Key Terms

single displacement reaction

activity series

double displacement reaction

5.2 Displacement Reactions

Geologists think that the Sudbury Basin resulted from a meteorite impact that is the second largest known impact crater on Earth. Today, the Sudbury Basin has an oval shape and measures approximately 60 km long and 30 km wide. The largest deposits of nickel in the world are in the Sudbury region, shown in **Figure 5.11**. These deposits are the result of nickel-rich molten rock that rose through the cracks caused by the meteorite impact. These deposits make Canada the world's second largest producer of nickel. Most nickel is used to produce stainless steel.

In Sudbury, the mines produce nickel(II) sulfide, which must go through several processing steps before the metallic element is formed. The final step in one of the methods for recovering nickel involves reacting nickel(II) sulfide with oxygen. The oxygen takes the place of, or displaces, the sulfur from the compound. This is just one example of many important reactions that involve the displacement of elements to produce new compounds.

Figure 5.11 The nickel deposits in Sudbury are the result of a meteorite impact. Isolating the nickel relies on a series of chemical reactions that include the displacement of one element by another to form a new compound.

Single Displacement Reactions

In a **single displacement reaction**, a reactive element (a metal or a non-metal) and a compound react to produce another element and another compound. Therefore, it is a chemical reaction in which an element takes the place of, or displaces, another element in a compound. Single displacement reactions can be represented by general chemical equations and pictorially as

single displacement reaction a chemical reaction in which one element takes the place of another element in a compound

$A + BC \rightarrow AC + B$ (for a single displacement, where A is a metal)

and

$A + BC \rightarrow BA + C$ (for a single displacement, where A is a non-metal)

Study Toolkit

Monitoring Comprehension
As you read through the material on this page, make note of points that you do not understand. Use the strategy on page 178 to help you understand the material.

The first equation represents a reaction involving a metal replacing another metal. The second equation represents a reaction involving a non-metal replacing another non-metal.

Recall that Activity 5-1 on page 177 involved placing aluminum foil into an aqueous solution of copper(II) chloride. The reaction that occurred was a single displacement reaction, which can be represented by the chemical equation

$$2Al(s) + 3CuCl_2(aq) \rightarrow 2AlCl_3(aq) + 3Cu(s)$$

The above reaction equation shows how the metals, coloured blue, behave. The aluminum displaces the copper to form an aqueous solution of aluminum chloride and a copper precipitate.

Displacing Metals with Metals

The reaction in **Figure 5.12** shows the result of placing a piece of copper wire into an aqueous solution of silver nitrate. Metallic silver forms on the surface of the wire. The solution turns blue because copper atoms from the wire turn into ions and dissolve into the solution. The copper displaces the silver from the compound silver nitrate in the solution. The balanced chemical equation for the reaction is

$$Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$$

Notice that copper, a metal, displaced silver, also a metal, during the reaction. Because a metal forms positive ions, it must displace the positive ion from the compound so that a new ionic compound can form.

Figure 5.12 In the single displacement reaction between copper metal and aqueous silver nitrate, copper displaces the silver to produce a blue copper(II) nitrate solution and solid silver deposits.

Activity Series

activity series a list of elements organized according to their chemical reactivity; the most reactive element appears at the top and the least reactive element appears at the bottom

You might be wondering why the reaction described on the previous page does not go in reverse. Why does silver not simply displace the copper? The answer lies in the reactivity of the metals. You may recall from your study of the periodic table that alkali metals (the elements in Group 1) are described as the most reactive metals. So, not all metals are equally reactive. By trying many combinations of metals and compounds, scientists organized the metals based on their reactivity into an activity series.

An **activity series** is a list of elements organized according to their chemical reactivity. The most reactive element is at the top of the list, and the least reactive element is at the bottom. **Figure 5.13** shows the activity series for metals. A reactive metal will displace or replace a metal in a compound that is below it in the activity series. As you can see in **Figure 5.13**, copper appears above silver in the activity series, so copper can displace silver ions in an aqueous solution, but silver cannot displace copper ions in an aqueous solution. If you place a piece of silver into an aqueous solution of a copper compound, no reaction occurs.

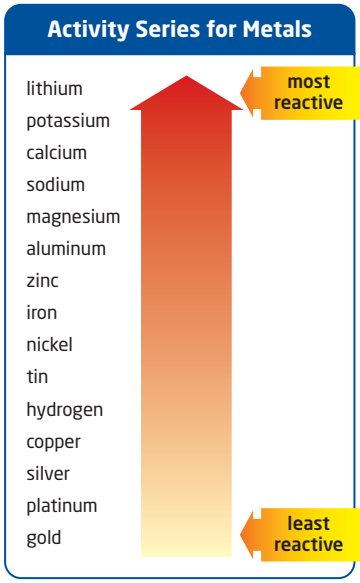


Figure 5.13 This activity series for metals provides information about what displacement reactions will take place.

