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.

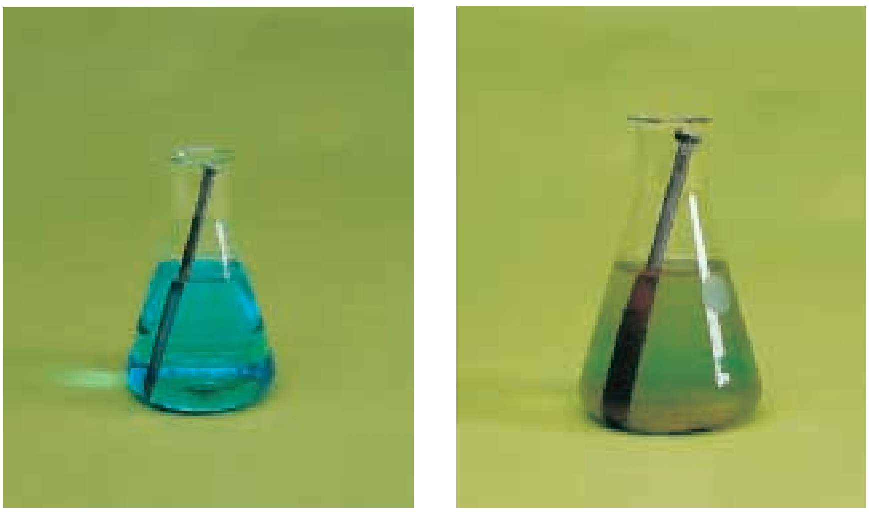


Figure 4.13 When an iron nail is placed in a solution of copper(II) sulfate, a single displacement reaction takes place.
$Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}$
Notice the formation of copper metal on the nail.

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

Investigation 4-A

MICROSCALE

SKILL FOCUS

- Predicting
- Performing and recording
- Analyzing and interpreting

Creating an Activity Series of Metals

Certain metals, such as silver and gold, are extremely unreactive, while sodium is so reactive that it will react with water. Zinc is unreactive with water. It *will*, however, react with acid. Why will magnesium metal react with copper sulfate solution, while copper metal will not react with aqueous magnesium sulfate? In Chapter 3, you learned that an alloy is a solution of two or more metals. Steel is an alloy that contains mostly iron. Is its reactivity different from iron's reactivity?

Question

How can you rank the metals, including hydrogen, in terms of their reactivity? Is the reactivity of an alloy very different from the reactivity of its major component?

Predictions

Based on what you learned in Chapter 3 about periodic trends, make predictions about the relative reactivity of copper, iron, magnesium, zinc, and tin. Explain your reasons for these predictions.

What do you know about alloys such as bronze, brass, and steel? Based on what you know, make a prediction about whether steel will be more or less reactive than iron, its main component.

Materials

well plate(s): at least a 6×8 matrix
wash bottle with distilled water
5 test tubes
test tube rack
dilute $HCl_{(aq)}$
6 small pieces each of copper, iron, magnesium, zinc, tin, steel, galvanized steel, stainless steel
dropper bottles of dilute solutions of $CuSO_4$, $FeSO_4$, $MgSO_4$, $ZnSO_4$, $SnCl_2$

Metal \ Cation or solution	HCl	H_2O	Cu^{2+}	Fe^{2+}	Mg^{2+}	Sn^{2+}
Cu						
Mg						
Sn						
Zn						
Fe						
steel						
galvanized steel						
stainless steel						

Safety Precautions

Handle the hydrochloric acid solution with care. It is corrosive. Wipe up any spills with copious amounts of water, and inform your teacher.

Procedure

1. Place your well plate(s) on a white sheet of paper. Label them according to the matrix on the previous page.
2. Place a rice-grain-sized piece of each metal in the appropriate well. Record the appearance of each metal.
3. Put enough drops of the appropriate solution to completely cover the piece of metal.
4. Record any changes in appearance due to a chemical reaction. In reactions of metal with acid, look carefully for the formation of bubbles. If you are unsure about any observation, repeat the experiment in a small test tube. This will allow you to better observe the reaction.
5. If you believe that a reaction has occurred, write "r" on the matrix. If you believe that no reaction has occurred, write "nr" on the matrix.
6. Dispose of the solutions in the waste beaker supplied by your teacher. Do not pour anything down the drain.

