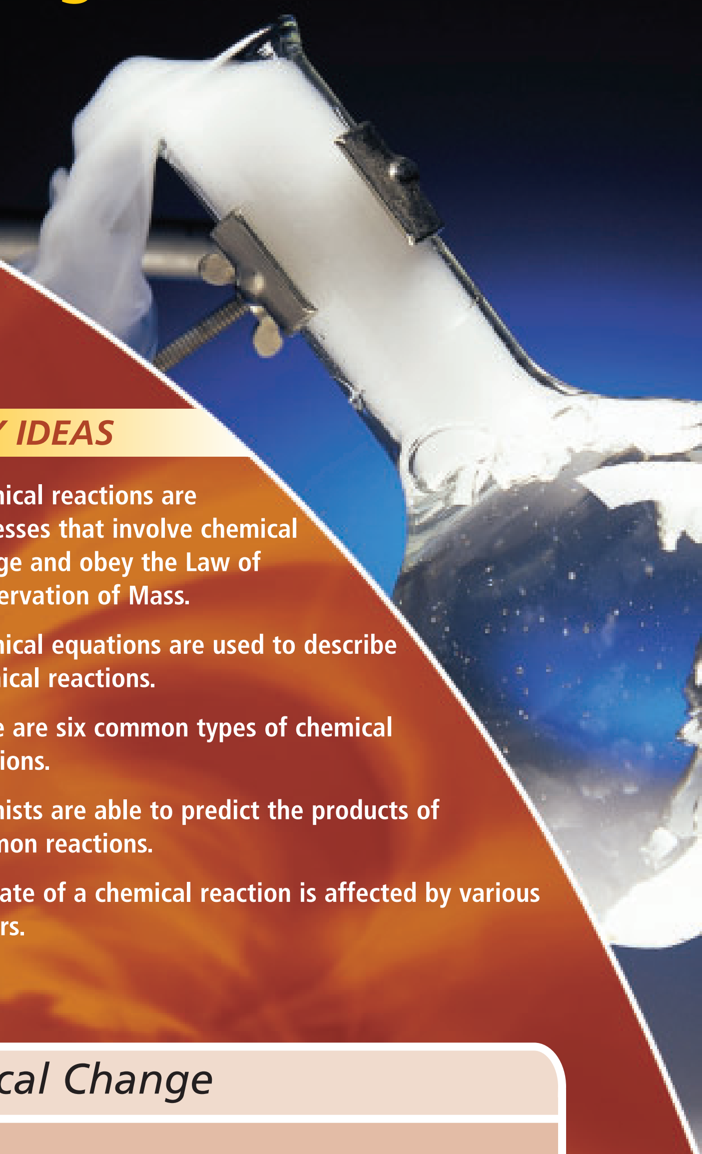
CHAPTER 9

Investigating Chemical Reactions



Chapter Preview

What chemical reactions occur in your daily life? Riding in a car, walking, breathing, and listening to a portable music player all depend on chemical reactions. A car obtains its energy to move from the reaction of gasoline with oxygen. From the food that we eat, the body's cells use chemical reactions to produce non-stop energy that is required for normal function and movement. Portable music players rely on the electrical energy produced from chemical reactions in batteries.

In this chapter, you will investigate the world of chemical reactions and learn how chemists make sense of and describe them.

KEY IDEAS

- **Chemical reactions are processes that involve chemical change and obey the Law of Conservation of Mass.**
- **Chemical equations are used to describe chemical reactions.**
- **There are six common types of chemical reactions.**
- **Chemists are able to predict the products of common reactions.**
- **The rate of a chemical reaction is affected by various factors.**

TRY THIS: Modelling Physical and Chemical Change

Skills Focus: creating models

Chemistry is just complicated common sense! One of the challenges of learning chemistry is trying to understand things that you cannot see. You cannot see the incredibly small, and that is precisely why chemists use models.

In this activity, you will use interlocking building blocks to model and demonstrate the difference between a physical change and a chemical change. Recall that in a physical change, no new substance is formed as is evident when water boils and changes into water vapour (gas). However, when water is broken down by electrolysis into hydrogen gas and oxygen gas, a chemical change occurs.

Materials: an assortment of interlocking building blocks

1. Choose six blocks and use them to show an example of physical change.
2. Use these same blocks to demonstrate an example of a chemical change.

A. Describe your example of physical change by sketching the blocks before and after.

B. Use a word statement to represent the sketches that you just made.

C. Make up some symbols for your blocks. For example, a red block could be "R." Convert your word statement of the physical change into a statement using symbols.

D. Repeat A through C for your example of a chemical change.

9.1 Describing Chemical Reactions

You have learned that chemists use classification schemes to make sense out of vast amounts of information. For instance, in Chapters 7 and 8 you saw patterns in how chemical compounds can be classified as ionic or molecular, as organic or inorganic, as acids, bases, and salts, and as organic family compounds (Figure 1).

LEARNING TIP
The key ideas in the chapter preview provide you with the "big ideas" that you need to look for as you read Chapter 9. Ask yourself, "What do I already know about chemical reactions and what do I need to pay close attention to?"

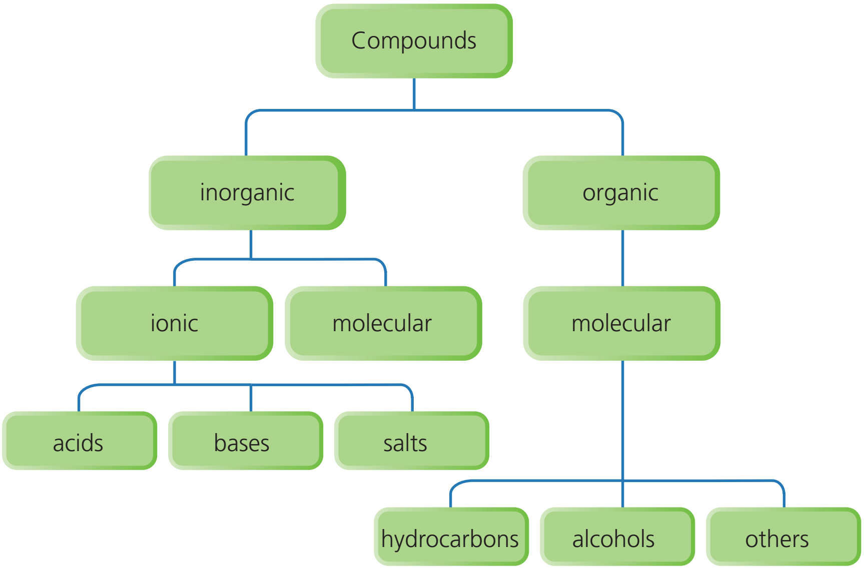


Figure 1 Many of the compounds you have studied can be produced by chemical reactions, or the compounds themselves can be used to produce other substances in chemical reactions.

Chemical reactions are used to manufacture things that we use every day. The plastics that are so common (keyboards, bottles, chair seats, TV monitors, toys), all of the metals you notice (coins, file cabinets, chair legs, car parts, structural supports), medicines, and even the fabrics in your clothing, are all examples of things that result from chemical reactions (Figure 2).

Figure 2 Chemical reactions are used in industrial processes to make many everyday items. The nylon used in these spools of rope is produced through a chemical reaction.

Chemical reactions are simply processes that involve chemical change. You may recall that a chemical change is one in which new substances are formed, whereas a physical change is one in which no new substances are formed. One everyday example of a chemical change is when iron combines with oxygen to form a new substance called rust (iron(II) oxide), as shown in Figure 3. Chemists are particularly interested in studying chemical changes and have developed a method to describe them.

Figure 3 Rusting is a slow chemical reaction.

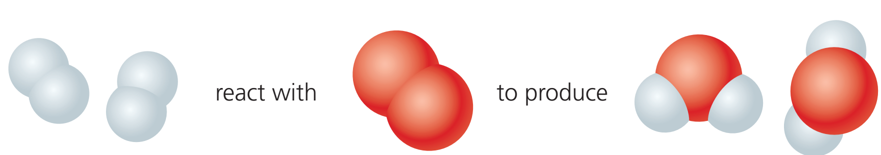
A fairly common occurrence in our modern world is the launching of the space shuttle. After the shuttle has left the launching pad, the huge amount of smoke that can be seen comes from the burning of the fuel in the two solid rocket booster engines. But other engines are at work here—the three engines on the shuttle itself. They derive their power simply from the reaction of hydrogen and oxygen, which produces pure water and a tremendous amount of energy. Most of the water is produced as colourless vapour, so you cannot see it coming out of the three shuttle engines (Figure 4). GO

To learn more about how the space shuttle works, go to **www.science.nelson.com** GO

Figure 4 The three shuttle engines produce colourless water vapour during launch. The three blue cones of light coming from the engines are called blue mach diamonds. Their presence and distance from the main engines indicate a good lift-off.

To understand what happens in the space shuttle launch reaction, we need to use our imaginations at a molecular level. At this molecular level, imagine observing molecules of hydrogen (H_2) flying around and colliding with molecules of oxygen (O_2). Some of these collisions would result in breaking the bonds holding the molecules together, therefore allowing new bonds to form between the hydrogen and oxygen atoms. The result is the formation of water molecules.

One way to describe this chemical reaction is to use molecular models as in Figure 5.



$$2H_2 + O_2 \longrightarrow 2H_2O$$

Figure 5 A chemical word equation for this reaction is: "2 molecules of hydrogen react with 1 molecule of oxygen to produce 2 molecules of water."

Another method to describe the water formation reaction from the space shuttle is to use a chemical formula equation or chemical equation. A **chemical equation** uses chemical formulas to describe the chemicals that react (the **reactants**) and those that are produced (the **products**). The chemical equation for water formation is shown like this:

$$\underset{\text{reactants}}{2H_2 + O_2} \rightarrow \underset{\text{products}}{2H_2O}$$

An arrow ($\rightarrow$) is used as a symbol to represent "changes into" or "produces." The plus sign (+) can be read as "reacts with" or "and," depending on the circumstance. Think of a chemical equation simply as a chemical sentence or statement that describes a chemical reaction. The equation above can then be read as "2 molecules of hydrogen react with 1 molecule of oxygen to produce 2 molecules of water."

Chemical equations are understood by chemists throughout the world. Although a chemist in France may not understand the words of a chemist from China, these scientists are able to communicate through the writing of chemical equations. 9A *Investigation*

9A *Investigation*

Mass and Chemical Reactions

To perform this investigation, turn to page 258.

In this investigation, you will look at what happens to the overall mass of chemicals in a chemical reaction.

Conservation of Mass and Atoms

Antoine Lavoisier was a French chemist who investigated chemical changes and discovered an important fundamental principle. He observed that as long as no material was allowed to enter into or escape from a reaction vessel (a situation known as a closed system), then the total mass of the chemicals produced was equal to the total mass of the chemicals that reacted. This is now known as the Law of Conservation of Mass. An everyday version of this law can expressed as, "What goes in, must come out!" That is, in a chemical reaction, matter is neither gained nor lost. The **Law of Conservation of Mass** for a chemical reaction states that the total mass of the reactants is equal to the total mass of the products.

In order for this to be true, the number of atoms of each element in the reactants must be equal to those in the products. For example, looking back at Figure 5, you will notice that 4 atoms of hydrogen exist in the reactants and 4 atoms of hydrogen appear in the products. Similarly, you will see 2 atoms of oxygen in both the reactants and the products.

We have been using the term "equation" on a regular basis, and the term itself suggests that something is equal. You can now answer the question, "What is equal in a chemical equation?" The answer is that the number of *atoms* of each element in the reactants is equal to those in the products. In other words, *atoms are also conserved in a chemical reaction.*

LEARNING TIP

Check your understanding. The Law of Conservation of Mass can be explained in this way: The atoms in use today have been recycled time after time. Atoms that exist today are essentially the same ones that existed thousands of years ago. Discuss with a partner.

