4.3 Chemical Equations

A chemical change is a change in the arrangements and connections between ions and atoms. One or more chemical changes that occur at the same time are called a chemical reaction. Chemical reactions can be represented using a chemical equation. A chemical equation may be written in words or in chemical symbols. In a chemical reaction, the reactants are written to the left of an arrow and the products are written to the right. The symbols for states of matter may be used to show whether each reactant or product is solid, liquid, gas, or aqueous. Chemical reactions obey the law of conservation of mass, and atoms are neither destroyed nor produced in a chemical reaction. Chemical equations are balanced using the lowest whole number coefficients, which are numbers written in front of the pure substances in the reaction.

Words to Know

balanced chemical equation
chemical equation
chemical reaction
conservation of mass
products
reactants
skeleton equation
symbolic equation

A chemical change can be very spectacular (Figure 4.29A). Bubbling liquids, fumes, and new colours may appear. Light and heat may be produced, or energy may be consumed. However, many chemical changes happen very quietly and are not visible. Thousands of kinds of chemical changes happen in your body every day to help you digest your food and supply the nutrients needed by your body to grow and be active.

Figure 4.29A Copper reacting in nitric acid

Chemical change always involves the conversion of pure substances (elements and compounds) called **reactants** into other pure substances called **products** with different properties from the reactants. One or more chemical changes that occur at the same time are called a **chemical reaction**. A chemical reaction may be represented using a **chemical equation**. A chemical equation may be written in words or symbols. A **symbolic equation** is a set of chemical symbols and formulas that identify the reactants and products in a chemical reaction. For example, a reaction happening in the beaker in Figure 4.29A produces nitrogen dioxide, an air pollutant, which is a major component of smog in many cities (Figure 4.29B).

word equation: nitrogen monoxide + oxygen → nitrogen dioxide
symbolic equation: $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Figure 4.29B Smog over Vancouver

A chemical equation may also show the following.

Coefficients: Integers are placed in front of the formula or a chemical symbol for an element. These coefficients can be used to determine the ratios between the various compounds in a chemical reaction. For example, in the reaction above, the coefficients show that two molecules of NO react with one molecule of O_2 to form two molecules of NO_2. In other words, NO and O_2 react in a 2:1 ratio.

State of matter: Letters indicate the compound's state: (g) for gas; (ℓ) for liquid; (s) for solid; (aq) for aqueous (dissolved in water).

Did You Know?

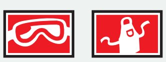
Some chemical changes produce electricity, as in a battery; some produce heat, as in a fire; and some produce light, as in a glow stick. Other chemical changes consume energy, as in cooking food.

4-3A Investigating Mass Changes in a Reaction

Find Out ACTIVITY

How do the masses of reactants compare to the masses of products? In this activity, you will seal the reactants of a chemical reaction in a closed container and then combine them, keeping the seal in place. You will measure and record the total mass before and after the reaction.

Safety



- Avoid touching all reactants and products.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

Materials

- small test tube that will fit inside sealed flask
- small Erlenmeyer flask
- solid rubber stopper to seal flask
- calcium chloride solution
- sodium carbonate solution
- small graduated cylinder (10–50 mL)
- paper towel
- balance

What to Do

1. Place the empty test tube into the Erlenmeyer flask and fit the rubber stopper into the flask. Make sure that the flask will seal properly with the test tube inside it. Open the flask, and take the test tube out.
2. Choose one of the solutions. Measure about 10 mL of the solution into a graduated cylinder and pour this into the Erlenmeyer flask. Wipe the outside of the flask with the paper towel to ensure it is dry.
3. Fill the test tube $\frac{2}{3}$ full with the second solution. Wipe the outside of the test tube to ensure it is dry.
4. Carefully slide the test tube filled with the second solution into the Erlenmeyer flask. Do not allow the solutions to combine. Seal the flask.
5. Check closely for any leaks, but do not allow the liquids to combine yet. If any leaking occurs, dispose of the chemicals as directed by your teacher, wash and dry your equipment thoroughly, and start again from the beginning.
6. Find and record the total mass of the flask and contents.
7. Tip the apparatus to allow the two solutions to combine. Observe what happens.
8. Predict whether the mass after combining is greater than, equal to, or less than the mass before combining.
9. Record the total mass of the flask and contents.
10. Compare your results with all students in your class.
11. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

What Did You Find Out?

1. As a general trend, did the chemical reaction cause the mass to increase, decrease, or stay the same?
2. It is unlikely that all the results were the same. Explain why results varied from one group to another.

Conservation of Mass in Chemical Change

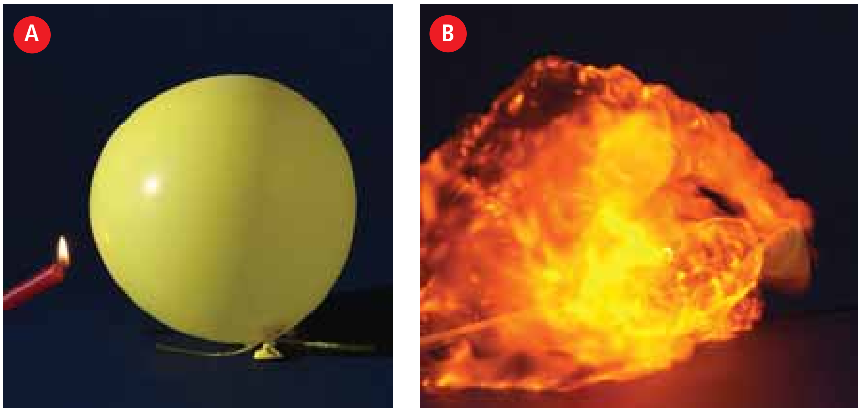


Figure 4.30 The hydrogen and oxygen in the balloon do not react until the balloon is touched by a flame (A). Then, an explosive chemical reaction occurs (B).

