UNIT B

Chemical Reactions

The energy to launch the Delta II rocket comes from chemical reactions. This rocket is carrying a Canadian communications satellite.

Contents

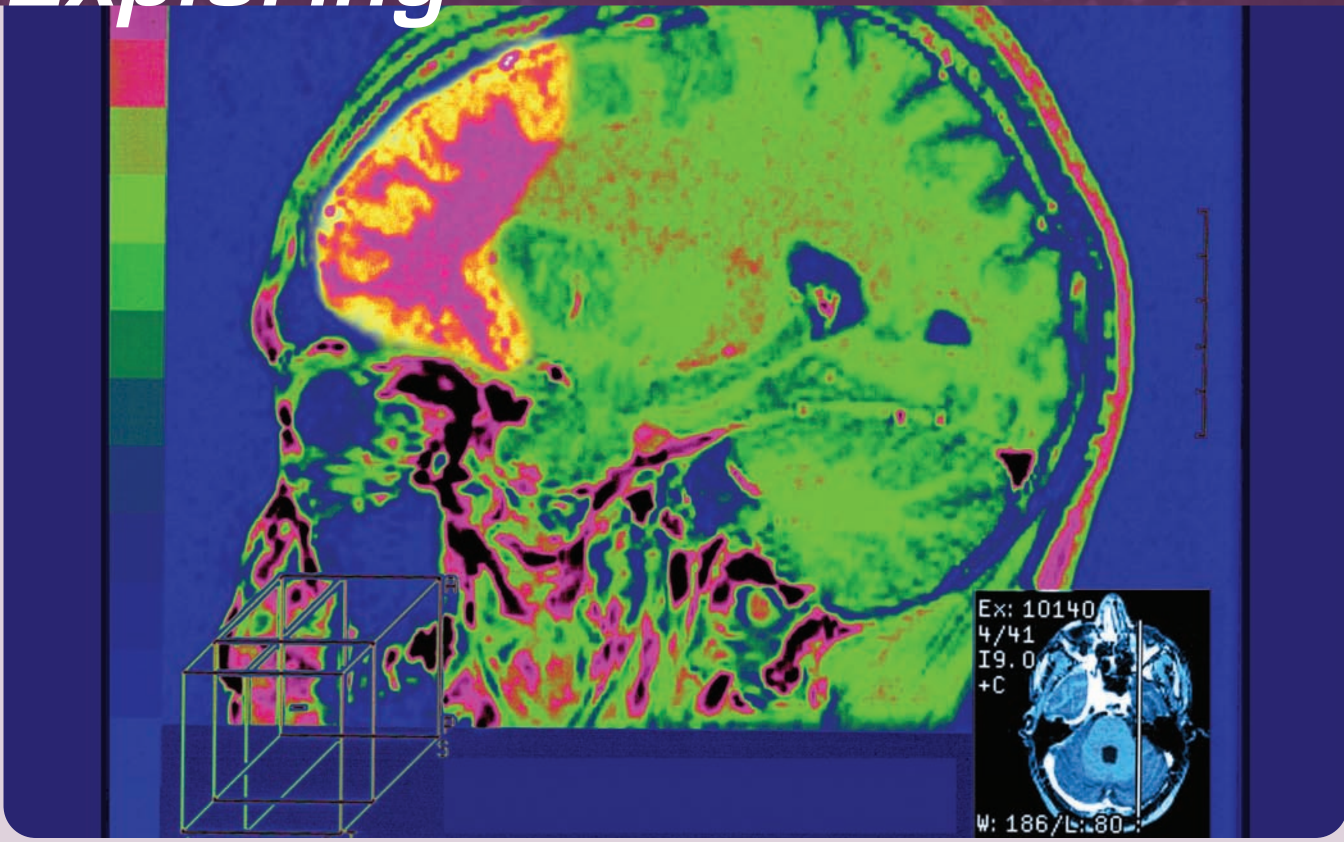
Unit Task

In the Unit Task, you will carry out a number of chemical reactions involving substances that contain magnesium. You will identify the types of substances used in the chemical reactions. You will use this knowledge to predict the results of three different chemical reactions and then test your predictions by carrying out the reactions.

Essential Question

What role do chemical reactions play in my life at home, at school, at work, during leisure activities, and in the environment?

Exploring



This type of brain scan detects areas that are highly active. It can be used to find which parts of the brain are involved in specific mental tasks.

Individuals of the jellyfish species *Aequorea victoria* use a chemical reaction to produce a blue light.

Green fluorescent protein from jellyfish is being used to light up the brains of mice.

Lighting the Brain with Chemistry

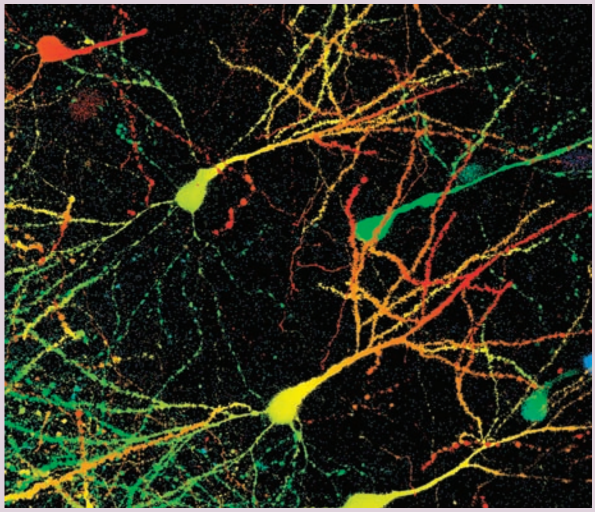
Your brain carries out an incredible number of tasks. As well as being the source of all your thoughts, your brain controls your heart rate, breathing, body temperature, and blood pressure. It co-ordinates the movement of your body and processes all the information from your senses. These functions depend on electrical impulses and involve many different chemical reactions.

We still have an incomplete picture of how the brain works. Brain scans, such as the functional magnetic resonance imaging (fMRI) scan shown above, allow us to see which part of a brain is most active during some task. For example, a patient might be asked to name an object in a photograph or to multiply two numbers during the fMRI scan. However, this technology does not allow researchers to see the working brain in much detail. Recently, the chemistry of a species of jellyfish that glows green has been brought together with genetics and the study of the brain to develop a way of lighting up the brains of mice in great detail.

Green fluorescent protein (GFP) is produced by the jellyfish species *Aequorea victoria*, which lives in the Pacific Ocean (see photo on the left). These jellyfish use a chemical reaction to produce a blue light, which is immediately absorbed by the green fluorescent protein, causing it to glow green.

Colouring Brain Activity

Recently, researchers have been able to transfer the ability of the jellyfish to produce green fluorescent protein to certain mice. The mice were genetically altered by giving them a special modified version of the gene that produces green fluorescent protein in the jellyfish. The result is that genetically altered mice, which look and behave normally in daylight, have brain cells that will glow in up to 90 different colours in blue light, as shown in the photo on the right. Since each individual brain cell is a different colour than the cell beside it, it now possible to identify individual electrical connections inside the brains of these mice. This can, in turn, build knowledge that can help us all to have healthy brains all of our lives.



The differerent colours of fluorescent proteins can be used to detect proteins in the brain, creating a "brainbow."

B1 STSE Science, Technology, Society, and the Environment

How Does Chemistry Improve My Life?

Advances in medicine, such as new prescription and non-prescription drugs, depend on chemistry.

Consider ways in which chemistry and/or knowledge of chemistry has positive effects in your life. For example, new medicines often rely on the synthesis of new chemicals. Chemistry is also at the centre of the development of paints and household cleaners that are less harmful to the environment.

1. In a group, do a two-minute brainstorm. Outline in a list as many ways as you can think of in which chemicals or chemical reactions have improved your life or the lives of those around you.
2. Organize your list into examples that improve your life at home, school, work, and play.
3. Create a mind map or other graphic organizer to share your ideas with others. You may want to use chart paper or a computer program to create your graphic organizer.
4. Look at the work of other groups in your class. You may wish to add some of their ideas to your graphic organizer.
5. As a class, discuss the question: Why is knowledge of chemistry important to me?

4 Chemical change occurs during chemical reactions.

These beautiful Canada Day fireworks are excellent examples of chemical changes. The colours you see depend on the chemical elements used.

Skills You Will Use

In this chapter, you will:

- construct molecular models to illustrate the structure of molecules in simple chemical reactions and produce diagrams of these models
- use an inquiry process to investigate the law of conservation of mass in a chemical reaction
- plan and conduct an inquiry about chemical change

Concepts You Will Learn

In this chapter, you will:

- analyze safety and environmental issues
- analyze how an understanding of the properties and reactions of chemicals can be applied to solve environmental challenges
- describe the relationships between chemical formulas, composition, and names of binary compounds
- explain, using the law of conservation of mass and atomic theory, the rationale for balancing chemical equations
- describe the types of evidence that indicate chemical change
- write word equations and balanced chemical equations
- identify and write the formulas for simple compounds

Why It Is Important

Chemical reactions help to keep your body healthy, sustain the environment, and provide many of the products you use every day. They can also cause negative effects on your health and the environment.

Before Reading

Thinking Literacy

Determining Importance

Readers often have to decide what information is interesting and what is important. This textbook includes features to help you do this. Scan the top of this page, the summary boxes that start each section of this chapter, and any other features that help you determine what is important. Create a web of these features, indicating how each points you towards important information.

Key Terms

- balanced chemical equation • chemical reaction • ion
- ionic compound • law of conservation of mass
- molecular compound • polyatomic ion

4.1 Matter and the Periodic Table

Here is a summary of what you will learn in this section:

- Matter is composed of atoms, which are composed of protons, neutrons, and electrons.
- In the periodic table, the elements are represented by symbols and organized by atomic number.
- According to the Bohr-Rutherford atomic model, protons and neutrons are in the nucleus and electrons occur in shells around the nucleus.
- Atoms can combine to form new substances.

Figure 4.1 Close to 40 percent of Canada's chemical companies are located in the Chemical Valley near Sarnia, Ontario.

Ontario's Chemical Industry and Research

Ontario is a world leader in developing new chemicals and new plastic products. Eight of the 10 largest chemical companies in the world operate in Ontario. Our chemical companies are centred in three major regions of the province: the Greater Toronto area, Ontario East, and Sarnia (Figure 4.1). Chemical manufacturing in Ontario is the province's third-largest manufacturing industry. In 2008, Ontario's chemical industry employed over 50 000 people and produced products worth over $22 billion.

An important part of the chemical industry is the manufacture of plastic and plastic products. Ontario's plastic manufacturing industry employs over 80 000 people and has annual sales of over $18 billion. Consider your own connection to plastic. On a typical day, you likely use several of the following products that involve plastic somewhere in their manufacture: music players, televisions, carpeting, paints and dyes (on walls, pencils, table tops), clothing (made from plastic fibres such as polyester, rayon, and nylon), packaging materials (plastic wrap including food wrap), and cellphones (Figure 4.2).

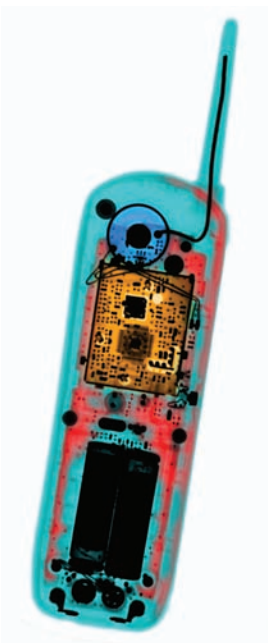


Figure 4.2 The outer case and the electronic boards of a cellphone are all made of plastic.

Chemistry researchers employed by industry, universities, or the government look for new ways to solve everyday problems, including environmental issues. For example, scientists at the National Research Council of Canada Institute for Research in Construction, situated in Ottawa, are investigating ways that we can reduce or prevent concrete roads, bridges, and other structures from corroding. Dr. E.K. Yanful at the University of Western Ontario in London is one of many scientists studying new methods to reduce the environmental impact of the waste from mining operations (Figure 4.3).

The chemical industry is responsible for ensuring that it manufactures products and deals with wastes in a responsible and environmentally friendly manner. Just as we recycle household items that were once considered waste, chemical industries now try to find uses for the different by-products of their processes rather than simply disposing of them.

Companies and government agencies carry out monitoring to ensure that nothing hazardous escapes or is released from manufacturing sites. By gradually raising standards and awareness among chemical producers and communities, we have greatly decreased the negative impacts of industrial production.

Figure 4.3 Dr. E.K. Yanful (P.Eng.) is associate director of the Geotechnical Reseach Centre and professor and chair of the Civil and Environmental Engineering Department at the University of Western Ontario.

B2 *Quick Lab*

What Do I Know about Chemistry?

In this activity, you will create an individual mind map focussed on the question "What do I know about chemistry?" This will help you build a foundation for new learning.