To learn more about the Law of Conservation of Mass, view the animations at **www.science.nelson.com**

9.1 CHECK YOUR Understanding

1. What is the main difference between a physical change and a chemical change?
   A. In a physical change, no new substances are formed, whereas in a chemical change, new substances are formed.
   B. In a chemical change, no new substances are formed, whereas in a physical change, new substances are formed.
   C. A chemical change involves a transfer of electrons, whereas a physical change involves a sharing of electrons.
   D. A physical change involves a transfer of electrons, whereas a chemical change involves a sharing of electrons.
2. For each of the following, state whether it is a physical change or a chemical change. Give reasons for each answer.
   (a) freezing water to form an ice cube
   (b) burning toast
   (c) placing a nail in water and allowing it to rust
   (d) pouring concrete onto a driveway and allowing it to set
   (e) pouring molten silver into a mould to solidify and make jewellery
   (f) composting leaves by allowing them to rot and decay in a box
   (g) shredding leaves with a lawn mower
3. Hydrogen gas (burns extremely fast) and oxygen gas (supports burning) can be combined to make water, which can put out fires. Explain why water is so different from its components.
4. What is a chemical equation?
5. Use words to describe the following chemical equations.
   (a) $S + O_2 \rightarrow SO_2$
   (b) $2\,SO_2 + O_2 \rightarrow 2\,SO_3$
   (c) $N_2 + 3\,H_2 \rightarrow 2\,NH_3$
6. (a) Identify the reactants and products in the following chemical word equations:
   (i) magnesium + oxygen → magnesium oxide
   (ii) water → hydrogen + oxygen
   (iii) methanol + oxygen → carbon dioxide + water
   (iv) aluminum + copper(II) chloride → aluminum chloride + copper
   (b) Rewrite the word equations as formula equations. The formula for methanol in (iii) is CH_3OH.
   (c) What is not equal in the chemical formula equations in 6 (b)?
7. State the Law of Conservation of Mass for a chemical reaction.
8. Use the Law of Conservation of Mass to provide the missing numbers.
   (a) calcium + chlorine → calcium chloride
   40.1 g 71.0 g ? g
   (b) ammonia → nitrogen + hydrogen
   34 g ? g 6 g
   (c) ethanol + oxygen → carbon dioxide + water
   46 g ? g 88 g 54 g
   (d) magnesium + copper(II) chloride →
   24.3 g 134.5 g
   aluminum chloride + copper
   ? g 63.5 g
9. What particles are conserved in a chemical reaction?
   A. atoms
   B. molecules
   C. simple ions
   D. polyatomic ions

9.2 Writing and Balancing Chemical Equations

Equations used in chemistry, like sentences, can be general statements with very little detail or more specific statements with more detail. A word equation is very general and can be used to describe the formation of water:

$$\text{hydrogen} + \text{oxygen} \rightarrow \text{water}$$

However, chemists usually prefer to use chemical equations because of the greater detail that they provide. Recall from Chapter 7 that certain elements like hydrogen and oxygen exist as diatomic molecules. Using the formulas for hydrogen, oxygen, and water, the chemical equation would be:

$$H_2 + O_2 \rightarrow H_2O$$

Examining the atoms though, reveals that they are not conserved in this equation. Notice the number of O atoms on each side of the equation.

H_2	+	O_2	$\rightarrow$	H_2O
2 H atoms		2 O atoms		2 H atoms, 1 O atom

This incomplete chemical equation is called a **skeleton equation**. Although the chemical formulas are correct, the atoms are not conserved. Chemists use an important process called *balancing* to correct this.

LEARNING TIP
Check your understanding. Explain to a partner why skeleton equations are sometimes called unbalanced equations.

Counting Atoms

Before you learn how to balance chemical equations, you first need to know how to count atoms. For example, "5 H_2O" represents 5 water molecules (Figure 1), so the coefficient "5" describes the number of molecules. The subscripts describe the number of atoms of the element in front of them. In Figure 1, you can easily see that there are a total of 10 H atoms and 5 O atoms.

Using the coefficients and subscripts, we can easily count atoms. Arithmetically, 5 H_2O contains $5 \times 2 = 10$ H atoms and $5 \times 1 =$ 5 O atoms (Figure 2).

Consider this example: 5 $Ca_3(PO_4)_2$ contains 15 Ca atoms, 10 P atoms, and 40 O atoms. Recall that polyatomic ions such as PO_4 are written as a group in a formula.

This expression can be viewed as	The atoms can be calculated arithmetically
Ca Ca Ca (PO_4) (PO_4)	Ca atoms $= 5 \times 3 = 15$
Ca Ca Ca (PO_4) (PO_4)	P atoms $= 5 \times 1 \times 2 = 10$
Ca Ca Ca (PO_4) (PO_4)	O atoms $= 5 \times 4 \times 2 = 40$
Ca Ca Ca (PO_4) (PO_4)	
Ca Ca Ca (PO_4) (PO_4)	

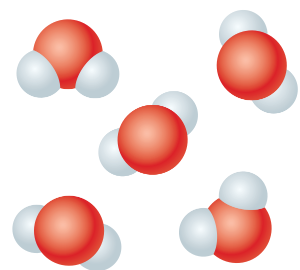


Figure 1 Five water molecules are described as 5 H_2O.

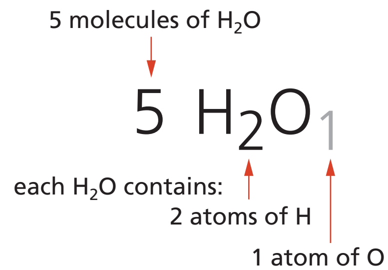


Figure 2 The coefficients and subscripts tell us how many atoms are represented by the expression 5 H_2O.

Balancing Chemical Equations

Skeleton equations show the correct formulas for the reactants and products in a chemical reaction, but usually they are not balanced.

TRY THIS: *Modelling Chemical Equations*

Skills Focus: creating models

Chemical equations are the "sentences" or statements that chemists write in order to describe chemical reactions. In this activity you will use interlocking building blocks to better understand the nature of these equations.

Materials: an assortment of interlocking building blocks

1. Obtain the following blocks: eight identical red blocks and four identical white blocks. (You may use different colours, but have eight of one colour and four of another colour.)
2. On a piece of blank note paper, draw an arrow in the middle of the page and set up the words "reactants" and "products" as shown.

   reactants → products
3. Clip two of the red blocks together and place this "molecule" on the reactant side of the arrow. Do the same with two white blocks. You now have two molecules on the reactant side. Remember, some "atoms" just naturally pair up to form diatomic molecules. You have just built two diatomic molecules!
4. For the product side, build a molecule that has three joined blocks: one white block sandwiched between two reds. Assume that this is just the bonding nature of these blocks.

A. If R is the symbol for a red block, what is an appropriate symbol for a white block?

B. Sketch the difference between 2 R and R_2. What would be the formula for the red blocks and the white blocks on the reactant side? What would be the formula for the product you have built?

C. Make a sketch of your display. Write a "chemical" equation to describe the reaction on your display using formulas.

D. You have now constructed three molecules on your display, but what problem do you notice that would violate the Law of Conservation of Mass? Use the unused blocks to build more of the same molecules as necessary, and place them on your display to resolve this problem.

E. Make a sketch of your new display. Rewrite your equation to reflect your new display.

F. Record the number of reactant red "atoms" and reactant white "atoms." Record the number of product red "atoms" and product white "atoms." How do they compare?

G. In the world of chemistry, R could represent a hydrogen (H) atom and W could represent an oxygen (O) atom. Rewrite your equation and substitute the elements H and O. Is your chemical equation balanced? How do you know?

A **balanced equation** contains important information about the relative amounts of each chemical in the reaction. This vital information is similar to the relative amounts of ingredients that appear in a baking recipe. The process of balancing an equation involves starting with a skeleton equation, and then adjusting its coefficients so that the atoms of each element are equal on both sides of the equation.

Using our example again of hydrogen and oxygen reacting to form water, we know that the skeleton equation would be:

skeleton equation:	H_2	+	O_2	→	H_2O
check atom count:	2 H atoms		2 O atoms		2 H atoms, 1 O atom

To balance the equation, we need 2 O atoms on the right side of the equation. A quick fix for O atoms would be:

$$H_2 + O_2 \rightarrow H_2O_2$$

But this would be incorrect. What just happened was that we changed the chemical, water, into a totally different chemical called hydrogen peroxide! We no longer have an accurate description for making water as we are now making hydrogen peroxide. You cannot change any chemical in a skeleton equation. That would be similar to changing a cake recipe so that powdered flour was replaced with powdered cement!

When balancing an equation, it is important to remember that you can never change the subscript numbers—only the coefficients can be altered.

To balance our equation for making water then, we must change the coefficients in order to change the atom count. If you need 2 atoms of O on the right side, then you can change the coefficient so that you have 2 H_2O. That corrects the O atom count.

skeleton equation:	H_2	+	O_2	$\rightarrow$	H_2O
balancing Step 1:	H_2	+	O_2	$\rightarrow$	***2*** H_2O
check atom count:	2 H		2 O		4 H, 2 O

Now the O atoms are equal, but the H atoms are unequal. You can change the coefficient for hydrogen on the left side so that you have 4 H atoms.

balancing Step 2:	***2*** H_2	+	O_2	$\rightarrow$	2 H_2O
check atom count:	4 H	+	2 O	$\rightarrow$	4 H, 2 O

To balance equations, choose one element at a time and alternate between the left side of the equation and the right side, changing and, if necessary, re-changing coefficients until the atom count works. The process of balancing equations is similar to puzzle solving and involves a lot of trial and error (guess and test). But because of its importance in describing chemical reactions, it is a skill that chemists must practise repeatedly. Since you may find yourself regularly changing coefficients, use a pencil and an eraser for all balancing equation exercises.

Some Balancing Tips

- Usually start with the furthest left element and work your way to the right. Remember, only change coefficients to balance.
- If O atoms appear in several different formulas, leave O until last.
- If polyatomic ion groups appear on both sides of the equation, count them as a group. For example, count SO_4 groups on both sides—don't count individual S and O atoms.

LEARNING TIP

A tip for balancing equations is to draw a box around the chemical formulas as a reminder that subscript numbers can't be changed. Since you may find yourself changing coefficients often, record all your changes. It is difficult to keep these numbers in your head for very long.

To practise your skills in balancing equations, go to **www.science.nelson.com**

9.2 CHECK YOUR Understanding

1. (a) What is the difference between a chemical word equation and a chemical formula equation?
   (b) Provide two reasons why a chemical formula equation is most commonly used by chemists.
2. Rewrite the following sentences, first as chemical word equations, and then as chemical formula equations.
   (a) Sodium carbonate reacts with hydrochloric acid to produce sodium chloride, carbon dioxide, and water.
   (b) Octane (C_8H_{18}) burns by reacting with pure oxygen gas to produce carbon dioxide and water.
   (c) Sodium metal reacts with water to form sodium hydroxide and hydrogen gas.
   (d) Sulfuric acid reacts with sodium hydroxide to give sodium sulfate and water.
   (e) Zinc metal reacts with copper sulfate solution to produce zinc sulfate solution and copper metal.
3. How many atoms of each element are represented in the following expressions?
   (a) 3 NaCl
   (b) H_2SO_4
   (c) $4H_2SO_4$
4. What are you trying to make equal when you balance a chemical equation?
5. Rewrite the following word equations as skeleton chemical equations, then balance:
   (a) Propane (C_3H_8) reacts with oxygen gas to produce carbon dioxide and water.
   (b) Calcium oxide reacts with hydrochloric acid to form calcium chloride and water.
   (c) Phosphoric acid and potassium hydroxide react to form potassium phosphate and water.
   (d) Calcium carbonate reacts with nitric acid to produce calcium nitrate, carbon dioxide, and water.
   (e) Silver nitrate reacts with copper to form copper(II) nitrate and silver.
   (f) Nitrogen trichloride and hydrogen gas react to produce hydrochloric acid and nitrogen gas.
6. Balance the following chemical equations:
   (a) $K + Cl_2 \rightarrow KCl$
   (b) $Li + O_2 \rightarrow Li_2O$
   (c) $K + N_2 \rightarrow K_3N$
   (d) $Ba + O_2 \rightarrow BaO$
   (e) $Ca + F_2 \rightarrow CaF_2$
   (f) $Sr + N_2 \rightarrow Sr_3N_2$
   (g) $NaNO_3 \rightarrow NaNO_2 + O_2$
7. Balance the following chemical equations:
   (a) $K + H_2O \rightarrow KOH + H_2$
   (b) $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$
   (c) $Mg_3N_2 + H_2O \rightarrow MgO + NH_3$
   (d) $Ca(ClO_3)_2 \rightarrow CaCl_2 + O_2$
   (e) $(NH_4)_2SO_4 + KOH \rightarrow NH_3 + H_2O + K_2SO_4$
   (f) $Fe + H_2O \rightarrow Fe_3O_4 + H_2$
   (g) $AlBr_3 + Cl_2 \rightarrow AlCl_3 + Br_2$
8. Balance the following chemical equations. Show an atom count check for each equation (similar to the one on page 235).
   (a) $NH_4Cl + Ba(OH)_2 \rightarrow NH_3 + H_2O + BaCl_2$
   (b) $AgNO_3 + CuCl_2 \rightarrow AgCl + Cu(NO_3)_2$
   (c) $RuS_2 + O_2 \rightarrow RuO_3 + SO_2$
   (d) $SrCl_2 + (NH_4)_2CO_3 \rightarrow SrCO_3 + NH_4Cl$
   (e) $SnS_2 + O_2 \rightarrow Sn_2O_3 + SO_2$
   (f) $FeCl_2 + Li_3PO_4 \rightarrow Fe_3(PO_4)_2 + LiCl$
   (g) $CuSO_4 + Mn \rightarrow Mn_2(SO_4)_3 + Cu$
   (h) $C_6H_{14} + O_2 \rightarrow CO_2 + H_2O$
   (i) $Al + Pb(NO_3)_2 \rightarrow Al(NO_3)_3 + Pb$
   (j) $C_7H_6O_3 + O_2 \rightarrow CO_2 + H_2O$

9.3 Types of Chemical Reactions

You have learned how chemists describe chemical reactions with balanced chemical equations. Now we will examine a variety of different types of reactions that chemists have discovered by noticing patterns. Patterns such as metals reacting with non-metals and metals reacting with ionic compounds have been observed and classified. We will examine six types of reactions: synthesis, decomposition, single replacement, double replacement, acid–base neutralization, and combustion.

