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.

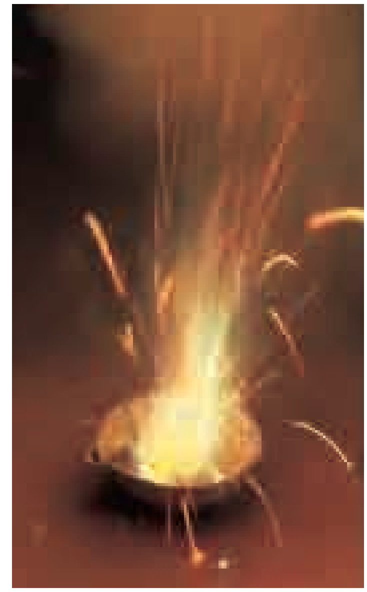

Figure 4.9 At high temperatures, ammonium nitrate explodes, decomposing into dinitrogen monoxide and water.

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.

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

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

4.3 Single Displacement and Double Displacement Reactions

Section Preview/ Specific Expectations

In this section, you will

- **distinguish** between synthesis, decomposition, combustion, single displacement, and double displacement reactions
- **write** balanced chemical equations to represent single displacement and double displacement reactions
- **predict** the products of chemical reactions and **test** your predictions through experimentation
- **demonstrate** an understanding of the relationship between the type of chemical reaction and the nature of the reactants
- **investigate**, through experimentation, the reactivity of different metals to produce an activity series
- **communicate** your understanding of the following terms: *single displacement reaction, activity series, double displacement reaction, precipitate, neutralization reactions*

In section 4.2, you learned about three different types of chemical reactions. In section 4.3, you will learn about two more types of reactions. You will learn how performing these reactions can help you make inferences about the properties of the elements and compounds involved.

Single Displacement Reactions

In a **single displacement reaction**, one element in a compound is displaced (or replaced) by another element. Two general reactions represent two different types of single displacement reactions. One type involves a metal replacing a metal cation in a compound, as follows:

$$A + BC \rightarrow AC + B$$

For example, $Zn_{(s)} + Fe(NO_3)_{2(aq)} \rightarrow Zn(NO_3)_{2(aq)} + Fe_{2(s)}$

The second type of single displacement reaction involves a non-metal (usually a halogen) replacing an anion in a compound, as follows:

$$DE + F \rightarrow DF + E$$

For example, $Cl_{2(g)} + CaBr_{2(aq)} \rightarrow CaCl_{2(aq)} + Br_{2(\ell)}$

Single Displacement Reactions and the Metal Activity Series

Most single displacement reactions involve one metal displacing another metal from a compound. In the following equation, magnesium metal replaces the zinc in $ZnCl_2$, thereby liberating zinc as the free metal.

$$Mg_{(s)} + ZnCl_{2(aq)} \rightarrow MgCl_{2(aq)} + Zn_{(s)}$$

The following three reactions illustrate the various types of single displacement reactions involving metals:

1. $Cu_{(s)} + 2AgNO_{3(aq)} \rightarrow Cu(NO_3)_{2(aq)} + 2Ag_{(s)}$
   In this reaction, *one metal replaces another metal in an ionic compound*. That is, copper replaces silver in $AgNO_3$. Because of the +2 charge on the copper ion, it requires two nitrate ions to balance its charge.

2. $Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$
   In this reaction, magnesium metal replaces hydrogen from hydrochloric acid, $HCl_{(aq)}$. Since hydrogen is diatomic, it is "liberated" in the form of H_2. This reaction is similar to reaction 1 if
   - you treat hydrochloric acid as an ionic compound (which it technically is not), and if
   - you treat hydrogen as a metal (also, technically, not the case).

3. $2Na_{(s)} + 2H_2O_{(\ell)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$
   Sodium metal displaces hydrogen from water in this reaction. Again, since hydrogen is diatomic, it is produced as H_2. As above, you can understand this reaction better if
   - you treat hydrogen as a metal, and if
   - you treat water as an ionic compound, $H^+(OH^-)$.