What happens to atoms of hydrogen and atoms of oxygen when the two gases are brought together and ignited (Figure 4.30)? Are new atoms created in the flash? Are some destroyed?

These are questions that the English chemist John Dalton (1766–1844) thought about 200 years ago (Figure 4.31). He imagined that tiny particles called atoms rearranged themselves in new ways during chemical reactions (Figure 4.32). He also imagined that during chemical reactions no atoms were ever created or destroyed. The total number of each kind of atom present at the start of the reaction equalled the total number of each kind of atom after the reaction. Dalton used these ideas to draw symbols for compounds as combinations of the atoms of different elements (Figure 4.33).

Figure 4.31 Dalton thought of atoms as combining when compounds form.

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

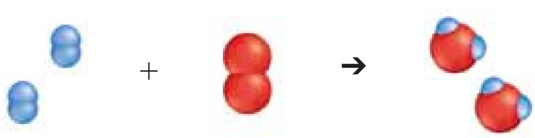


Figure 4.32 The reaction of oxygen molecules with hydrogen molecules involves rearranging atoms in new ways.

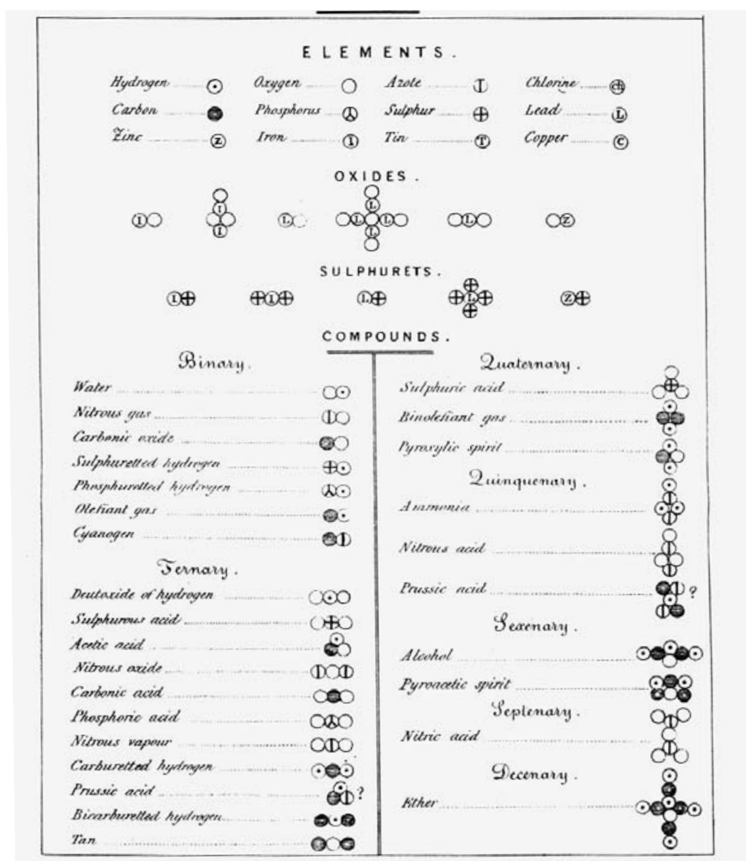


Figure 4.33 Once Dalton had visualized the way atoms can join to make compounds, he could picture how these atoms might rearrang in a chemical reaction.

The law of conservation of mass

Other researchers, such as Antoine Lavoisier (Figure 4.34) (1743–1794), who was a French chemist, and his wife, Marie-Anne, made careful measurements of the masses of reactants and products in many chemical reactions (Figure 4.34). They found that the total mass of the system never changed during a chemical change. Antoine Lavoisier identified and named oxygen in 1778 and hydrogen in 1783. He is credited with determining that water results from the combination of the elements oxygen and hydrogen. Lavoisier also devised a system of naming the elements.

Building on the work of other scientists and on the results of his own carefully controlled experiments, Lavoisier formulated the law of conservation of mass. The law of **conservation of mass** states that mass is conserved in a chemical reaction; the total mass of the products is always equal to the total mass of the reactants in a chemical reaction. The idea that atoms are conserved (neither made nor destroyed) is believed to be true for all chemical reactions (Figure 4.35).

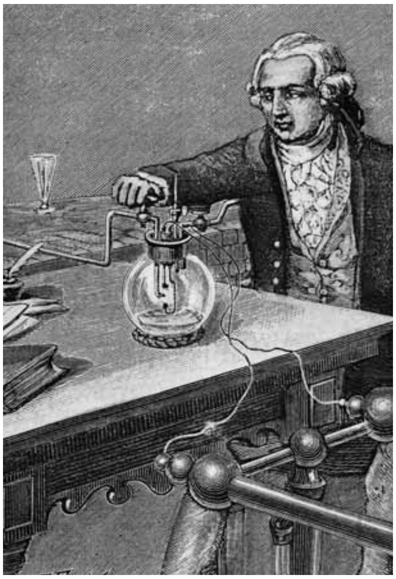
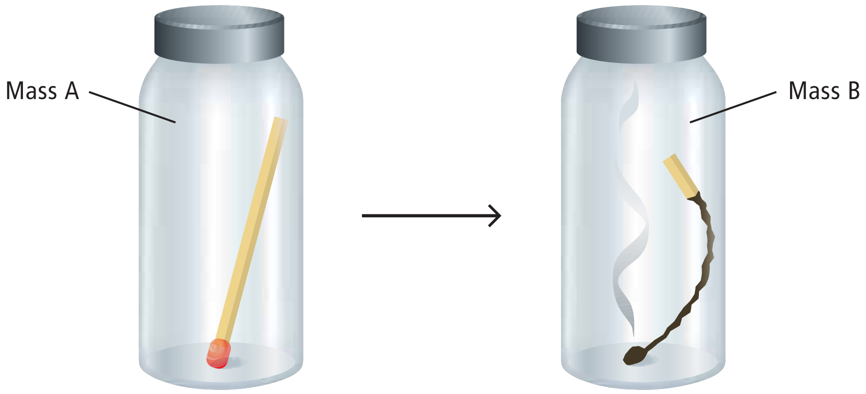


Figure 4.34 Antoine Lavoisier and his apparatus for a hydrogen combustion experiment

Conservation of Mass



Mass A [wood + air] = Mass B [carbon + CO_2 + H_2O]

Figure 4.35 Mass is conserved in a chemical reaction.