STUDY TIP

In preparation for reading Section 9.3, label six study cards, one for each type of reaction. As you read the section, write a brief summary for each type of reaction including a definition and equation. You can use your study cards later to study for a chapter test.

Synthesis Reactions

A **synthesis reaction** is one in which two elements combine to form a compound. Since combining elements makes a compound, this reaction type is also called "combination" by some chemists. A general equation to describe a synthesis reaction could be:

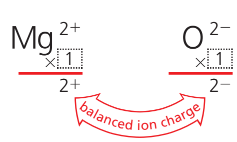
$$\underbrace{A + B}_{\text{combine}} \rightarrow AB$$

An example of a synthesis reaction is the combination of a metal with a non-metal to produce a metal oxide such as magnesium oxide:

$$\underbrace{Mg + O_2}_{\text{combine}} \rightarrow MgO$$

skeleton equation: $Mg + O_2 \rightarrow MgO$

Why is the product formed MgO and *not* MgO_2, since we are combining Mg and O_2? The reason is that metal/non-metal elements always form ionic compounds according to the rules of ion charge balancing learned in Chapter 7:



To complete our equation, we need to balance it:

balanced equation:	$2\ Mg$	$+$	O_2	$\rightarrow$	$2\ MgO$
	element		element		compound

By examining the combination of elements in the above balanced equation, chemists are able to easily recognize the process of synthesis that occurs.

Another example of a synthesis reaction is the combination of sodium metal with chlorine gas to form sodium chloride (table salt). Recall that certain elements, such as chlorine, exist in pairs when they are free elements (not combined with others), and are called diatomic molecules. The balanced equation would be:

2 Na	+	Cl_2	$\rightarrow$	2 NaCl
element		element		compound

Another example of a synthesis reaction occurs when carbonated beverages are made. Carbonation simply means that carbon dioxide gas has been added under pressure to water, where it reacts, and becomes "stored" in molecules of carbonic acid (Figure 1). The equation for the carbonation synthesis reaction is:

H_2O	+	CO_2	$\rightarrow$	H_2CO_3
compound		compound		compound

Figure 1 Your favourite soft drink is produced in a carbonation system like this. The machine mixes water with a flavoured syrup and then infuses it with carbon dioxide before cooling.

Did You KNOW?

Atmospheric CO_2 (carbon dioxide) reacts with rainwater to make all rainwater slightly acidic (pH $\approx$ 6). When the atmospheric CO_2 exists in unnaturally high quantities, the rain produced is considered to be acid rain (pH $<$ 5). Acid rain is also produced from polluting gases such as SO_2 and NO_2.

In general, a synthesis reaction is the combination of two substances to form one new compound. *In simple terms, two parts become one.* This would then include:

Na	+	Cl_2	$\rightarrow$	NaCl (skeleton equation)
element		element		compound
KCl	+	O_2	$\rightarrow$	$KClO_3$ (skeleton equation)
compound		element		compound
H_2O	+	CO_2	$\rightarrow$	H_2CO_3 (balanced equation)
compound		compound		compound

Decomposition Reactions

In a **decomposition reaction**, a compound decomposes (breaks apart) into its parts. A decomposition reaction is really just the opposite of a synthesis reaction. A general equation to describe decomposition could be:

$$AB \rightarrow A + B$$

break apart

For example, molten (melted) table salt can be decomposed by using an electrical process called electrolysis to manufacture sodium metal and chlorine gas (Figure 2).

$$NaCl \rightarrow Na + Cl_2$$

break apart

skeleton equation:	$NaCl$	$\rightarrow$	Na	$+$	Cl_2
balanced equation:	$2\ NaCl$	$\rightarrow$	$2\ Na$	$+$	Cl_2
	compound		element		element

LEARNING TIP

Diagrams play an important part in reader comprehension. As you study Figure 2, look at the overall diagram and read the caption. Look at each part of the diagram and examine the use of labels, lines and arrows. Try to visualize (make a mental picture) of the decomposition of molten table salt.

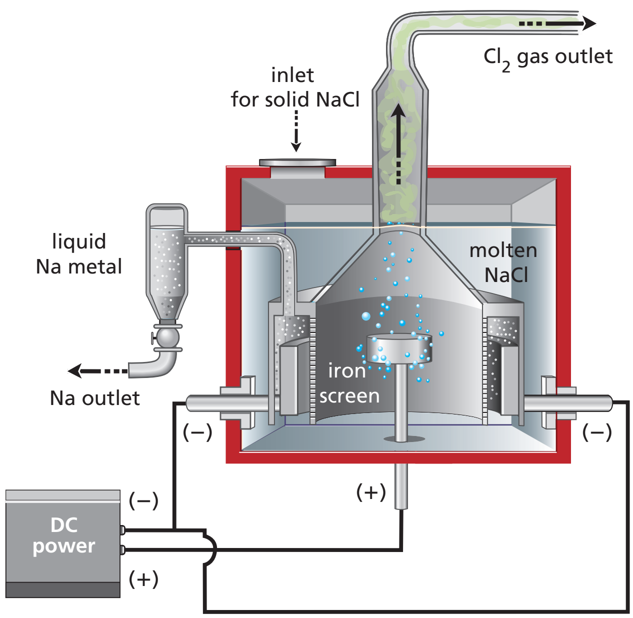


Figure 2 Molten table salt, NaCl (at 800 °C), is decomposed by electricity into sodium metal and chlorine gas. Chlorine is used in water purification and bleaches. Sodium is used in sodium vapour lights, the bright yellow streetlights that shine through fog.

Decomposition reactions can also involve the breaking apart of one compound into two new compounds. Consider a carbonated beverage. The carbonic acid in the pop remains stable as long as the pop is kept under pressure. As soon as the cap is removed, the carbonic acid breaks apart to form water and carbon dioxide gas (the bubbles) (Figure 3). The equation for the decomposition reaction of carbonic acid in pop is:

H_2CO_3	$\rightarrow$	H_2O	$+$	CO_2
compound		compound		compound

The presence of a mild acid gives a carbonated beverage a desirable taste. When the acid is entirely decomposed, the beverage goes "flat" (no more bubbles) and a different taste results.

Figure 3 The carbon dioxide bubbles in a newly opened bottle of pop are products of a decomposition reaction.

LEARNING TIP

Check your understanding of single and double replacement reactions. In your own words, explain to a partner how they are different.

Single Replacement Reactions

In a **single replacement reaction**, an element reacts with a compound (containing elements) and one of the elements is replaced.
A general equation to describe a single replacement reaction could be:

$$\overset{\text{free}}{\underset{\text{replace}}{AB + C}} \rightarrow CB + A$$

One element replaces another similar element from the compound. The most common single replacement reactions involve metals replacing metals, such as the metal Cd (cadmium) in $CdSO_4$ solution being replaced by Zn (zinc) metal in the following reaction:

$$\overset{\text{free}}{\underset{\text{replace}}{CdSO_4 + Zn}} \rightarrow ZnSO_4 + Cd$$

$CdSO_4$	+	Zn	$\rightarrow$	$ZnSO_4$	+	Cd
compound		element		compound		element

Figure 4 Copper metal is replaced by silver in a single replacement reaction.

Consider another single replacement reaction:

skeleton equation: $AgNO_3 + Cu \rightarrow Cu(NO_3)_2 + Ag$

Why is this formula *not* $CuNO_3$? The more common ion charge for copper is Cu^{2+}, which leads us to a charge-balanced formula of $Cu(NO_3)_2$.

balanced equation:	$2\ AgNO_3$	+	Cu	$\rightarrow$	$Cu(NO_3)_2$	+	2 Ag
	compound		element		compound		element

This reaction is shown in Figure 4 where you can see that the silver crystals are growing in place of the copper wire, and the blue Cu^{2+} ions are now in solution as $Cu(NO_3)_2$.

Double Replacement Reactions

In a **double replacement reaction**, two compounds (containing elements) react and two of the elements replace each other.

A general equation to describe a double replacement reaction could be:

$$\overset{\text{replace}}{\underset{\text{replace}}{AB + CD}} \rightarrow CB + AD$$

For example, a solution of potassium iodide and a solution of lead(II) nitrate will react when mixed (Figure 5). What happens here is that the lead(II) and potassium ions exchange places and an interesting phenomenon occurs. One of the new compounds formed is a yellow solid called a precipitate.

Chemists describe this double replacement reaction by writing:

replace

$$KI + Pb(NO_3)_2 \rightarrow PbI_2 + KNO_3$$

replace

Figure 5 Pb^{2+} ions and K^+ ions exchange places in a double replacement reaction, and a yellow precipitate of PbI_2 is formed.

skeleton equation:	KI	+	$Pb(NO_3)_2$	$\rightarrow$	PbI_2	+	KNO_3
	colourless solution		colourless solution		yellow solid		colourless solution
balanced equation:	$2\ KI$	+	$Pb(NO_3)_2$	$\rightarrow$	PbI_2	+	$2\ KNO_3$
	compound		compound		compound		compound

Remember that one metal will usually exchange places with another metal. This means that in the reaction in Figure 5, potassium ions would only exchange places with the lead(II) ions and would not trade places with the nitrate ions.

Acid–Base Neutralization Reactions

A special type of chemical reaction is an **acid–base neutralization reaction**. This name is appropriate because it describes what happens when an acid neutralizes (completely reacts with) a base, resulting in a neutral solution.

The products of a neutralization reaction are a salt and water.

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

A general equation for neutralization can be written as follows, where X represents the negative ion in the acid and B the positive ion in the base:

$$\text{H-X} + \text{B-OH} \rightarrow \text{BX} + \text{HOH}$$

One example of acid–base neutralization is the reaction of hydrochloric acid with sodium hydroxide solution. This neutralization is expressed as:

replace

$$HCl + NaOH \rightarrow NaCl + HOH$$

replace

$$\begin{array}{c} HCl + NaOH \rightarrow NaCl + HOH \\ \text{acid} + \text{base} \rightarrow \text{salt} + \text{water} \end{array}$$

Notice that a neutralization reaction is simply an example of a double replacement reaction. Note also the formula for water used in this reaction. Remember that in chemical reactions involving water forming from H^+ and OH^- ions, it is acceptable and encouraged to write the formula for water as HOH to aid your understanding (Figure 6).

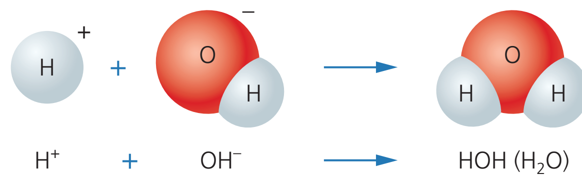


Figure 6 A water molecule can be formed from H^+ and OH^- ions.

Another example of neutralization is the reaction of sulfuric acid with potassium hydroxide:

replace

$$H_2SO_4 + KOH \rightarrow K_2SO_4 + HOH$$

replace

skeleton equation:	H_2SO_4	+	KOH	→	K_2SO_4	+	HOH
	acid	+	base	→	salt	+	water
balanced equation:	H_2SO_4	+	2 KOH	→	K_2SO_4	+	2 HOH

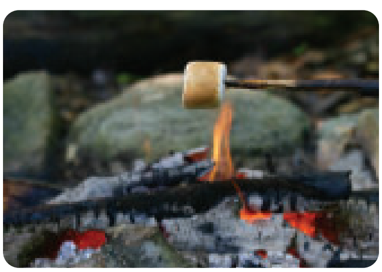


Figure 7 A combustion reaction produces a flame to cook the marshmallow.