All of the reactions just described follow the original general example of a single displacement reaction:

$$A + BC \rightarrow AC + B$$

Figures 4.12 and 4.13 show two examples of single displacement reactions.

When analyzing single displacement reactions, use the following guidelines:

- Treat hydrogen as a metal.
- Treat acids, such as HCl, as ionic compounds of the form H^+Cl^-. (Treat sulfuric acid, H_2SO_4, as $H^+H^+SO_4^{2-}$).
- Treat water as ionic, with the formula $H^+(OH^-)$.

Figure 4.12 Lithium metal reacts violently with water in a single displacement reaction. Lithium must be stored under kerosene or oil to avoid reaction with atmospheric moisture, or oxygen.

Figure 4.13 When an iron nail is placed in a solution of copper(II) sulfate, a single displacement reaction takes place.
$Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}$
Notice the formation of copper metal on the nail.

Practice Problems

21. Each of the following incomplete equations represents a single displacement reaction. Copy each equation into your notebook, and write the products. Balance each chemical equation. When in doubt, use the most common valence.

(a) $Ca + H_2O \rightarrow$ **(e)** $Pb + H_2SO_4 \rightarrow$
(b) $Zn + Pb(NO_3)_2 \rightarrow$ **(f)** $Mg + Pt(OH)_4 \rightarrow$
(c) $Al + HCl \rightarrow$ **(g)** $Ba + FeCl_2 \rightarrow$
(d) $Cu + AgNO_3 \rightarrow$ **(h)** $Fe + Co(ClO_3)_2 \rightarrow$

Through experimentation, chemists have ranked the relative reactivity of the metals, including hydrogen (in acids and in water), in an **activity series**. The reactive metals, such as potassium, are at the top of the activity series. The unreactive metals, such as gold, are at the bottom. In Investigation 4-A, you will develop an activity series using single displacement reactions.

PROBLEM TIP

A single displacement reaction always favours the production of the less reactive metal. In other words, the "free" metal that is formed from the compound must always be less reactive than the metal that displaced it. For example,

$$2AgNO_{3(aq)} + Cu_{(s)} \rightarrow Cu(NO_3)_{2(aq)} + 2Ag_{(s)}$$

Silver metal is more stable than copper metal. In other words, silver is below copper in the activity series.

The Metal Activity Series

As you can see in Table 4.2, the more reactive metals are at the top of the activity series. The less reactive metals are at the bottom. *A reactive metal will displace or replace any metal in a compound that is below it in the activity series*. Metals from lithium to sodium will displace hydrogen as a gas from water. Metals from magnesium to lead will displace hydrogen as a gas only from acids. Copper, mercury, silver, and gold will not displace hydrogen from acids.

Table 4.2 Activity Series of Metals

Metal	Displaces hydrogen from acids	Displaces hydrogen from cold water	
lithium			Most Reactive
potassium			
barium			
calcium			
sodium			
magnesium			
aluminum			
zinc			
chromium			
iron			
cadmium			
cobalt			
nickel			
tin			
lead			
hydrogen			
copper			
mercury			
silver			
platinum			
gold			Least Reactive

You can use the activity series to help you predict the products of the reaction of a metal and a metal-containing compound. For example, consider the following incomplete equation.

$$Fe_{(s)} + CuSO_{4(aq)} \rightarrow$$

You can see from the activity series that iron is above copper. This means that iron is more reactive than copper. This reaction will proceed.

$$Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}$$

The copper metal produced is less reactive than iron metal. What about the following incomplete reaction between silver and calcium chloride?

$$Ag_{(s)} + CaCl_{2(aq)} \rightarrow$$

Silver is below calcium in the activity series, meaning that it is less reactive. There would be no reaction between these two substances. Predict whether the substances in the following Practice Problem will react.

CHEM FACT

Most metals that we use in everyday life are actually alloys. An alloy is a solid solution of one metal (or non-metal) in another metal. For example, steel is an alloy of iron. Steel has many uses, from construction to the automobile industry. If the iron were not alloyed with other elements, it would not have the physical and chemical properties required, such as hardness and corrosion resistance.

