(OH)_2(s) \rightarrow CaO(s) + H_2O(g)$$

Based on the few general patterns of the decomposition reactions presented in this section, you will now be able to predict the likely products of the decomposition of many compounds.

Sample Problem

Predicting Decomposition Products

Problem

Write a balanced chemical equation that shows the likely products of the decomposition of rubidium carbonate.

What Is Required?

Determine the products that are likely to form when rubidium carbonate decomposes, and write a balanced chemical equation for the reaction.

What Is Given?

You are given the type of reaction: decomposition.

You are given the reactant: rubidium carbonate.

Plan Your Strategy	Act on Your Strategy
Identify the type of compound that is decomposing.	A metal carbonate is decomposing.
Determine the types of products that usually form in this type of reaction.	A metal oxide and carbon dioxide are the usual products of the decomposition of a metal carbonate.
Write a word equation for the reaction.	rubidium carbonate → rubidium oxide + carbon dioxide
Write and balance a chemical equation for the reaction.	$Rb_2CO_3(s) \rightarrow Rb_2O(s) + CO_2(g)$

Check Your Solution

Each chemical formula is correct, and the chemical equation is balanced. The products are those that you would expect to be produced from the decomposition of a metal carbonate.

Practice Problems

Determine the products that are likely to form in the decomposition of each compound, and write a balanced chemical equation for the reaction.

31. potassium bromide

32. aluminum oxide

33. magnesium hydroxide

34. calcium nitrate

35. copper(II) carbonate

36. chromium(III) chloride

37. barium carbonate

38. rubidium nitrate

39. lithium hydroxide

40. magnesium chloride

Other Decomposition Reactions

Some decomposition reactions produce more than two products. One of these reactions is the decomposition of the explosive trinitrotoluene (TNT), shown in **Figure 3.18**. The chemical formula for TNT is $C_7H_5N_3O_6(s)$. Its decomposition produces four products:

$$\begin{array}{ccccccccc} \text{trinitrotoluene} & \rightarrow & \text{nitrogen} & + & \text{water} & + & \text{carbon monoxide} & + & \text{carbon} \\ 2C_7H_5N_3O_6(s) & \rightarrow & 3N_2(g) & + & 5H_2O(g) & + & 7CO(g) & + & 7C(s) \end{array}$$

The explosive force of TNT comes from the gases that are produced. These gases are heated by the energy that is released during the reaction, and they rapidly expand outward. TNT has applications for military, demolition, and industrial uses. It is also used for underwater blasting because it is insoluble in water.

Figure 3.18 In 1917, the ship *SS Mont-Blanc* collided with another ship and caught on fire in the harbour of Halifax, Nova Scotia. *SS Mont-Blanc* had been loaded with explosives, including hundreds of rounds of ammunition and about 180 000 kg of TNT. The fire caused the explosives to detonate, sending a huge cloud into the sky.

Another decomposition reaction that produces multiple products is the decomposition of ammonium dichromate, $(NH_4)_2Cr_2O_7(s)$. This reaction is often used in chemistry demonstrations, as shown in **Figure 3.19**, because of the dramatic and energetic change in the compound. Three products form in the decomposition of ammonium dichromate:

$$\begin{array}{ccccccc} \text{ammonium dichromate} & \rightarrow & \text{nitrogen} & + & \text{chromium(III) oxide} & + & \text{water} \\ (NH_4)_2Cr_2O_7(s) & \rightarrow & N_2(g) & + & Cr_2O_3(s) & + & 4H_2O(g) \end{array}$$

Figure 3.19 Ammonium dichromate is a bright orange powder **(A)**. As it decomposes **(B)**, it releases heat and light. The transformation of ammonium dichromate into a dark green powder, chromium(III) oxide **(C)**, makes an ammonium dichromate "volcano," a popular chemistry demonstration.

Go to **scienceontario** to find out more

Section 3.2 REVIEW

Section Summary

- In a synthesis reaction, two or more reactants combine to form a single product. This reaction can be represented by the general form $A + B \rightarrow AB$.
- The product of a synthesis reaction between a metal and a non-metal is usually a binary ionic compound. The product of a synthesis reaction between a multivalent metal and a non-metal depends on the charge of the metal ion formed.
- In a synthesis reaction, a non-metal can combine with another non-metal in several different ratios.
- A non-metal oxide reacts with water to form an acid in a synthesis reaction. A metal oxide reacts with water to form a metal hydroxide, which is a base.
- In a decomposition reaction, a single reactant breaks apart to form two or more products. This reaction can be represented by the general form $AB \rightarrow A + B$. A binary compound generally decomposes into its elements.
- A metal nitrate generally decomposes into a metal nitrite and oxygen gas.
- A metal carbonate generally decomposes into a metal oxide and carbon dioxide gas. A metal hydroxide generally decomposes into a metal oxide and water.

Review Questions

1. K/U Describe the two main types of chemical reactions presented in this section.
2. C Using a graphic organizer, compare and contrast synthesis and decomposition reactions.
3. A Some electrical power plants use the energy that is released by burning coal to generate electrical energy. Why would using coal that has a low sulfur content help to protect the environment?
4. K/U What types of reactants form a binary ionic compound in a synthesis reaction?
5. T/I Predict the product(s) and write a balanced chemical equation for the reaction of aluminum and sulfur.
6. C Describe the steps you would take to predict the products of the reaction between a metal and a non-metal.
7. T/I Predict whether each compound would form an acid or a base in a reaction with water.
   a. dinitrogen trioxide
   b. lithium oxide
   c. sulfur trioxide
   d. calcium oxide
8. A Explain why techniques that are used to combat acid precipitation focus on removing the non-metal oxide and not the other reactant in the reaction.
9. K/U In a decomposition reaction, what type of reactant generally forms two elements?
10. K/U If you wanted to generate carbon dioxide gas by using a decomposition reaction, what type of reactant would you use?
11. T/I The photograph below shows the decomposition of mercury(II) oxide, $HgO(s)$, a red powder.
    a. Which product is visible in the photograph?
    b. Which product is not visible?
    c. How could you test for the presence of the product that is not visible?

12. C Using a graphic organizer, compare the types of reactants in each of the synthesis reactions associated with the formation of acid precipitation.
13. K/U What products would you expect to form when a metal nitrate decomposes?
14. C A student thinks that sodium carbonate will decompose into sodium, carbon, and oxygen. Create a labelled diagram to show why the student is incorrect.
15. A If you wanted to generate lithium oxide, what are two decomposition reactions you could try?
16. A The term *pyrotechnics* refers to the use of chemicals to produce explosive displays for special effects and similar purposes. Infer why ammonium dichromate, rather than trinitrotoluene, would be used in a theatrical pyrotechnics display.