Purpose

To determine what you already know about chemistry

Materials & Equipment

- coloured pens/pencils
- chart paper
- computer (optional)
- graphics program (optional)

Procedure

1. Use chart paper or a computer graphics program. Start your mind map by writing the question "What do I know about chemistry?"
2. Record what you know and what you think you know about chemicals and chemical reactions on your mind map.
3. On the sides or back of your mind map, list any questions you have about chemistry and chemical reactions.
4. When you have completed your mind map, share it with a partner. Add your partner's ideas to your map using another colour.

Question

5. Were there any concepts you thought you knew that you are no longer sure about after working with your partner? If so, add these to the questions on your mind map.

During Reading

Thinking Literacy

Words Indicate Important Ideas

In any sentence, there are *content* words — usually nouns or verbs — that carry the real meaning of the sentence, and *function* words — pronouns, prepositions, articles — that create the sentence structure but carry little meaning. Read several sentences, and find the content words that tell you what is important.

Figure 4.4 Crystals of the mineral quartz. The formation of crystals is a physical property that can be used to classify substances.

Suggested Activity •
B3 Inquiry Activity on page 151

Matter

You and every object around you are made of matter. **Matter** is anything that has mass and takes up space (has volume). Matter does not include any form of energy, such as light, heat, and sound. There are millions of forms of matter that have been discovered or synthesized. To understand more about matter, many substances have been classified according to shared properties.

Physical Properties of Matter

A **physical property** is a property that describes the physical appearance and composition of a substance. Table 4.1 lists common physical properties used for classifying substances.

Table 4.1 Common Physical Properties Used for Classifying Substances

Physical Property	Description
boiling point or **condensation point**	temperature of boiling or condensing
melting point or **freezing point**	temperature of melting or freezing
malleability	ability to be beaten or rolled into sheets without crumbling
ductility	ability to be stretched without breaking
colour	colour
state	solid, liquid, gas
solubility	ability to dissolve in a liquid
crystal formation	crystalline appearance (Figure 4.4)
conductivity	ability to conduct heat or electricity

Chemical Properties of Matter

A **chemical property** is a property that describes the ability of a substance to change into a new substance or substances. Table 4.2 lists some common chemical properties used for classifying substances.

Table 4.2 Common Chemical Properties Used for Classifying Substances

Chemical Property	Description
ability to burn	combustion (flame, heat, light)
flash point	lowest temperature at which a flammable liquid will ignite in air
behaviour in air	tendency to degrade, react, or tarnish
reaction with water	tendency to corrode or dissolve
reaction to heating	tendency to melt or decompose

Pure Substances and Mixtures

All forms of matter can be classified as either a pure substance or a mixture, based on their physical and chemical properties. These two classes can then be further divided, as shown in Figure 4.5.

A **pure substance** is made up of only one kind of matter and has a unique set of properties, such as colour, hardness, melting point, and conductivity. A pure substance is either an element or a compound.

- An **element** is a substance that cannot be broken down into any simpler substance by chemical means. Iron, oxygen, and neon are examples of elements.
- A **compound** is a pure substance that is made from two or more elements that are combined together chemically. For example, methane (CH_4) is a compound containing the elements carbon and hydrogen.

A **mixture** is a combination of pure substances. The proportions of the pure substances in a mixture can vary, so the properties of the mixture vary as well.

- A **homogeneous mixture** is a mixture that looks the same throughout and the separate components are not visible. Solutions are homogeneous mixtures. For example, iced tea is a solution of sugar and other substances dissolved in water (Figure 4.6(a)).
- A **heterogeneous mixture** is one in which different parts of the mixture are visible. In a **suspension**, a cloudy mixture is formed in which tiny particles of one substance are held within another substance. Salad dressing is an example of a suspension (Figure 4.6(b)). Another kind of mixture, called a **mechanical mixture**, may contain several solids combined together, such as in a chocolate-chip cookie.

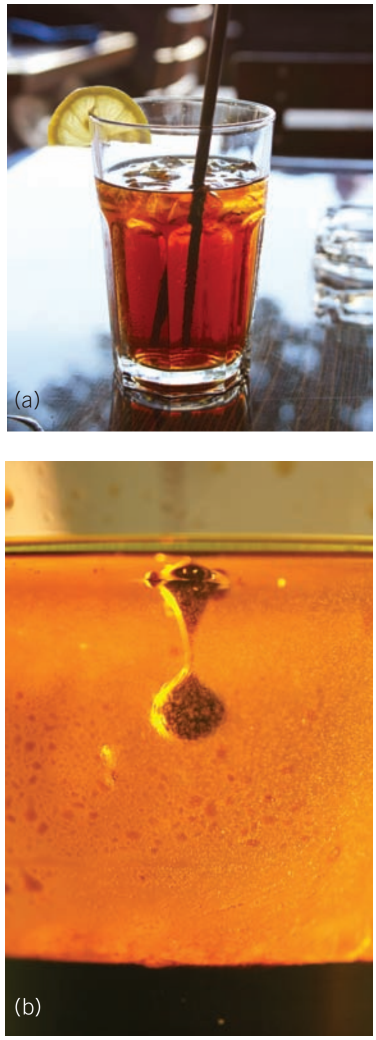
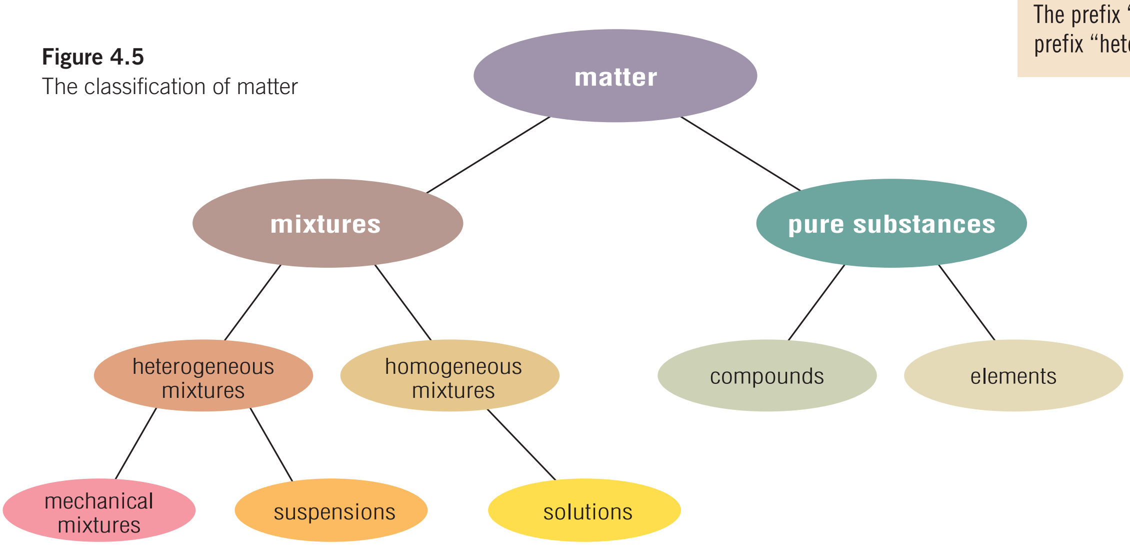


Figure 4.6 (a) Iced tea is a solution of sugar and other substances in water. It is homogeneous. (b) Salad dressing is a suspension of oil in vinegar. It is heterogeneous.

WORDS MATTER

The prefix "homo-" means same. The prefix "hetero-" means different.

Figure 4.5
The classification of matter



Matter Is Made of Atoms

WORDS MATTER

The word "subatomic" is derived from the Latin *sub*, meaning under or smaller than, and the Greek *atomos*, meaning indivisible.

The word "electron" comes from *elektron*, the Greek word for amber.

All matter is made up of tiny particles called atoms. An **atom** is the smallest part of an element that has all the element's properties. For example, gold and silver are both elements. Atoms of gold are similar to each other but different from atoms of silver, giving each element different properties, such as colour.

Atomic Theory

Atomic theory is the study of the nature of atoms and how atoms combine to form all types of matter. Each element has its own unique kind of atom. Atoms of different elements vary in mass, volume, and reactivity. For example, gold atoms are heavier and less reactive than silver atoms.

Atoms are not the smallest particles in matter. Subatomic particles combine together to form atoms. Three subatomic particles (protons, neutrons, and electrons) combine in different combinations to make all known atoms.

Electrons and protons have an electric charge. **Protons** have a positive charge of 1+ . **Electrons** have a negative charge of 1−. Any particle with no charge is called neutral. **Neutrons** are neutral. They can also be said to have a charge of 0.

Like all forms of matter, subatomic particles have mass. The masses of protons and neutrons are almost 2000 times greater than the mass of electrons.

Inside an atom, protons and neutrons are in a tiny central core called a **nucleus** (Figure 4.7). The protons and neutrons are held together by a strong force that exists only in the nucleus. Surrounding the nucleus, and more than 10 000 times larger than it, are a series of cloud-like energy levels called **shells**. These shells are occupied by electrons (Table 4.3).

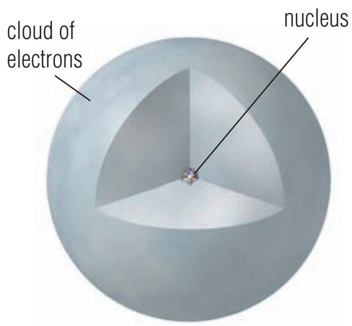


Figure 4.7 Atoms are composed of a tiny, massive nucleus, surrounded by large cloud-like energy levels containing electrons.

Table 4.3 Properties of Subatomic Particles

Name	Symbol	Relative Mass	Charge	Location
Proton	p	1836	1+	nucleus
Neutron	n	1837	0	nucleus
Electron	e	1	1−	in shells surrounding the nucleus

Sulphur — A Typical Atom

Sulphur is an element. Elemental sulphur is a yellow non-metal (Figure 4.8). The basic arrangement of the nucleus and electrons in a sulphur atom is typical of all atoms. The atoms of every element have a unique number of protons. Only sulphur atoms have 16 protons.

Figure 4.9(a) is a Bohr diagram of a sulphur atom. A **Bohr diagram** is an illustration of an atom that shows the arrangement and number of electrons in each shell. A Bohr diagram is named after Niels Bohr, the Danish physicist who made important contributions to the development of atomic theory (Figure 4.10). Figure 4.9(b) illustrates the nucleus of the sulphur atom. In reality, the nucleus is thousands of times smaller than the part of the atom occupied by electrons.

Figure 4.8 Sulphur is a yellow, non-metallic element. Sulphur has many uses, such as in making sulphuric acid. Sulphuric acid is used in vehicle batteries.

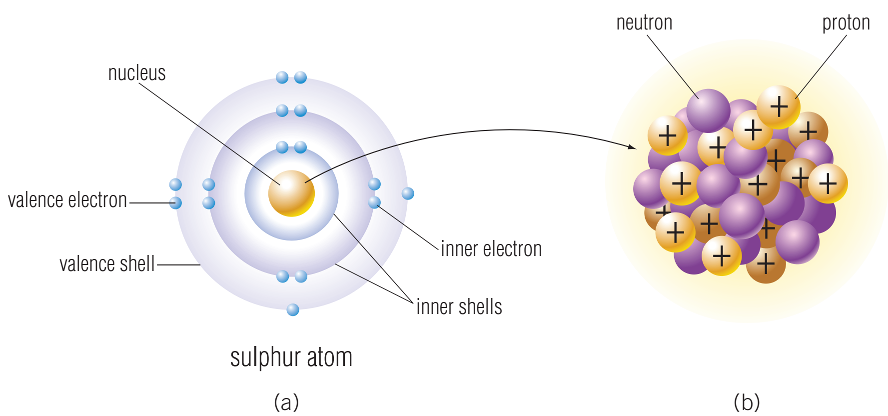


Figure 4.9 (a) A Bohr diagram of sulphur, which contains 16 protons and 16 electrons. The number of neutrons varies between sulphur atoms. (b) A diagram of the nucleus of a sulphur atom

Sulphur atoms have certain properties representative of all atoms:

- Sulphur atoms always have 16 protons. Each different element has its own unique number of protons. Later in this section, a chart called the periodic table will be used to determine the number of protons in any given element.
- Sulphur atoms have 16 electrons, equal to the number of protons. In all atoms, the number of electrons is equal to the number of protons.
- The electrons surround the nucleus in shells. Each shell has a specific energy level. The innermost shell can hold two electrons at most. The next two shells can hold up to eight electrons each. The outermost shell of an atom is called the valence shell. In a sulphur atom, the **valence shell** holds six electrons. The electrons in the valence shell of an atom are called **valence electrons**.

Figure 4.10 Niels Bohr proposed a model of the atom in 1913, when he was 28 years old. In 1922, he received the Nobel Prize in physics for this work.