Combustion Reactions

In a **combustion reaction**, an organic (carbon–hydrogen) substance reacts with oxygen, releases heat and perhaps light energy (Figure 7). It is a very common type of reaction. Combustion can be rapid or slow: burning is rapid combustion, whereas cellular respiration is slow combustion. A substance that burns is often classified as a fuel, and some common fuels are organic compounds such as hydrocarbons.

A general skeleton equation for the combustion of a hydrocarbon is:

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

Here, the formula C_xH_y suggests a variety of subscripts for the C and H atoms. You could argue that combustion is a double synthesis reaction since oxygen combines with both carbon and hydrogen! Nevertheless, chemists have chosen to use the term "combustion."

We rely on combustion reactions every day when we burn hydrocarbon fuels such as methane, also known as natural gas (CH_4), in our furnaces, propane (C_3H_8) in barbecues and some automobiles, and butane (C_4H_{10}) in lighters. The products of complete combustion reactions of hydrocarbons are always carbon dioxide gas and water vapour. Note the pattern of predictability in the following skeleton equations:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$
$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$
$$C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$$

Did You KNOW?

Incomplete Combustion

Incomplete combustion occurs when there is not enough oxygen available to react. As a result, some of the carbon atoms do not form CO_2 but instead form CO (carbon monoxide). Carbon monoxide reacts with the blood's hemoglobin and interferes with its ability to transport necessary oxygen to the cells. The result can be death.

You have just learned that chemists typically classify chemical reactions as one of six types, summarized in Table 1. 9B Investigation

Table 1 A Summary of Reaction Types

Reaction type	General form
synthesis (or combination)	$A + B \rightarrow AB$
decomposition	$AB \rightarrow A + B$
single replacement	$AB + C \rightarrow CB + A$
double replacement	$AB + CD \rightarrow CB + AD$
acid–base neutralization	$H\text{-}X + B\text{-}OH \rightarrow BX + HOH$
combustion (of hydrocarbons)	$C_xH_y + O_2 \rightarrow CO_2 + H_2O$

9B Investigation

Types of Chemical Reactions

To perform this investigation, turn to page 260.

In this investigation, you will examine evidence from chemical reactions that allows you to classify them.

Predicting Products of Chemical Reactions

One of the most important activities in science is the ability to make predictions. Doctors must be able to predict the effect of certain medications on their patients. Engineers must be able to predict the effect of storms and earthquakes on certain structures like high-rise buildings and bridges. Similarly, chemists must be able to predict what will happen when certain chemicals are reacted. Will there be a release of useful and desirable new substances or will the products be dangerous and harmful?

Using what you have learned so far—formula writing of elements and compounds, writing chemical equations, balancing chemical equations, and recognizing reaction types—you will be able to predict the products of certain chemical reactions. Following are some examples of reaction predictions that you can make.

Example 1

Suppose you are asked to predict the products of a reaction between sodium and oxygen and write a balanced equation for the reaction. The reactants then are: $Na + O_2 \rightarrow$

Step 1: Predict the reaction type. Upon inspection of the reactants, it appears that two elements are about to combine, so it is a synthesis reaction.

$$\underbrace{Na + O_2}_{\text{combine}} \rightarrow Na_2O$$

$$\boxed{\begin{array}{c}\text{use ion charges}\\ Na^+ \quad O^{2-}\end{array}}$$

Step 2: Write the skeleton equation for the reaction. Based on the reaction type, predict the product that will form. In this case, Na combines with O_2 as Na_2O (formula written according to ion charges).

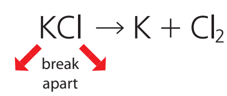
skeleton equation: $Na + O_2 \rightarrow Na_2O$

Step 3: Balance the equation: $4\ Na + O_2 \rightarrow 2\ Na_2O$

Example 2

Predict the products if potassium chloride is heated, and write a balanced equation for the reaction. The reactant is KCl.

Step 1: Examine the reactants. Since no other reactants are involved, the reaction type has to be the decomposition of the compound KCl.



Step 2: Breaking up KCl results in the elements K and Cl_2 (a diatomic molecule).

skeleton equation: $KCl \rightarrow K + Cl_2$

Step 3: Balance the equation: $2\ KCl \rightarrow 2\ K + Cl_2$

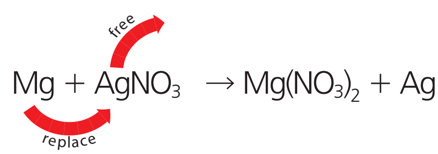
LEARNING TIP

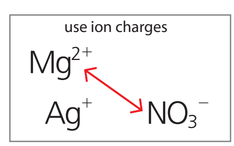
Adjust your reading pace. Pause after each step in Examples 2 and 3 and think about what each step has asked you to do. Rephrase each step in your own words (paraphrase).

Example 3

Predict the products if magnesium reacts with silver nitrate, and write a balanced equation for the reaction. The reactants are $Mg + AgNO_3$.

Step 1: Examine the reactants. The reaction type appears to be a single replacement reaction, so replace the metal element in the compound with the free metal element.





Step 2: Write the skeleton equation: $Mg + AgNO_3 \rightarrow Mg(NO_3)_2 + Ag$

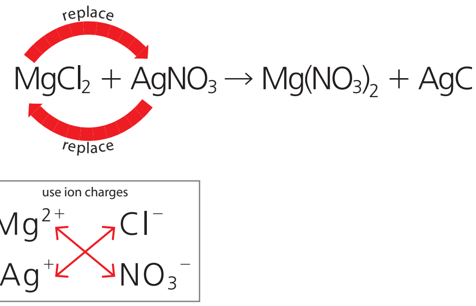
Step 3: Write the balanced equation: $Mg + 2\ AgNO_3 \rightarrow Mg(NO_3)_2 + 2\ Ag$

Note that the order of the products is unimportant. As in math: $3 + 4 = 4 + 3$; $Mg(NO_3)_2 + 2\ Ag$ is the same as $2\ Ag + Mg(NO_3)_2$

Example 4

Predict the products if magnesium chloride reacts with silver nitrate and write a balanced equation for the reaction. The reactants are $MgCl_2 + AgNO_3$.

Step 1: Examine the reactants. The reaction type appears to be a double replacement reaction, so replace both metal elements with each other.



Step 2: Write the skeleton equation:

$$MgCl_2 + AgNO_3 \rightarrow Mg(NO_3)_2 + AgCl$$

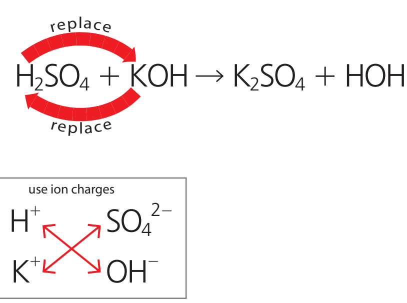
Step 3: Write the balanced equation:

$$MgCl_2 + 2\ AgNO_3 \rightarrow Mg(NO_3)_2 + 2\ AgCl$$

Example 5

Predict the products if sulfuric acid reacts with potassium hydroxide, and write a balanced equation for the reaction. The reactants are $H_2SO_4 + KOH$.

Step 1: Examine the reactants. The reaction type appears to be an acid–base neutralization (double replacement) reaction in which a salt and water (HOH) is formed.



Step 2: Write the skeleton equation: $H_2SO_4 + KOH \rightarrow K_2SO_4 + HOH$

Step 3: Write the balanced equation: $H_2SO_4 + 2\ KOH \rightarrow K_2SO_4 + 2\ HOH$

Example 6

Predict the products of the combustion of methane (CH_4) and write a balanced equation for the reaction. Recall that combustion means to react a carbon–hydrogen (organic) compound with oxygen. Therefore, the reactants are $CH_4 + O_2$.

Step 1: Examine the reactants. This is a hydrocarbon combustion reaction, which always produces CO_2 and H_2O.

Step 2: Write the skeleton equation: $CH_4 + O_2 \rightarrow CO_2 + H_2O$

Step 3: Write the balanced equation: $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

9.3 CHECK YOUR Understanding

1. A decomposition reaction can be described by using the following symbols:

$$\triangle\bigcirc \rightarrow \triangle + \bigcirc$$

   Use any symbol shapes (squares, circles, triangles, hearts) to describe what happens in each of the following reaction types:
   (a) synthesis
   (b) single replacement
   (c) double replacement

2. Classify each of the following reactions as synthesis, decomposition, single replacement, double replacement, acid–base neutralization, or combustion. Then, balance each equation.
   (a) $Fe + CuSO_4 \rightarrow Fe_2(SO_4)_3 + Cu$
   (b) $PCl_5 \rightarrow PCl_3 + Cl_2$
   (c) $KCl + O_2 \rightarrow KClO_3$
   (d) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
   (e) $LiNO_3 \rightarrow LiNO_2 + O_2$
   (f) $HCl + Ca(OH)_2 \rightarrow CaCl_2 + HOH$
   (g) $Ca + N_2 \rightarrow Ca_3N_2$
   (h) $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$

3. Write a balanced chemical equation and state the reaction type for each of the following reactions:
   (a) Nitrogen gas reacts with hydrogen gas forming ammonia (NH_3).
   (b) Carbonic acid breaks down to form carbon dioxide gas and water.
   (c) Aluminum foil reacts with copper(II) chloride solution to produce aluminum chloride solution and copper metal.
   (d) Aluminum chloride reacts with lead(II) nitrate to form lead(II) chloride and aluminum nitrate.
   (e) Water undergoes electrolysis to produce hydrogen gas and oxygen gas.

4. Use the general equations for the following reactions to predict the most likely products. Then, classify each equation according to reaction type: synthesis, decomposition, single replacement, double replacement, acid–base neutralization, or combustion.
   (a) $A + B \rightarrow$
   (b) $AB + XY \rightarrow$
   (c) $H\text{-}X + A\text{-}OH \rightarrow$
   (d) $AB + X \rightarrow$
   (e) $AB \rightarrow$
   (f) $C_xH_y + O_2 \rightarrow$

5. Examine the reactants below to determine the reaction type. Then, predict the products by writing a skeleton equation. Balance each skeleton equation.
   (a) $K + O_2 \rightarrow$
   (b) $Pb(NO_3)_2 + Na_2SO_4 \rightarrow$
   (c) $C_5H_{12} + O_2 \rightarrow$
   (d) $H_2SO_4 + NaOH \rightarrow$
   (e) $Ca + Cl_2 \rightarrow$
   (f) $Li_2S \rightarrow$
   (g) $HgO \rightarrow$
   (h) $HCl + Ca(OH)_2 \rightarrow$
   (i) $C_3H_7OH + O_2 \rightarrow$
   (j) $Al + S \rightarrow$
   (k) $Al + CuSO_4 \rightarrow$

6. For the following, write the chemical formulas for the reactants and predict the most likely reaction type. Then, write balanced equations for each.
   (a) Magnesium chloride is heated.
   (b) Silver nitrate is reacted with sodium sulfide.
   (c) Methanol (CH_3OH) is burned in the presence of oxygen.
   (d) Hydrofluoric acid is reacted completely with strontium hydroxide.

CHEMICAL REACTIONS THAT SAVE LIVES

Thousands of lives are saved through the cushioning action of airbags during high-speed automobile accidents. What makes the airbag deploy faster than a blink of an eye?

The idea of landing against a protective air cushion in a crash is not a new one. In fact, the first inflatable crash-landing device was created for airplanes as early as the 1940s. Later, airbags were used in cushioning crash landings of spacecraft like the Soviet Luna 9 and Luna 13, NASA's Mars Pathfinder, and the two Mars Exploration Rover Mission landers (Figure 1). However, the most familiar airbags are the ones found in our cars.

So how do airbags work? They do not utilize a compressed gas, but rather the products of chemical reactions. The undeployed airbag is folded within a car's steering wheel, for example. At the front of a car is an airbag sensor that functions as an accelerometer (a device that measures acceleration). When the car decelerates very quickly, it triggers the inflator connected to the airbag. This produces an electric spark to initiate the chemical process that will deploy the airbag.

Figure 1 The Mars Pathfinder's airbags were tested under simulated Martian conditions.