Replacing Hydrogen with Metals

Notice that there is one element on the activity series of metals that is not a metal. This element is hydrogen. Because hydrogen ions can be positively charged, metals can take the place of hydrogen in compounds. The element formed in these single displacement reactions is hydrogen gas. In **Figure 5.14**, you can see the result of placing a piece of zinc metal into hydrochloric acid. (You will learn more about acids in the next chapter.) The balanced chemical equation for this reaction is

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

Keep in mind that the metals above hydrogen in the activity series can replace hydrogen from an acid, but that the metals below hydrogen cannot.

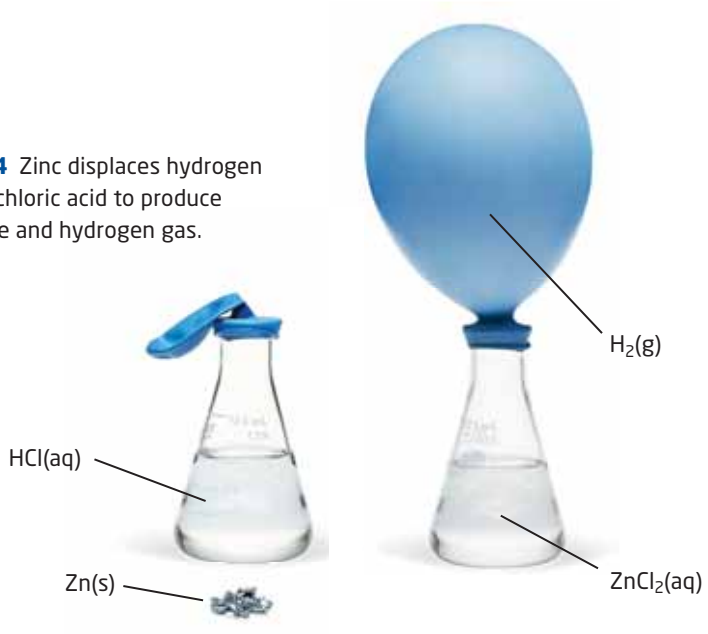


Figure 5.14 Zinc displaces hydrogen from hydrochloric acid to produce zinc chloride and hydrogen gas.

Sample Problem: Predicting Products of a Single Displacement Reaction for Metals

Problem

Use the activity series to predict if the following single displacement reaction occurs. If so, complete and balance the chemical equation.

$$Al(s) + NiBr_3(aq) \rightarrow$$

Solution

Step 1: Aluminum is a metal and is higher in the activity series than nickel. Aluminum will replace nickel in the compound.

Step 2: In forming the new compound, the aluminum becomes Al^{3+}. The bromide ion remains Br^-. For the ionic compound formed from these two ions to have a net charge of zero, the product must be $AlBr_3$. The cross-over method for determining the chemical formula is shown in the margin.

Step 3: As a pure element, nickel is written as Ni(s); nickel has no charge as a pure element.

Step 4: The problem also asks for a balanced chemical equation for the reaction. First, write the skeleton equation.

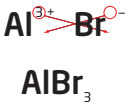
$$Al(s) + NiBr_3(aq) \rightarrow Ni(s) + AlBr_3(aq)$$

This also represents the balanced chemical equation.

Check Your Solution

First, ensure that the reacting metal, aluminum, is higher in the activity series than the metal in the reacting compound, nickel. Then check to make sure that the metals have been switched to produce a new metal product and a new compound. Ensure the compound product has the correct ratio of cations to anions, so it has a net charge of zero. Finally, count the number of each type of atom in the chemical equation to ensure it is balanced.

Cross-Over Method



GRASP

Go to **Science Skills Toolkit 11** to learn about an alternative problem solving method.

Suggested Investigation

Data Analysis Investigation 5-D, Can Metals Be "Active"?, on page 212

Practice Problems

1. Complete and balance the following single displacement reactions. If the reaction will not happen, based on the activity series, write "no reaction." **Note:** All metal products are solids, and products that are compounds are in aqueous solution.

a. $SnCl_4(aq) + Al(s) \rightarrow$

b. $CuF_2(aq) + Mg(s) \rightarrow$

c. $Cu(s) + HCl(aq) \rightarrow$

d. $Au(NO_3)_3(aq) + Ag(s) \rightarrow$

e. $Al(s) + Fe_2O_3(s) \rightarrow$

f. $Li(s) + HCl(aq) \rightarrow$

2. When magnesium metal is added to a blue copper(II) sulfate solution, the blue colour fades as colourless magnesium sulfate and brown pieces of copper form. Write a balanced chemical equation for this reaction, shown in **Figure 5.15**.