The Periodic Table of Elements

Figure 4.11 on the facing page shows the periodic table of the elements. The periodic table contains a standard set of symbols to represent the elements, laid out in a specific pattern. It is based on the organization developed by Dmitri Mendeleev in 1869 (Figure 4.12). The periodic table has the following characteristics:

- The horizontal rows of the periodic table are called **periods**.
- The vertical columns are called **families** (or **groups**). Elements in the same family in the periodic table have similar physical and chemical properties.
- Metals are on the left and in the centre of the table. **Metals** are elements with the following properties: they are good conductors of heat and electricity, they are ductile and malleable, they are shiny and usually silver coloured, and all but one are solids at room temperature. Mercury is a metal, but it is liquid at room temperature.
- Non-metals are located on the right-hand side of the table. **Non-metals** are elements that share these properties: they are not metals, and they generally are poor conductors of heat and electricity. At room temperature, some non-metals are solids, some are gases, and one, bromine, is a liquid.
- Metals are separated from non-metals by a staircase of elements called the metalloids. **Metalloids** are elements with properties intermediate between the properties of metals and non-metals.

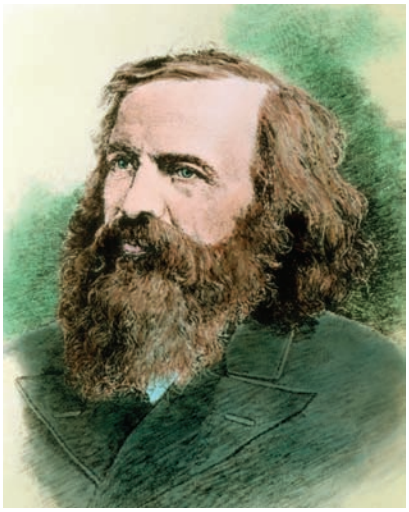


Figure 4.12 Dmitri Mendeleev was the first person to create a table that organized all the elements logically, including those that were undiscovered at the time.

Learning Checkpoint

1. List the name and charge of three subatomic particles.
2. (a) Which two subatomic particles exist together in the nucleus?

   (b) Which subatomic particle is located in shells surrounding the nucleus?
3. The atoms of each element have a unique number of which subatomic particle?

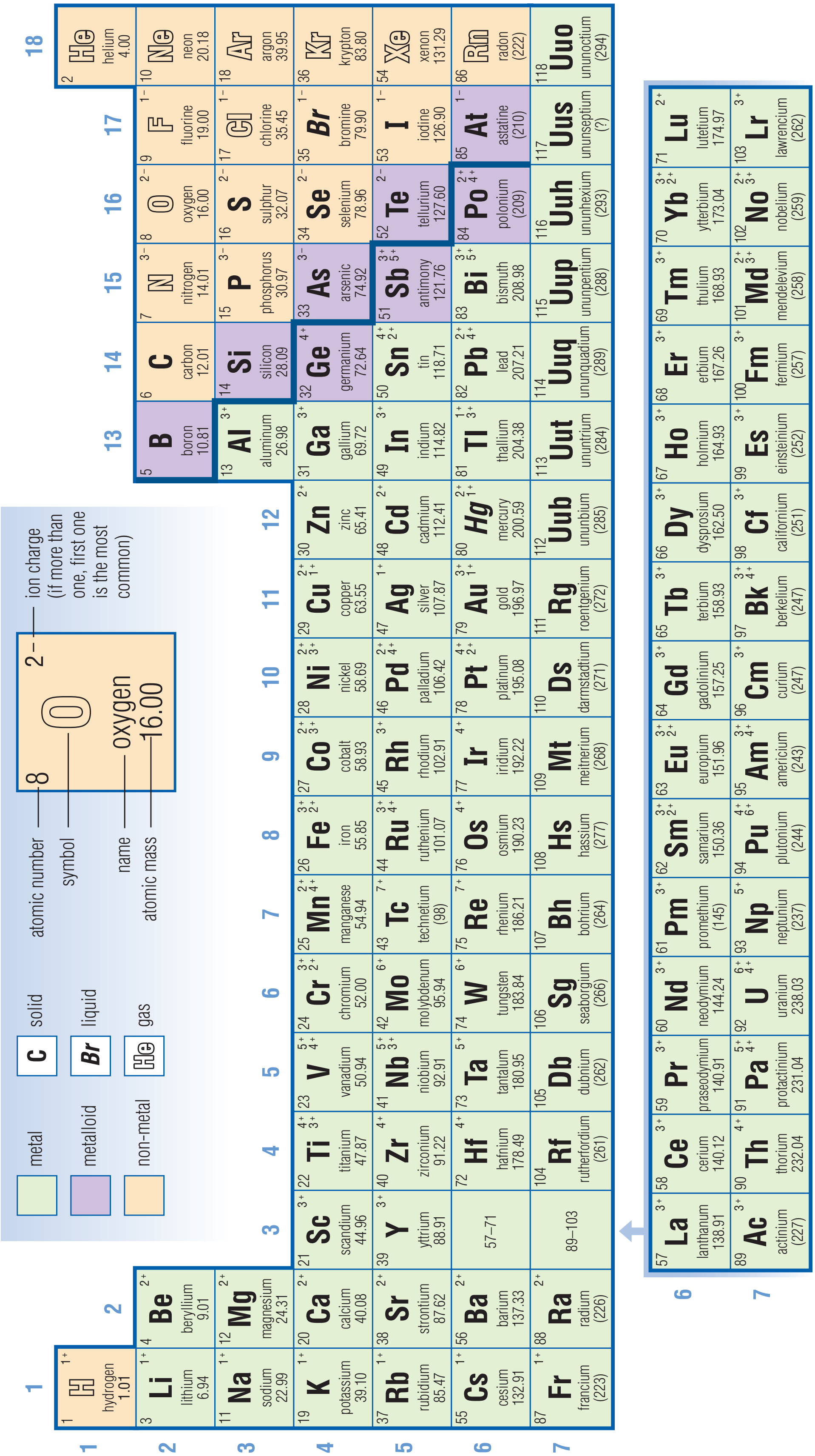


Figure 4.11 The modern periodic table of elements displays the elements and some of their properties in an organized chart.

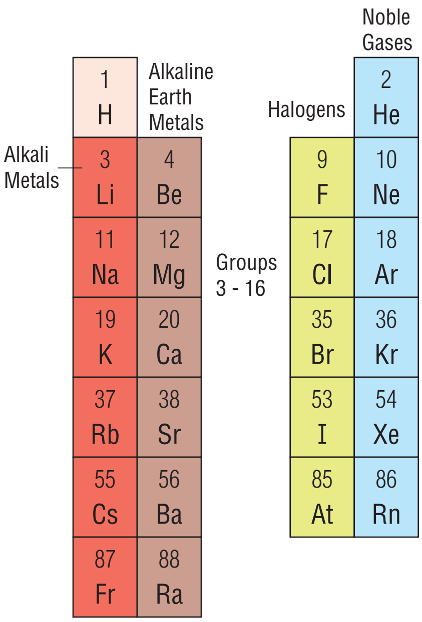


Figure 4.13 Four families in the periodic table are known by both a group number and a special name.

Figure 4.14 Three alkali metals

Four Common Chemical Families

Four common chemical families are known both by their group number and special names. The location of these families in the periodic table is shown in Figure 4.13. As in all chemical families, elements within each family share similar chemical and physical properties.

- **alkali metals** (group 1): soft, silver-grey metals that react easily with water and with oxygen in the air (Figure 4.14). Note that hydrogen is not an alkali metal.
- **alkaline earth metals** (group 2): silver-grey metals that are harder and less reactive than group 1 metals. A reactive atom combines easily with other atoms.
- **halogens** (group 17): coloured non-metals that are very reactive
- **noble gases** (group 18): non-metals that are colourless, odourless gases and very unreactive. An unreactive atom does not combine easily with other atoms.

Learning Checkpoint

Refer to the periodic table (Figure 4.11, page 147) to answer questions 1 to 5.

1. What are the names of the eight elements in period 2 on the periodic table, going from left to right?

2. Other than carbon, what elements are in group 14 on the periodic table?

3. For each of the following, identify the element from the description of its location on the periodic table:

(a) period 1, group 18
(b) period 3, group 2
(c) period 4, group 17
(d) period 2, group 16

4. (a) Which period contains the highest number of non-metals?

(b) What are the names of the non-metallic elements in this period?

5. (a) Which group contains the highest number of non-metals?

(b) List three properties that are common to all the elements in this family.

Elements on the Periodic Table

Each element is represented by a square on the periodic table. For example, Figure 4.15 shows the square that represents copper (see Figure 4.11 on page 147), and Figure 4.16 shows the square that represents fluorine. The information given in the square may vary between different periodic tables, but it usually includes the name, symbol, atomic number, atomic mass, and ion charge of the element. The last three of these are described on the next page.

Atomic Number

The **atomic number** is the number of protons in an atom of an element. The atomic number of copper is 29, so an atom of copper has 29 protons (Figure 4.15). Also, any atom that has 29 protons is an atom of copper. Since all atoms have an equal numbers of protons and electrons, an atom of copper has 29 electrons. The lowest atomic number is 1, which is the atomic number of the element hydrogen (H). Fluorine has an atomic number of nine, so a fluorine atom has nine protons (Figure 4.16).

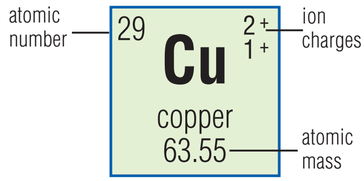


Figure 4.15 Information from the periodic table about an atom of copper (Cu)

Atomic Mass

The **atomic mass** of an element is a measure of the average mass of an atom of that element. Hydrogen atoms have an atomic mass of about 1, which is the lowest of all the elements. The atomic mass of copper is 63.55. This means that the mass of a copper atom is about 64 times the mass of a hydrogen atom. As Figure 4.16 shows, the atomic mass of fluorine is 19.00. This is about 19 times the mass of a hydrogen atom.

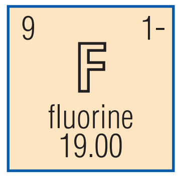


Figure 4.16 Information on the periodic table shows that an atom of the element fluorine (F) has 9 protons, 9 electrons, is about 19 times heavier than an atom of hydrogen, and forms an ion with a charge of 1–.

Ion Charge

An **ion** is an atom or group of atoms with a negative charge or a positive charge. Atoms of some elements can gain or lose electrons during chemical change. An atom that gains electrons becomes a negatively charged ion. An atom that loses electrons becomes a positively charged ion.

For example, if an atom of the metal copper loses two electrons, it becomes a copper ion with an ion charge of 2+. The information on the periodic table shows that a copper atom can form two different ions, one with an ion charge of 2+ and one with an ion charge of 1+. In contrast, an atom of the non-metal fluorine can form only one ion with an ion charge of 1–.

Learning Checkpoint

Refer to the periodic table (Figure 4.11 on page 147) to answer questions 1 to 3.

1. Write the name and symbol for elements with the following atomic numbers:

(a) 1 (b) 11 (c) 17 (d) 29 (e) 92

2. By how many times is the atomic mass of each of the following elements greater than the atomic mass of hydrogen?

(a) helium (b) carbon (c) oxygen (d) lead (e) gold

3. Suppose that atoms of the following elements form ions. Write all the possible ion charges that the ion(s) could have.

(a) lithium (b) oxygen (c) iodine (d) nickel

Patterns in the Arrangements of Electrons

Figure 4.17 shows Bohr diagrams for the first 20 elements of the periodic table. As you examine the Bohr diagrams, look carefully at the electrons in the outer shells. Recall that the outermost electrons are called valence electrons, and the shells they occupy are called valence shells.

- The maximum number of electrons in the innermost shell is two. The maximum number of electrons in the next two shells is eight.
- All atoms of elements in the same group have the same number of valence electrons. For example, all elements in group 1 have one valence electron.
- All atoms of elements in the noble gas family (group 18) have completely full valence shells. In other words, the valence shell of atoms in this group has the maximum number of electrons. As a result, atoms of elements in this family are extremely unreactive.