At the core of airbag chemistry is a stable solid compound called sodium azide (NaN_3). Once ignited, the resulting explosion rapidly releases a large volume of non-toxic nitrogen gas (N_2) through the decomposition of the sodium azide pellets:

$$2NaN_3 \rightarrow 2Na + 3N_2$$

The other product of this first reaction is sodium metal (Na), an unstable and potentially explosive substance. The sodium metal then reacts with a second compound, potassium nitrate. This second reaction generates additional nitrogen for the airbag while stabilizing the sodium:

$$10Na + 2KNO_3 \rightarrow K_2O + 5Na_2O + N_2$$

Finally, the products potassium oxide and sodium oxide from the second reaction react with a compound, silicon dioxide, forming a harmless silicate glass:

$$K_2O + Na_2O + SiO_2 \rightarrow \text{alkaline silicate}$$

A handful of sodium azide will yield about 70 L of nitrogen gas, which is enough to inflate a normal airbag at a velocity up to 322 km/h in about a third of a second. Once an airbag deploys, deflation begins immediately as the gas escapes through vents to soften the impact of the forward-moving occupant. In addition, dust-like particles of cornstarch or talcum powder, used to lubricate the airbag during deployment, are also released during the process (Figure 2).

Issues around safety have surrounded the use of airbags. Landfills full of vehicles with unused airbags, hence, unused sodium azide (a very toxic compound), pose an environmental hazard. In addition, they could potentially cause explosions, and thus put workers' lives in danger. Consequently, many authorities now require airbags to be physically deployed before disposal, so that the sodium azide is converted to a harmless product.

Figure 2 Deflation of an airbag begins immediately after deployment to protect the person from injury caused by the sudden inflation.

9.4 Rates of Chemical Reactions

We regularly observe that chemical reactions take place at different rates. That is, some reactions such as the corrosion of copper or bronze occur very slowly, whereas a matchstick burns quite rapidly (Figure 1). What factors affect the rates of reactions and what can you do if you want to change a reaction's rate? Imagine a campfire that is burning very slowly and you would like to speed it up. Experience and common sense might lead you to add more wood, or chop it into smaller pieces, or carefully blow on the fire. In this section, we will investigate methods we can use to increase or decrease the rates of chemical reactions and examine why these methods work.

To learn more about the need to control reaction rates, go to **www.science.nelson.com**

(a)

(b)

Figure 1 (a) The green coating on these bronze statues is a result of a slow chemical reaction. (b) The burning of a match is an example of a rapid chemical reaction.

STUDY TIP

Try this handy trick for remembering the formula for reaction rate by creating an example. On one side of a study card, write Finding Reaction Rate. On the other side, write out a problem and solve it.

Generally speaking, the **reaction rate** of a chemical reaction is the amount of a reactant consumed per unit time or the amount of a product formed per unit time. For example, if a gas such as hydrogen is being produced during the single replacement reaction of magnesium metal and nitric acid, the amount of hydrogen gas produced per minute could be used to describe the reaction's rate. This reaction is described as:

$$\mathrm{Mg(s)} + 2\ \mathrm{HNO_3(aq)} \rightarrow \mathrm{Mg(NO_3)_2(aq)} + \mathrm{H_2(g)}$$

Note that additional symbols (phase designations) are used in the above equation. Chemists use these symbols to describe the phases of matter when this information is relevant.

Using basic math concepts, the rate for the above reaction can be calculated using different formulas such as:

$$\text{reaction rate} = \frac{\text{mass of Mg reacted}}{\text{reaction time}}$$

or $$\text{reaction rate} = \frac{\text{volume of } \mathrm{H_2(g)} \text{ produced}}{\text{reaction time}}$$

In any case, a reaction's rate can be calculated from any measurable change in any one chemical involved in the reaction.

For example, if 2.0 g of magnesium react with hydrochloric acid in 40.0 s, we can use the first formula to calculate the reaction rate.

$$\text{reaction rate} = \frac{\text{mass of Mg reacted}}{\text{reaction time}} = \frac{2.0\ \text{g of Mg}}{40.0\ \text{s}} = 0.050\ \frac{\text{g of Mg}}{\text{s}}$$

Whether using mass or volume, all reaction rates are expressed as change per unit of time.

TRY THIS: *Calculating Reaction Rates*

Skills Focus: measuring, interpreting data

In this activity, you will examine some data and use it to calculate rate in a variety of ways.

1. Consider the reaction between zinc metal and hydrochloric acid in which hydrogen gas is vigorously produced. Zinc metal is obviously a solid, and hydrochloric acid exists in an aqueous (water) solution. The balanced single replacement reaction is:

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

2. In separate experiments, results were recorded for this reaction (Table 1).

A. Calculate the reaction rate for Trial 1 and show the units as $\frac{\text{g of Zn}}{\text{min}}$.

To calculate reaction rate, use the following formula:

$$\text{reaction rate} = \frac{\text{measurable change in any chemical}}{\text{change in time}}$$

Table 1

	Temperature	Before reaction	After reaction	Time
Trial 1	20.0 °C	4.8 g of Zn(s)	2.8 g of Zn(s)	1.2 min
Trial 2	25.2 °C	5.2 g of Zn(s)	3.2 g of Zn(s)	0.82 min
Trial 3	22.4 °C	0 mL of H_2(g)	20.4 mL of H_2(g)	25.6 s
Trial 4	24.8 °C	0 mL of H_2(g)	35.6 mL of H_2(g)	23.5 s

B. Calculate the individual reaction rates for Trials 2, 3, and 4 and include appropriate units for each.

C. Analyze the results and suggest a reason for the differences in rates between Trials 1 and 2 and the differences in rates between Trials 3 and 4.

What Makes Reactions Go? The Collision Theory

In previous chemistry courses, you learned about an idea that helps us explain the behaviour of matter in its different states. The **kinetic molecular theory** suggests that matter is made up of tiny particles in constant, random motion. Solid particles are very closely packed together and are barely moving. Liquid particles have very small spaces between them and are moving relatively slowly. Gas particles, on the other hand, are really spread out and move very fast.

An extension of this theory helps us understand why certain factors can affect reaction rates. In its simplest form, the **collision theory** states that in order for moving particles to react, they must first collide! However, there is more to it than that. In the air, a huge number of molecules of nitrogen and oxygen are colliding without reacting. But place these same gases in a combustion chamber, such as is found in an automobile engine, and a rapid reaction occurs.

LEARNING TIP

Diagrams play an important part in reader comprehension. As you examine Figure 2, look at each part carefully. Ask yourself, "How are they different visually? What does each part show?"

Not just any collision will result in a reaction. The collision must be an *effective collision*; that is, it must have a certain minimum amount of energy or it will be a dud. Effective collisions are strong enough to overcome repulsive forces between reactants and break the necessary reactant bonds to bring about the reaction. To illustrate this point, consider the reaction of hydrogen gas and iodine gas (Figure 2):

$$H_2(g) + I_2(g) \rightarrow 2\ HI(g)$$

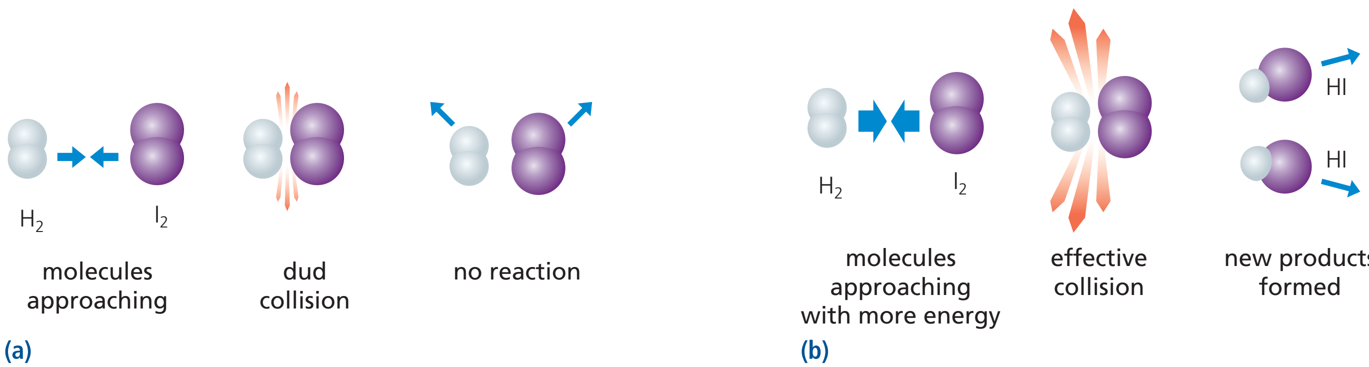


Figure 2 (a) Some collisions of H_2 and I_2 molecules are duds, and (b) some collisions are effective.

In any group (number) of collisions, only a certain fraction will be effective. For example, if 15 % of collisions are effective, then 100 total collisions would yield 15 that are effective, and 200 total collisions would yield 30 effective collisions. A chemical reaction's rate is determined by the number of effective collisions that occur in a given amount of time (the frequency of effective collisions).

Changing the frequency of effective collisions changes the reaction rate.

Based on the collision theory, there are four factors that can be changed in chemical reactions to increase or decrease their rates. The four factors are concentration of the reactants, surface area of the reactants, temperature, and the addition of catalysts. 9C **Investigation**

9C **Investigation**

Factors that Affect Reaction Rates

To perform this investigation, turn to page 262.

In this investigation, you will examine two factors that affect reaction rate.

Concentration of Reactants

Concentration describes the number of particles of a substance that are present in a certain volume. Concentration can be varied in solutions and gases but not in solids. For example, a highly concentrated solution of sugar water will have many sugar molecules and taste very sweet, however, a solution that is not as highly concentrated will taste less sweet because it has fewer sugar molecules in it. Such a solution could be called dilute since it has a low concentration.

When the concentration of one of the reactants is increased, reaction rate also increases. Once again, consider the reaction of hydrochloric acid and zinc metal:

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

If the concentration of HCl is increased, the result is an increase in not only the frequency of total collisions, but more importantly, the frequency of effective collisions (Figure 3).

Figure 3 The beaker on the right has a higher concentration of hydrochloric acid reacting with zinc metal, which results in a higher rate of reaction than the beaker on the left.

Increasing the concentration of a reactant increases reaction rate by increasing the frequency of effective collisions.

Surface Area of Reactants

We have all experienced the effect of surface area on the rate of chemical reactions. Surface area is the amount of area on a solid that is open and exposed. This exposure affects the number of collisions that can happen with other substances. The surface area of a piece of firewood is increased when the wood is chopped into kindling. The increased surface area allows for more collisions with oxygen molecules, and, as a result, the chopped wood will burn faster.

Another example is the reaction of iron with oxygen:

$$4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$$

Even at high temperatures, iron reacts slowly with oxygen. However, if the surface area of the iron is increased, we observe a dramatic increase in reaction rate (Figure 4).

(a) **(b)**

Figure 4 (a) An iron nail reacts slowly with oxygen in air. (b) But when the surface area of iron is increased, as in steel (iron) wool, the rate dramatically increases.

In fact, many slow reacting solids become potential explosives when their surface areas have been increased (Figure 5).

(a) (b)

Figure 5 Increasing the surface area of combustible materials like coal and grain can create the opportunities for reactions that are so fast that they are explosive. (a) A pile of coal and (b) a coal dust explosion.

Increasing the surface area of a solid reactant increases the amount of exposed solid, and this increases the reaction rate by increasing the frequency of effective collisions.

Temperature

Most chemical reactions have higher rates at higher temperatures. Examples of this are all around us. Hamburgers cook faster on a hotter grill. Meat spoils more rapidly if left outside on a summer's day compared with a winter's day. In fact, we typically use *low* temperatures to prevent food from spoiling.

Increasing temperature appears to have the most dramatic effect in increasing reaction rates. In many cases, a mere 10 °C increase in temperature can cause a reaction rate to double. How can we explain this using collision theory? The kinetic molecular theory reminds us that when the temperature of a substance increases, the added heat energy causes the particles to move faster and, as a result, with more energy. The resulting collisions between reacting molecules are therefore both more numerous and more energetic. An analogy here might be useful.

Clap your hands together slowly and softly for 30 s. This represents low-temperature collisions. Now clap your hands much faster and harder for 30 s. This represents high-temperature collisions. At the "higher temperature," the "collisions" are obviously greater in number and also more of these have greater energy (louder). The end result is that a higher frequency of total collisions occur, and a larger fraction of these collisions are effective.

Increasing the temperature of reactants significantly increases reaction rate by increasing the frequency of effective collisions in two ways: (1) increasing the frequency of all collisions, and (2) increasing the energy of all collisions.