Reading Check

1. What is the definition of a chemical reaction?
2. What are two ways a chemical equation may be written?
3. What ratio can you determine using the coefficient in a chemical formula?
4. What are the four abbreviations for a compound's state of matter?
5. According to the law of conservation of mass, what does the total mass of the products in a chemical reaction equal?

Word Connect

"Conservation" means keeping or protecting. In science, there are many conservation laws. In each conservation law, some quantity, such as mass or energy, remains unchanged under all conditions.

Writing and Balancing Chemical Equations

The simplest form of a chemical equation is a word equation. For example, potassium metal reacts with oxygen gas to produce potassium oxide.

Arrow means "produces."

Reactants appear on left side of arrow.

potassium metal + oxygen gas ➔ potassium oxide

Products appear on right side of arrow.

Plus sign on left side means "reacts with."

Plus sign on right side means "plus."

A word equation provides only limited information about a chemical reaction. You can write a more useful equation by replacing words with chemical symbols and formulas. A **skeleton equation** simply shows the formulas of the reactants and products. The skeleton equation for the reaction of potassium metal with oxygen gas to form potassium oxide is:

skeleton equation: $K + O_2 \rightarrow K_2O$

Notice that the formula of potassium oxide is K_2O because it is an ionic compound made from K^+ ions and O^{2-} ions. The ions combine in a ratio of 2:1.

A skeleton equation does not show the correct proportions in which the reactants will actually combine and the products will be produced. So your next step would be to balance the skeleton equation. A **balanced chemical equation** shows the identities of each pure substance involved as well as the matching number of atoms of each element on both sides of a chemical equation. According to the law of conservation of mass, the mass of each element present is conserved during a chemical reaction. In other words, the number of atoms of an element is the same after a chemical reaction as it was before a chemical reaction. You can use this information to determine the coefficients that balance the equation. The balanced chemical equation for the above reaction is:

balanced chemical equation: $4K + O_2 \rightarrow 2K_2O$

The coefficient in front of the K is 4. The O_2 has a coefficient of 1, but it is not shown. The coefficient of 1 means that only one molecule of oxygen is required.

You can read this equation as "Four atoms of potassium (K) will combine with one molecule of oxygen (O_2) to produce two potassium oxides (K_2O)." This is much like a recipe used in cooking. For example, it is possible to "double" a recipe, which for this reaction means that eight atoms of K will react with two molecules of O_2 to produce four K_2O. Keep in mind that, in a balanced chemical equation, the smallest whole number ratio is always used, which for the above reaction is 4:1:2.

Reading Check

Refer to the following balanced chemical equation to answer these questions: $3H_2 + N_2 \rightarrow 2NH_3$

1. List the names of the reactants.
2. Give the formula of the product.
3. How many molecules of hydrogen (H_2) will combine exactly with one molecule of nitrogen (N_2)?
4. How many molecules of nitrogen are required to produce 10 molecules of ammonia (NH_3)?
5. What is the symbol that means "produces" in a chemical reaction?

Counting Atoms to Balance an Equation

You can use the law of conservation of mass to help you balance equations that contain compounds. Consider the combustion of methane (CH_4) in air (Figure 4.36).

word equation: methane + oxygen ➔ water + carbon dioxide
skeleton equation: $CH_4 + O_2 \rightarrow H_2O + CO_2$
balanced chemical equation: $CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$

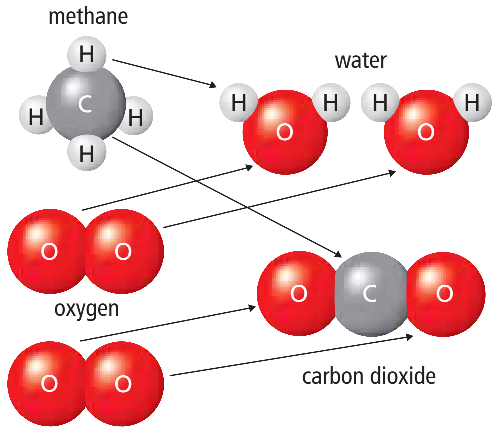


Figure 4.36 For an equation to be balanced, the same number of atoms of each element must be present on both sides of the equation.

We count the atoms in the balanced chemical equation as follows:
Reactants
CH_4 means 1 molecule of CH_4 (1 C atom and 4 H atoms).
$2O_2$ means 2 molecules of O_2 ($2 \times 2 = 4$ atoms of O).
Reactants total: 1 C, 4 H, 4 O

Products
$2H_2O$ means 2 molecules of H_2O ($2 \times 2 = 4$ H atoms and $2 \times 1 = 2$ O atoms)
CO_2 means 1 molecule of CO_2 (1 C atom and $1 \times 2 = 2$ O atoms)
Products total: 4 H, 1 C, 4 O
Since the numbers of atoms of carbon, hydrogen, and oxygen are equal in both the reactants and in the products, the equation is correctly balanced.