Suggested STSE Activity
B4 Decision-Making Analysis Case Study on page 152

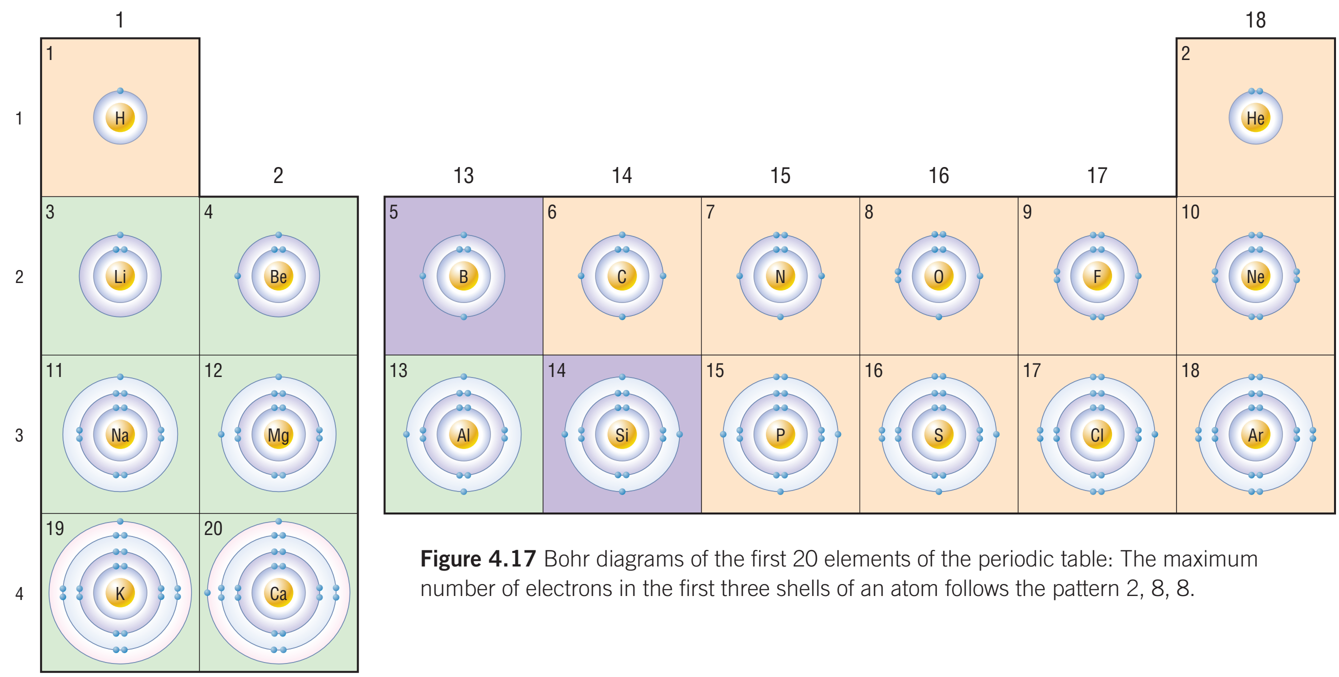


Figure 4.17 Bohr diagrams of the first 20 elements of the periodic table: The maximum number of electrons in the first three shells of an atom follows the pattern 2, 8, 8.

Learning Checkpoint

Refer to Figure 4.17 to answer questions 1 to 3.

1. For each of the following elements, write the total number of electrons and the number of valence electrons in one atom.

(a) lithium (b) nitrogen (c) neon (d) silicon (e) calcium

2. What do all elements of the same period (or row) have in common, with respect to the arrangements of their electrons?

3. Write the name and atomic number of the three elements in Figure 4.17 that have completely filled valence shells.

Take It ***Further***

There is more than one arrangement of the periodic table used today. Find some examples of other ways of representing the periodic table at ***ScienceSource***.

DI Key Activity

B3 *Inquiry Activity* Skills References 1, 2, 6, 9

SKILLS YOU WILL USE

- Gathering, organizing, and recording relevant data from inquiries
- Interpreting data/information to identify patterns or relationships

Water and Calcium

Question

What changes can you observe when you place calcium metal in water?

Materials & Equipment

- medium test tube
- test-tube rack
- water
- candle, in sand on a metal tray
- matches or flame striker
- 2 wooden splints
- calcium metal
- tweezers
- large test tube (must fit over medium test tube)
- blue cobalt chloride paper

CAUTION
- Do not touch the calcium, since it will react with moisture on your hands.
- Tie back any loose hair or clothing.

Procedure

1. Place the medium test tube in the test-tube rack, and then fill it with water to a depth of about 3 cm.

2. Light the candle. Light a wooden splint, and bring it near the mouth of the large test tube. Observe. Put the splint out. Record your observations.

3. Obtain a piece of calcium metal. Use tweezers to handle the calcium metal. Do not touch the calcium metal with your bare hands.

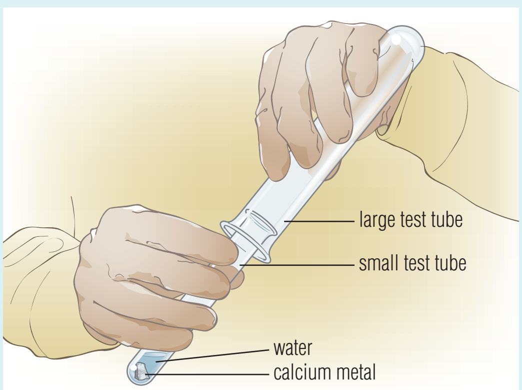


Figure 4.18 Fit the large test tube over the mouth of the medium one.

4. Using the tweezers, place a small piece of calcium metal into the water in the medium test tube. Place the large test tube over the mouth of the medium one, as shown in Figure 4.18. Observe what happens for 30 s. Record your observations.

5. Use the candle to light a wooden splint.

6. Lift the large test tube off the medium tube, keeping the mouth of the large tube facing down. Keep firm hold of the large test tube and be prepared for a reaction. With the large test tube still facing down, bring a lit wooden splint near the mouth of the large test tube. Observe. Put the splint out. Record your observations.

7. Examine the inside surface of the large test tube. Using the tweezers, put a piece of blue cobalt chloride paper inside the large test tube. Record your observations.

8. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Analyzing and Interpreting

9. Make a table of the changes you observed when the calcium metal was placed into water.

10. What was the purpose of testing the large test tube with a lighted splint in step 2?

11. Blue cobalt chloride paper changes to pink in the presence of water. Explain what you observed in step 7.

12. What information in section 4.1 helps you interpret any changes you observed?

Skill Practice

13. Suggest why you must be careful to avoid touching calcium metal.

Forming Conclusions

14. What evidence do you have that one or more new pure substances was produced?

CASE STUDY

B4 **STSE** ***Decision-Making Analysis*** **Skills References 4, 5, 6**

SKILLS YOU WILL USE
- Justifying conclusions
- Identifying bias

Ada Lockridge and the Chemical Valley

Issue

Why is knowledge about chemicals and chemical reactions important to everyone in society?

Background Information

Chemicals play an important role in business in Ontario. Ontario's chemical industry directly employs over 50 000 people, who created and sold products worth over $22 billion in 2008. In addition, almost two dozen manufacturing sectors depend on the chemical industry, including food processing, aerospace, alternative energy, automotive, chemical manufacturing, environmental services, pharmaceuticals, and mining. Therefore, the chemical industry has had many positive effects on Ontario's economy.

However, as with many human activities, the chemical industry can have unintended negative effects. Ada Lockridge knows this more than most people (Figure 4.19). Lockridge grew up in Aamjiwnaang First Nation Reserve near Sarnia, Ontario. Here, 62 different chemical plants make up Canada's Chemical Valley, which surrounds the reserve. Like many residents of the area, Lockridge first ignored the strong smells and occasional chemical spills and accidents. As the years went by and she had children of her own, Lockridge grew concerned that there might be negative environmental effects from chemicals released from the Chemical Valley.

In 2003, Lockridge learned from biologist Michael Gilbertson that the environment of the reserve had higher-than-normal levels of certain chemicals that could be hazardous to human health. Some of these chemicals were known to affect the number of male babies born. Were these chemicals affecting the health of the Aamjiwnaang First Nation community?

To answer that question, Lockridge checked the birth records for her reserve. The results were shocking. Between the mid-1990s and 2003, the number of male babies had dropped off significantly.

Figure 4.19 Ada Lockridge

In 2005, in the well-respected journal *Environmental Health Perspectives*, Lockridge and her colleagues published a paper relating the skewed birth ratio to chemicals in the environment.

Analyze and Evaluate

1. Answer the question posed under the heading "Issue." Support your answer using the information in this activity.
2. **Web 2.0** Develop your answer as a Wiki, a presentation, a video, or a podcast. For support, go to ***ScienceSource***.
3. Would you expect an employee of a chemical plant to come to the same conclusions about the health problems on the Aamjiwnaang First Nation Reserve as Lockridge and her colleagues? Why?
4. *Environmental Health Perspectives* is a peer-reviewed journal. A peer-reviewed journal is one in which expert scientists must review and approve research before it is published. Do you think it was important for Lockridge and her colleagues to publish their research in a peer-reviewed journal? Why?

Skill Practice

5. Identify any sources of bias in this report.

4.1 CHECK and REFLECT

Key Concept Review

1. Name two properties of matter.
2. What are the two categories of pure substances in the matter classification tree shown in Figure 4.5 on page 143?
3. How is an element different from a compound?
4. Name four families of elements in the periodic table.
5. What is the relationship between an element's atomic number and the number of protons in the nucleus of each of its atoms?
6. Name three types of subatomic particles, and then state the charge on each.
7. What is an ion?

Connect Your Understanding

8. Invent and describe a simple way to remember that a horizontal row on the periodic table is called a period and a vertical column is called a family or group. For example, you could use a sentence, an image, or word association.
9. Design and draw a table to compare the names and characteristics of the three subatomic particles described in this section.
10. Draw a Bohr diagram of an atom that has five protons, six neutrons, and five electrons. Using the periodic table on page 147, identify the element. Label the nucleus, the subatomic particles, and the valence shell.
11. The atomic number of lithium is 3, and the atomic number of neon is 10.
    (a) Draw a Bohr diagram of a lithium atom and of a neon atom.
    (b) How many valence electrons are in the lithium atom and in the neon atom?
12. Compare the structure of atoms to the structure of something else in everyday life. For example, you could compare an atom to an onion. Use as many of the chemistry terms in this section as you can.
13. Suppose you place a kettle on the stove and boil some water. Is the steam that forms evidence of a chemical change or a physical change? Explain.
14. The photo shows what happens when calcium metal is placed in liquid water. Suggest whether a chemical or a physical change occurs when this happens. Explain.

Question 14

Reflection

15. Describe three things about atoms that you did not know before starting work on this section.

For more questions, go to ***ScienceSource***.

4.2 Ions, Molecules, and Compounds

Here is a summary of what you will learn in this section:

- An ion is any atom (or group of atoms) that has lost or gained one or more electrons.
- All ions have either a positive or a negative charge.
- Metals and non-metals combine to form ionic compounds.
- Molecules can form between atoms of the same non-metal.
- Molecular compounds form between at least two different non-metal atoms.

Figure 4.20 Laptop computers first become truly portable in 1999, when ion batteries became more widely available.

Powering Up with Lithium Ions

Many devices rely on a portable power source, including calculators, cellphones, handheld music and video players, and laptops (Figure 4.20). Most portable power sources use ions to generate electrical energy. Ions are electrically charged atoms or groups of atoms. They form when electrons are traded between atoms of different elements. Ions are actually forming around us all the time. For example, when iron atoms and oxygen atoms interact in the presence of salt and water, the iron corrodes and rust is formed. As iron corrodes, iron ions and oxygen ions are formed. Iron ions have a positive charge, and oxygen ions have a negative charge. The formation of these ions releases energy, but the energy is lost when a car body turns to rust.

When corrosion happens inside the tiny battery inside a hearing aid, however, the energy is not lost. This type of battery uses the corrosion of zinc by oxygen to produce enough electricity to power the speaker and microphones in the hearing aid. As zinc ions form during corrosion, electrons are released. These electrons travel from the battery and through the components of the hearing aid, providing electrical energy. The electrons travel back to the other pole of the battery and toward oxygen atoms in the air, completing the electrical circuit.

Ion batteries depend on atoms of reactive metals. The more reactive the metal, the more electrical energy they can potentially produce. Lithium metal is far more reactive than either iron or zinc metal. Lithium ion batteries are therefore able to supply far more electrical energy than ion batteries made from these other metals. However, the reactivity of lithium initially caused problems. Early lithium ion batteries produced a lot of heat and sometimes hydrogen gas. This sometimes caused these early batteries to catch fire or explode while in use. These problems have been eliminated in lithium-based batteries. Fortunately, battery technology constantly changes. Lithium ion batteries are now so safe that they are used in medical devices such as pacemakers (Figure 4.21).

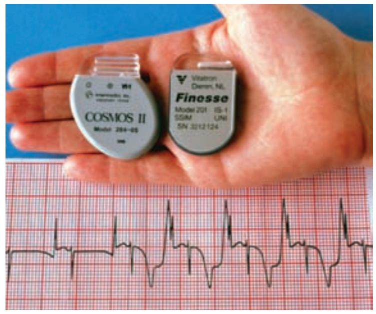


Figure 4.21 The medical devices pictured here are called artificial pacemakers. Each one has a battery that uses ions to produce electricity. People whose natural pacemaker in their heart does not function properly may use an artificial pacemaker.

B5 *Quick Lab*

Solubility of Chemical Compounds

In this activity, you will divide four compounds into groups by determining if they are soluble in water at room temperature.

