Section 10.2

Classifying Chemical Reactions

Objectives

- **Classify** chemical reactions.
- **Identify** the characteristics of different classes of chemical reactions.

Vocabulary

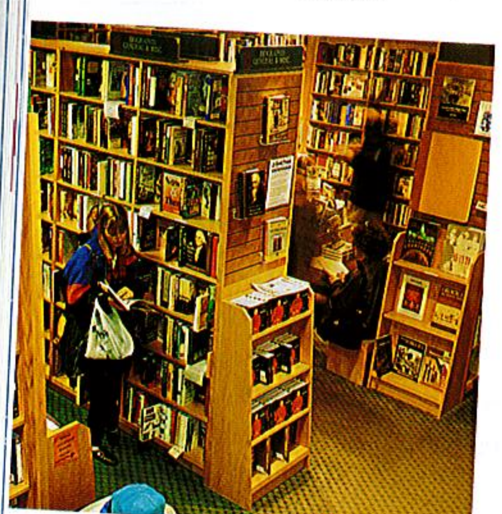
synthesis reaction
combustion reaction
decomposition reaction
single-replacement reaction
double-replacement reaction
precipitate

In order to access this redo you must first have the Reaction Types Notes and Check questions completed.

Instructions: At the end of the chapter on page 291 and on page 305 copy the questions and answer in complete sentences.

Failure to meet the requirements or follow instructions will result in the assignments not being graded.

replacement reactions.



How long do you think it would take you to find your favorite author's new novel in an unorganized book store? Because there are so many books in book stores, it could take you a very long time. Book stores, such as the store shown in **Figure 10-5**, supermarkets, and music stores are among the many places where things are classified and organized. Chemists classify chemical reactions in order to organize the many reactions that occur daily in living things, laboratories, and industry. Knowing the categories of chemical reactions can help you remember and understand them. It also can help you recognize patterns and predict the products of many chemical reactions.

Chemists classify reactions in different ways. One way is to distinguish among five types of chemical reactions: synthesis, combustion, decomposition, single-replacement, and double-replacement reactions. Some reactions fit equally well into more than one of these classes.

Synthesis Reactions

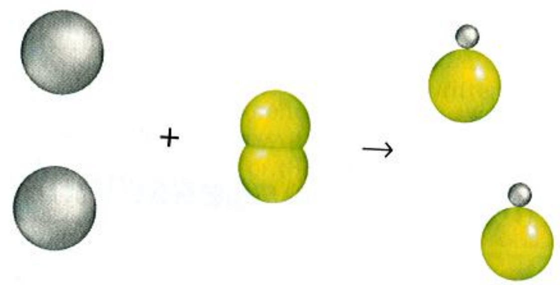
In the previous section, you read about the reaction that occurs between iron and chlorine gas to produce iron(III) chloride. In this reaction, two elements (A and B) combine to produce one new compound (AB).

$$A + B \rightarrow AB$$

$$2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(s)$$

The reaction between iron and chlorine gas is an example of a **synthesis reaction**—a chemical reaction in which two or more substances react to produce a single product. When two elements react, the reaction is always a synthesis reaction. Another example of a synthesis reaction is shown below. In this reaction, sodium and chlorine react to produce sodium chloride.

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$



Just as two elements can combine, two compounds can also combine to form one compound. For example, the reaction between calcium oxide and water to form calcium hydroxide is a synthesis reaction.

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$$

Another type of synthesis reaction may involve a reaction between a compound and an element, as happens when sulfur dioxide gas reacts with oxygen gas to form sulfur trioxide.

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

Combustion Reactions

The synthesis reaction between sulfur dioxide and oxygen can be classified also as a combustion reaction. In a **combustion reaction**, oxygen combines with a substance and releases energy in the form of heat and light. Oxygen can combine in this way with many different substances, making combustion reactions common.

A combustion reaction, such as the one shown in **Figure 10-6**, occurs between hydrogen and oxygen when hydrogen is heated. Water is formed during the reaction and a large amount of energy is released.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

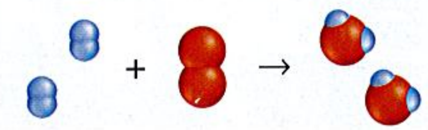


Figure 10-6
The tragedy of the *Challenger* space mission was the result of a combustion reaction between oxygen and hydrogen.