Analysis

1. For any reactions that occurred, write the corresponding single displacement reaction.
2. (a) What was the most reactive metal that you tested?
   (b) What was the least reactive metal that you tested?
3. Look at Figure 4.12. Lithium reacts violently with water to form aqueous lithium hydroxide and hydrogen gas. Do you expect lithium to react with hydrochloric acid?
   (a) Write the balanced chemical equation for this reaction.
   (b) Is lithium more or less reactive than magnesium?
4. What evidence do you have that hydrogen in hydrochloric acid is different from hydrogen in water?

Conclusion

5. (a) Write the activity series corresponding to your observations. Include hydrogen in the form of water and also as an ion (H^+). Do not include the alloys.
   (b) How did the reactivity of the iron compare with the reactivity of the various types of steel?
6. How do you think an activity series for metal would help you predict whether or not a single displacement reaction will occur? Use examples to help you explain your answer.
7. You have learned that an alloy is a homogeneous mixture (solution) of two or more metals. Steel consists of mostly iron.
   (a) Which type of steel appeared to be the most reactive? Which type was the least reactive? Did you notice any differences?
   (b) What other components make up steel, galvanized steel, and stainless steel?

Application

8. For what applications are the various types of steel used? Why would you not use iron for these applications?

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) $Ni + H_2SO_4 \rightarrow$

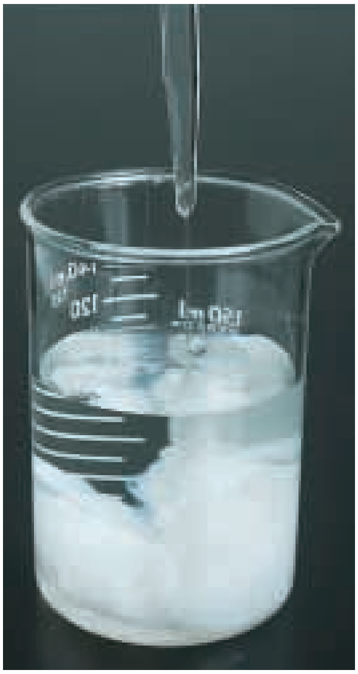


Figure 4.14 When a few drops of silver nitrate, $AgNO_3$, are added to a sample of salt water, $NaCl_{(aq)}$, a white precipitate of silver chloride, AgCl, is formed.

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.

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.

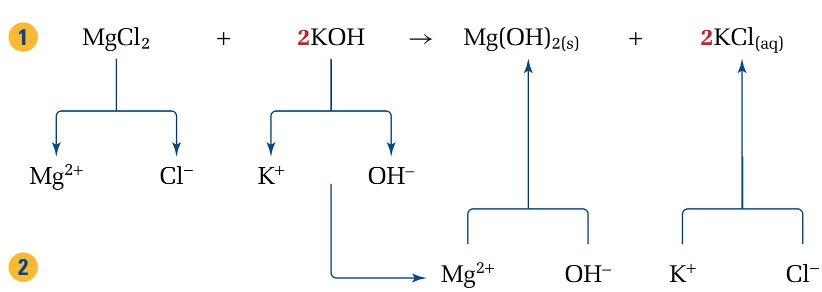


Figure 4.16 **Predicting a double displacement reaction.**

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.

PROBLEM TIP

When aqueous solutions of barium chloride and sodium chromate are mixed, a precipitate is formed. The balanced equation for this double replacement reaction is

$$BaCl_{2(aq)} + Na_2CrO_{4(aq)} \rightarrow BaCrO_{4(?)} + 2NaCl_{(?)}$$

What is the precipitate? From experience, you know that NaCl *is* water soluble. So, *by process of elimination*, the precipitate must be barium chromate, $BaCrO_{4(s)}$.

Practice Problems

25. Write a balanced chemical equation for each double displacement reaction. Write "NR" if you predict that no reaction will occur. Note that K^+, Na^+, and Li^+ ions form soluble compounds with all anions. All nitrate compounds are soluble. Sulfate compounds with Ca^{2+}, Sr^{2+}, Ba^{2+}, Ra^{2+}, and Pb^{2+} are insoluble, but most other sulfate compounds are soluble. Lead(II) iodide is insoluble.