Catalysts

A **catalyst** is a substance that, when added to a reaction, increases the reaction rate without being consumed. In other words, a catalyst somehow assists the reactants in their collisions but remains unchanged at the end of the reaction. Catalytic behaviour can be very complex and is not always clearly understood. Catalysts are used in the industrial manufacture of chemicals where the rate of production is important. Some industries in British Columbia that use catalysts include oil refining to produce gasoline and ammonia manufacturing to produce fertilizers. Oil refineries use catalysts to "crack" (decompose) long hydrocarbon molecules into shorter ones to boost gasoline production. Fertilizer manufacturers rely on catalysts to increase the rate of synthesis of ammonia, NH_3, which is then combined with other chemicals to make a variety of fertilizers. GO

To learn how catalysts are used to reduce emissions in car exhausts, go to **www.science.nelson.com** GO

The nature of a catalyst is similar to the effect of climbing over a mountain and discovering a shortcut tunnel halfway up (Figure 6).

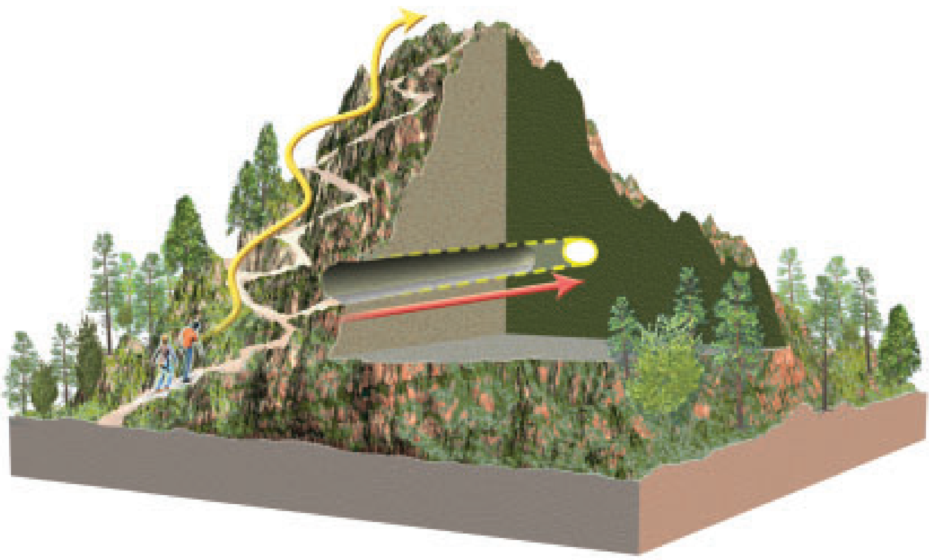


Figure 6 A catalyst increases a reaction's rate, providing an easier means for colliding particles to react. This can be compared to a hiker using a tunnel as an easier path to get from one side of a mountain to another.

Using less energy by taking the shortcut, you are able to complete the journey more easily and more quickly. Now imagine 100 mountain climbers of which only 10 are fit enough to get over the mountaintop. If the tunnel shortcut is available, perhaps 20 climbers have enough energy to make the trip. A higher percentage of climbers are now successful. A catalyst has a similar effect on reacting molecules by lowering the energy requirement for an effective collision. As a result, a higher *percentage* of the collisions are effective.

Adding a catalyst increases reaction rate by increasing the percentage of effective collisions.

9.4

CHECK YOUR Understanding

1. What is meant by the term "rate of a chemical reaction"?
2. What variable always appears in any reaction rate calculation?
3. A sample of magnesium metal reacts with hydrochloric acid solution to produce magnesium chloride solution and hydrogen gas.
   (a) Write a balanced chemical equation for this reaction and include phase designations.
   (b) If 0.80 g of magnesium react in 40.0 s, calculate the reaction rate.
   (c) If 20.0 mL of hydrogen gas are produced in 60.0 s, calculate the reaction rate.
4. The electrolysis (decomposition) of water produces hydrogen gas at the rate of 30.0 mL/min.
   (a) Write a balanced chemical equation for this reaction and include phase designations.
   (b) What volume of hydrogen gas can be produced in 4.5 min?
   (c) Based on your balanced equation, predict the rate of oxygen gas produced.
5. Name four factors that can affect the rate of a chemical reaction. How does the rate of a chemical reaction change in response to a change in each factor?
6. What is the fundamental premise of the collision theory?
7. What is necessary for a collision between reacting molecules to be effective?
8. Explain, using the collision theory, how each of the following factors affects reaction rate:
   (a) concentration of reactants
   (b) surface area of a solid reactant
   (c) temperature of the reactants
   (d) adding a catalyst
9. Describe the two features of a catalyst.
10. The following describes the reaction between a copper penny and nitric acid in an open beaker:
    $$Cu\ (s) + 4\ HNO_3\ (aq) \rightarrow Cu(NO_3)_2\ (aq) + 2\ H_2O\ (l) + 2\ NO_2\ (g)$$
    The mass of the beaker and contents was monitored until the reaction ended. The results are recorded in Table 2.

Table 2

Mass of beaker and contents (g)	Time (s)
224.6	0.0
215.8	118.6

    (a) What chemical is represented by the change in mass? Explain why it *cannot* be the mass change of copper.
    (b) Calculate the rate of reaction and express your answer with appropriate units.
    (c) Would this reaction be considered a closed system? Why or why not?
11. The following equation shows the reaction between marble chips (calcium carbonate) and hydrochloric acid:
    $$CaCO_3\ (s) + 2\ HCl\ (aq) \rightarrow CaCl_2\ (aq) + H_2O\ (l) + 2\ CO_2\ (g)$$
    The volume of the gas produced was monitored over time. The results are in Table 3 below. Calculate the rate of reaction and express your answer with appropriate units.

Table 3

Volume of CO_2 gas (mL)	Time (s)
0	0.0
24.8	50.5

12. How could you experimentally determine if a substance acted as a catalyst in a chemical reaction?
13. Normally, as a reaction proceeds, its rate decreases. Explain using the collision theory.

FIREWORKS: FROM ALCHEMY TO PYROTECHNICS

"Ooooh" went the crowd, followed by "aaaaaah." Nothing seems to awe us more than watching sparkling lights explode to heart-stopping bangs. This is where art meets science in the craft of pyrotechnics, otherwise known as fireworks. Have you ever wondered how fireworks create these magnificent displays?

The history of fireworks dates back over a thousand years ago to India and China. From there, the work of these early alchemists spread throughout the Western world. What started out as a way to ward off evil spirits is now used to celebrate special occasions from New Year's to the Olympics. Vancouver hosts one of the largest musical fireworks competitions in the world—the *Celebration of Lights*—where countries compete to dazzle and delight the crowds as they cast their magical spells (Figure 1).

Figure 1 A fireworks display

Firework displays are a marvellous mixture of the arts, science, technology, and more importantly, a vivid imagination! A great pyrotechnician is one who understands the magic she or he can create by applying the principles of physics and chemistry. The physics involve velocities, vectors, the force of explosions, and other variables.

An understanding of chemistry is also essential from controlling reaction rates to balancing equations of synthesis, decomposition, and replacement reactions—in particular, combustion reactions. Once firework shells are ignited, a chemical reaction takes place where the bonds of the reactants break and rearrange to form new chemical compounds in an explosive reaction. Here, the combination of chemical powders are transformed into hot gases that cause shells to burst open, and the energy is converted into light, sound, and thermal energy, creating a spectacular show.

How are colours produced from fireworks? Firework shells are stuffed with potassium chlorate, along with other compounds. Lithium and strontium salts produce red; calcium salts produce orange; sodium compounds produce yellow; and barium compounds produce green. Aluminum compounds will generate brilliant white sparks. Like any artist, pyrotechnicians realize that they can produce any hue on their palette through the careful combination of compounds (Figure 2).

One of the greatest innovations in pyrotechnics involves advances in launch technology. Computers are now used to coordinate the launching of shells a tenth of a second apart, and as such, synchronize the firing of thousands of fireworks. Since explosions can happen faster and with greater accuracy, this revolutionized the design and coordination of firework shows, especially when harmonized to music.

Figure 2 Technicians prepare firework shells

9A

Investigation

Mass and Chemical Reactions

What happens to the overall mass when chemicals change in chemical reactions? In all chemical reactions, the reacting chemicals (reactants) produce new substances (products). Chemists in industrial situations must keep track of the amounts of these reactants and products much like someone who is following a recipe in the kitchen.

INQUIRY SKILLS

○ Questioning	● Conducting	● Evaluating
○ Hypothesizing	● Recording	● Synthesizing
● Predicting	● Analyzing	● Communicating
○ Planning		

Question

How is mass affected by chemical change?

Prediction

Predict what will happen to the mass of the chemicals in a container if a chemical change occurs, but none of the chemicals are allowed to escape.

Experimental Design

In this investigation, you will examine a chemical reaction in a container that has been sealed so that no matter will be able to enter or leave. The mass of the container and contents will be measured before and after the reaction.

Materials

- safety goggles
- 500 mL clear plastic bottle with lid
- mass balance (scales)
- weighing paper
- sodium bicarbonate (baking soda)
- 1 test tube (16 mm × 150 mm)
- test tube rack
- 5 % acetic acid solution (vinegar)

Do not use more than the recommended amount of sodium bicarbonate.
Any time gases are produced, there is a potential hazard to your eyes and lungs. When loosening the lid, keep the bottle pointed away from all involved.

Procedure

1. Put on your safety goggles.
2. Obtain from your teacher a plastic bottle with its lid and a test tube that will fit inside the bottle. Temporarily assemble this empty equipment as shown in Figure 1 to make sure that everything fits.

Figure 1 Assembled apparatus, ready for weighing before the reaction

3. On weighing paper, weigh approximately 1.0 g of sodium bicarbonate powder. The mass does not have to be exact, but it should be close. As a precaution, show the weighed amount to your teacher before proceeding.
4. Transfer the sodium bicarbonate powder to your bottle.
5. Place the test tube in the test tube rack and half fill with acetic acid.

6. Tilt the bottle at an angle and carefully lower the test tube into the bottle without spilling the acetic acid (Figure 2).

Figure 2

7. Place the lid on the bottle and give it a twist to ensure a tight seal. The acetic acid and the sodium bicarbonate powder are the reactants.
8. Record the appearance of the reactants in your copy of Table 1.

Table 1

	Observations	Total mass (g)
sealed apparatus + reactants		
sealed apparatus + products		
unsealed apparatus + contents		

9. Weigh your assembled apparatus containing the reactants and record this mass in Table 1.
10. Once again, make sure that the bottle is tightly sealed. Start the reaction by slowly and gently turning the bottle upside down to allow the reactants to mix and form products. Do this a few times to ensure good mixing. Observe what happens and record your observations.
11. Weigh your apparatus containing the products and record this mass.
12. Remove the sealed apparatus from the scales and *carefully* loosen the lid. As you unseal the apparatus, observe and record what happens.
13. With the lid on loosely, reweigh your apparatus and record this mass.
14. Empty the bottle into a sink to remove the test tube and all chemicals. Clean up all materials with lots of water.

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

(a) What evidence indicates that a chemical reaction took place between the sodium bicarbonate and the acetic acid?

(b) Calculate the mass change between reactants and products in the sealed bottle. Use a positive value for a gain in mass, a negative value for a loss, and "0" if no change in mass occurs.

(c) Calculate the mass change between reactants and contents in the unsealed bottle. Again, use a positive or negative value or "0."

(d) Generally speaking, what change in mass results from a chemical reaction? How do you explain your results from (c)?

Evaluation

(e) Compare your results with those of another group. What might account for any differences in mass changes?

Synthesis

(f) With reference to atoms, suggest an explanation for the change (or no change) in mass in the sealed bottle.

(g) Again, with reference to atoms, suggest an explanation for the change (or no change) in mass in the unsealed bottle.

9B Investigation

Types of Chemical Reactions

As you have learned, there are certain patterns that exist in the ways that chemicals react to form products. Chemists have found six common types of chemical reactions: synthesis, decomposition, single replacement, double replacement, acid–base neutralization, and combustion.

Question

What evidence is presented by chemical reactions that will allow you to classify them?

Experimental Design

In this investigation, you will examine some chemical reaction types simply by studying reactions that can be used to analyze the products that appear when you exhale (breathe out).

Materials

- safety goggles
- 250 mL beaker
- water
- bromothymol blue indicator solution
- 2 drinking straws
- limewater

The chemicals used in this investigation are relatively harmless, but any time gases are produced, there is a potential hazard to your eyes.

Bromothymol blue can stain clothing. Use care when using this substance.