Another important combustion reaction occurs when coal is burned to produce energy. Coal is called a fossil fuel because it contains the remains of plants that lived long ago. It is composed primarily of the element carbon. Coal-burning power plants generate electric power in many parts of the United States. The primary reaction that occurs in these plants is between carbon and oxygen.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

Note that the combustion reactions just mentioned are also synthesis reactions. However, not all combustion reactions are synthesis reactions. For example, the reaction involving methane gas, CH_4, and oxygen illustrates a combustion reaction in which one substance replaces another in the formation of products.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Methane, which belongs to a group of substances called hydrocarbons, is the major component of natural gas. All hydrocarbons contain carbon and hydrogen and burn in oxygen to yield the same products as methane does—carbon dioxide and water. For example, most cars and trucks are powered by gasoline, which contains hydrocarbons. In engines, gasoline is combined with oxygen, producing carbon dioxide, water, and energy that powers the vehicles. You will learn more about hydrocarbons in Chapter 22.

PRACTICE PROBLEMS

Write chemical equations for the following reactions. Classify each reaction into as many categories as possible.

14. The solids aluminum and sulfur react to produce aluminum sulfide.

15. Water and dinitrogen pentoxide gas react to produce aqueous hydrogen nitrate.

16. The gases nitrogen dioxide and oxygen react to produce dinitrogen pentoxide gas.

17. Ethane gas (C_2H_6) burns in air, producing carbon dioxide gas and water vapor.

Practice!
For more practice with writing synthesis and combustion equations, go to **Supplemental Practice Problems** in Appendix A.

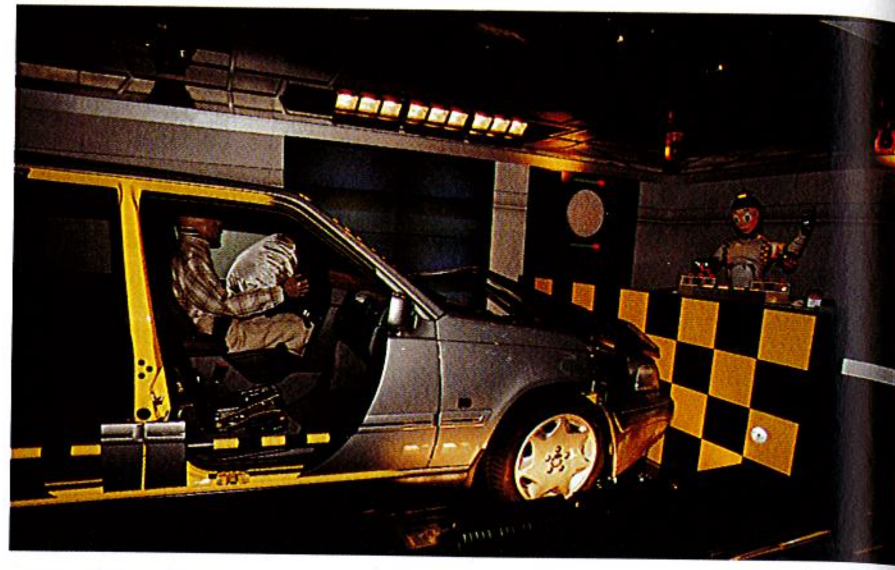


Figure 10-7

The decomposition of sodium azide, which produces a gas, is the key to inflatable air bags.

Decomposition Reactions

Some chemical reactions are essentially the opposite of synthesis reactions. These reactions are classified as decomposition reactions. A **decomposition reaction** is one in which a single compound breaks down into two or more elements or new compounds. In generic terms, decomposition reactions look like the following.

$$AB \longrightarrow A + B$$

Decomposition reactions often require an energy source, such as heat, light, or electricity, to occur. For example, ammonium nitrate breaks down into dinitrogen monoxide and water when the reactant is heated to high temperature.

$$NH_4NO_3(s) \longrightarrow N_2O(g) + 2H_2O(g)$$

You can see that this decomposition reaction involves one reactant breaking down into more than one product.