Practice Problems

List the total number of each type of atoms in the following reactants.

1. $2H_2O + 2NaF$
2. $3Br_2 + 2FeI_3$
3. $Pb(NO_3)_2 + 2NaI$
4. $2K_3PO_4 + 3(NH_4)_2SO_4$

Answers provided on page 591

Figure 4.37 During photosynthesis in a leaf, carbon dioxide and water react to produce glucose and oxygen.

1	14	15	16	17	18
1 H + Hydrogen 1.0					2 He 0 Helium 4.0
	6 C Carbon 12.0	7 N 3– Nitrogen 14.0	8 O 2– Oxygen 16.0	9 F – Fluorine 19.0	10 Ne 0 Neon 20.2
	14 Si Silicon 28.1	15 P 3– Phosphorus 31.0	16 S 2– Sulfur 32.1	17 Cl – Chlorine 35.5	18 Ar 0 Argon 39.9
	32 Ge 4+ Germanium 72.6	33 As 3– Arsenic 74.9	34 Se 2– Selenium 79.0	35 Br – Bromine 79.9	36 Kr 0 Krypton 83.8
	50 Sn 4+ 2+ Tin 118.7	51 Sb 3+ 5+ Antimony 121.8	52 Te 2– Tellurium 127.6	53 I – Iodine 126.9	54 Xe 0 Xenon 131.3
	82 Pb 2+ 4+ Lead 207.2	83 Bi 3+ 5+ Bismuth 209.0	84 Po 2+ 4+ Polonium (209)	85 At – Astatine (210)	86 Rn 0 Radon (222)

Figure 4.38 Diatomic elements are shown in pink.

Did You Know?

Astatine is predicted to form diatomic molecules, but it is extremely rare, making it difficult to study. It is estimated that in the entire Earth's crust there is less than 30 g of astatine.

Hints for Writing Word Equations

Chemical equations can be written using chemical names instead of formulas. For example, a chemical reaction in plants consumes light energy and converts it into chemical energy in the form of sugar (Figure 4.37).

word equation: carbon dioxide + water ➔ glucose + oxygen

Translating this word equation into a skeleton equation presents several problems. It is likely that you know the formula for water is H_2O. But if you did not know, the formula would not be obvious from the name. Similarly, glucose is the correct chemical name for the sugar produced in photosynthesis, but the formula $C_6H_{12}O_6$ cannot be deduced from it. Finally, you would need to know that oxygen is a diatomic molecule.

skeleton equation: $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$
balanced chemical equation: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

When you translate a word equation into a skeleton equation, remember these points.

- We use the chemical symbol for nearly all elements when they are not in a compound. For example, we use Cu to symbolize pure copper.
- Three common compounds containing hydrogen that you can memorize are methane (CH_4), ammonia (NH_3), and water (H_2O).
- There are seven common diatomic elements, all of which are non-metals. When these elements occur on their own (not in a compound), they are written as H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2. They are sometimes remembered as the "-gens": hydro*gen*, nitro*gen*, oxy*gen*, and the halo*gens*. A second nickname for the diatomic elements is "the special seven." If you look carefully at their location on the periodic table, you will see they form a "7" with the exception of hydrogen, as shown in Figure 4.38.

You can translate the following word equation into a skeleton equation and balance it.

hydrogen + nitrogen ➔ ammonia

Both reactants are diatomic.
The chemical formula for ammonia is NH_3.

$H_2 + N_2 \rightarrow NH_3$

Balancing gives:
$3H_2 + N_2 \rightarrow 2NH_3$

Strategies for Balancing Equations

Some strategies you can use to help you balance a skeleton equation include the following.

- Use trial and error. If you are not sure where to place the first coefficient, just start anywhere. For simple equations, this is often the fastest method.
- Balance compounds first and single elements last.
- Finish balancing all atoms in one formula after you have placed a coefficient in front. Do not jump from one pure substance to another before balancing the first formula.
- Add coefficients only in front of formulas. Do not change subscripts.
- Sometimes, oxygen or hydrogen will appear in more than one place on the reactants side or on the products side of the chemical equation. This is your signal to balance oxygen and hydrogen last. Once you have finished balancing the other elements, you may find that the oxygen and hydrogen are already balanced.
- You can sometimes treat polyatomic ions as a unit. For example, if SO_4^{2-} appears on both sides of the equation, count the number of SO_4^{2-} groups on both sides. This is often faster than counting S and O separately.
- Perform a final check once you are finished to be sure that all elements are balanced.

Hints for Balancing Equations

Some helpful hints for balancing equations are shown in the following examples. The goal is to determine the correct coefficient for each chemical symbol or formula in order to balance the equation. Read the examples, but do not write in your textbook.

Example 1

iron + bromine ➔ iron(III) bromide

___ Fe + ___ Br_2 ➔ ___ $FeBr_3$

- The subscripts in the formulas of Br_2 and $FeBr_3$ cannot be changed. There are two Br atoms on the left and three Br atoms on the right.

___ Fe + $3Br_2$ ➔ $2FeBr_3$

- You can balance the Br atoms by placing a 3 in front of the Br_2 while at the same time placing a 2 in front of the $FeBr_3$. This gives a total of six Br atoms on each side.

$2Fe + 3Br_2$ ➔ $2FeBr_3$ (balanced)

- The Fe atoms are no longer in balance. Finish by placing a 2 in front of the Fe on the reactant side.

Did You Know?

Most diatomic elements are gases at room temperature. However, bromine is a liquid at room temperature, and iodine is a solid at room temperature.