Purpose

To observe the solubility of four compounds

Materials & Equipment

- 4 test tubes
- test-tube rack
- waterproof marker
- water
- 10-mL graduated cylinder
- scoopula
- single chip of calcium carbonate
- piece of candle wax
- sodium chloride
- sugar

Procedure

1. Place the test tubes in the test-tube rack. Using the graduated cylinder, measure and add 5 mL of room temperature water to each test tube.
2. Using the scoopula, place a few crystals of sodium chloride into the water in a test tube. Observe whether any crystals dissolve (Figure 4.22). The fewer the number of crystals you place in the test tube, the easier it will be to observe if any dissolve.
3. Record your observations.
4. Repeat steps 2 and 3 for each of the remaining three substances.
5. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Questions

6. Which substance was most soluble? Which was least soluble? Explain how you decided.
7. Do you think that the property of solubility is enough to identify the compounds? If yes, explain. If no, suggest other properties that might be helpful in identifying these compounds.

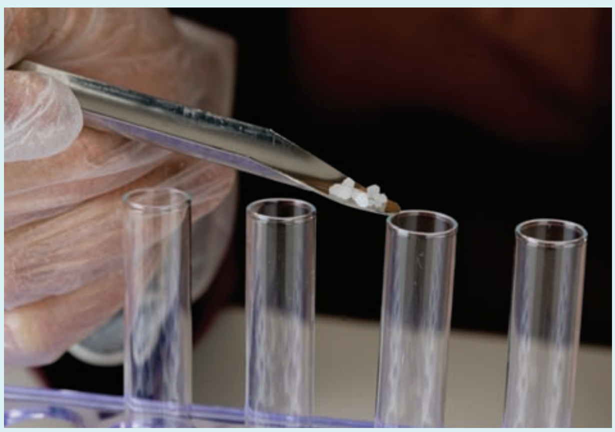


Figure 4.22 Add a few crystals, and then observe whether they dissolve. You can gently swirl the test tube.

During Reading — Thinking Literacy

Text Features Indicate Important Ideas

Textbook authors give you clues about what is important by using special text features. Words may be in bold type. Charts summarize important information. Diagrams and pictures help you to see and understand objects and concepts. Make a note of four text features and how they helped you to understand new information and ideas.

Compounds: Ionic and Molecular

A compound is a pure substance made up of two or more elements, in which the elements are chemically combined. For example, water (H_2O) is a compound that consists of the elements hydrogen and oxygen. In it, the hydrogen atoms are joined to the oxygen atoms by connections called chemical bonds. There are two main types of compounds: ionic compounds and molecular compounds.

Ionic Compounds

Recall that an ion is an atom or group of atoms that has either a positive charge or a negative charge. An **ionic compound** is a compound that is formed from one or more positively charged ions and one or more negatively charged ions.

Ions form when atoms of different elements combine in a process involving the transfer of electrons from one atom to another. For example, this process occurs when atoms of sodium metal combine with atoms of chlorine to form sodium chloride, which is commonly called table salt (Figure 4.23). During the formation of sodium chloride, one electron is transferred from a sodium atom to a chlorine atom. This is illustrated by Bohr diagrams in Figure 4.24. Each sodium metal atom loses one electron and becomes a positively charged ion, which is symbolized as Na^+. The symbol " + " is written as a superscript to indicate that the sodium has a charge of 1+. Each chlorine atom gains one electron to become a negatively charged ion. A chlorine ion is symbolized as Cl^-, where the "–" indicates a charge of 1–.

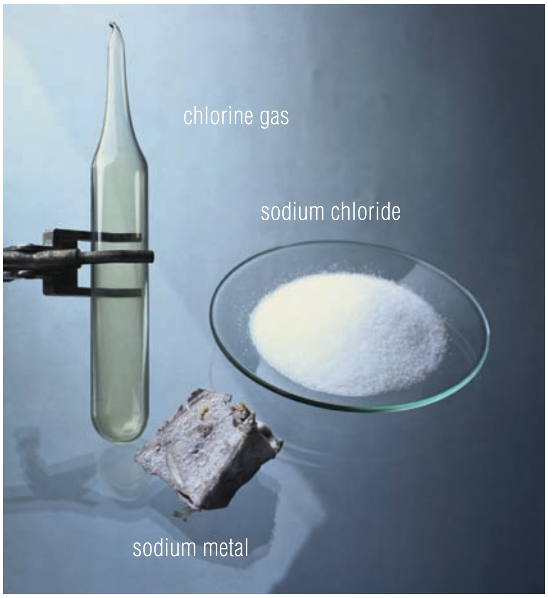


Figure 4.23 Sodium metal and chlorine gas react to form the ionic compound sodium chloride (NaCl).

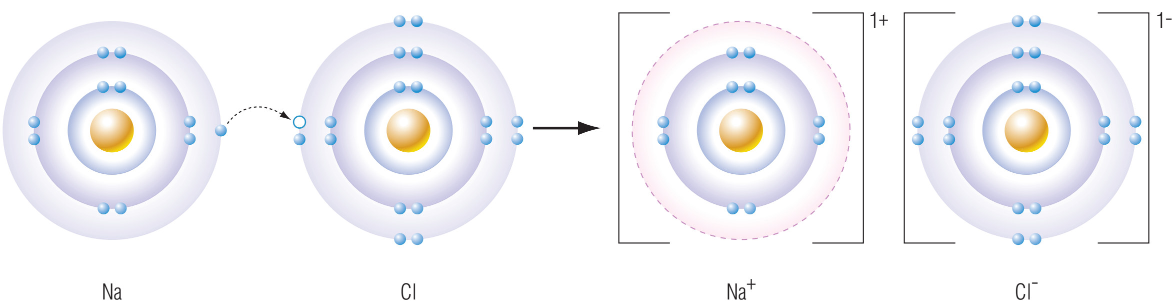


Figure 4.24 Bohr diagrams can be used to show the transfer of an electron from a Na atom to a Cl atom. This process forms the ions Na^+ and Cl^-.

Notice in Figure 4.24 (on the previous page) that both ions have eight electrons in their outermost shells. Ions often form in a way that produces filled outermost shells. Metal atoms tend to lose electrons, while non-metal atoms tend to gain them. Often, all that is needed for this to happen is for atoms of the two elements to be brought together.

Ionic compounds have a number of properties in common.

- At room temperature, most are hard, brittle solids that can be crushed.
- Ionic compounds form crystals that have an alternating arrangement of positively charged ions and negatively charged ions (Figure 4.25). As a result, when ionic crystals are broken, flat surfaces and well-defined edges are formed.
- In an ionic crystal, every ion is attracted to every other ion in the crystal. As a result, ionic crystals have very high melting points. For example, sodium chloride melts at 800°C.
- When an ionic compound dissolves in water, the crystal structure breaks down and the ions become free to move. Solutions of ionic compounds therefore conduct electricity.

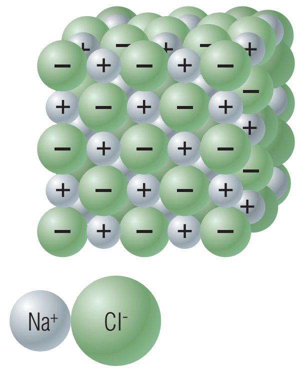


Figure 4.25 The structure of crystals of sodium chloride

Ion Symbols and Names

Not all atoms will form ions, and some atoms can form an ion in more than one way. Information on the periodic table shows the ion charge of ions that will form for each element (see Figure 4.11 on page 147). Table 4.4 shows some examples of ions of some elements.

Table 4.4 Some Examples of Ions

Element	Ion Charge	Symbol	Name
sodium	1+	Na^{+}	sodium
calcium	2+	Ca^{2+}	calcium
aluminum	3+	Al^{3+}	aluminum
fluorine	1–	F^{-}	fluoride
oxygen	2–	O^{2-}	oxide
nickel	2+ 3+	Ni^{2+} Ni^{3+}	nickel(II) nickel(III)
lead	2+ 4+	Pb^{2+} Pb^{4+}	lead(II) lead(IV)
gold	3+ 1+	Au^{3+} Au^{+}	gold(III) gold(I)

Ion Symbols

To write the symbol for an ion, write the symbol of the element and show the ion charge as a superscript. For example, the symbol of a calcium ion is Ca^{2+}. When an ion has a charge of 1+ or 1–, the symbol has no number in the superscript, such as for Na^+ and F^-.

Ion Names

When an element can form only one type of ion, such as calcium, the ion has the same name as the element. However, the atoms of many metals can form more than one type of ion. For example, an atom of copper can form one of two different ions, one with a charge of 1+ or one with a charge of 2+.

A **multivalent element** is an element that can form an ion in more than one way. Many metal elements are multivalent. The name of an ion of a multivalent element always contains a Roman numeral that indicates the ion charge. Table 4.5 shows the numbers one to seven written as Roman numerals.

For example, Cu^+ is named copper(I), which is read as "copper one." Similarly, Cu^{2+} is named copper(II), which is read "copper two." Copper(II) ions are found in the ionic compound copper(II) chloride (Figure 4.26). Only multivalent metals have Roman numerals in their names.

Figure 4.26 Crystals of the ionic compound copper(II) chloride

Table 4.5 Some Roman Numerals

Number	Roman Numeral
1	I
2	II
3	III
4	IV
5	V
6	VI
7	VII

Learning Checkpoint

Refer to the periodic table in Figure 4.11 on page 147 to answer questions 1 and 2.

1. Write the symbol for the following ions:

(a) magnesium
(b) chloride
(c) iron(II)
(d) chromium(III)
(e) uranium(VI)

2. Write the name of the following ions:

(a) Zn^{2+}
(b) N^{3-}
(c) Co^{2+}
(d) Co^{3+}
(e) Pb^{4+}

Naming Ionic Compounds

Use the following rules to name an ionic compound from its formula.

1. Name the metal ion first. The name of the metal ion is the same as the element name. For example, in KBr, the name of the K+ ion is potassium. If the element can form an ion in more than one way, include a Roman numeral to indicate the charge.
2. Name the non-metal ion second. When a non-metal becomes a negative ion, the ending of its name changes to "ide." For example, a brom**ine** atom (Br) gains an electron to become a brom**ide** ion (Br^-).
3. Name the ionic compound by combining the ion names. The name of KBr is, therefore, potassium bromide.

Name of metal	Name of non-metal + ide
potassium	**bromide**

WORDS MATTER

"Subscript" derives from the Latin word *subscribere*, which means written below.

Table 4.6 shows some examples of how these rules are applied. The formulas of ionic compounds often contain numbers, called subscripts, such as the "3" in Na_3P. (You will find out what subscripts mean later in this section.) If the metal forms only one type of ion, the subscript can be ignored when determining the name.

Table 4.6 Naming Ionic Compounds

Formula	Positive Ion	Negative Ion	Name
CaS	Ca^{2+}	S^{2-}	calcium sulphide
$MgCl_2$	Mg^{2+}	Cl^-	magnesium chloride
Na_3P	Na^+	P^{3-}	sodium phosphide

Example Problem 4.1

Write the name of the ionic compound ZnF_2.

1. Name the metal ion: Zn forms only one type of ion (Zn^{2+}), so the name is zinc.
2. Name the non-metal ion: The atom is fluorine, so the ion is fluoride.
3. Combine the names: zinc fluoride.

Practice Problems

Write the names of the following ionic compounds.

1. LiBr
2. CaI_2
3. Al_2O_3
4. Mg_3N_2

Compounds Containing Multivalent Elements

Recall that the name of an ion of a multivalent element always contains a Roman numeral to indicate its charge. For example, the name nickel(II) sulphide indicates that the Ni^{2+} ion forms the compound, while the name nickel(III) bromide indicates that the Ni^{3+} ion is present.

Figure 4.27 Chromium(III) chloride is used in the manufacture of coloured glass.

You can determine which Roman numeral to use in the name of a multivalent ion from the subscript(s) in the compound's formula. For example, the subscript 3 in the formula $CrCl_3$ is a guide to the charge of the chromium ion in this compound. There is a special relationship between the numbers of positive and negative charges in any ionic compound. All ion charges in an ionic compound must add up to zero. Another way of saying this is that although an ionic compound is made up of charged particles, the compound itself has no net charge.

From this, we get the following rule:

- The positive and negative charges in an ionic compound must be equal.

According to this rule, a Cr^{3+} ion must always combine with three Cl^- ions, which gives the 1:3 ratio in the formula. The name of $CrCl_3$ is written as chromium(III) chloride. Chromium(III) chloride is a beautiful colour and is used to colour glass (Figure 4.27).

Practice Problems

Write the names of the following ionic compounds.

1. $FeCl_2$
2. $FeCl_3$
3. Cu_3N_2
4. Ni_2O_3

Example Problem 4.2

Write the name of the ionic compound TiI_4.

1. Identify the ions that form the compound: Ti^{4+} and I^-.
2. Use the charge on the non-metal ion and the rule that the total positive and negative charges in the formula must be equal.
   - One titanium ion is present in the formula, so it must have a charge of $4+$.
3. Name the metal ion.
   - The ion has a $4+$ charge, so the name is titanium(IV).
4. Name the non-metal ion.
   - The name of the atom is iodine, so the ion is iodide.
5. Combine the names: titanium(IV) iodide.