The outcome of another decomposition reaction is shown in **Figure 10-7**. Automobile safety air bags inflate rapidly as sodium azide pellets decompose. A device that can provide an electric signal to start the reaction is packaged inside air bags along with the sodium azide pellets. When the device is activated, sodium azide decomposes, producing nitrogen gas that quickly inflates the safety bag.

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

Practice!

For more practice with writing decomposition equations, go to **Supplemental Practice Problems** in Appendix A.

PRACTICE PROBLEMS

Write chemical equations for the following decomposition reactions.

18. Aluminum oxide(s) decomposes when electricity is passed through it.

19. Nickel(II) hydroxide(s) decomposes to produce nickel(II) oxide(s) and water.

20. Heating sodium hydrogen carbonate(s) produces sodium carbonate(aq), carbon dioxide(g), and water.

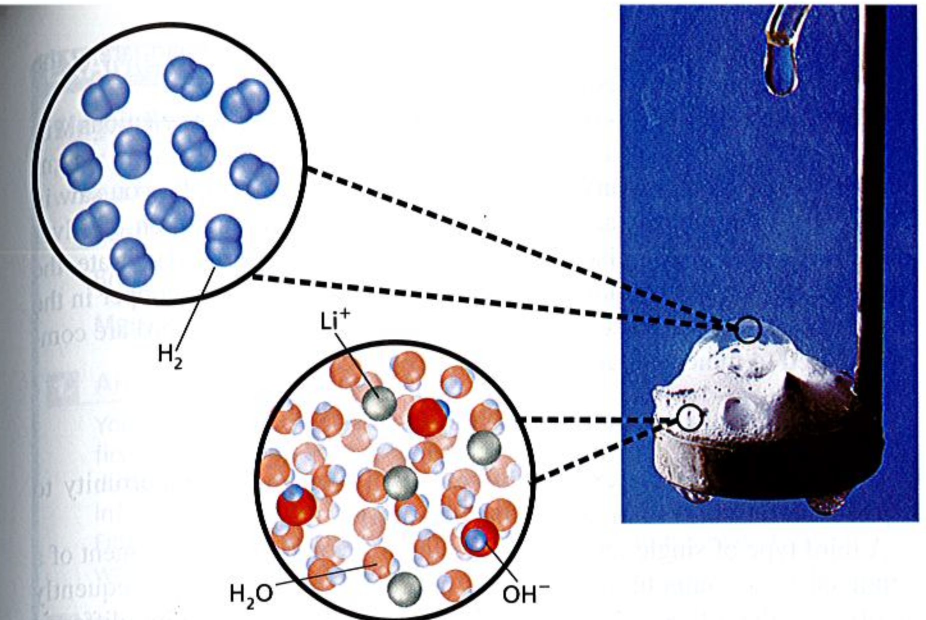


Figure 10-8

The reaction of lithium and water is a single-replacement reaction. Lithium replaces a hydrogen in water, and the products of the reaction are aqueous lithium hydroxide and hydrogen gas. Lithium hydroxide exists as lithium and hydroxide ions in solution.

Replacement Reactions

In contrast to synthesis, combustion, and decomposition reactions, many chemical reactions involve the replacement of an element in a compound. There are two types of replacement reactions: single-replacement reactions and double-replacement reactions.

Single-replacement reactions Now that you've seen how atoms and molecules rearrange in synthesis and combustion reactions, look closely at the reaction between lithium and water that is shown in **Figure 10-8**. The expanded view of the reaction at the molecular level shows that a lithium atom replaces one of the hydrogen atoms in a water molecule. The following chemical equation describes this activity.

$$2Li(s) + 2H_2O(l) \longrightarrow 2LiOH(aq) + H_2(g)$$

A reaction in which the atoms of one element replace the atoms of another element in a compound is called a **single-replacement reaction**.

$$A + BX \longrightarrow AX + B$$

The reaction between lithium and water is one type of single-replacement reaction in which a metal replaces a hydrogen in a water molecule. Another type of single-replacement reaction occurs when one metal replaces another metal in a compound dissolved in water. For example, **Figure 10-9** shows a single-replacement reaction occurring when a spiral of pure copper wire is placed in aqueous silver nitrate. The shiny crystals that are accumulating on the copper wire are the silver atoms that the copper atoms replaced.