Practice Problems

22. Using the activity series, write a balanced chemical equation for each single displacement reaction. If you predict that there will be no reaction, write "NR."

(a) $Cu + MgSO_4 \rightarrow$
(b) $Zn + FeCl_2 \rightarrow$
(c) $K + H_2O \rightarrow$
(d) $Al + H_2SO_4 \rightarrow$
(e) $Fe + Al_2(SO_4)_3 \rightarrow$
(f) $Ni + NiCl_2 \rightarrow$
(g) $Zn + H_2SO_4 \rightarrow$
(h) $Mg + SnCl_2 \rightarrow$

Single Displacement Reactions Involving Halogens

Non-metals, typically halogens, can also take part in single displacement reactions. For example, molecular chlorine can replace bromine from KBr, an ionic compound, producing bromine and potassium chloride.

$$Cl_{2(g)} + 2KBr_{(aq)} \rightarrow 2KCl_{(aq)} + Br_{2(\ell)}$$

The **activity series for halogens** directly mirrors the position of halogens in the periodic table. It can be shown simply in the following way. Fluorine is the most reactive, and iodine is the least reactive.

$$F > Cl > Br > I$$

In the same way as you used the activity series for metals, you can use the activity series for halogens to predict whether substances will undergo a single displacement reaction. For example, fluorine is above chlorine in the activity series. So, given the reactants fluorine and sodium chloride, you can predict that the following reaction will occur:

$$F_{2(g)} + 2NaCl_{(aq)} \rightarrow 2NaF_{(aq)} + Cl_{2(aq)}$$

On the other hand, iodine is below bromine in the activity series. So, given the reactants iodine and calcium bromide, you can predict that no reaction will occur.

$$I_{2(aq)} + CaBr_{2(aq)} \rightarrow NR$$

Try the following problems to practise using the metal and halogen activity series to predict whether reactions will occur.

CHECKPOINT

Based on what you know about the electronegativity and electron affinity for the halogens, explain the organization of the halogen activity series.

Practice Problems

23. Using the activity series for halogens, write a balanced chemical equation for each single displacement reaction. If you predict that there will be no reaction, write "NR".

(a) $Br_2 + KCl \rightarrow$
(b) $Cl_2 + NaI \rightarrow$

24. Using the appropriate activity series, write a balanced chemical equation for each single displacement reaction. If you predict that there will be no reaction, write "NR".

(a) $Pb + HCl \rightarrow$
(b) $KI + Br_2 \rightarrow$
(c) $KF + Cl_2 \rightarrow$
(d) $Ca + H_2O \rightarrow$
(e) $MgSO_4 + Zn \rightarrow$
(f) $Ni + H_2SO_4 \rightarrow$

Double Displacement Reactions

A **double displacement reaction** involves the exchange of cations between two ionic compounds, usually in aqueous (water) solution. A double displacement reaction is also known as a double replacement reaction. A general equation for a double displacement reaction is:

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

In this equation, A and C are cations and B and D are anions.

Consider the following situation. You have two unlabelled beakers. One contains distilled water, and the other contains salt water. The two samples look virtually identical. How can you quickly determine which is the salt water without tasting them? (You should never taste anything in a chemistry laboratory.)

A common test for the presence of chloride ions in water is the addition of a few drops of silver nitrate solution. The formation of a white solid indicates the presence of chloride ions, as you can see in Figure 4.14.

Figure 4.14 When a few drops of silver nitrate, $AgNO_3$, are added to a sample of salt water, $NaCl_{(aq)}$, a white precipitate of silver chloride, AgCl, is formed.

A double displacement reaction has occurred. That is, the cations in the reactants have essentially changed places. This switch is modelled in Figure 4.15.

$$NaCl_{(aq)} + AgNO_{3(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$$

Figure 4.15 Sodium chloride and silver nitrate form ions in solution. When silver ions and chloride ions come into contact, they form a solid.