Example 2

tin(IV) nitrite + potassium phosphate ➔ potassium nitrite + tin(IV) phosphate

___ $Sn(NO_2)_4$ + ___ K_3PO_4 ➔ ___ KNO_2 + ___ $Sn_3(PO_4)_4$

- Oxygen is present in all four chemical formulas. Balance all the other elements first. By the time you get to oxygen, it may already be balanced.
- One Sn atom appears on the left, and three Sn atoms appear on the right. Balance Sn by putting a 3 in front of $Sn(NO_2)_4$. A 1 is implied in front of $Sn_3(PO_4)_2$.

$3Sn(NO_2)_4$ + ___ K_3PO_4 ➔ ___ KNO_2 + $Sn_3(PO_4)_4$

- Now that a coefficient has been placed in front of $Sn(NO_2)_4$, finish balancing the compound by considering the NO_2^- group.
- The NO_2^- group appears on both sides, so balance it as a unit. Since there are $3 \times 4 = 12$ NO_2^- groups on the left, place a 12 in front of KNO_2 on the right.

$3Sn(NO_2)_4$ + ___ K_3PO_4 ➔ $12KNO_2$ + $Sn_3(PO_4)_4$

- The coefficient 12 in front of KNO_2 should lead you to balance K next.
- Balance the K by placing a 4 in front of K_3PO_4.

$3Sn(NO_2)_4 + 4K_3PO_4$ ➔ $12KNO_2 + Sn_3(PO_4)_4$ (balanced)

- Notice the phosphate group is balanced with $4PO_4^-$ on each side.
- A final check of individual oxygen atoms shows 40 on each side.

Example 3

ethane (C_2H_6) + oxygen ➔ carbon dioxide + water

Figure 4.39 Ethane is a by-product of petroleum refining.

___ C_2H_6 + ___ O_2 ➔ ___ CO_2 + ___ H_2O

- Bring C into balance by placing a 2 in front of CO_2.

C_2H_6 + ___ O_2 ➔ $2CO_2$ + ___ H_2O

- Because O appears in three of the four formulas and it is in elemental form, leave it for last.
- Balance H by placing a 3 in front of H_2O to give 6 H on each side.

C_2H_6 + ___ O_2 ➔ $2\ CO_2 + 3H_2O$

- The oxygen is now a problem because on the right there are $(2 \times 2) + (3 \times 1) = 7$ oxygen atoms. Since we wish to place an integer in front of O_2, there is a problem. For now, do not use an integer. Instead, balance O using a fraction. A coefficient of $3\frac{1}{2}$ will work.

$C_2H_6 + 3\frac{1}{2}\,O_2 \rightarrow 2\,CO_2 + 3H_2O$

- Now the equation is balanced, but the idea of having half a molecule of O_2 may seem odd, though it is correct. To make all coefficients integers, simply seems a problem. The solution is to double all the coefficients at once, giving the following set of integers.

$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$ (balanced)

Practice Problems

1. Balance each of the following skeleton equations.

(a) $NaI + AlCl_3 \rightarrow NaCl + AlI_3$
(b) $Li + Br_2 \rightarrow LiBr$
(c) $CH_4 + O_2 \rightarrow CO_2 + H_2O$
(d) $PbO \rightarrow Pb + O_2$
(e) $Na_4C + Ca \rightarrow Na + Ca_2C$
(f) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
(g) $Ca(NO_3)_2 + Cu_2SO_4 \rightarrow CaSO_4 + CuNO_3$
(h) $NaN_3 \rightarrow Na + N_2$
(i) $Mg(ClO_4)_2 + Na \rightarrow NaClO_4 + Mg$
(j) $AlCl_3 \rightarrow Al + Cl_2$

2. Write the skeleton equation for each of the following reactions. Then balance each of the equations.

(a) nitrogen monoxide + oxygen → nitrogen dioxide
(b) iron(III) bromide + sodium hydroxide → sodium bromide + iron(III) hydroxide
(c) methane + oxygen → carbon dioxide + water
(d) calcium nitrate + potassium carbonate → potassium nitrate + calcium carbonate
(e) phosphorus trichloride + chlorine → phosphorus pentachloride
(f) potassium permanganate + nickel(II) nitrate → potassium nitrate + nickel(II) permanganate
(g) iron + copper(II) chloride → iron(II) chloride + copper
(h) sodium phosphate + barium hydroxide → sodium hydroxide + barium phosphate

Answers provided on page 591

Suggested Activity

Conduct an Investigation 4-3B on page 212

Explore More

John Dalton thought that atoms had some kind of hooks that attached when they formed compounds. Find out more about early models of chemical compounds. Start your research at **www.bcscience10.ca**.

4-3B Observing Chemical Change

SkillCheck

- Observing
- Predicting
- Communicating
- Working co-operatively

Safety

- Follow your teacher's directions regarding using open flames.
- Tie back long hair.
- Be sure to wear eye protection.
- Avoid touching all reactants and products.
- Wash your hands and equipment thoroughly after completing this activity.
- Do not remove any materials from the science room.

Materials

- hydrochloric acid solution (HCl)
- 50 mL graduated cylinder
- small Erlenmeyer flask
- rubber stopper with glass tube insert and rubber tube attachment
- 400 mL beaker
- water
- 3 medium test tubes
- sodium carbonate powder
- paper towel
- flame striker or matches
- Bunsen burner or candle
- wooden splints
- test tube tongs
- magnesium metal ribbon
- zinc metal (mossy)

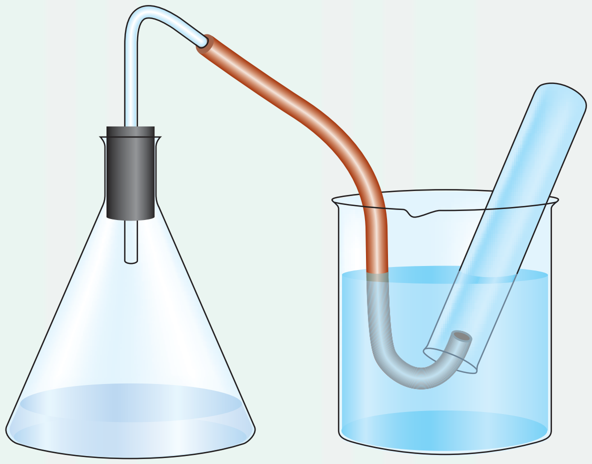
In this activity, you will observe three similar chemical reactions, all of which happen in solution (dissolved in water). You will write chemical equations representing these reactions.