(a) $Pb(NO_3)_{2(aq)} + KI_{(aq)} \rightarrow$

(b) $FeCl_{3(aq)} + Na_2SO_{4(aq)} \rightarrow$

(c) $NaNO_{3(aq)} + MgSO_{4(aq)} \rightarrow$

(d) $Ba(NO_3)_{2(aq)} + MgSO_{4(aq)} \rightarrow$

Double Displacement Reactions That Produce a Gas

In certain cases, you know that a double displacement reaction has occurred because a gas is produced. The gas is formed when one of the products of the double displacement reaction decomposes to give water and a gas.

Consider the reaction of aqueous sodium carbonate (washing soda) and hydrochloric acid, shown in Figure 4.17. Hydrochloric acid is sold at the hardware store under the common name "muriatic acid." If you carry out this reaction, you immediately see the formation of carbon dioxide gas. The first reaction that takes place is a double displacement reaction. Determine the products in the following way. Separate the reactions into ions, and switch the anions. Write chemical formulas for the products and balance the equation.

$$Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2CO_{3(aq)}$$

But this isn't all that is happening! The carbonic acid, H_2CO_3, is unstable and subsequently decomposes to carbon dioxide and water.

$$H_2CO_{3(aq)} \rightarrow H_2O_{(\ell)} + CO_{2(g)}$$

Overall, we can write this two-step reaction as follows:

$$Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + H_2O_{(\ell)} + CO_{2(g)}$$

Another double displacement reaction results in the formation of gaseous ammonia, NH_3. Ammonia, a pungent-smelling gas, is an important industrial chemical. It is used as a fertilizer and, when dissolved in water, as a household cleaner. Ammonium hydroxide is formed in the reaction below

$$NH_4Cl_{(aq)} + NaOH_{(aq)} \rightarrow NH_4OH_{(aq)} + NaCl_{(aq)}$$

The ammonium hydroxide, NH_4OH, immediately decomposes to give ammonia and water, according to the equation

$$NH_4OH_{(aq)} \rightarrow NH_{3(g)} + H_2O_{(\ell)}$$

Combining these equations gives

$$NH_4Cl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + NH_{3(g)} + H_2O_{(\ell)}$$

This example illustrates the formation of a gas by an initial double displacement reaction, followed by the decomposition of one of the products to a gas and water.

Figure 4.17 The reaction of hydrochloric acid and sodium carbonate, Na_2CO_3 (washing soda), is a double displacement reaction. This reaction initially forms sodium chloride and carbonic acid, H_2CO_3. The carbonic acid spontaneously decomposes to water and carbon dioxide gas.

Practice Problems

26. (a) When sodium sulfite, $Na_2SO_{3(aq)}$, is mixed with hydrogen chloride, $HCl_{(aq)}$ (hydrochloric acid), the odour of sulfur dioxide gas, $SO_{2(g)}$, is detected. Write the balanced chemical equation for this reaction.

(b) Hydrogen sulfide, H_2S, is a poisonous gas that has the odour of rotten eggs. When aqueous calcium sulfide, CaS, is reacted with sulfuric acid, a rotten egg smell is detected. Write the balanced chemical equation for this reaction.

The Formation of Water in a Neutralization Reaction

Neutralization reactions are a special type of double displacement reaction that produces water. Neutralization involves the reaction of an acid with a base to form water and an ionic compound. You will learn more about neutralization reactions in Chapter 10. For example, the neutralization of hydrogen nitrate (nitric acid) with sodium hydroxide (a base) is a double displacement reaction.

$$HNO_{3(aq)} + NaOH_{(aq)} \rightarrow NaNO_{3(aq)} + H_2O_{(\ell)}$$

Often neutralization reactions produce no precipitate or gas. In Chapter 10, you will learn how chemists recognize when neutralization reactions take place.

Practice Problems

27. Write the balanced chemical equation for each neutralization reaction.

(a) $HCl_{(aq)} + LiOH_{(aq)} \rightarrow$

(b) $HClO_{4(aq)} + Ca(OH)_{2(aq)} \rightarrow$

(c) $H_2SO_{4(aq)} + NaOH_{(aq)} \rightarrow$

28. Write the balanced chemical equation for each double replacement reaction. Be sure to indicate the physical state of all products.

(a) $BaCl_{2(aq)} + Na_2CrO_{4(aq)} \rightarrow$ (A precipitate is produced.)

(b) $H_3PO_{4(aq)} + NaOH_{(aq)} \rightarrow$ (Water is produced.)