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

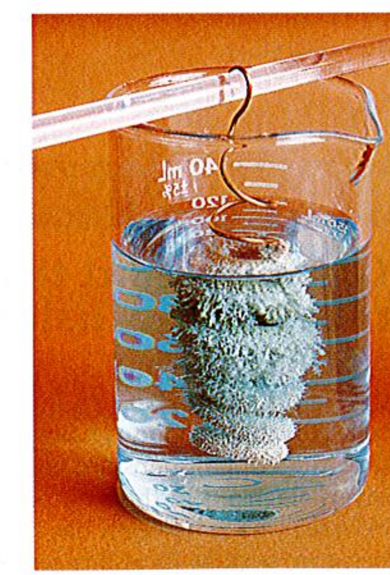


Figure 10-9

The chemical equation for the single-replacement reaction involving copper and silver nitrate clearly describes the replacement of silver by copper, but the visual evidence of this chemical reaction is a solid precipitate.

A metal will not always replace another metal in a compound dissolved in water. This is because metals differ in their reactivities. A metal's reactivity is its ability to react with another substance. In **Figure 10-10** you see an activity series of some metals. This series orders metals by their reactivity with other metals. Single-replacement reactions like the one between copper and aqueous silver nitrate determine a metal's position on the list. The most active

Most active

METALS
Lithium
Rubidium
Potassium
Calcium
Sodium
Magnesium
Aluminum
Manganese
Zinc
Iron
Nickel
Tin
Lead
Copper
Silver
Platinum
Gold

Least active

Most active

HALOGENS
Fluorine
Chlorine
Bromine
Iodine

Least active

Figure 10-10

An activity series, similar to the series shown here for various metals and halogens, is a useful tool for determining whether a chemical reaction will take place and for determining the result of a replacement reaction.

metals, which are those that do replace the metal in a compound, are at the top of the list. The least active metals are at the bottom.

You can use **Figure 10-10** to predict whether or not certain reactions will occur. A specific metal can replace any metal listed below it that is in a compound. It cannot replace any metal listed above it. For example, you saw in **Figure 10-9** that copper atoms replace silver atoms in a solution of silver nitrate. However, if you place a silver wire in aqueous copper(II) nitrate, the silver atoms will not replace the copper. Silver is listed below copper in the activity series and no reaction occurs. The letters NR (no reaction) are commonly used to indicate that a reaction will not occur.

$$Ag(s) + Cu(NO_3)_2(aq) \longrightarrow NR$$

The **CHEMLAB** at the end of this chapter gives you an opportunity to explore the activities of metals in the laboratory.

A third type of single-replacement reaction involves the replacement of a nonmetal in a compound by another nonmetal. Halogens are frequently involved in these types of reactions. Like metals, halogens exhibit different activity levels in single-replacement reactions. The reactivities of halogens, determined by single-replacement reactions, are also shown in **Figure 10-10.** The most active halogen is fluorine, and the least active is iodine. A more reactive halogen replaces a less reactive halogen that is part of a compound dissolved in water. For example, fluorine replaces bromine in water containing dissolved sodium bromide. However, bromine does not replace fluorine in water containing dissolved sodium fluoride.

$$F_2(g) + 2NaBr(aq) \longrightarrow 2NaF(aq) + Br_2(l)$$

$$Br_2(g) + 2NaF(aq) \longrightarrow NR$$

The **problem-solving LAB** below will help you to relate periodic trends of the halogens to their reactivities.

problem-solving LAB

Can you predict the reactivities of halogens?

Analyzing and Concluding The location of all the halogens in group 7A in the periodic table tells you that halogens have common characteristics. Indeed, halogens are all nonmetals and have seven electrons in their outermost orbitals. However, each halogen has its own characteristics, too, such as its ability to react with other substances.

Analysis

Examine the accompanying table. It includes data about the atomic radii, ionization energies, and electronegativities of the halogens.

Properties of Halogens

Halogen	Atomic radius (pm)	Ionization energy (kJ/mol)	Electro-negativity
Fluorine	72	1681	3.98
Chlorine	100	1251	3.16
Bromine	114	1140	2.96
Iodine	133	1008	2.66
Astatine	140	—	2.2

Thinking Critically

1. Describe any periodic trends that you identify in the table data.
2. Relate any periodic trends that you identify among the halogens to the activity series of halogens shown in **Figure 10-10**.
3. Predict the location of the element astatine in the activity series of halogens. Explain your answer.