Question

How can you observe, capture, and test the products of a chemical reaction?

Procedure

1. Measure 50 mL of HCl solution using a graduated cylinder, and pour it into the Erlenmeyer flask. Place the rubber stopper with the glass tube insert into the mouth of the Erlenmeyer flask to make sure it fits correctly. Attach a rubber tube to the outside of the glass tube.
2. Fill a 400 mL beaker $\frac{2}{3}$ with water. Fill a medium test tube with water, and invert it into the beaker without letting any air back into the test tube. Try not to spill any water. You may have to get your hands wet for this part of the procedure.
3. Place the end of the rubber tube inside the inverted test tube. Dry your hands.



Step 3

Adding sodium carbonate to the HCl solution:

4. Obtain about 3 g of sodium carbonate powder on a paper towel. Lift the rubber stopper out of the Erlenmeyer flask, and add the powder to the acid. Reseal the flask so no gas can get out. Observe as gas enters the inverted test tube.
5. Light the candle or Bunsen burner. Light a wooden splint. Lift the gas-filled inverted test tube out of the water, holding it in your hand or with test tube tongs. Bring the lit splint close to the mouth of the test tube, and attempt to ignite the gas that was collected. Record your observations.
6. Dispose of the HCl solution from the Erlenmeyer flask as directed by your teacher. Clean and dry the flask.

Adding magnesium metal ribbon to the HCl solution:

7. Repeat procedure steps 1 to 3.
8. Obtain a piece of magnesium ribbon on a paper towel from your teacher. Lift the rubber stopper out of the Erlenmeyer flask, and add the magnesium ribbon to the acid. Reseal the flask so no gas can get out. Observe as gas enters the inverted test tube.
9. Light a wooden splint. Lift the gas-filled inverted test tube out of the water, holding it in your hand or with test tube tongs. Bring the lit splint close to the mouth of the test tube, and attempt to ignite the gas that was collected. Record your observations.
10. Dispose of the HCl solution from the Erlenmeyer flask as directed by your teacher. Clean and dry the flask.

Adding zinc metal (mossy) to the HCl solution:

11. Repeat procedure steps 1 to 3.
12. Obtain a piece of mossy zinc metal on a paper towel from your teacher. Lift the rubber stopper out of the Erlenmeyer flask, and add the zinc metal to the acid. Reseal the flask so no gas can get out. Observe as gas enters the inverted test tube.
13. Light a wooden splint. Lift the gas-filled inverted test tube out of the water, holding it in your hand or with test tube tongs. Bring the lit splint close to the mouth of the test tube, and attempt to ignite the gas that was collected. Record your observations.
14. Dispose of the HCl solution from the Erlenmeyer flask as directed by your teacher.
15. Clean up and put away the equipment you have used. Follow your teacher's instructions for disposal of wastes.

Analyze

1. In step 4, a chemical reaction occurred between hydrochloric acid (HCl) and sodium carbonate. The products were sodium chloride, carbon dioxide gas, and water. For this reaction, write:
   (a) the word equation
   (b) the skeleton equation
   (c) the balanced chemical equation
2. In step 8, a chemical reaction occurred between hydrochloric acid (HCl) and magnesium metal. The products were magnesium chloride and hydrogen gas (H_2). For this reaction, write:
   (a) the word equation
   (b) the skeleton equation
   (c) the balanced chemical equation
3. In step 12, a chemical reaction occurred between hydrochloric acid (HCl) and zinc metal. The products were zinc chloride and hydrogen gas (H_2). For this reaction, write:
   (a) the word equation
   (b) the skeleton equation
   (c) the balanced chemical equation

Conclude and Apply

1. (a) In what ways were the three chemical reactions similar?
   (b) In what ways were the three chemical reactions different?
2. The hydrogen in the test tube reacted with the oxygen in the air.
   (a) What do you think is the product of this reaction?
   (b) What is the balanced equation for this reaction?

Science Watch

Antoine and Marie-Anne Lavoisier

In 1783, the brilliant chemist Antoine Lavoisier presented an experiment to the French Academy of Sciences that shocked the scientific world. Lavoisier showed how he had been able to separate water into two gases, which he called hydrogen and oxygen. He then recombined the two gases and ignited them with a spark. The result was the formation of water. In recombining the two gases, he had shown that water is not an element, something not known at the time.

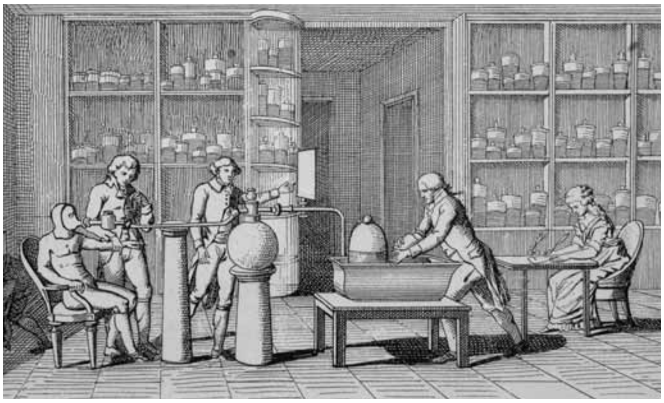
Although this was not the first time these chemical reactions had been studied, Lavoisier was the first person to correctly explain what was happening during the reactions. His understanding revolutionized scientists' knowledge of everyday processes such as combustion, by showing that it is the reaction of substances with oxygen.