Polyatomic Ions

A **polyatomic ion** is a group of atoms, usually of different elements, that act as a single ion. For example, one atom of sulphur and four atoms of oxygen form the polyatomic ion called sulphate, or SO_4^{2-}. This ion is present in many compounds. For example, the sulphate ion is combined with the lead(II) ion in $PbSO_4$, which is used in car batteries, with the copper(II) ion in $CuSO_4$, which can kill fungus, and with the magnesium ion in $MgSO_4$, which is called Epsom salts and is added to bathwater.

Similar polyatomic ions are named using the suffixes "-ate" or "-ite." For example, nitrate (NO_3^-) is similar to nitrite (NO_2^-). Compounds that contain nitrates and nitrites are present in many preserved foods, such as hot dogs (Figure 4.28).

Most common polyatomic ions have a negative charge. However, one common polyatomic ion has a positive charge. The ammonium ion, NH_4^+, is composed of one nitrogen atom and four hydrogen atoms and it has a charge of 1+. Examples of common polyatomic ions are given in Table 4.7.

In some cases, the formula of an ionic compound uses brackets to help identify the polyatomic ion. Table 4.8 gives some examples and hints for writing the names of ionic compounds with polyatomic ions.

Figure 4.28 Preserved meats, such as hot dogs, stay red due to the addition of potassium nitrate and sodium nitrite.

Table 4.7 Common Polyatomic Ions

Name	Formula
ammonium	NH_4^+
carbonate	CO_3^{2-}
hydrogen carbonate (bicarbonate)	HCO_3^-
hydroxide	OH^-
nitrate	NO_3^-
nitrite	NO_2^-
permanganate	MnO_4^-
phosphate	PO_4^{3-}
phosphite	PO_3^{3-}
sulphate	SO_4^{2-}
sulphite	SO_3^{2-}

Table 4.8 Naming Ionic Compounds with Polyatomic Ions

Formula	Positive Ion	Negative Ion	Name	Hint for Writing Name
$Al(OH)_3$	Al^{3+}	OH^-	aluminum hydroxide	• The polyatomic ion is often found in brackets.
$NiSO_4$	Ni^{2+}	SO_4^{2-}	nickel(II) sulphate	• Brackets are not always used. • Everything after the metal is part of the polyatomic ion.

Example Problem 4.3

Write the name of the ionic compound $LiHCO_3$.

1. Name the metal ion (or ammonium ion).
   - Li forms only one type of ion (Li^+), so the name is lithium.
2. Identify the polyatomic ion by examining the formula and cross-checking with the table of common polyatomic ions.
   - The name for HCO_3^- is hydrogen carbonate.
3. Combine the names: lithium hydrogen carbonate.

Practice Problems

Using Table 4.8, write the names of the following ionic compounds.

1. $Al_2(SO_4)_3$
2. $Ca_3(PO_4)_2$
3. $Fe(OH)_2$
4. $(NH_4)_2S$

Writing Formulas for Ionic Compounds

It is possible to write the chemical formula for an ionic compound from its name. In many cases, the chemical formula must include one or more subscripts. In the formula of an ionic compound, a subscript tells you the ratio of each ion that is in the compound. When there is no subscript, there is only one of that ion.

For example, in the formula for aluminum trioxide, Al_2O_3, there is a subscript 2 next to the symbol Al and subscript 3 by the symbol O. Aluminum oxide therefore contains two aluminum ions for every three oxygen ions. The semi-precious stone called sapphire is composed mainly of Al_2O_3. The blue colour is produced by trace impurities, such as the element chromium (Figure 4.29).

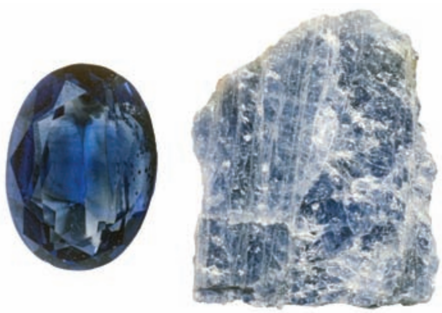


Figure 4.29 Sapphires are composed mostly of aluminum oxide.

How do you determine if the chemical formula includes a subscript? Recall the rule that the positive and negative charges in an ionic compound must be equal. If the charges are not equal, add ions until the charges are balanced. Indicate in the formula the total number of each ion with a subscript. If there is only one of an ion, do not add a subscript.

Table 4.9 presents steps for writing the formulas for ionic compounds and shows how they are used in three examples.

Table 4.9 Steps for Writing Formulas for Binary Ionic Compounds

Steps	**Examples**		
	calcium bromide	**magnesium nitride**	**copper(II) oxide**
1. Examine the name of the compound. Identify the ions and their charges.	calcium: Ca^{2+} bromide: Br^-	magnesium: Mg^{2+} nitride: N^{3-}	copper(II): Cu^{2+} oxide: O^{2-}
2. Determine the number of each ion needed to balance the charges.	Ca^{2+} Br^- Br^-	Mg^{2+} Mg^{2+} Mg^{2+} N^{3-} N^{3-}	Cu^{2+} O^{2-}
3. Note the ratio of positive to negative ions, and write the formula.	1 to 2	3 to 2	1 to 1
4. Write the chemical formula, using subscripts if needed.	$CaBr_2$	Mg_3N_2	CuO

Example Problem 4.4

Write the formula for aluminum oxide.

1. Identify the ions and their charges: Al^{3+} and O^{2-}.
2. Determine the number of each ion needed to balance the charges.

   Al^{3+} Al^{3+} O^{2-} O^{2-} O^{2-}
3. Note the ratio of positively charged ions to negatively charged ions, and write the formula: Al_2O_3.

Practice Problems

Write the formulas for the following ionic compounds.

1. potassium iodide
2. magnesium phosphide
3. silver sulphide
4. iron(III) bromide

Formulas for Compounds with Polyatomic Ions

The rules for writing formulas for compounds containing polyatomic ions are similar to the rules for other ionic compounds. The rule is still that the positive and negative charges in an ionic compound must be equal. The main difference is that brackets may be used to show the ratio of ions. For example, in $Cr(HCO_3)_3$, there is one Cr^{3+} ion for every three HCO_3^- ions.

Table 4.10 shows how to identify ions for four examples of this type of ionic compound and how to write their formulas. Consider calcium carbonate, a common ingredient in antacids (Figure 4.30). Notice that for calcium carbonate, the 2+ charge on the Ca^{2+} balances the 2– charge on the polyatomic ion CO_3^{2-}. Since there is one Ca^{2+} for every CO_3^{2-}, the formula for calcium carbonate is $CaCO_3$. Brackets are not needed.

Suggested Activity •
B6 Quick Lab on page 169

Figure 4.30 Calcium carbonate is commonly used in antacids.

Table 4.10 Examples of Polyatomic Ions in Formulas

Name	calcium carbonate	ammonium sulphide	iron(III) hydroxide	ammonium phosphate
Ions	Ca^{2+} CO_3^{2-}	NH_4^+ S^{2-}	Fe^{3+} OH^-	NH_4^+ PO_4^{3-}
Ratio of Ions	Ca^{2+} CO_3^{2-}	NH_4^+ NH_4^+ S^{2-}	Fe^{3+} OH^- OH^- OH^-	NH_4^+ NH_4^+ NH_4^+ PO_4^{3-}
Formula	$CaCO_3$	$(NH_4)_2S$	$Fe(OH)_3$	$(NH_4)_3PO_4$

Practice Problems

Write the formulas for the following ionic compounds.

1. magnesium hydroxide
2. sodium sulphate
3. lead(IV) nitrate
4. ammonium carbonate

Example Problem 4.5

Write the formula for nickel(II) phosphate.

1. Identify the ions and their charges: Ni^{2+} and PO_4^{3-}.
2. Determine the number of each ion needed to balance the charges.

   Ni^{2+} Ni^{2+} Ni^{2+} PO_4^{3-} PO_4^{3-}
3. Note the ratio of positively charged ions to negatively charged ions.

   three Ni^{2+} for every one PO_4^{3-}
4. Use the ratio to determine what subscripts to use. If a subscript is needed for a polyatomic ion, include brackets and place the subscript outside the brackets.

   A subscript of 3 is needed after the Ni^{2+}.
   A subscript of 2 outside a bracket is needed for PO_4^{3-}.
5. Write the formula: $Ni_3(PO_4)_2$.

WORDS MATTER

The word "diatomic" is formed from the prefix "di-" (two) and the word "atomic" (made of atoms).

Molecular Elements

A **molecule** is a combination of two or more atoms held together by covalent bonds. A **covalent bond** is a connection, usually between the atoms of non-metals, in which the two atoms share a pair of electrons. The electron pair belongs to both atoms, and the attraction of the atoms for the same electron pair holds them together.

Several important non-metals exist as molecules. In a **molecular element**, two or more atoms, all of the same element, are joined by covalent bonds. A **diatomic molecule** is a molecule that is made from two atoms. For example, the element chlorine is a molecular element that exists as a diatomic molecule (Figure 4.31).

The formulas for diatomic molecules contain a subscript. In the formula of a molecule, a subscript tells you the number of each atom in the molecule. A chlorine molecule is symbolized as Cl_2. The subscript 2 indicates that two chlorine atoms are present. Other non-metal elements exist as molecules too. The elements oxygen and nitrogen, which form 99 percent of the air, are also diatomic.

Figure 4.31 Elemental chlorine is a diatomic molecule (Cl_2). Chlorine dissolves in water and is used to disinfect water in drinking supplies and swimming pools.

Figure 4.32 uses Bohr diagrams to illustrate the sharing of electrons in a covalent bond between two chlorine atoms. Table 4.11 shows the elements that commonly exist as diatomic molecules.

Another form of oxygen is called ozone and has the formula O_3. Ozone is essential in the upper atmosphere to filter out deadly UV rays. At ground level, O_3 is a pollutant. The elements hydrogen, sulphur, phosphorus, nitrogen, and all the halogens, such as fluorine, exist as molecules.

Table 4.11 Elements That Commonly Form Diatomic Molecules

Element	Formula
bromine	Br_2
chlorine	Cl_2
fluorine	F_2
hydrogen	H_2
iodine	I_2
nitrogen	N_2
oxygen	O_2

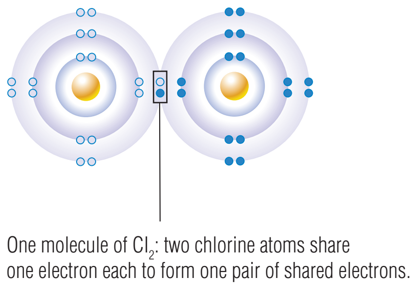


Figure 4.32 A molecule of chlorine gas forms when two chlorine atoms join by sharing one pair of electrons.

Molecular Compounds

When atoms of two or more different non-metals combine, a pure substance known as a **molecular compound** is formed. Glucose is an example of a molecular compound. Molecules of glucose are carried by your blood to the cells of your body, where they are broken down to supply energy. The chemical formula for glucose is $C_6H_{12}O_6$. The subscripts in this formula show that a single glucose molecule contains 6 carbon atoms, 12 hydrogen atoms, and 6 oxygen atoms. Altogether, there are 24 atoms connected together in one glucose molecule, as shown in Figure 4.33.

As with molecular elements, the atoms in molecular compounds are joined together by covalent bonds. In each bond, the atoms share a single pair of electrons. For example, water is a molecular compound (Figure 4.34). There are two covalent bonds in water. Each hydrogen atom shares one pair of electrons with an oxygen atom.

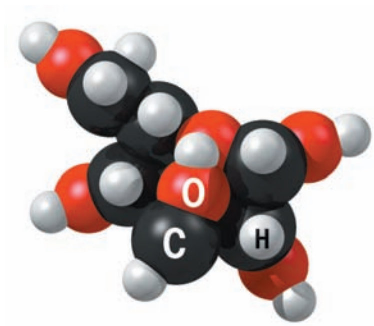


Figure 4.33 This model of a molecule of glucose is composed of 6 carbon atoms (black), 12 hydrogen atoms (white) and 6 oxygen atoms (red).

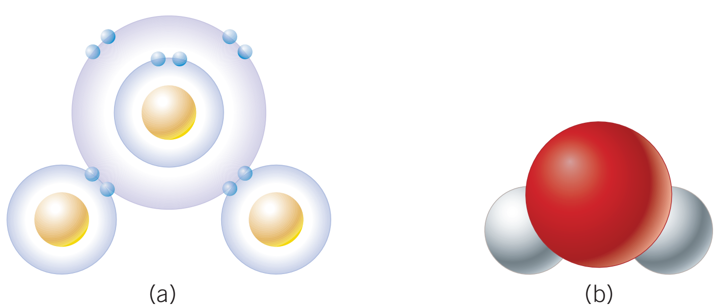


Figure 4.34 (a) Bohr diagram of a water molecule, showing how an oxygen atom (centre) shares a pair of electrons with each of two hydrogen atoms (below). (b) Diagram of a water molecule, showing an oxygen atom (red) connected by covalent bonds to hydrogen atoms (white)

Table 4.12 shows some examples of molecular compounds that may be familiar.