EXAMPLE PROBLEM 10-2

Single-Replacement Reactions

Predict the products that will result when these reactants combine and write a balanced chemical equation for each reaction.

$Fe(s) + CuSO_4(aq) \longrightarrow$

$Br_2(l) + MgCl_2(aq) \longrightarrow$

$Mg(s) + AlCl_3(aq) \longrightarrow$

1. Analyze the Problem

You are given three sets of reactants. Using **Figure 10-10,** you must first determine if each reaction takes place. Then, if a reaction is predicted, you can determine the product(s) of the reaction. With this information you can write a skeleton equation for the reaction. Finally, you can use the steps for balancing chemical equations to write the complete balanced chemical equation.

2. Solve for the Unknown

Iron is listed above copper in the metals activity series. Therefore, the first reaction will take place because iron is more reactive than copper. In this case, iron will replace copper. The skeleton equation for this reaction is

$Fe(s) + CuSO_4(aq) \longrightarrow FeSO_4(aq) + Cu(s)$

This equation is balanced.

In the second reaction, chlorine is more reactive than bromine because bromine is listed below chlorine in the halogen activity series. Therefore, the reaction will not take place. The skeleton equation for this situation is $Br(l) + MgCl_2(aq) \longrightarrow NR$. No balancing is required.

Magnesium is listed above aluminum in the metals activity series. Therefore, the third reaction will take place because magnesium is more reactive than aluminum. In this case, magnesium will replace aluminum. The skeleton equation for this reaction is

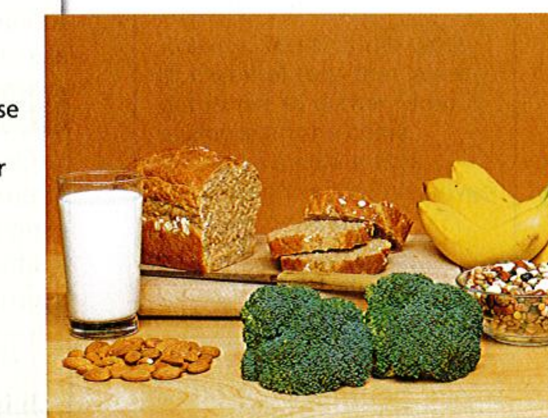
$Mg(s) + AlCl_3(aq) \longrightarrow Al(s) + MgCl_2(aq)$

This equation is not balanced. The balanced equation is

$3Mg(s) + 2AlCl_3(aq) \longrightarrow 2Al(s) + 3MgCl_2(aq)$

3. Evaluate the Answer

The activity series shown in **Figure 10-10** supports the reaction predictions. The chemical equations are balanced because the number of atoms of each substance is equal on both sides of the equation.



Magnesium is an essential element for the human body. You can ensure an adequate magnesium intake by eating magnesium-rich foods.

PRACTICE PROBLEMS

Predict if the following single-replacement reactions will occur. If a reaction occurs, write a balanced equation for the reaction.

21. $K(s) + ZnCl_2(aq) \longrightarrow$

22. $Cl_2(g) + HF(aq) \longrightarrow$

23. $Fe(s) + Na_3PO_4(aq) \longrightarrow$

Practice!

For more practice with predicting if single-replacement reactions will occur, go to **Supplemental Practice Problems** in Appendix A.

Double-replacement reactions The final type of replacement reaction which involves an exchange of ions between two compounds is called a **double-replacement reaction.**

$$AX + BY \rightarrow AY + BX$$

In this generic equation, A and B represent positively charged ions (cations), and X and Y represent negatively charged ions (anions). You can see that the anions have switched places and are now bonded to the other cations in the reaction. In other words, X replaces Y and Y replaces X—a double replacement. More simply, you might say that the positive and negative ions of two compounds switch places. The reaction between calcium hydroxide and hydrochloric acid is a double-replacement reaction.

$$Ca(OH)_2(aq) + 2HCl(aq) \rightarrow CaCl_2(aq) + 2H_2O(l)$$

The ionic components of the reaction are Ca^{2+}, OH^-, H^+, and Cl^-. Knowing this, you can now see the two replacements of the reaction. The anions (OH^- and Cl^-) have changed places and are now bonded to the other cations (Ca^{2+} and H^+) in the reaction.