Lavoisier was guided towards his discoveries through an idea that he had pursued since early in his scientific career. His idea became the most important concept in chemistry since Dalton's suggestion that matter was made of atoms. The idea was that all chemical reactions occur in such a way that the total mass of the chemicals involved never changes. For example, consider a campfire. The burning wood changes into gases, which, if captured and weighed, would equal the mass of the original wood and oxygen that burned it. Such a hypothesis is very difficult to prove, especially with gases, which tend to escape and are difficult to contain and weigh.

Lavoisier had help in his endeavours. His wife, Marie-Anne was interested in chemistry, which she studied along with English and art. She became Lavoisier's assistant and colleague. They worked together in their laboratory. Antoine spoke only French, and Marie translated many of his writings into English. She also translated the writings of English scientists into French.

Together, the Lavoisiers laboured for 20 years to gather data that showed that the masses of the reactants always equalled the masses of the products. Their data provided evidence of the law of conservation of mass.

Modern chemistry has its basis in the law of conservation of mass. For example, when 4 g of hydrogen gas react to produce 36 g of water, the law tells us that some other substance must have reacted with the hydrogen to make the water. The law even tells how much of the other substance was used: 32 g. Through understanding the law of conservation of mass, Antoine and Marie-Anne Lavoisier were able to discover the role of oxygen in combustion.



Marie-Anne Lavoisier is shown taking notes as Antoine presents an experiment.

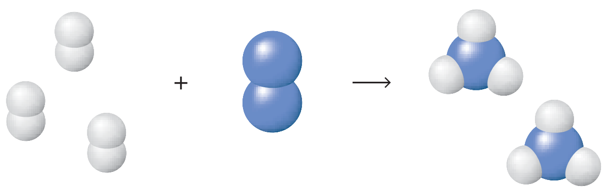
Questions

1. How did the Lavoisiers demonstrate that water is not an element?
2. What idea about the behaviour of chemical reactions guided Antoine Lavoisier for most of his career?
3. In what ways were Marie-Anne and Antoine Lavoisier colleagues?

Check Your Understanding

Checking Concepts

1. Most commercial trucks use diesel fuel. Consider the following reaction that occurs during the combustion of diesel fuel.
   heptane + oxygen ➔ carbon dioxide + water
   $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$
   (a) List the names of the reactants.
   (b) Give the formulas of the products.
   (c) What is the coefficient of the carbon dioxide?
   (d) What is the meaning of the + symbol on the left side of the equation?
2. Study the following diagram, and then write a skeleton equation for the reaction it represents. A white circle represents an H atom. A blue circle represents an N atom.



$3\ H_2 + N_2 \longrightarrow 2\ NH_3$

Understanding Key Ideas

3. Copy and balance the following skeleton equations.
   (a) $Al + F_2 \rightarrow AlF_3$
   (b) $PbCl_4 + K_3PO_4 \rightarrow KCl + Pb_3(PO_4)_4$
   (c) $Br_2 + FeI_3 \rightarrow I_2 + FeBr_3$
   (d) $Na_2CO_3 + Cr(NO_3)_3 \rightarrow NaNO_3 + Cr_2(CO_3)_3$
   (e) $Mn + I_2 \rightarrow MnI_4$
   (f) $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$
   (g) $K_2SO_4 + AgNO_3 \rightarrow Ag_2SO_4 + KNO_3$
   (h) $Ca(OH)_2 + HCl \rightarrow CaCl_2 + H_2O$
   (i) $Mg_3N_2 \rightarrow Mg + N_2$
   (j) $Fe + CuCl_2 \rightarrow FeCl_3 + Cu$
4. Write skeleton equations for the following chemical reactions and then balance them. Be sure to check your formulas carefully before you begin to balance.
   (a) lithium phosphate + magnesium sulfate ➔ lithium sulfate + magnesium phosphate
   (b) zinc iodide + copper(I) nitrate ➔ zinc nitrate + copper(I) iodide
   (c) mercury(II) nitrate + sodium hydrogen carbonate ➔ sodium nitrate + mercury(II) hydrogen carbonate
   (d) nickel(III) iodide and iron(II) sulfide ➔ nickel(III) sulfide + iron(II) iodide
   (e) aluminum hydroxide + hydrogen fluoride ➔ aluminum fluoride + water
   (f) hydrogen chloride + barium hydroxide ➔ barium chloride + water
   (g) calcium bromide + potassium carbonate ➔ calcium carbonate + potassium bromide
   (h) titanium(III) fluoride + cesium sulfite ➔ cesium fluoride + titanium(III) sulfite
   (i) barium sulfate + sodium hydroxide ➔ sodium sulfate + barium hydroxide
   (j) calcium chloride + potassium ➔ potassium chloride + calcium
   (k) hydrogen nitrate + strontium carbonate ➔ strontium nitrate + water + carbon dioxide

Pause and Reflect

The law of conservation of mass was developed after many experiments consistently showed that mass is neither gained nor lost during a chemical reaction. How does our understanding of atoms help explain why mass does not change during chemical reactions?

Chapter Review

Prepare Your Own Summary

In this chapter, you investigated atomic theory, chemical bonding, compounds, and balancing chemical equations. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with graphic organizers.) Use the following headings to organize your notes:

1. Atomic Theory and the Periodic Table
2. Bohr Diagrams and Lewis Diagrams of Compounds
3. Names and Chemical Formulas of Ionic Compounds
4. Names and Chemical Formulas of Covalent Compounds
5. Balancing Chemical Equations

Checking Concepts

1. Copy and complete the following chart in your notebook.

Property	Proton	Electron	Neutron
Relative mass		1	
Charge	+		
Location in the atom			

2. (a) List the names of four chemical families in the periodic table.
(b) State the group number of each family.
(c) Describe a special property of each family.