Figure 5.15 As magnesium metal reacts with an aqueous solution of copper(II) sulfate, copper metal forms.

Sense of scale

Activity series for halogens include only the first four halogens. Astatine, which is element number 85 and appears below iodine in the periodic table, is omitted because there is so little of it that studying it is difficult. Estimates place the amount of astatine in Earth's crust at less than 30 g–about the mass of four $2 coins.

Replacing Non-metals with Non-metals

The ion of a non-metal, such as a chloride ion, is negatively charged, so it can be replaced only with another non-metal. For example, in the reaction between fluorine and sodium iodide, fluorine replaces the iodine to produce iodine and sodium fluoride. The balanced chemical equation for the reaction is

$$F_2(g) + 2NaI(s) \rightarrow I_2(s) + 2NaF(s)$$

There is a separate activity series for non-metals. You can determine this activity series yourself by doing Activity 5-3. The activity series for non-metals works in the same way as the activity series for metals, with the most reactive element at the top of the list.

Activity 5-3

How Active Are the Non-Metals?

A scientist wished to determine the reactivity of five elements (oxygen, bromine, iodine, chlorine, and fluorine) in order from most active to least active. The scientist conducted six tests, putting one element and one compound together in each test. The results of six chemical tests based on the scientist's observations are expressed below as balanced chemical equations.

A. $Cl_2(g) + MgBr_2(aq) \rightarrow Br_2(\ell) + MgCl_2(aq)$

B. $I_2(s) + MgCl_2(aq) \rightarrow$ no reaction

C. $Br_2(\ell) + MgI_2(aq) \rightarrow I_2(s) + MgBr_2(aq)$

D. $2F_2(g) + 2MgO(aq) \rightarrow O_2(g) + 2MgF_2(aq)$

E. $O_2(g) + 2MgBr_2(aq) \rightarrow 2Br_2(\ell) + 2MgO(aq)$

F. $Cl_2(g) + MgO(aq) \rightarrow$ no reaction

Materials

- molecular modelling kit

Procedure

1. Make a table like the one below for each of the six equations. Give your table a title.

Balanced Chemical Equation	
Word Equation	
Model Equation	

2. Copy each balanced chemical equation into your table, and write the word equation beneath it. Use the molecular modelling kit to make a model of each substance in the equation. Draw a diagram of each model in your table.
3. Examine one equation, and infer which non-metal element was more active for that equation. Repeat for each equation.

Questions

1. What type of chemical reaction was the scientist studying?
2. Write the names of the five elements in a list, arranged from most active to least active.
3. Explain how you decided on the order of your list.

Learning Check

1. What are two general chemical equations for single displacement reactions?
2. Classify each of the following chemical equations as representing a synthesis reaction, a decomposition reaction, or a single displacement reaction. Provide an explanation for your choice.
   a. $2FeBr_3(s) \rightarrow 3Br_2(\ell) + 2Fe(s)$
   b. $Au(NO_3)_3(aq) + 3Ag(s) \rightarrow Au(s) + 3AgNO_3(aq)$
   c. $Br_2(\ell) + F_2(g) \rightarrow 2BrF(g)$
3. Draw a diagram that helps to illustrate the change that happens during a single displacement reaction.
4. Gold, silver, and platinum are found in nature as pure elements. Using the activity series, provide an explanation for this observation.

Suggested Investigation
Inquiry Investigation 5-C, Displacement Reactions, on page 210

Double Displacement Reactions

A **double displacement reaction** is a chemical reaction in which the positive ions of two compounds change places and form two new compounds. The reactants of a double displacement reaction are often aqueous solutions of ionic compounds. For the purposes of this chapter, you will only be studying the double displacement reactions of aqueous solutions that result in a precipitate as one of the products. Double displacement reactions can be represented by a general chemical equation and pictorially as

double displacement reaction a chemical reaction in which the positive ions of two different compounds exchange places, resulting in the formation of two new compounds–one of which may be a precipitate

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

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

For example, as shown in **Figure 5.16,** when a colourless aqueous solution of silver nitrate, $AgNO_3(aq)$, is added to a yellow aqueous solution of potassium chromate, $K_2CrO_4(aq)$, a red precipitate, $Ag_2CrO_4(s)$, is formed. In a later science course, you will learn how to determine which products form precipitates and which combinations of compounds do not react by double displacement.