The reaction between sodium hydroxide and copper(II) chloride in solution is also a double-replacement reaction.

$$2NaOH(aq) + CuCl_2(aq) \rightarrow 2NaCl(aq) + Cu(OH)_2(s)$$

In this case, the anions (OH^- and Cl^-) changed places and are now associated with the other cations (Na^+ and Cu^{2+}). The result of this reaction is a solid product, copper(II) hydroxide. A solid produced during a chemical reaction in a solution is called a **precipitate.**

One of the key characteristics of double-replacement reactions is the type of product that is formed when the reaction takes place. All double-replacement reactions produce either a precipitate, a gas, or water. An example of a double-replacement reaction that forms a gas is that of potassium cyanide and hydrobromic acid.

$$KCN(aq) + HBr(aq) \rightarrow KBr(aq) + HCN(g)$$

It is important to be able to evaluate the chemistry of double-replacement reactions and predict the products of these reactions. The basic steps to do this are given in **Table 10-2.**

Table 10-2

Guidelines for Double-Replacement Reactions

Step	Example
1. Write the components of the reactants in a skeleton equation.	$Al(NO_3)_3 + H_2SO_4$
2. Identify the cations and anions in each compound.	$Al(NO_3)_3$ has Al^{3+} and NO_3^- H_2SO_4 has H^+ and SO_4^{2-}
3. Pair up each cation with the anion from the other compound.	Al^{3+} pairs with SO_4^{2-} H^+ pairs with NO_3^-
4. Write the formulas for the products using the pairs from step 3.	$Al_2(SO_4)_3$ HNO_3
5. Write the complete equation for the double-replacement reaction.	$Al(NO_3)_3 + H_2SO_4 \rightarrow Al_2(SO_4)_3 + HNO_3$
6. Balance the equation.	$2Al(NO_3)_3 + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6HNO_3$

Now use this information to work the following practice problems.

PRACTICE PROBLEMS

Write the balanced chemical equations for the following double-replacement reactions.

24. Aqueous lithium iodide and aqueous silver nitrate react to produce solid silver iodide and aqueous lithium nitrate.

25. Aqueous barium chloride and aqueous potassium carbonate react to produce solid barium carbonate and aqueous potassium chloride.

26. Aqueous sodium oxalate and aqueous lead(II) nitrate react to produce solid lead(II) oxalate and aqueous sodium nitrate.

Practice!

For more practice with writing double-replacement equations, go to **Supplemental Practice Problems** in Appendix A.

Now that you have learned about the various types of chemical reactions, you can use **Table 10-3** to help you organize them in a way such that you can identify each and predict its products.

As the table indicates, the components of double-replacement reactions are dissolved in water. As you continue with Section 10.3, you will learn more about double-replacement reactions in aqueous solutions.

Chemistry Online

Topic: Chemical Reactions in Forensics

To learn more about chemical reactions in forensics, visit the Chemistry Web site at **chemistrymc.com**

Activity: Research the types of chemical tests that investigators use to gather forensic evidence after a crime. Prepare a media article explaining the forensics investigation to the public.

Table 10-3

Predicting Products of Chemical Reactions

Class of reaction	Reactants	Probable products
Synthesis	Two or more substances	One compound
Combustion	A metal and oxygen A nonmetal and oxygen A compound and oxygen	The oxide of the metal The oxide of the nonmetal Two or more oxides
Decomposition	One compound	Two or more elements and/or compounds
Single-replacement	A metal and a compound A nonmetal and a compound	A new compound and the replaced metal A new compound and the replaced nonmetal
Double-replacement	Two compounds	Two different compounds, one of which is often a solid, water, or a gas

Section 10.2 Assessment

27. What are the five classes of chemical reactions?

28. Identify two characteristics of combustion reactions.

29. Compare and contrast single-replacement reactions and double-replacement reactions.

chemistrymc.com/self_check_quiz

a. boron + fluorine ⟶

86.

d. liquid octane (C_8H_{18})

88.

c. potassium + aluminum nitrate ⟶

89.

d. calcium nitrate + aluminum hydroxide ⟶

In each of the following questions identify the type of reaction, create the formula equation, and then balance the equation.

85.