(c) $K_2CO_{3(aq)} + HNO_{3(aq)} \rightarrow$ (A gas is produced.)

You have learned about a variety of double displacement reactions. In Investigation 4-B, you will make predictions about whether double displacement reactions will take place. Then you will make observations to test your predictions.

In Investigation 4-C, you will perform reactions that involve copper compounds to reinforce what you have learned about the different types of reactions. You will identify the series of reactions that begin by reacting copper and finish by producing copper.

CHEM FACT

To non-chemists, the term "salt" refers solely to sodium chloride. To chemists, "salt" is a generic term that describes an ionic compound with an anion that is not OH^- or O^{2-} and with a cation that is not H^+. Sodium chloride, NaCl, and potassium fluoride, KF, are two examples.

mind STRETCH

Consider the reaction

$$KNO_{3(aq)} + NaI_{(aq)} \rightarrow KI_{(aq)} + NaNO_{3(aq)}$$

The products are both water soluble. Has a chemical reaction occurred? If the water is allowed to evaporate, what compounds will remain?

SKILL FOCUS

Predicting

Performing and recording

Analyzing and interpreting

MICROSCALE

Investigation 4-B

Observing Double Displacement Reactions

A double displacement reaction involves the exchange of cations between two ionic compounds, usually in aqueous solution. It can be represented with the general equation

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

Most often, double displacement reactions result in the formation of a precipitate. However, some double displacement reactions result in the formation of an unstable compound which then decomposes to water and a gas.

The reaction of an acid and a base—a neutralization reaction—is also a type of double displacement reaction. It results in the formation of a salt and water.

Question

How can you tell if a double displacement reaction has occurred? How can you predict the products of a double displacement reaction?

Prediction

For each reaction in Tables A and B, write a balanced chemical equation. Use the following guidelines to predict precipitate formation in Table A.

- Hydrogen, ammonium, and Group I ions form soluble compounds with all negative ions.
- Chloride ions form compounds that are not very soluble when they bond to silver, lead(II), mercury(I), and copper(I) positive ions.
- All compounds that are formed from a nitrate and a positive ion are soluble.
- With the exception of the ions in the first bulleted point, as well as strontium, barium, radium, and thallium positive ions, hydroxide ions form compounds that do not dissolve.
- Iodide ions that are combined with silver, lead(II), mercury(I), and copper(I) are not very soluble.
- Chromate compounds are insoluble, except when they contain ions from the first bulleted point.

Materials

well plate
sheet of white paper
several test tubes
test tube rack
test tube holder
2 beakers (50 mL)
tongs
scoopula
laboratory burner
flint igniter
red litmus paper
wooden splint
wash bottle with distilled water
HCl solution
the following aqueous solutions in dropper bottles: $BaCl_2$, $CaCl_2$, $MgCl_2$, Na_2SO_4, $NaOH$, $AgNO_3$, $Pb(NO_3)_2$, KI, $FeCl_3$, solid Na_2CO_3 and NH_4Cl

Safety Precautions

- Hydrochloric acid is corrosive. Use care when handling it.
- Before lighting the laboratory burner, check that there are no flammable liquids nearby.
- If you accidentally spill a solution on your skin, immediately wash the area with copious amounts of water.
- Wash your hands thoroughly after the experiment.

Procedure

1. Copy Tables A and B into your notebook. Do not write in this textbook.
2. Place the well plate on top of the sheet of white paper.
3. Carry out each of the reactions in Table A by adding several drops of each solution to a well. Record your observations in Table A.

If you are unsure about the formation of a precipitate, repeat the reaction in a small test tube for improved visibility.

4. Place a scoopula tipful of Na_2CO_3 in a 50 mL beaker. Add 5 mL of HCl. Use a burning wooden splint to test the gas produced. Record your observations in Table B.
5. Place a scoopula tipful of NH_4Cl in a test tube. Add 2 mL NaOH. To detect any odour, gently waft your hand over the mouth of the test tube towards your nose. Warm the tube gently (do not boil) over a flame. Record your observations in Table B.
6. Dispose of all chemicals in the waste beaker supplied by your teacher. Do not pour anything down the drain.