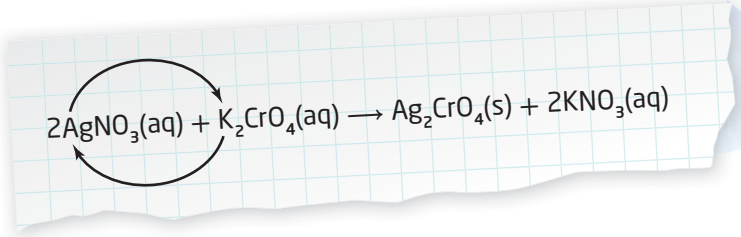
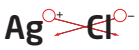


Figure 5.16 A red precipitate, $Ag_2CrO_4(s)$, forms when two ionic solutions, $AgNO_3(aq)$ and $K_2CrO_4(aq)$, undergo a double displacement reaction.

Sense of Value

Silver nitrate, $AgNO_3(s)$, is a chemical that formed the basis of modern photography. The ability to produce an image on film was accomplished by incorporating this light-sensitive compound into an emulsion layer on film. Although most modern films now use silver halides, such as silver chloride, silver nitrate is still required. It is used as a reactant in the synthesis of the silver halide compounds.

Cross-Over Method



$AgCl$

$NaNO_3$

GRASP

Go to **Science Skills Toolkit 11** to learn about an alternative problem solving method.

Sample Problem: Predicting Products of Double Displacement Reactions

Problem

Complete and balance the following double displacement reaction. You do not need to predict the states of the products.

$$NaCl(aq) + AgNO_3(aq) \rightarrow$$

Solution

Step 1: This is a double displacement reaction. Therefore, the two cations in the reacting compounds switch places.

Step 2: Sodium and silver will displace each other to form two new compounds. Since both cations have a 1+ charge, the ratio of anions in each new compound does not change for this reaction. The cross-over method for determining the chemical formulas is shown in the margin.

Step 3: The problem also asks for a balanced chemical equation for the reaction. First, write the skeleton equation.

$$NaCl(aq) + AgNO_3(aq) \rightarrow AgCl + NaNO_3$$

This also represents the balanced chemical equation.

Check Your Solution

First, check to make sure that the sodium and silver cations have been switched to form two new ionic compounds. Then, check to make sure that each product has the correct ratio of cations to anions, so the ionic compounds have a net charge of zero. Finally, count the number of each type of atom in the chemical equation to ensure that it is balanced.

Practice Problems

1. The following are double displacement reactions that are experimentally known to produce precipitates. Complete and balance the chemical equations. You do not need to show the states of the products.

a. $Pb(NO_3)_2(aq) + KI(aq) \rightarrow$

b. $SrCl_2(aq) + Pb(NO_3)_2(aq) \rightarrow$

c. $AlCl_3(aq) + CuNO_3(aq) \rightarrow$

d. $KCl(aq) + AgNO_3(aq) \rightarrow$

e. $CaI_2(aq) + Na_2CO_3(aq) \rightarrow$

2. Aqueous solutions of potassium phosphate and magnesium iodide are known to undergo a double displacement reaction and produce a precipitate. Write a balanced chemical equation for this reaction.

Chemical Reactions and Food Preservation

Sulfur dioxide has traditionally been used to preserve the light colour of certain dried fruits, such as dried apples, golden raisins, and dried apricots, shown in **Figure 5.17**. Sulfur dioxide gas is produced from an initial double displacement reaction, which is followed by a decomposition reaction. The balanced chemical equations for these reactions are

$$Na_2SO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2SO_3(aq)$$

$$H_2SO_3(aq) \rightarrow H_2O(\ell) + SO_2(g)$$

Sulfur dioxide gas is absorbed into the skin of the fruit. Without the sulfur dioxide, the fruit would darken and change flavour as it dried. When a package of dried fruit is first opened, residual sulfur dioxide gas and the smell of sulfur may be noticeable. Some individuals are allergic to sulfites or "sulfiting agents." This has prompted many companies that produce dried fruit to place a cautionary statement on the packaging to alert people about the presence of these agents in the food.