Table 4.12 Some Molecular Compounds and Their Formulas

Formula	Name	Application/Use
PCl_5	phosphorus pentachloride	production of lithium ion batteries
C_3H_8	propane	camp fuel
SO_2	sulphur dioxide	production of sulphuric acid for car batteries
C_2F_4	tetrafluoro ethylene	production of Teflon plastics
$C_9H_8O_4$	acetylsalicylic acid	pain control medication
$C_6H_8O_6$	ascorbic acid	vitamin C

Properties of Molecular Compounds

Molecular compounds have a number of properties in common.

- They are often soft.
- If they dissolve in water, they form solutions that do not conduct electricity.
- They tend to have relatively low melting points. For example, white table sugar can be melted on a stove. The chemical name for table sugar is sucrose, and its formula is $C_{12}H_{22}O_{11}$. Melted sugar is used to make candies such as caramel, butterscotch, and peanut brittle (Figure 4.35).

The same two non-metallic elements can also combine in different ways and form different molecular compounds with different properties. For example, hydrogen and oxygen can combine to make water (H_2O) or hydrogen peroxide (H_2O_2). A molecule of water is made up of two atoms of hydrogen combined with one atom of oxygen. A molecule of hydrogen peroxide is made up of two atoms of hydrogen combined with two atoms of oxygen.

Figure 4.35 Melted sugar is used to make a number of types of candy.

Naming Binary Molecular Compounds

Recall that a binary compound contains exactly two elements. The names of binary molecular compounds that do not contain hydrogen atoms use Greek prefixes to indicate how many atoms of each element are present in a compound. The prefixes are listed in Table 4.13. For example, P_2O_5 is a molecular compound used in the manufacture of medicines. Its name is diphosphorus pentoxide. The "di" means "2," and the "pent" comes from "penta" and means "5".

Table 4.13 Prefixes Used in Naming Molecules

Number of Atoms	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Suggested Activity •
B7 Quick Lab on page 170

The rules in Table 4.14 will help you to name binary molecular compounds. Note that the prefix "mono-" is not used when the first element is only one atom. When the prefix "mono-" is required before "oxide," the last "o" in the prefix is dropped. For example, it is "monoxide," not "monooxide."

Table 4.14 Examples for Naming Binary Molecular Compounds

Steps	Examples	
	N_2O	PBr_3
1. Name the first element.	nitrogen	phosphorus
2. Name the second element, using the suffix "-ide".	oxide	bromide
3. Add prefixes to indicate the number of each atom.	dinitrogen monoxide	phosphorus tribromide

Figure 4.36 These ball-and-stick models of water and hydrogen peroxide show that both molecules contain atoms of hydrogen and oxygen, but in different proportions.

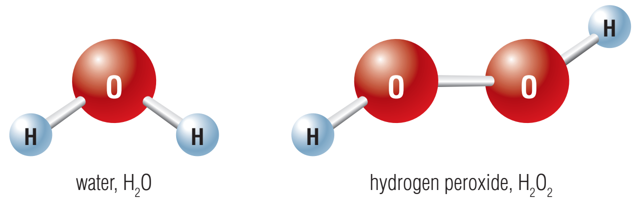


Table 4.15 Common Binary Molecular Compounds Containing Hydrogen

Name	Formula
water	H_2O
hydrogen peroxide	H_2O_2
ammonia	NH_3
methane	CH_4

Hydrogen is unique in many ways, and this is reflected in naming systems. Many compounds containing hydrogen have simply been given names. For example, the name "water" was chosen as the chemical name for H_2O simply because it was convenient to do so. Another binary compound containing only hydrogen and oxygen, H_2O_2, is called hydrogen peroxide. This compound is a disinfectant and bleaching agent. The structures of these compounds are shown in Figure 4.36. Two other common binary compounds of hydrogen are CH_4, called methane, and NH_3, called ammonia. These are summarized in Table 4.15.

Practice Problems

Write the names of the following binary molecular compounds:

1. SO_3
2. P_4S_{10}
3. NF_3
4. N_2O

Example Problem 4.6

Write the name for N_2S_3.

1. Name the first element: nitrogen.
2. Name the second element, which ends with "ide": sulphide.
3. Add prefixes indicating the numbers of atoms: dinitrogen trisulphide.

Naming Binary Molecular Compounds

Using the name, you can write the formula of a binary molecular compound. The prefix indicates the number of atoms of each type of element (Table 4.13 on page 167).

Practice Problems

Write the chemical formulas for the following binary molecular compounds:

1. sulphur hexabromide
2. carbon tetrachloride
3. dinitrogen tetroxide
4. tetraphosphorus decaoxide

Example Problem 4.7

Write the formula for disulphur decafluoride.

1. Identify the first element, and give its symbol: sulphur, S.
2. Identify the second element, and give its symbol: fluorine, F.
3. Add subscripts to indicate the numbers of atoms.
   - The prefix "di" indicates that a subscript of 2 is needed after S.
   - The prefix "deca" indicates that a subscript of 10 is needed after F.
4. Write the formula: S_2F_{10}.

B6 Quick Lab

Paper Models of Ionic Compounds

Paper models of individual ions can be used to find the correct ratio of the ions in a compound.

Purpose

To use paper models of polyatomic ions and atoms and the periodic table to work out formulas for ionic compounds

Materials & Equipment

- templates for ions with various charges
- scissors
- envelope
- periodic table
- table of common polyatomic ions

Procedure

1. Cut out the paper ions with various charges from the templates.
2. Observe that some paper ions will have one, two, three, or four extra pieces pointing out, while others will have one, two, three, or four pieces missing. These represent the charge on each ion. For example, three pieces missing means “3+”.
3. Use the periodic table and the table of common polyatomic ions on page 161 to work out the charges for each of the ions in the compounds listed below. Pick a template with the right charge for each ion and label it (Figure 4.37).
   (a) calcium chloride
   (b) aluminum fluoride
   (c) magnesium bromide
   (d) lithium nitride
   (e) ammonium hydroxide
   (f) barium sulphate
4. Using the paper ions, create models for each of the ionic compounds listed in step 3. Some compounds will need more than one of each kind of ion.

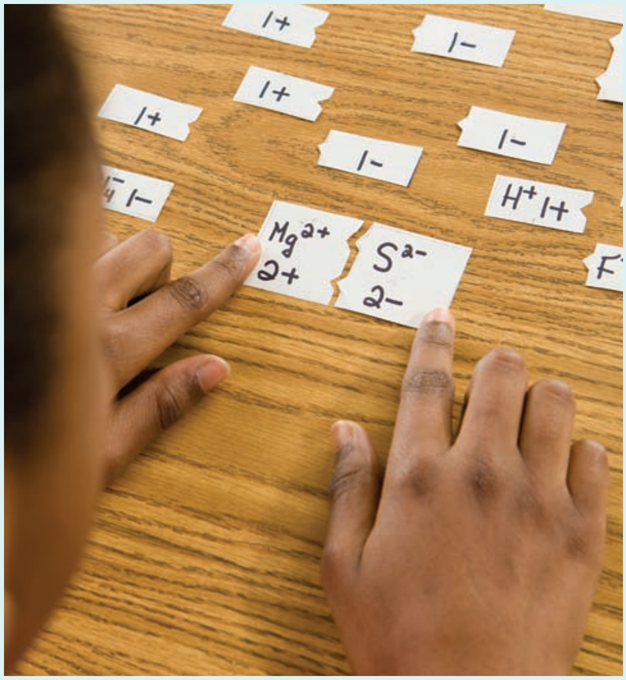


Figure 4.37 Paper models of atoms and polyatomic ions can help you to see how to balance the charges to form an ionic compound with a neutral charge.

5. Choose a binary ionic compound that is not on the list. Write its name and its chemical formula, and build a model of the compound using the paper ions.

Questions

6. Although each ion that makes up an ionic compound has a charge, the ionic compound itself is neutral. Why?
7. Did making models of compounds with polyatomic ions differ from making models of compounds without polyatomic ions? How were they the same or different?

B7 Quick Lab

Modelling Molecules

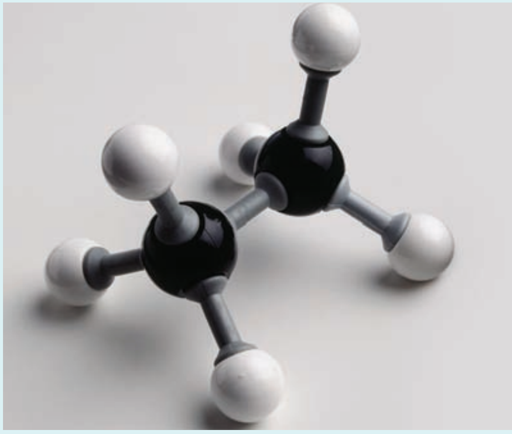


Figure 4.38 A ball-and-stick model of a molecule

Purpose

To construct ball-and-stick models of some simple molecules using a molecular modelling kit

Materials & Equipment

- ball-and-stick chemical modelling kit

Procedure

1. Following your teacher's instructions, work in a small group to use the molecular model kit. When building molecular models, keep the following guidelines in mind:
   - Each molecule is complete when all the balls are connected so that all holes are filled and every connector ends in a hole (Figure 4.38).
   - In some cases, more than one connection can exist between the same two atoms.
2. For each of the following, build the model and then draw and label a sketch of it. Do not take your models apart until you have completed step 3.
   (a) H_2 (hydrogen gas, used in some balloons)
   (b) O_2 (oxygen, a gas we breathe in)
   (c) H_2O (water, makes up about 60% of your body)
   (d) H_2O_2 (hydrogen peroxide, a bleaching agent)
   (e) CO_2 (carbon dioxide, a gas we breathe out)
3. Compare the models built in step 2.
   (a) Name and sketch one molecule containing three atoms that has a bent shape and one that is not bent. Include labels on your sketches.
   (b) Explain how water can be a pure substance even though it contains two different elements.
4. Build models of carbon tetrachloride (CCl_4) and of methane (CH_4) and compare their shapes. Draw and label one diagram only of the shape of both molecules. Try to draw the shape in 3D.
5. The following molecules can be constructed in only one way. Build, sketch and label each. It is not necessary to try to show them in 3D. Do not take your models apart until you have completed step 6.
   (a) C_2H_2 (acetylene, used in welding)
   (b) C_2H_4 (ethylene, used in plastics manufacture)
   (c) C_2H_6 (ethane, used in plastics manufacture)
6. Compare the models built in step 5. One model has parts that can rotate. The other two do not. Using the terms single bond, double bond, and triple bond, explain why only some molecules have parts capable of rotating.
7. The following molecules can be constructed in more than one way. Each different way of constructing a molecule produces a different pure substance. Build and sketch all possible forms of each of the following molecules.
   (a) C_3H_7Cl (two ways)
   (b) C_2H_6O (two ways)
   (c) $C_2H_2Cl_2$ (three ways)

Questions

8. Examine the drawings you made for hydrogen gas, oxygen gas, and chlorine gas. What is the difference between bonding in hydrogen and chlorine, compared to oxygen?
9. Consider all the models you built during this lab, and suggest a reason why there are many different kinds of compounds containing carbon.

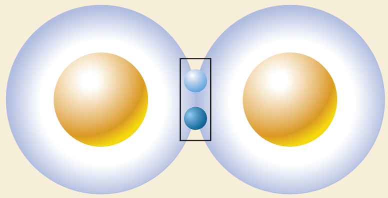
4.2 CHECK and REFLECT

Key Concept Review

1. What is an ion?
2. What symbols do we use to indicate that atoms have become ions?
3. What is the purpose of a subscript when writing the formula for the following?
   (a) a binary ionic compound
   (b) a molecular compound
4. What combinations of two elements combine to form ionic compounds?
5. What is a molecular compound?

Connect Your Understanding

6. Name the following ions.
   (a) Al^{3+}
   (b) Ca^{+}
   (c) Br^{-}
   (d) S^{2-}
   (e) SO_4^{2-}
   (f) PO_4^{3-}
7. Write the chemical formula for each of the following ionic compounds.
   (a) beryllium oxide
   (b) rubidium bromide
   (c) barium hydroxide
   (d) ammonium iodide
   (e) magnesium phosphate
   (f) iron(III) oxide
   (g) copper(I) sulphate
   (h) chromium(III) phosphate
8. Write the chemical name of each the following ionic compounds.
   (a) $ZnCl_2$
   (b) CaS
   (c) K_2SO_4
   (d) NH_4NO_3
   (e) $Sr_3(PO_4)_2$
   (f) $AuCl_3$
   (g) Ni_2S_3
   (h) PbF_4
9. How would you recognize a molecular compound from its formula?
10. A polyatomic ion, such as NH_4^{+} or CO_3^{2-}, has several atoms joined together. Why is a polyatomic ion not called a molecule?
11. The Bohr diagram below illustrates the electrons involved in the formation of H_2. Explain the position of the electrons in the illustration.