Table A Double Displacement Reactions That May Form a Precipitate

Skeleton equation	Observations
$MgCl_2 + NaOH$	
$FeCl_3 + NaOH$	
$BaCl_2 + Na_2SO_4$	
$CaCl_2 + AgNO_3$	
$Pb(NO_3)_2 + KI$	

Table B Double Displacement Reactions That May Form a Gas

Reaction	Observations
$Na_2CO_3 + HCl$	
$NH_4Cl + NaOH$	

Analysis

1. Write the balanced chemical equation for each reaction in Table A.
2. For each reaction in Table B, write the appropriate balanced chemical equation for the double displacement reaction. Then write a balanced chemical equation for the decomposition reaction that leads to the formation of a gas and water.

Conclusion

3. How did you know when a double displacement reaction had occurred? How did your results compare with your predictions?

Application

4. Suppose that you did not have any information about the solubility of various compounds, but you did have access to a large variety of ionic compounds. What would you need to do before predicting the products of the displacement reactions above? Outline a brief procedure.

Investigation 4-C

MICROSCALE

SKILL FOCUS

Predicting

Performing and Recording

Analyzing and Interpreting

From Copper to Copper

This experiment allows you to carry out the sequential conversion of copper metal to copper(II) nitrate to copper(II) hydroxide to copper(II) oxide to copper(II) sulfate and back to copper metal. This conversion is carried out using synthesis, decomposition, single displacement, and double displacement reactions.

Question

What type of chemical reaction is involved in each step of this investigation?

Prediction

Examine the five reactions outlined in the procedure. Predict what reactions will occur, and write equations to describe them.

Materials

hot plate
glass rod
wash bottle with distilled water
50 mL Erlenmeyer flask
beaker tongs
250 mL beaker containing ice and liquid water
red litmus paper
$Cu(NO_3)_2$ solution
*6 mol/L NaOH solution in dropping bottle
*3 mol/L H_2SO_4 solution in dropping bottle
0.8 g of flaked zinc

Safety Precautions

- Constantly stir, or swirl, any precipitate-containing solution that is being heated to avoid a sudden boiling over, or *bumping*.
- Unplug any hot plate not in use.
- Do not allow electrical cords to hang over the edge of the bench.
- NaOH and H_2SO_4 solutions are corrosive. Handle them with care. If you accidentally spill a solution on your skin, wash the area immediately with copious amounts of cool water. Inform your teacher.

Procedure

Reaction A: Reaction of Copper Metal to form Copper(II) Nitrate

$$Cu_{(s)} + 4HNO_{3(aq)} \rightarrow Cu(NO_3)_{2(aq)} + 2NO_{2(g)} + 2H_2O_{(\ell)}$$

CAUTION Your teacher will carry out steps 1 to 4 in the fumehood before class. Concentrated nitric acid is required, and the $NO_{2(g)}$ produced is poisonous. Furthermore, this reaction is quite slow. Your teacher will perform a brief demonstration of this reaction so that you may record observations.

1. Place 0.100 g (100 mg) of Cu in a 50 mL Erlenmeyer flask.
2. Add 2 mL of 6 mol/L $HNO_{3(aq)}$ to the flask in the fumehood.
3. Warm the flask on a hot plate in the fumehood. The heating will continue until all the Cu dissolves and the evolution of brown $NO_{2(g)}$ ceases.
4. Cool the flask in a cool water bath.
5. Add about 2 mL of distilled water to the flask containing the $Cu(NO_3)_2$ solution.

*The unit mol/L refers to concentration. You will learn more about this in Unit 3. For now, you should know that 6 mol/L NaOH and 3 mol/L H_2SO_4 are highly corrosive solutions, and you should treat them with respect.

Reaction B: Preparation of Copper(II) Hydroxide

6. At room temperature, while stirring with a glass rod, add 6 mol/L NaOH, drop by drop, until the solution is basic to red litmus paper. (Red litmus paper turns blue in basic solution.) Do not put the red litmus paper in the solution. Dip the glass rod into the solution and touch it to the red litmus paper. Record your observations.

Reaction C: Preparation of Copper(II) Oxide

7. While constantly stirring the solution with a glass rod, heat the mixture from step 6 on a hot plate until a black precipitate is formed. If necessary, use the wash bottle to wash loose any unreacted light blue precipitate that is adhering to the side of the flask.

8. When all of the light blue precipitate has reacted to form the black precipitate, cool the flask in an ice bath or a cool water bath for several minutes.