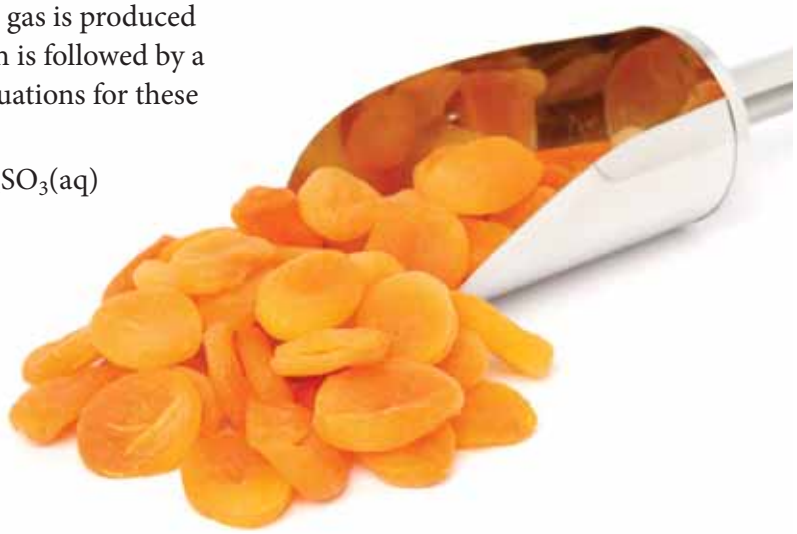


Figure 5.17 Sulfur dioxide is used to maintain the light colour of these apricots during the drying process.

Summary of Chemical Reaction Types

Table 5.1 summarizes the four types of chemical reactions that you have studied in this chapter. The characteristics will help you to identify each type of reaction and determine the products most likely to form.

Table 5.1 Summary of Chemical Reaction Types

Reaction Type	General Chemical Equation	Example	Characteristics
Synthesis	A + B → AB 	$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$	Two reactants join to form a single compound.
Decomposition	AB → A + B 	$2C_7H_5N_3O_6(s) \rightarrow 3N_2(g) + 5H_2O(g) + 7CO(g) + 7C(s)$	A single compound breaks apart into two or more products.
Single displacement	A + BC → AC + B A + BC → BA + C 	$2Al(s) + 3CuCl_2(aq) \rightarrow 2AlCl_3(aq) + 3Cu(s)$ (metal displacement) $F_2(g) + 2NaI(s) \rightarrow I_2(s) + 2NaF(s)$ (non-metal displacement)	A reactive element takes the place of a less reactive element in a compound.
Double displacement (precipitate)	AB + CD → AD + BC 	$NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$	Two ionic compounds in a solution switch ions and form two new compounds, including a precipitate.

Section 5.2 Review

Section Summary

- In a single displacement reaction, a metal replaces the ion of a different metal, or a non-metal replaces the ion of a non-metal. The products are an element and a compound that differ from the reactants.
- An activity series is a list of elements arranged in order from the most reactive to the least reactive. For a single displacement reaction to happen, a more reactive element must replace the ion of a less reactive element.
- During a double displacement reaction between two compounds in aqueous solutions, the cations of the two compounds switch places to form two new compounds. For a certain type of double displacement reaction, one of the products is a precipitate.

Review Questions

K/U **1.** Describe a single displacement reaction.

K/U **2.** Using the activity series for metals in **Figure 5.13** on page 192, predict whether each of the following single displacement reactions will occur. If it will occur, complete the balanced chemical equation for the reaction.

a. $Ca(s) + AgNO_3(aq) \rightarrow$

b. $Cu(s) + ZnSO_4(aq) \rightarrow$

c. $Al(s) + HCl(aq) \rightarrow$

A **3.** Why would it be easier to recover silver from an aqueous solution than to recover lithium from the same solution?

K/U **4.** Describe a double displacement reaction.

C **5.** Make a Venn diagram to show the similarities and differences between single displacement reactions and double displacement reactions.

K/U **6.** Classify each of the following as a single displacement or double displacement reaction. Predict the products of each reaction, and provide the complete balanced chemical equation. You do not need to indicate the states of the products.

a. $Cl_2(g) + CsBr(aq) \rightarrow$

b. $AgNO_3(aq) + Na_2CrO_4(aq) \rightarrow$

c. $MgCl_2(aq) + AgNO_3(aq) \rightarrow$

d. $F_2(g) + NaI(aq) \rightarrow$

T/I **7.** The photograph on the right shows the reaction between a piece of aluminum wire and a solution of copper(II) sulfate. Identify the type of reaction that is occuring, and write a balanced chemical equation for the reaction. What is the brown solid that is forming on the surface of the wire?

A **8.** As a result of a chemical spill, the water in a holding pond contains harmful levels of dissolved arsenate ions. Which type of reaction would be best to remove the ions? Explain.