Synthesis and Decomposition Reactions

4.2

How are different kinds of compounds formed? In section 4.1, you learned that they are formed by chemical reactions that you can describe using balanced chemical equations. Just as there are different types of compounds, there are different types of chemical reactions. In this section, you will learn about five major classifications for chemical reactions. You will use your understanding of chemical formulas and chemical equations to predict products for each class of reaction.

Section Preview/ Specific Expectations

In this section, you will

- **distinguish** between synthesis, decomposition, and combustion reactions
- **write** balanced chemical equations to represent synthesis, decomposition, and combustion reactions
- **predict** the products of chemical reactions
- **demonstrate** an understanding of the relationship between the type of chemical reaction and the nature of the reactants
- **communicate** your understanding of the following terms: *synthesis reaction, decomposition reaction, combustion reaction, incomplete combustion*

Why Classify?

People use classifications all the time. For example, many types of wild mushrooms are edible, but many others are poisonous—even deadly! How can you tell which is which? Poisonous and deadly mushrooms have characteristics that distinguish them from edible ones, such as odour, colour, habitat, and shape of roots. It is not always easy to distinguish one type of mushroom from another; the only visible difference may be the colour of the mushroom's spores. Therefore, you should never try to eat any wild mushrooms without an expert's advice.

Examine Figure 4.5. Which mushroom looks more appetizing to you? An expert will always be able to distinguish an edible mushroom from a poisonous mushroom based on the characteristics that have been used to classify each type. By classifying, they can predict the effects of eating any wild mushroom.

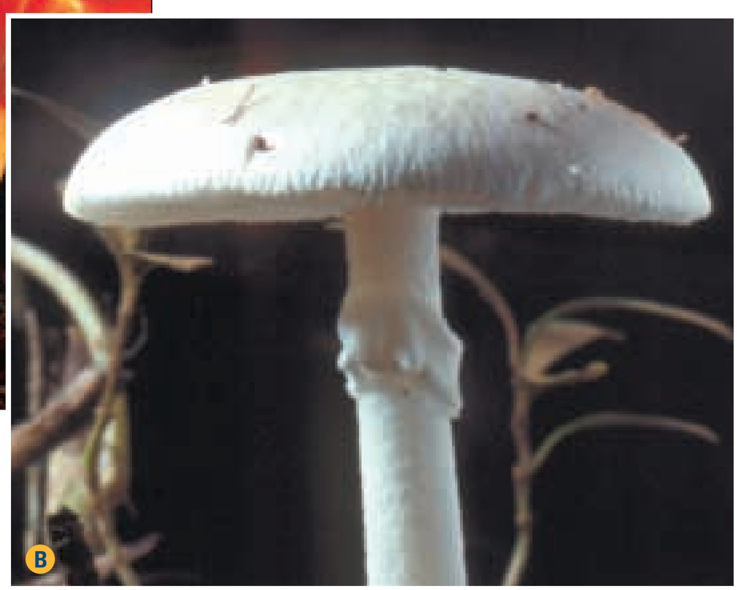

Figure 4.5 The mushroom on the left, called a chanterelle, is edible and very tasty. The mushroom on the right is called a death cap. It is extremely poisonous.

In the same way, you can recognize similarities between chemical reactions and the types of reactants that tend to undergo different types of reactions. With this knowledge, you can predict what will happen when one, two, or more substances react. In this section, you will often see chemical reactions without the subscripts showing the states of matter. They are omitted deliberately because, in most cases, you are not yet in a position to predict the states of the products.

Synthesis Reactions

In a **synthesis reaction**, two or more elements or compounds combine to form a new substance. Synthesis reactions are also known as combination or formation reactions. A general equation for a synthesis reaction is

$$A + B \rightarrow C$$

In a simple synthesis reaction, one element reacts with one or more other elements to form a compound. Two, three, four, or more elements may react to form a single product, although synthesis reactions involving four or more reactants are extremely rare. Why do you think this is so? When two elements react together, the reaction is almost always a synthesis reaction because the product is almost always a single compound. There are several types of synthesis reactions. Recognizing the patterns of the various types of reactions will help you to predict whether substances will take part in a synthesis reaction.