Reaction D: Preparation of Copper(II) Sulfate Solution

9. Carefully add about 6 mL of 3 mol/L sulfuric acid to the flask. Stir it until all the black precipitate has dissolved. Record your observations. CAUTION The sulfuric acid is highly corrosive. If any comes in contact with your skin, rinse the area thoroughly and immediately with water.

Reaction E: Regeneration of Copper Metal

10. In the fumehood or in a well ventilated area, carefully add about 0.8 g of powdered zinc to the solution of copper(II) sulfate. Stir or swirl the solution until the blue colour disappears. Record your observations. CAUTION You should wear a mask for this step to avoid breathing in the powdered zinc.

11. When the reaction is complete, add 5 mL of 3 mol/L sulfuric acid while stirring or swirling the solution. This removes any unreacted zinc but does not affect the copper metal. Carefully decant the liquid into a clean waste container. Wash the copper metal carefully several times with water. Return the copper metal to your teacher. Wash your hands. CAUTION This sulfuric acid is highly corrosive. If any comes in contact with your skin, rinse the area thoroughly and immediately with water.

Analysis

1. What type of reaction is occurring in reactions A through E?

2. Write a balanced chemical equation for reactions B through E.

3. Explain why H_2SO_4 reacts with Zn but not with Cu. (See step 11 in the procedure.)

4. Could another metal have been used in place of Zn in step 10? Explain.

5. Why was powdered Zn used in step 10, rather than a single piece of Zn?

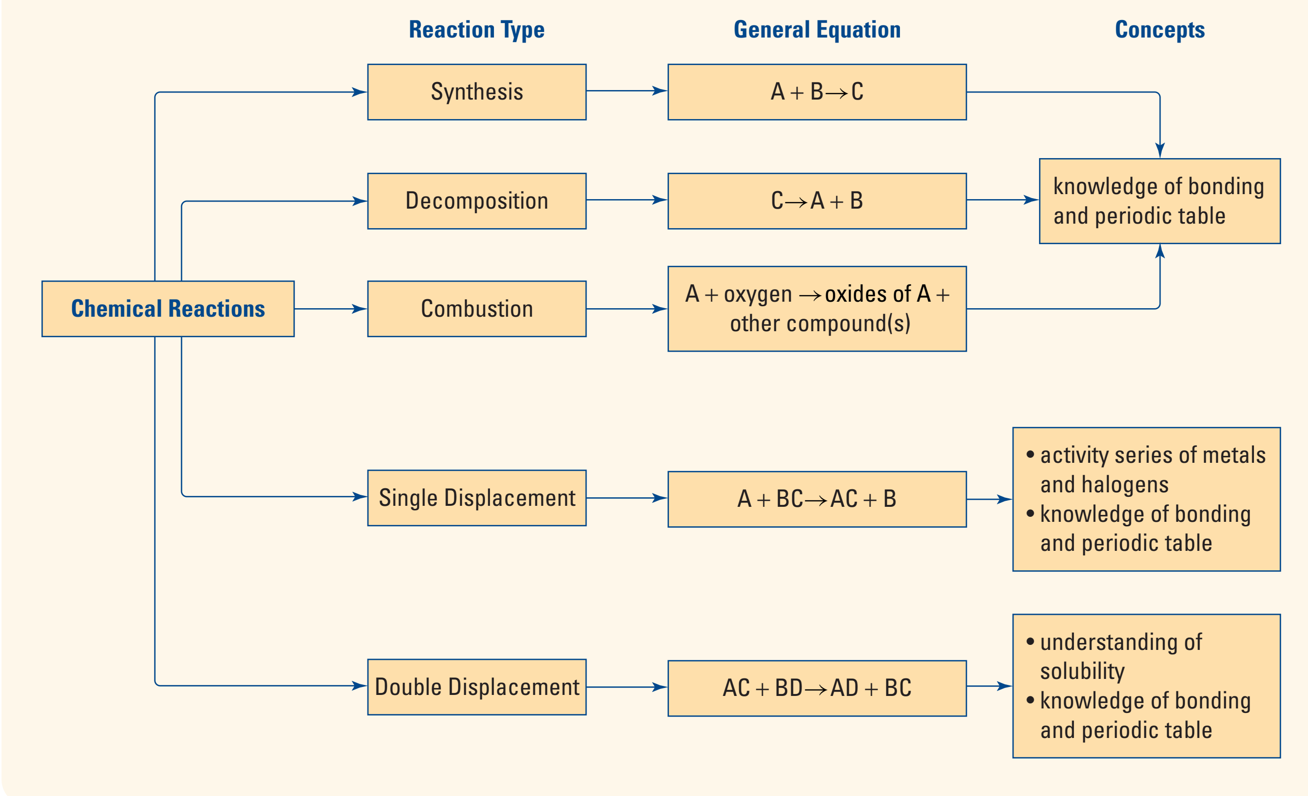
6. You used 0.100 g of Cu metal in reaction A. How much copper should theoretically be recovered at the end of reaction E?