Procedure

1. Put on your safety goggles.
2. Obtain a 250 mL beaker and fill it with 100 mL of water.
3. Add four drops of bromothymol blue indicator to the water and record your results in your copy of Table 1.

INQUIRY SKILLS

○ Questioning
○ Hypothesizing
○ Predicting
○ Planning
● Conducting
● Recording
● Analyzing
● Evaluating
● Synthesizing
● Communicating

Table 1

Sample tested	Test	Result
water in beaker	bromothymol blue	
water and bromothymol blue in beaker after blowing air into it	exhaled air	
limewater	bromothymol blue	
limewater after blowing air into it	exhaled air	

4. Use a drinking straw to gently blow bubbles in the water (Figure 1). Take care not to spill water out of the beaker or to suck in the water. Continue to blow gently, taking breaks, for about 3 min.

Figure 1

5. Observe what happens to the bromothymol blue and record your results. Rinse out the beaker and save it for later.

6. Class test a small sample of the limewater with bromothymol blue and record the results.
7. Obtain 100 mL of limewater in your beaker.
8. Use a new straw to once again gently blow bubbles into the limewater. Again, blow gently for about 3 min, then record your results.

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

(a) The products of respiration are described by the following skeleton equation:

$$C_6H_{12}O_6(s) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

The products leave the body when you exhale. Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to its reaction type.

(b) Carbon dioxide will react with water according to the following skeleton equation:

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$$

Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to its reaction type.

(c) What evidence do you have that H_2CO_3 was produced when you blew into the water?

(d) Limewater is a solution of lime or calcium hydroxide, $Ca(OH)_2(aq)$. Calcium metal reacts with water according to the following skeleton equation:

$$Ca(s) + HOH(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$$

Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to its reaction type.

(e) What evidence do you have that limewater contains $Ca(OH)_2(aq)$?

(f) As you have learned, the CO_2 from your breath forms an H_2CO_3 solution when added to water. If limewater is mixed with the H_2CO_3 solution, a reaction occurs according to the following skeleton equation:

$$Ca(OH)_2(aq) + H_2CO_3(aq) \rightarrow CaCO_3(s) + H_2O(l)$$

Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to *two* possible reaction types.

(g) What evidence do you have that one of the products of the reaction in (f) is $CaCO_3(s)$?

Evaluation

(h) What kinds of evidence allowed you to identify the reaction types for each reaction?

Synthesis

(i) Create a chart to summarize the reactions studied in this investigation. Include balanced equations and reaction types in the chart.

9C Investigation

Factors That Affect Reaction Rates

All chemical reactions can occur at different rates depending on various conditions or factors. Some reactions will take place very slowly, while others are extremely fast. Recall that the rate of a reaction is expressed as the change in the amount of one of the chemicals involved (reactants or products) in a measured period of time.

Questions

What effect will increasing the concentration of a reactant have on the reaction rate? What effect will increasing surface area of a reactant have on reaction rate?

Prediction

Predict the effect of increasing reactant concentration on reaction rate. Predict the effect of increasing surface area on reaction rate.

Experimental Design

This investigation has two parts. In Part I, you will react magnesium metal with increasing concentrations of hydrochloric acid. In Part II, you will react an Alka-Seltzer tablet in water and observe what happens when its surface area is increased.

Materials

- safety goggles
- 3.0 cm length of magnesium ribbon
- metric ruler
- scissors
- 3 test tubes (18 mm × 150 mm)
- water-soluble marker
- test tube rack
- 3 hydrochloric acid (HCl) solutions (different concentrations)
- timer (in seconds)
- 2 250 mL beakers
- water
- 2 Alka-Seltzer tablets
- weighing paper
- mass balance (scales)
- teaspoon

INQUIRY SKILLS

○ Questioning
○ Hypothesizing
● Predicting
○ Planning
● Conducting
● Recording
● Analyzing
● Evaluating
● Synthesizing
● Communicating

Acids can cause chemical burns. Always wear eye protection when working with acids. If any solution splashes on skin or in eyes, flush immediately with plenty of cold water and inform your teacher.

Procedure

Part I: Effect of Concentration on Reaction Rate

1. Put on your safety goggles. Work with a partner.
2. Obtain a 3.0 cm length of magnesium ribbon from your teacher, and carefully measure and cut it into 3 identical 1.0 cm strips. Your teacher will provide you with the mass of a 1.0 cm strip. Record this mass 3 times in your copy of Table 1.

Table 1

Test tube	Concentration of HCl	Mass of magnesium ribbon (g)	Reaction time (s)	Reaction rate (g Mg/s)
A	50.0 %			
B	25.0 %			
C	12.5 %			

3. Obtain three test tubes and use a water-soluble marker to label them A, B, and C near the top. Next, place a mark about one third up one of the tubes and mark the other tubes to match. Place these test tubes in a test tube rack.

4. In test tube A, add 50.0 % HCl solution to the mark. Similarly, in test tube B, add 25.0 % HCl, and in test tube C, add 12.5 % HCl.
5. Add one magnesium ribbon strip to test tube A and have your partner start timing as soon as the magnesium ribbon begins to react. Stop timing when the reaction ends. Record the reaction time in seconds in Table 1.
6. Repeat Step 5 for test tubes B and C.

Part II: Effect of Surface Area on Reaction Rate

Alka-Seltzer is often used by people for relief of upset stomachs. It contains a mixture of solid citric acid and baking soda (sodium bicarbonate), along with some aspirin.

7. Obtain two 250 mL beakers and label them A and B. Fill each one with 100 mL of water.
8. Using a piece of weighing paper, determine the mass of a whole Alka-Seltzer tablet and record just the mass of the Alka-Seltzer in your copy of Table 2.

Table 2

Beaker	Mass of Alka-Seltzer (g)	Reaction time (s)	Reaction rate (g Alka-Seltzer/s)
A (whole tablet)			
B (crushed tablet)			

9. Place a second Alka-Seltzer tablet on a piece of weighing paper and crush it with the back of a spoon. Press the spoon into the tablet carefully but firmly, to crush it into powder. Try not to spill any powder. Weigh this second crushed tablet on its weighing paper and record the mass of the Alka-Seltzer.
10. Add the whole (uncrushed) tablet to beaker A and time the reaction from start to finish. Record the time (in seconds) for the reaction to be completed.
11. Add the crushed tablet to beaker B and time the reaction from start to finish. Record the time taken for the reaction to be completed.

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

Part I: Effect of Concentration on Reaction Rate

(a) Complete the last column in Table 1 by calculating the reaction rate for each test tube.

For the reactions in Part I use

$$\text{reaction rate} = \frac{\text{mass of Mg reacted}}{\text{reaction time}} = \text{g Mg/s}$$

(b) Analyze your rate calculations in Table 1. What effect does increasing reactant concentration have on the rate of a reaction?

Part II: Effect of Surface Area on Reaction Rate

(c) Complete the last column in Table 2 by calculating the reaction rate for each beaker.

For the reactions in Part II use

$$\text{reaction rate} = \frac{\text{mass of Alka-Seltzer reacted}}{\text{reaction time}} = \text{g Alka-Seltzer/s}$$

(d) Analyze your rate calculations in Table 2. What effect does increasing surface area have on the rate of a reaction?

Evaluation

(e) Were your predictions supported by the experimental evidence? Explain.

Synthesis

(f) Using similar techniques as in this investigation, how could you maximize the rate of the reaction of magnesium metal and hydrochloric acid?

(g) Describe an experimental design that you might use to determine the effect of temperature on reaction rate.

CHAPTER 9

Review

Investigating Chemical Reactions

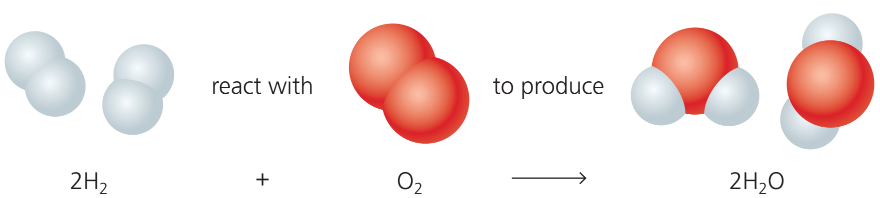
Key Ideas

Chemical reactions are processes that involve chemical change and obey the Law of Conservation of Mass.

- Chemical reactions are descriptions of chemical change.
- Mass is conserved in a chemical reaction (Law of Conservation of Mass). This is true since the number of atoms of each element is conserved.

Chemical equations are used to describe chemical reactions.

- A chemical equation is balanced when the atoms of the reactant element(s) are the same as the atoms of the product element(s).
- Coefficients in a chemical equation describe the number of molecules of each compound or element, whereas subscripts describe the number of atoms of each element. Example: $2H_2O$ represents 2 molecules of H_2O, each of which contains 2 atoms of H and 1 atom of O.
- Balancing an equation involves changing the coefficients throughout the equation so that atoms are conserved.



There are six common types of chemical reactions.

- Patterns exist in chemical reactions that allow most to be classified as one of six types:

Reaction type	General form
1. synthesis (or combination)	A + B → AB
2. decomposition	AB → A + B
3. single replacement	AB + C → CB + A
4. double replacement	AB + CD → CB + AD
5. acid–base neutralization	H-X + B-OH → BX + HOH
6. combustion (of hydrocarbons)	C_xH_y + O_2 → CO_2 + H_2O

Vocabulary

chemical reaction, p. 232
chemical equation, p. 233
reactants, p. 233
products, p. 233
Law of Conservation of Mass, p. 233
skeleton equation, p. 235
balanced equation, p. 236
synthesis reaction, p. 239
decomposition reaction, p. 241
single replacement reaction, p. 242
double replacement reaction, p. 242
acid–base neutralization reaction, p. 243
combustion reaction, p. 244
reaction rate, p. 250
kinetic molecule theory, p. 251
collision theory, p. 251
catalyst, p. 255

Chemists are able to predict the products of common reactions.

- Given the reactants for a reaction, you can often predict the products that will form, as well as relative amounts of reactants and products.
- Predicting the reactants or products of a reaction requires an understanding of reaction types, chemical formula writing, and balancing equations.

The rate of a chemical reaction is affected by various factors.

- Some chemical reactions are slow, some are fast.
- Reaction rate is a measure of the rate of change of any one of the chemicals in the reaction.
- Reaction rate is explained by the collision theory, which states that molecules must collide in order to react.
- Collisions must also be *effective*, which means that they must have sufficient energy for a reaction to occur.
- Reaction rate can be increased by increasing the concentration of reactants, increasing the surface area of reactants, increasing the temperature, or by adding a catalyst.

Many of these questions are in the style of the Science 10 Provincial Exam.
The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Chemists use chemical equations to describe which of the following?

I	chemical change
II	chemical reactions
III	physical change

A. I and II only
B. I and III only
C. II and III only
D. I, II, and III

K 2. Which of the following ideas apply to all chemical reactions?

I	mass is conserved
II	atoms are conserved
III	molecules are conserved

A. I only
B. I and II only
C. II and III only
D. I, II, and III

K 3. Which of the following is true for all balanced chemical equations?
A. The sum of the reactant subscripts equals the sum of the product subscripts.
B. The sum of the reactant coefficients equals the sum of the product coefficients.
C. The number of molecules of reactants equals the number of molecules of products.
D. The number of atoms of reactant elements equals the number of atoms of product elements.