When a metal or a non-metal element reacts with oxygen, the product is an oxide. Figure 4.6 shows a familiar example, in which iron reacts with oxygen according to the following equation:

$$3Fe_{(s)} + O_{2(g)} \rightarrow Fe_2O_{3(s)}$$

Figure 4.6 **The iron in this car undergoes a synthesis reaction with the oxygen in the air. Iron(III) oxide, also known as rust, is formed.**

Two other examples of this type of reaction are:

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$$

$$2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$$

A second type of synthesis reaction involves the reaction of a metal and a non-metal to form a binary compound. One example is the reaction of potassium with chlorine.

$$2K_{(s)} + Cl_{2(g)} \rightarrow 2KCl_{(s)}$$

Synthesis Reactions Involving Compounds

In the previous two types of synthesis reactions, two elements reacted to form one product. There are many synthesis reactions in which one or more compounds are the reactants. For the purpose of this course, however, we will deal only with the two specific types of synthesis reactions involving compounds that you should recognize: oxides and water.

When a non-metallic oxide reacts with water, the product is an acid. You will learn more about acids and the rules for naming them in Chapter 10. The acids that form when non-metallic oxides and water react are composed of hydrogen cations and polyatomic anions containing oxygen and a non-metal. For example, one contributor to acid rain is hydrogen sulfate (sulfuric acid), H_2SO_4, which forms when sulfur trioxide reacts with water. The sulfur trioxide comes from sources such as industrial plants that emit the gas as a byproduct of burning fossil fuels, as shown in Figure 4.7.

$$SO_{3(g)} + H_2O_{(\ell)} \rightarrow H_2SO_{4(aq)}$$

Figure 4.7 Sulfur trioxide, emitted by this factory, reacts with the water in the air. Sulfuric acid is formed in a synthesis reaction.

Conversely, when a metallic oxide reacts with water, the product is a metal hydroxide. Metal hydroxides belong to a group of compounds called bases. You will learn more about bases in Chapter 10. For example, when calcium oxide reacts with water, it forms calcium hydroxide, $Ca(OH)_2$. Calcium oxide is also called lime. It can be added to lakes to counteract the effects of acid precipitation.

$$CaO_{(s)} + H_2O_{(\ell)} \rightarrow Ca(OH)_{2(aq)}$$

Sometimes it is difficult to predict the product of a synthesis reaction. The only way to really know the product of a reaction is to carry out the reaction and then isolate and identify the product. For example, carbon can react with oxygen to form either carbon monoxide or carbon dioxide. Therefore, if all you know is that your reactants are carbon and oxygen, you cannot predict with certainty which compound will form. You can only give options.

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

$$2C_{(s)} + O_{2(g)} \rightarrow 2CO_{(g)}$$

You would need to analyze the products of the reaction by experiment to determine which compound was formed.

History LINK

Today we have sophisticated lab equipment to help us analyze the products of reactions. In the past, when such equipment was not available, chemists sometimes jeopardized their safety and health to determine the products of the reactions they studied. Sir Humphry Davy (1778–1829), a contributor to many areas of chemistry, thought nothing of inhaling the gaseous products of the chemical reactions that he carried out. He tried to breathe pure CO_2, then known as *fixed air*. He nearly suffocated himself by breathing hydrogen. In 1800, Davy inhaled dinitrogen monoxide, N_2O, otherwise known as nitrous oxide, and discovered its anaesthetic properties. What is nitrous oxide used for today?

CHECKPOINT

As you begin learning about different types of chemical reactions, keep a separate list of each type of reaction. Add to the list as you encounter new reactions.

Try predicting the products of synthesis reactions in the following Practice Problems.

Practice Problems

10. Copy the following synthesis reactions into your notebook. Predict the product of each reaction. Then balance each chemical equation.
    (a) $K + Br_2 \rightarrow$
    (b) $H_2 + Cl_2 \rightarrow$
    (c) $Ca + Cl_2 \rightarrow$
    (d) $Li + O_2 \rightarrow$
11. Copy the following synthesis reactions into your notebook. For each set of reactants, write the equations that represent the possible products.
    (a) $Fe + O_2 \rightarrow$
    (suggest two different synthesis reactions)
    (b) $V + O_2 \rightarrow$
    (suggest four different synthesis reactions)
    (c) $Co + Cl_2 \rightarrow$
    (suggest two different synthesis reactions)
    (d) $Ti + O_2 \rightarrow$
    (suggest three different synthesis reactions)
12. Copy the following equations into your notebook. Write the product of each reaction. Then balance each chemical equation.
    (a) $K_2O + H_2O \rightarrow$
    (b) $MgO + H_2O \rightarrow$
    (c) $SO_2 + H_2O \rightarrow$
13. Ammonia gas and hydrogen chloride gas react to form a solid compound. Predict what the solid compound is. Then write a balanced chemical equation.