Conclusion

7. Create a flowchart that shows each step of the reaction series. Include the balanced chemical equations.

Concept Organizer

Predicting Chemical Reactions



Section Wrap-up

In sections 4.2 and 4.3, you have examined five different types of chemical reactions: synthesis, decomposition, combustion, single displacement, and double displacement. Equipped with this knowledge, you can examine a set of reactants and predict what type of reaction will occur and what products will be formed. The Concept Organizer above provides a summary of the types of chemical reactions.

Section Review

Unit Project Prep

Before you design your Chemistry Newsletter at the end of Unit 1, take a look at some of the labels of chemical products in your home. Are there any warnings about mixing different products together? Use what you know about chemical reactions to explain why mixing some chemical products might be dangerous.

1 K/U Write the product(s) of each single displacement reaction. If you predict that there will be no reaction, write "NR." Balance each chemical equation.

(a) $Li + H_2O \rightarrow$

(b) $Sn + FeCl_2 \rightarrow$

(c) $F_2 + KI \rightarrow$

(d) $Al + MgSO_4 \rightarrow$

(e) $Zn + CuSO_4 \rightarrow$

(f) $K + H_2O \rightarrow$

2 K/U Complete each double displacement reaction. Be sure to indicate the physical state of each product. Then balance the equation. **Hint:** Compounds containing alkali metal ions are soluble. Calcium chloride is soluble. Iron(III) hydroxide is insoluble.

(a) $NaOH + Fe(NO_3)_3 \rightarrow$

(b) $Ca(OH)_2 + HCl \rightarrow$

(c) $K_2CrO_4 + NaCl \rightarrow$

(d) $K_2CO_3 + H_2SO_4 \rightarrow$

3 **(a)** C Explain why the following chemical equation represents a double displacement reaction followed by a decomposition reaction.

$(NH_4)_2SO_{4(aq)} + KOH_{(aq)} \rightarrow NH_{3(g)} + H_2O_{(\ell)} + K_2SO_{4(aq)}$

(b) Balance the chemical equation in part (a).

4 K/U Identify each reaction as synthesis, combustion (complete or incomplete), decomposition, single displacement, or double displacement. Balance the equations, if necessary.

(a) $C_8H_{18(\ell)} + O_{2(g)} \rightarrow CO_{(g)} + H_2O_{(g)}$

(b) $Pb_{(s)} + H_2SO_{4(aq)} \rightarrow PbSO_{4(s)} + H_{2(g)}$

(c) $Al_2(SO_4)_{3(aq)} + K_2CrO_{4(aq)} \rightarrow K_2SO_{4(aq)} + Al_2(CrO_4)_{3(s)}$

(d) $C_3H_7OH_{(\ell)} + O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(g)}$

(e) $(NH_4)_2Cr_2O_{7(s)} \rightarrow N_{2(g)} + H_2O_{(g)} + Cr_2O_{3(s)}$

(f) $Mg_{(s)} + N_{2(g)} \rightarrow Mg_3N_{2(s)}$

(g) $N_2O_{4(g)} \rightarrow 2NO_{2(g)}$

5 MC Biosphere II was created in 1991 to test the idea that scientists could build a sealed, self-sustaining ecosystem. The carbon dioxide levels in Biosphere II were lower than scientists had predicted. Scientists discovered that the carbon dioxide was reacting with calcium hydroxide, a basic compound in the concrete.

(a) Write two balanced equations to show the reactions. Then classify the reactions. Hint: In the first reaction, carbon dioxide reacts with water in the concrete to form hydrogen carbonate. Hydrogen carbonate, an acid, reacts with calcium hydroxide, a base.

(b) Why do you think scientists failed to predict that this would happen?

(c) Suggest ways that scientists could have combatted the problem.

6 K/U What reaction is shown in the figure below? Write a balanced chemical equation to describe the reaction, then classify it.