3. (a) Explain how metal atoms become ions.
(b) Explain how non-metal atoms become ions.

4. Define "stable octet."

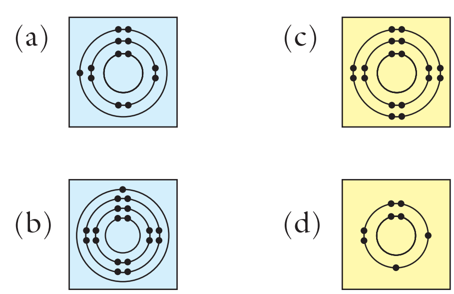
5. (a) Define "multivalent."
(b) Name one metal ion that is multivalent.
(c) Name one metal ion that is not multivalent.

6. Name and give the symbol for each of the following.
(a) the element in period 3 and group 2
(b) the halogen in period 4
(c) the element in period 6 and group 11
(d) the alkali metal in period 2
(e) the noble gas in period 1

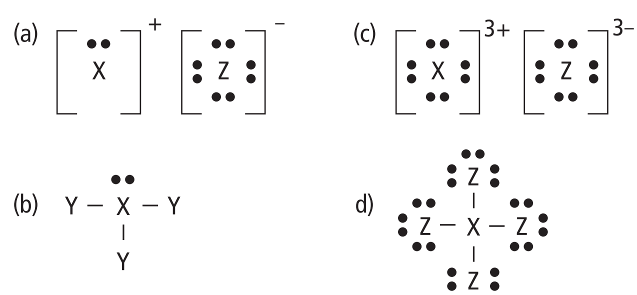
7. Draw a Bohr diagram of the protons and electrons in each of the following.
(a) an atom of magnesium
(b) a chloride ion, Cl^-
(c) a calcium ion, Ca^{2+}
(d) an atom of argon
(e) the ionic compounds lithium fluoride, LiF, and beryllium chloride, $BeCl_2$
(f) the covalent compounds ammonia, NH_3, and methane, CH_4

8. Draw a Lewis diagram for each of the following.
(a) one atom of each of the elements in the second period
(b) one atom of each of the elements in the halogen family (group 17)
(c) the molecules H_2 and F_2
(d) the covalent compounds HF, H_2O, and OBr_2

9. Identify the following atoms from their Bohr diagram.



10. (a) Identify the following compounds as ionic or covalent from their Lewis diagram.
(b) Write a formula for a compound that they might represent using elements with an atomic number less than 21.



11. Copy and complete the following chart in your notebook.

	Reactants	Name	Formula
(a)	sodium and nitrogen		
(b)	magnesium and oxygen		
(c)	aluminum and sulfur		
(d)	gallium and fluorine		
(e)	silver and selenium		
(f)	zinc and chlorine		

12. Write the formula for each of the following compounds involving a multivalent metal ion.
(a) gold(III) fluoride
(b) lead(IV) nitride
(c) copper(I) iodide
(d) nickel(III) sulfide
(e) chromium(II) oxide

13. Write the name for each of the following compounds involving a multivalent metal ion. Remember to include the Roman numeral in the metal ion's name.
(a) $SnCl_4$ (d) Bi_2O_5
(b) Au_3N (e) FeI_3
(c) PbS_2 (f) UF_6

14. Write the formula for each of the following ionic compounds, which may contain a multivalent metal ion or a polyatomic ion.
(a) sodium carbonate
(b) ammonium phosphate
(c) ammonium nitrate
(d) iron(III) nitrite
(e) calcium perchlorate

15. Write the name for each ionic compound.
(a) $Al_2(SO_4)_3$ (d) $Na_2Cr_2O_7$
(b) NH_4CH_3COO (e) KCN
(c) $Fe_2(CrO_4)_3$ (f) $Pb(HS)_2$

16. Write the formula for each covalent compound.
(a) phosphorus pentachloride
(b) nitrogen trichloride
(c) sulfur hexaiodide
(d) tetraphosphorus decaoxide
(e) dinitrogen trioxide

17. Write the name of each covalent compound.
(a) N_2F_4 (c) NBr_3
(b) PBr_3 (d) CO_2

18. Copy and complete the following chart in your notebook.

	Formula	Ionic or Covalent?	Name of Compound
(a)	$CaCl_2$		
(b)	$CuCl_2$		
(c)	SCl_2		
(d)	CoS		

19. List the total number of each type of atoms in the following reactants.
(a) $2HCl + Ca(OH)_2$
(b) $2Na_3PO_3 + 3Ca(NO_3)_2$

20. Balance each of the following skeleton equations.
(a) $KCl + Pb(NO_3)_2 \rightarrow PbCl_2 + KNO_3$
(b) $Na + F_2 \rightarrow NaF$
(c) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
(d) $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

Applying Your Understanding

21. Antoine and Marie-Anne Lavoisier did many chemical experiments involving the metal mercury. In one type of experiment, they put liquid mercury in a jar and sealed it in with oxygen gas. Suppose that, in one of these experiments, they observed that 10.0 g of silver-coloured mercury changed into 10.8 g of a red solid. As the solid formed, the pressure of the oxygen gas decreased.
(a) Why did the pressure drop in the sealed jar?
(b) What mass of gas was consumed in the reaction?
(c) What might be the identity of the new substance?

Pause and Reflect

How did reading this chapter change your understanding of the formation of chemical compounds? Create a graphic organizer showing what you knew (or predicted) before you read this chapter and what you know now.