Figure 4.8 **As electricity passes through the water, it decomposes to hydrogen and oxygen gas.**

Decomposition Reactions

In a **decomposition reaction**, a compound breaks down into elements or other compounds. Therefore, *a decomposition reaction is the opposite of a synthesis reaction*. A general formula for a decomposition reaction is:

$$C \rightarrow A + B$$

The substances that are produced in a decomposition reaction can be elements or compounds. In the simplest type of decomposition reaction, a compound breaks down into its component elements. One example is the decomposition of water into hydrogen and oxygen. This reaction occurs when electricity is passed through water. Figure 4.8 shows an apparatus set up for the decomposition of water.

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

More complex decomposition reactions occur when compounds break down into other compounds. An example of this type of reaction is shown in Figure 4.9. The photograph shows the explosive decomposition of ammonium nitrate.

When ammonium nitrate is heated to a high temperature, it forms dinitrogen monoxide and water according to the following balanced equation:

$$NH_4NO_{3(s)} \rightarrow N_2O_{(g)} + 2H_2O_{(g)}$$

Try predicting the products of the decomposition reactions in the following Practice Problems.

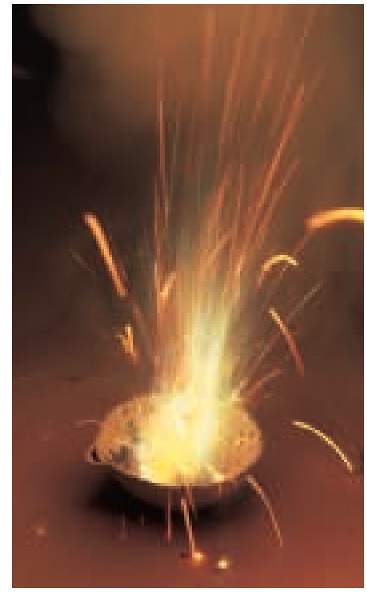

Figure 4.9 At high temperatures, ammonium nitrate explodes, decomposing into dinitrogen monoxide and water.

Practice Problems

14. Mercury(II) oxide, or mercuric oxide, is a bright red powder. It decomposes on heating. What are the products of the decomposition of HgO?

15. What are the products of the following decomposition reactions? Predict the products. Then write a balanced equation for each reaction.

(a) $HI \rightarrow$

(b) $Ag_2O \rightarrow$

(c) $AlCl_3 \rightarrow$

(d) $MgO \rightarrow$

16. Calcium carbonate decomposes into calcium oxide and carbon dioxide when it is heated. Based on this information, predict the products of the following decomposition reactions.

(a) $MgCO_3 \rightarrow$

(b) $CuCO_3 \rightarrow$

Combustion Reactions

Combustion reactions form an important class of chemical reactions. The combustion of fuel—wood, fossil fuel, peat, or dung—has, throughout history, heated and lit our homes and cooked our food. The energy produced by combustion reactions moves our airplanes, trains, trucks, and cars.

A complete **combustion reaction** is the reaction of a compound or element with O_2 to form the most common oxides of the elements that make up the compound. For example, a carbon-containing compound undergoes combustion to form carbon dioxide, CO_2. A sulfur-containing compound reacts with oxygen to form sulfur dioxide, SO_2.

Combustion reactions are usually accompanied by the production of light and heat. In the case of carbon-containing compounds, complete combustion results in the formation of, among other things, carbon dioxide. For example, methane, CH_4, the primary constituent of natural gas, undergoes complete combustion to form carbon dioxide, (the most common oxide of carbon), as well as water. This combustion reaction is represented by the following equation:

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

The combustion of methane, shown in Figure 4.10, leads to the formation of carbon dioxide and water.

The complete combustion of any compound that contains carbon, hydrogen, and oxygen (such as ethanol, C_2H_5OH) produces carbon dioxide and water.

Figure 4.10 This photo shows the combustion of methane in a laboratory burner.

Compounds that contain elements other than carbon also undergo complete combustion to form stable oxides. For instance, sulfur-containing compounds undergo combustion to form sulfur dioxide, SO_2, a precursor to acid rain. Complete combustion reactions are often also synthesis reactions. Metals, such as magnesium, undergo combustion to form their most stable oxide, as shown in Figure 4.11.