K 4. Given the general equation:
$PQ + X \rightarrow XQ + P$,
which reaction type does this equation represent?
A. synthesis
B. combustion
C. single replacement
D. double replacement

K 5. Given the general equation:
$PQ \rightarrow P + Q$,
which reaction type does this equation represent?
A. synthesis
B. neutralization
C. decomposition
D. double replacement

6. What is the difference between a reactant and a product?

7. Generally speaking, how does a catalyst increase the rate of a chemical reaction?

Use What You've Learned

8. Explain how the Law of Conservation of Mass applies to chemical reactions.

U 9. How many atoms of each element are in the expression $4\ Ca(NO_3)_2$?
A. 1 atom Ca, 1 atom N, 6 atoms O
B. 4 atoms Ca, 2 atoms N, 6 atoms O
C. 2 atoms Ca, 2 atoms N, 24 atoms O
D. 4 atoms Ca, 8 atoms N, 24 atoms O

10. State the number of atoms of each element in each of the following:
(a) H_2SO_4
(b) $5\ H_2O$
(c) $3\ NH_4Cl$
(d) $2\ Al_2(SO_4)_3$
(e) $2\ (NH_4)_2HPO_4$

11. (a) Why is the following equation not balanced?
$C + H_2 \rightarrow CH_4$
(b) What is wrong with the following attempt to balance the above equation?
$C + H_4 \rightarrow CH_4$

U 12. Which of the following sets of ordered coefficients will correctly balance the skeleton equation below?
$Fe_3O_4 + H_2 \rightarrow Fe + H_2O$
A. 1, 4, 3, 4
B. 1, 2, 3, 4
C. 1, 1, 3, 4
D. 2, 4, 6, 4

13. Balance the following skeleton equations. Then, classify them according to reaction type.
(a) $Ca + HCl \rightarrow CaCl_2 + H_2$
(b) $Al + O_2 \rightarrow Al_2O_3$
(c) $Ca(NO_3)_2 + KOH \rightarrow KNO_3 + Ca(OH)_2$
(d) $Ba + H_3PO_4 \rightarrow Ba_3(PO_4)_2 + H_2$
(e) $Mg + HBr \rightarrow MgBr_2 + H_2$
(f) $BaCO_3 \rightarrow BaO + CO_2$
(g) $C_5H_{12} + O_2 \rightarrow CO_2 + H_2O$
(h) $H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$

14. Predict the products of the following reactions, then balance the equations. Classify the equations according to reaction type.
(a) $Ca + O_2 \rightarrow$
(b) $Mg + HBr \rightarrow$
(c) $Ba(NO_3)_2 + NaOH \rightarrow$
(d) $Al + CuSO_4 \rightarrow$
(e) $H_2SO_4 + Sr(OH)_2 \rightarrow$
(f) $NaCl \rightarrow$
(g) $C_8H_{18} + O_2 \rightarrow$
(h) $Fe + H_3PO_4 \rightarrow$

Think Critically

15. Consider the reaction between hydrochloric acid and marble chips ($CaCO_3$) in an open beaker:

$$HCl\ (aq) + CaCO_3\ (s) \rightarrow CaCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$$

(a) Balance the above equation and suggest two reaction types that would explain the products produced. Explain your choice of reaction types.
(b) State three methods (other than a catalyst) you would use to increase the rate of this reaction.
(c) Use the collision theory to explain how your methods would increase the rate.
(d) A 4.05 g sample of $CaCO_3$ was placed in a beaker containing hydrochloric acid (HCl). After 40 s, the sample was removed from the acid and weighed. Its new mass was 2.55 g. Calculate the rate of the reaction in g $CaCO_3$/s.

HMP 16. Refer to the reaction in question 15. What change, other than the mass of $CaCO_3$, could you measure to determine the rate of this reaction?
A. mass of CO_2 produced
B. mass of H_2O produced
C. mass of HCl consumed
D. volume of H_2O produced

17. Provide several reasons why chemists rely more on formula equations than word equations when describing chemical reactions.

18. *The Law of Conservation of Mass is based on common sense.* Support this statement.

19. Why aren't molecules balanced in a balanced chemical equation?

20. Many people think that oxygen gas is explosive. Explain the error of their reasoning.

21. Draw a model of a cube (10 mm × 10 mm × 10 mm) of sodium metal and show how the surface area increases when the soft sodium metal is cut in half. Provide surface area calculations to support your drawings.

22. Give one example of a slow chemical reaction that should be kept slow and one that should have its reaction rate increased. Explain why.

23. Why do fuels such as gasoline not start to burn as soon as they come in contact with oxygen? What would be the consequences if they did?

Reflect on Your Learning

24. A skeleton equation is often compared to an incomplete recipe for baking. Do you think this is a good analogy? Explain why or why not.

25. How would your world be different if all chemical reactions were synthesis reactions?

Visit the Quiz Centre at
www.science.nelson.com GO

UNIT B

Review

Elements, Compounds, and Reactions

Unit Summary

In this unit, you have extended your understanding of matter. You have learned that matter can take different forms, and that the structure of matter helps explain how elements can combine to form compounds. Compounds can be placed in various groups depending on different classification schemes. Elements and compounds can also undergo chemical change at different rates, and chemical change can be described by chemical equations.

Create a mind map (concept map) that relates these ideas. Use sketches, diagrams, and text to show how the ideas interconnect. Check the chapter reviews to make sure that you have included all of the major concepts in your map.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge **U** Understanding and Application **HMP** Higher Mental Processes

Review Key Ideas and Vocabulary

K **1.** Which subatomic particles are responsible for chemical bonding?
A. protons
B. electrons
C. neutrons
D. nucleons

K **2.** In a Bohr diagram, how many electrons fill each shell?
A. 2, 2, 2
B. 2, 2, 8
C. 2, 8, 8
D. 8, 8, 8

K **3.** Which of the following describes the atomic number of an element?
A. It is equal to the mass of the nucleus.
B. It is the number of protons in the nucleus.
C. It is the number of electrons in the nucleus.
D. It is the number of neutrons in the nucleus.

K **4.** What appears on the Periodic Table, in order, when reading it from left to right?
A. metals, metalloids, non-metals
B. metalloids, metals, non-metals
C. alkali metals, noble gases, halogens
D. alkali metals, halogens, alkaline earths

K **5.** What determines the number of electrons transferred when an atom becomes an ion?
A. the ion charge balance
B. the number of protons in the nucleus
C. the number of valence electrons in the first shell
D. the number of valence electrons of the nearest noble gas

K **6.** What is the smallest particle of a covalently bonded compound?
A. ion
B. atom
C. electron
D. molecule

K **7.** How is a Lewis diagram different from a Bohr diagram of an atom?
A. All electrons are shown.
B. Only valence electrons are shown.
C. Electrons are drawn in pairs when possible.
D. The nucleus contains important information.

K **8.** When you balance a chemical equation, what are you balancing or making equal between the reactants and products?
A. the number of subscripts
B. the number of coefficients
C. the number of atoms of each element
D. the number of molecules of each compound

K **9.** Which reaction type does this general equation represent?

$$PQ + XY \rightarrow XQ + PY$$

A. synthesis
B. combustion
C. single replacement
D. double replacement

10. Write the chemical symbols for the following particles:
(a) fluorine atom
(b) oxygen ion
(c) oxygen molecule
(d) potassium ion

11. Draw Bohr diagrams for atoms of the following elements:
(a) lithium
(b) aluminum
(c) carbon
(d) neon

12. Write the chemical formulas for the seven elements that exist as diatomic molecules.

13. What does the crisscross method for writing chemical formulas actually do?

14. How are ionic compounds different from molecular compounds in their composition?

15. Ionic compounds can be classified as acids, bases, or salts. Match the following:

(a) acids	(i) release OH^- ions in solution
(b) bases	(ii) release ions other than H^+ or OH^- in solution
(c) salts	(iii) release H^+ ions in solution

K **16.** Which of the following applies only to acids and not to bases or salts?
A. They turn litmus red.
B. They turn phenolphthalein pink.
C. Their solutions conduct electricity.
D. They react with metals to form oxygen gas.

K **17.** What is the Arrhenius definition of a base?
A. It tastes sour.
B. It turns phenolphthalein pink.
C. It releases H^+ ions in solution.
D. It releases OH^- ions in solution.

18. Make a sketch of the pH scale and label the acidic, basic, and neutral sections.

19. State a modern definition of an organic compound.

20. Write a statement that describes the Law of Conservation of Mass for chemical reactions.

21. In order to react, what must colliding reactant molecules have and how can this be achieved?

K **22.** Which of the following sets of ordered coefficients will correctly balance the skeleton equation below?

$HBrO_3 + HBr \rightarrow H_2O + Br_2$

A. 1, 5, 3, 3
B. 1, 2, 1, 1
C. 2, 4, 6, 3
D. 2, 4, 3, 2

K **23.** Which of the following factors does not increase the rates of all chemical reactions?
A. adding oxygen
B. adding a catalyst
C. increasing the concentration of reactants
D. increasing the surface area of a solid reactant

Use What You've Learned

U **24.** Which of the following is a chemical property?

A. Water boils at 100 °C.
B. Acids have a sour taste.
C. Sugar dissolves in water.
D. Copper turns green when exposed to water and air.

25. An atom has 6 protons and 8 neutrons.

(a) Identify the element.
(b) Explain how that number of neutrons is possible.
(c) Draw a Bohr diagram of this atom.

26. Write the name of the elements described below.

(a) 7 protons and 8 neutrons
(b) 92 protons and mass number 240
(c) atomic number 84 and 126 neutrons

27. Explain why an ion cannot exist on its own.

28. Match each of the following elements with its nearest noble gas (from the choices given) and the number of valence electrons it would have when bonding is complete. You may use matching items more than once.

(a) Al	(i) He	(A) 2 valence electrons
(b) H	(ii) Ne	(B) 8 valence electrons
(c) Li	(iii) Ar	
(d) Mg		
(e) S		

29. Draw Bohr diagrams for the ions of magnesium and phosphorus.

U **30.** Which of the following does *not* represent a molecule?

A. CO_2
B. NH_3
C. H_2O
D. NaCl

U **31.** Why do molecular compounds have relatively low melting points?

A. Attractive forces between molecules are relatively weak.
B. Attractive forces between atoms are relatively weak.
C. Attractive forces between molecules are relatively strong.
D. Attractive forces between atoms are relatively strong.

32. First, classify each of the following compounds as ionic or molecular. Then, write the chemical formula for each compound.

(a) beryllium nitrate
(b) ammonium carbonate
(c) lead(II) fluoride
(d) aluminum selenide
(e) carbon tetrachloride

33. First, classify each of the following compounds as ionic or molecular. Then, write the chemical name for each compound.

(a) RbCl
(b) $(NH_4)_3P$
(c) N_3Br_6
(d) Ti_2O_3
(e) $Sr_3(PO_4)_2$

34. First, classify each of the following compounds as ionic or molecular. Then, write the chemical formula or name depending on what is given.

(a) KCl
(b) calcium nitrate
(c) N_2O_4
(d) lead(IV) sulfide
(e) $Ba(ClO_4)_2$

35. Describe the results you would expect from electrical conductivity tests on ionic and molecular solutions.

36. Write either the acid name or chemical formula, depending on what is given.
(a) HCl
(b) perchloric acid
(c) H_2SO_4
(d) chlorous acid
(e) HNO_2

37. Draw Lewis diagrams for ions of the following elements:
(a) Cl
(b) O
(c) Ca

38. Draw Lewis diagrams of atoms for the following elements:
(a) O
(b) N
(c) C
(d) B

39. Draw Lewis diagrams of the following molecules:
(a) BCl_3
(b) CF_4
(c) H_2O

40. Given that strontium chloride is a white crystalline solid with a high melting point, predict two properties of the compound barium chloride. Refer to the position of relevant elements in the Periodic Table to explain your predictions.

41. Balance the following skeleton equations. Then, classify the equations according to reaction type.
(a) $Ba + HCl \rightarrow BaCl_2 + H_2$
(b) $Al + S \rightarrow Al_2S_3$
(c) $Sr(NO_3)_2 + NaOH \rightarrow NaNO_3 + Sr(OH)_2$
(d) $Mg + H_3PO_4 \rightarrow Mg_3(PO_4)_2 + H_2$
(e) $CaCO_3 \rightarrow CaO + CO_2$
(f) $C_{10}H_{22} + O_2 \rightarrow CO_2 + H_2O$

42. Predict the products of the following reactions, then balance the equations. Classify the equations according to reaction type.
(a) $Ba + O_2 \rightarrow$
(b) $C_5H_{12} + O_2 \rightarrow$
(c) $Ba(NO_3)_2 + KOH \rightarrow$
(d) $Al + ZnSO_4 \rightarrow$
(e) $H_2SO_4 + Sr(OH)_2 \rightarrow$
(f) $NaCl \rightarrow$

Think Critically

43. Write out and number your own set of rules on how to place electrons in a Bohr diagram. Provide an example diagram with your rules.

HMP 44. When hydrogen chloride gas and ammonium hydroxide gas react, a white solid forms. What is the white solid?
A. HCl
B. H_2O
C. NH_4Cl
D. NH_4OH

45. When acids and bases are transported to industrial plants, there is a potential hazard for spills along the route. When spills occur, groups trained to deal with hazardous materials spring into action. Use the Internet to learn how these groups deal with these kinds of spills.

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HMP 46. Which of the following will increase the percentage of collisions that are effective, thereby increasing reaction rate?

I	adding a catalyst
II	increasing temperature
III	increasing concentration of reactants

A. I only
B. I and II only
C. I and III only
D. I, II, and III

Reflect on Your Learning

47. Write a short essay on “Chemical Reactions in My World” to share what you have learned. Give examples of reactions that are important to you and classify them according to reaction type. Where possible, provide chemical equations with your examples. In many cases, Internet research will be helpful.

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