Since silver chloride is virtually insoluble in water, it forms a solid compound, or precipitate.

Double displacement reactions tend to occur in aqueous solution. Not all ionic compounds, however, will react with one another in this way. You can tell that a double displacement reaction has taken place in the following cases:

- a solid (precipitate) forms
- a gas is produced
- some double displacement reactions also form a molecular compound, such as water. It is hard to tell when water is formed, because often the reaction takes place in water.

Double Displacement Reactions that Form a Precipitate

A **precipitate** is a solid that separates from a solution as the result of a chemical reaction. You will learn more about precipitates in Chapter 9. *Many double displacement reactions involve the formation of a precipitate.*

Examine the double displacement reaction that occurs when aqueous solutions of barium chloride and potassium sulfate are mixed. A white precipitate is immediately formed. The equation for the reaction is

$$BaCl_{2(aq)} + K_2SO_{4(aq)} \rightarrow BaSO_{4(s)} + 2KCl_{(aq)}$$

You should think about two questions when analyzing a double displacement reaction.

1. How do we determine the products?
2. Which of the products—if any—will precipitate out of solution?

Barium chloride solution contains Ba^{2+} ions and Cl^- ions. Potassium sulfate solution contains K^+ and SO_4^{2-} ions. When they are mixed, the Ba^{2+} ions come in contact with SO_4^{2-} ions. Because barium sulfate is insoluble, the product comes out of solution as a solid. The K^+ ions and Cl^- ions also come into contact with each other, but potassium chloride is soluble, so these ions stay in solution.

How do you know that the precipitate is $BaSO_4$ and *not* KCl? More generally, how can you predict whether a precipitate will be formed in a double displacement reaction? In this chapter, you will be given information on solubility as you need it. You will learn more about how to predict whether a compound is soluble or not in Chapter 9. Barium sulfate, $BaSO_4$ is not soluble in water, while potassium chloride, KCl, is. Therefore, a reaction will take place and barium sulfate will be the precipitate.

In summary, to determine the products and their physical states in a double displacement reaction, you must first "deconstruct" the reactants. Then switch the cations, and "reconstruct" the products using proper chemical formulas. You should then balance the chemical equation. You will be given information to determine which of the products, if any, will form a precipitate. Finally, you can write the physical state—(s) or (aq)—of each product and balance the equation.

Given the following reactants, how would you predict the products of the reaction and their state? Note that many hydroxide compounds, including magnesium hydroxide, are insoluble. Potassium cations form soluble substances with all anions.

$$MgCl_{2(aq)} + KOH_{(aq)} \rightarrow$$

Examine figure 4.16 to see how to separate the compounds into ions, Mg^{2+} and Cl^-; K^+ and OH^-. Then switch the anions and write chemical formulas for the new compounds. Check to ensure your equation is balanced.

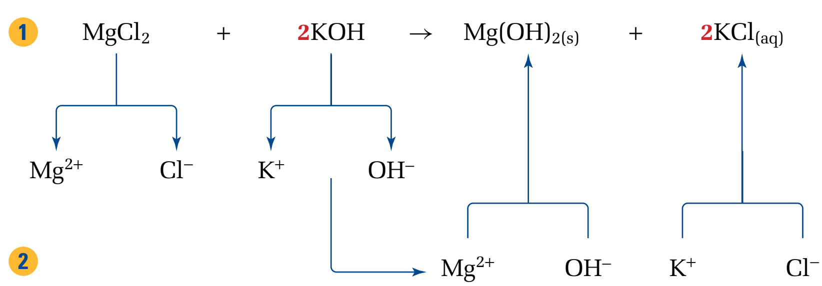

Figure 4.16 **Predicting a double displacement reaction.**

What happens if both products are soluble ionic compounds? Both ionic compounds will be ions dissolved in the water. If neither product precipitates out, no reaction occurs. Try the following problem to practise writing the products of double displacement reactions and predicting their states.