$$2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$$

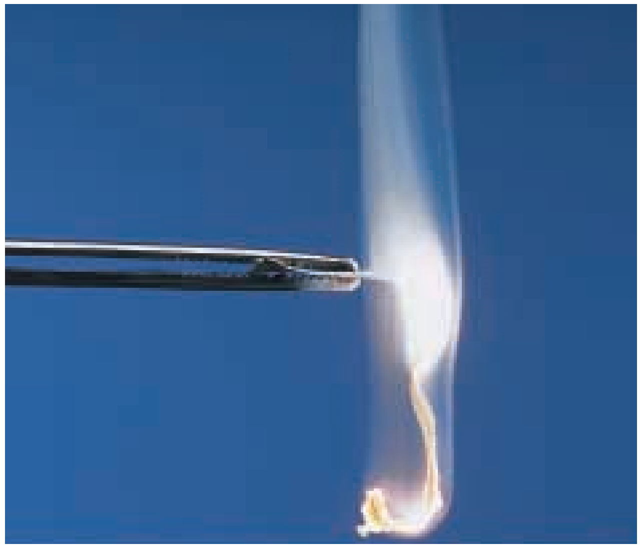

Figure 4.11 **Magnesium metal burns in oxygen. The smoke and ash that are produced in this combustion reaction are magnesium oxide.**

In the absence of sufficient oxygen, carbon-containing compounds undergo **incomplete combustion**, leading to the formation of carbon monoxide, CO, and water. Carbon monoxide is a deadly gas. You should always make sure that sufficient oxygen is present in your indoor environment for your gas furnace, gas stove, or fireplace.

Try the following problems to practise balancing combustion reactions.

CHECKPOINT

Copy the following skeleton equation for the combustion of pentane, C_5H_{12}, into your notebook and balance it.

$C_5H_{12} + O_2 \rightarrow CO_2 + H_2O$

If it took you a long time to balance this equation, chances are that you did not use the quickest method. Try balancing carbon first, hydrogen second, and finally oxygen. What is the advantage of leaving O_2 until the end? Would this method work for incomplete combustion reactions? Would this method work if the "fuel" contained oxygen in addition to C and H? Now try balancing the chemical equation for the combustion of heptane (C_7H_{16}) and the combustion of rubbing alcohol, isopropanol (C_3H_8O).

Practice Problems

17. The alcohol lamps that are used in some science labs are often fuelled with methanol, CH_3OH. Write the balanced chemical equation for the complete combustion of methanol.

18. Gasoline is a mixture of compounds containing hydrogen and carbon, such as octane, C_8H_{18}. Write the balanced chemical equation for the complete combustion of C_8H_{18}.

19. Acetone, C_3H_6O, is often contained in nail polish remover. Write the balanced chemical equation for the complete combustion of acetone.

20. Kerosene consists of a mixture of hydrocarbons. It has many uses including jet fuel and rocket fuel. It is also used as a fuel for hurricane lamps. If we represent kerosene as $C_{16}H_{34}$, write a balanced chemical equation for the complete combustion of kerosene.

Section Wrap-up

In this section, you learned about three major types of reactions: synthesis, decomposition, and combustion reactions. Using your knowledge about these types of reactions, you learned how to predict the products of various reactants. In section 5.3, you will increase your understanding of chemical reactions even further, learning about two major types of chemical reactions. As well, you will observe various chemical reactions in three investigations.

Section Review

1 K/U Write the product for each synthesis reaction. Balance the chemical equation.

(a) $Be + O_2 \rightarrow$

(b) $Li + Cl_2 \rightarrow$

(c) $Mg + N_2 \rightarrow$

(d) $Al + Br_2 \rightarrow$

(e) $K + O_2 \rightarrow$

2 K/U Write the products for each decomposition reaction. Balance the chemical equation.

(a) $K_2O \rightarrow$

(b) $CuO \rightarrow$

(c) $H_2O \rightarrow$

(d) $Ni_2O_3 \rightarrow$

(e) $Ag_2O \rightarrow$

3 C Write a balanced chemical equation for each of the following word equations. Classify each reaction.

(a) With heating, solid tin(IV) hydroxide produces solid tin(IV) oxide and water vapour.

(b) Chlorine gas reacts with crystals of iodine to form iodine trichloride.

4 K/U Write a balanced chemical equation for the combustion of butanol, C_4H_9OH.

5 I A red compound was heated, and the two products were collected. The gaseous product caused a glowing splint to burn brightly. The other product was a shiny pure metal, which was a liquid at room temperature. Write the most likely reaction that would explain these results. Classify the reaction. **Hint:** Remember that the periodic table identifies the most common valences.

6 MC Explain why gaseous nitrogen oxides emitted by automobiles and industries contribute to acid rain. Write balanced chemical reactions to back up your ideas. You may need to look up chemical formulas for your products.

Unit Project Prep

Before you design your Chemistry Newsletter at the end of Unit 1, consider that fuels are composed of compounds containing hydrogen and carbon (hydrocarbons). What kind of reaction have you seen in this section that involves those kinds of compounds? What type of warning would you expect to see on a container of lawnmower fuel? How is the warning related to the types of reaction that involve hydrocarbons?