Question 11

12. Write the chemical name for each of the following molecular compounds.
   (a) SO_2
   (b) SO_3
   (c) PI_3
   (d) OF_2
   (e) SI_6
   (f) P_2S_4
13. Write the chemical formula for each of the following molecular compounds.
   (a) sulphur hexabromide
   (b) nitrogen tribromide
   (c) sulphur hexachloride
   (d) diphosphorus pentoxide
   (e) carbon monoxide

Reflection

14. List questions for further study that you have about ions, ionic compounds, and molecules.

For more questions, go to ***ScienceSource***.

4.3 Chemical Reactions

Here is a summary of what you will learn in this section:

- In a chemical reaction, the atoms in one or more pure substances are rearranged to produce at least one new pure substance.
- The law of conservation of mass describes what happens to the atoms involved in a chemical reaction.
- Word equations and chemical equations are two ways to write a chemical reaction.
- In a balanced chemical equation, the number of each kind of atom on the reactants side of the equation is the same as the number of those atoms on the products side of the equation.

Figure 4.39 Many highways and roads in Ontario have heavy traffic every day. This increases the risk of being involved in a traffic accident.

Chemistry and Automobile Safety

Many of Ontario's major highways are highly congested (Figure 4.39). Heavy traffic increases the chance that a vehicle will be involved in a collision. Over the years, changes in vehicle designs have made it less likely that you will be badly injured or killed in a collision. These changes include adding seat belts with shoulder restraints, making specific zones in a vehicle body that will easily crumple and absorb the energy of a collision, and even placing the bumpers of all vehicles at the same height above the road.

Another important safety feature is the airbag. Airbags are built into the steering wheels and dashboards and, in some cases, the sides of a vehicle. If the vehicle slows down very suddenly, like it might in a collision, the airbags inflate, which prevents the driver and passenger from hitting the inside of the vehicle cabin. Collisions can happen very quickly, so airbags must inflate very fast to be effective. Modern airbags take less than 0.05 seconds to inflate. This fast response time relies on a chemical reaction within the airbag.

During a collision, a sensor in the airbag detects that the vehicle has slowed down suddenly. In response, a small pellet of sodium azide ($NaN_3(s)$) is heated, producing harmless nitrogen gas ($N_2(g)$), which inflates the airbag (Figure 4.40). This reaction is written using chemical symbols as shown below. In the equation, "s" stands for solid and "g" stands for gas.

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

The other product of this reaction is sodium metal (Na). Sodium metal will react with water to form a chemical that will damage skin and tissues, so it would be harmful if it got into your eyes, nose, or mouth. Airbags contain other substances that quickly react with the sodium metal. These reactions convert the sodium to less harmful chemicals, which prevents a person being injured by sodium metal when an airbag inflates.

Figure 4.40 Airbags have helped to reduce the number of deaths due to head-on collisions.

B8 *Quick Lab*

Observing Chemical Changes (Teacher Demonstration)

Purpose

To observe your teacher combine chemicals to produce chemical change

Materials & Equipment

- steel wool
- 9.0-V battery
- magnesium ribbon
- large beaker
- tongs
- lab burner
- matches or flame striker

CAUTION
- Use a fume hood.
- Keep back to the distance instructed by your teacher. Burning steel wool can create sparks that could cause burns.
- Observe the reaction only through UV-absorbing glass.
- If you have a history of seizures, avoid looking directly at the light.
- Do not touch the reactants and products.

Procedure

1. Working in a fume hood, your teacher will use the steel wool to make a short circuit between the terminals of the 9.0-V battery. Record your observations.
2. Working in a fume hood, your teacher will light a small piece of magnesium ribbon in the beaker. Observe and record what happens.

Questions

3. What gas or gases in the air may have been involved in the chemical changes you observed?
4. New pure substances are formed during a chemical change. What pure substance(s) do you think were formed in step 1 and step 2?

Chemical Reactions

A **chemical change** is the transformation of one or more substances into different substances, with different properties. A **chemical reaction** is a process by which chemical change happens. All chemical reactions are also accompanied by changes in energy. Some chemical reactions absorb energy, such as in the chemical reactions that cook food. Other chemical reactions release energy in the form of heat, light, and/or sound, such as the burning of wood in a campfire (Figure 4.41).

Figure 4.41 When wood burns, it releases energy as light, sound, and heat.

Chemical reactions happen at different rates. Some chemical reactions are fast, such as when rocket fuel burns. Other chemical reactions happen slowly, such as the formation of rust on a corroding bicycle chain. The chemical reactions in your own body, which are keeping you alive and allowing you to read the words on this page, are among the fastest chemical reactions known.

Chemical reactions are used in many ways in daily life. For example, chemical reactions produce the glow in glow sticks (Figure 4.42(a)), generate instant cold without ice in a cold pack (Figure 4.42(b)), and are used to manufacture pigments in artists' paints, such as the bright yellow pigment in Figure 4.42(c).

Scientists are constantly working with chemical reactions to produce new substances with useful properties. For example, the chemical reaction shown in Figure 4.42(c) is no longer used commercially because it involves the element lead. Today, lead is avoided as much as possible, because it is toxic to living organisms. Other kinds of chemical reactions have been developed to produce yellow pigments that do not contain lead.

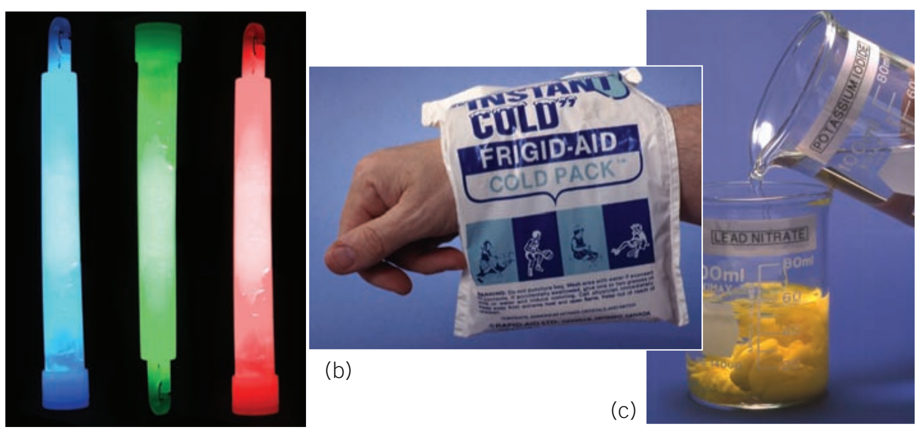
(a)


Figure 4.42 (a) Chemical reactions cause light sticks to glow, which makes them useful in an emergency. (b) The chemical reaction in cold packs absorbs heat, causing the temperature to fall. (c) The chemical reaction between these two solutions produces a yellow solid.

Reactants and Products

All chemical reactions involve the conversion of starting materials, called **reactants**, into new substances, called **products**. The products have different properties than the reactants. These new reactions may produce substances with different colours or states. Recall that the term "state" refers to solid, liquid, and gas, as well as aqueous, which means dissolved in water.

Consider the chemical reaction that occurs when a piece of solid magnesium metal is placed into a solution of hydrochloric acid. Bubbles of hydrogen gas are formed during the reaction (Figure 4.43). A second product, aqueous magnesium chloride, also forms.

Figure 4.43 Some chemical reactions involve a change of state, such as the formation of bubbles in a liquid.

Chemical Equations

A chemical reaction is often described by writing a chemical equation. A **chemical equation** uses either words or symbols and formulas to describe the changes that occur during a chemical reaction. For example, the chemical reaction between solid magnesium metal and hydrochloric acid is:

word equation:	magnesium	+	hydrochloric acid	$\rightarrow$	magnesium chloride	+	hydrogen
formula equation:	$Mg(s)$	+	$2HCl(aq)$	$\rightarrow$	$MgCl_2(aq)$	+	$H_2(g)$

Notice that the hydrogen is expressed in the formula equation as H_2. Recall from Section 4.2 that pure hydrogen exists as a molecule. You will need to know which elements exist as molecules when writing formula equations. The chemical formulas in a formula equation often will include the following:

- the state of matter of each substance. The state of each substance is indicated by placing the appropriate symbol in brackets after the formula. These symbols are (s) for solid, (*l*) for liquid, (g) for gas, and (aq) for aqueous.
- one or more coefficients. A coefficient is an integer that is placed in front of the symbol of an element or a chemical formula. The coefficients show the ratios of the different substances that are present in the chemical reaction. In the formula equation above, a coefficient of 2 is in front of the formula HCl. This means that Mg and HCl combine in a ratio of 1:2.

Learning Checkpoint

To answer questions 1 to 5, refer to the word equation and formula equation for the chemical reaction above between magnesium metal and hydrochloric acid.

1. List the names of the reactants.
2. List the formulas of the products.
3. What is the state of the hydrochloric acid (HCl) and of the hydrogen (H_2)?
4. What is the meaning of the arrow ($\rightarrow$) in the chemical equation?
5. Which symbol in the chemical equation means "reacts with" or "is produced with"?

Suggested Activity •
B10 Quick Lab on page 183

During Reading

Thinking Literacy

Set a Purpose for Reading

Having a purpose for reading helps you to determine what is important. You may be able to turn a subheading into a question to create your purpose for reading. You may have to read a sentence in the paragraph and then set a purpose. For example, in reading about the work of Antoine Lavoisier and Marie-Anne Paulze, you might want to know how that information is related to chemistry. Choose a paragraph or topic, and set a purpose for reading.

Conservation of Mass

The most important advancement in understanding what happens during chemical reactions was made about two centuries ago by the brilliant French chemist Antoine Lavoisier (1743–1794), with the assistance of his wife and research colleague Marie-Anne Paulze (1758–1836). The couple made meticulous measurements of the masses of reactants and products in many kinds of chemical reactions. Sometimes, this was extremely difficult to do, especially when gases were involved.

What they discovered was that the total mass of reactants and the total mass of products in a given reaction are always the same. Another way of saying this is that the mass is conserved: the mass does not change during a chemical reaction. No known exceptions to this have ever been observed. For this reason, this experimental result has come to be known as a law.

> The **law of conservation of mass** states that, in a chemical reaction, the mass of the products always equals the mass of the reactants.

The law of conservation of mass is very important in understanding what happens to the atoms in chemical reactions. It implies that no atoms are destroyed and no new atoms are produced during a chemical reaction. Instead, the atoms in the reactants of a chemical reaction are simply rearranged to form the products. Chemical bonds between atoms are broken and new ones are formed, and the atoms simply reconnect in new ways.

Counting Atoms in Reactants and Products

The rearrangement of atoms that occurs during a chemical reaction can be illustrated using models or diagrams. Consider the vehicle in Figure 4.44. It runs on electricity produced in a fuel cell. The electricity comes from a reaction between hydrogen gas and oxygen gas to form liquid water. The chemical equations for this reaction are:

word equation: hydrogen + oxygen → water
formula equation: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

Figure 4.44 Hydrogen and oxygen gas combine chemically in a fuel cell. The reaction in the fuel cell produces electrical energy to operate the vehicle.

In the formula equation for this reaction, there are equal numbers of hydrogen atoms (four) and equal numbers of oxygen atoms (two) on both the reactants side and the products side. When the number of each kind of atom is the same in reactants and products, an equation is said to be balanced.

The balanced formula equation for the reaction between hydrogen gas and oxygen gas is illustrated in Figure 4.45. You can check that it is balanced by counting atoms. Table 4.16 shows the count of atoms on the reactants side of the formula equation, and Table 4.17 shows the count of atoms on the products side.

Suggested Activity •
B11 Inquiry Activity on page 184

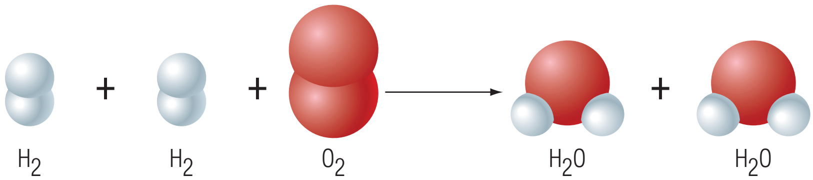


Figure 4.45 There are equal numbers of hydrogen atoms and oxygen atoms on both sides of this equation.

Table 4.16 Number of Atoms in the Reactants of the Formula Equation $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

Symbols	Description	Elements	Number of Atoms
$2H_2(g)$	2 molecules of H_2	H	2 molecules of H_2 = (2 molecules) × (2 H atoms per molecule) = 4 H atoms
$O_2(g)$	1 molecule of O_2	O	1 molecule of O_2 = (1 molecule) × (2 O atoms per molecule) = 2 O atoms

Table 4.17 Number of Atoms in the Products of the Formula Equation $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

Symbols	Description	Elements	Number of Atoms
$2H_2O(l)$	2 molecules of H_2O	H	2 molecules of H_2O = (2 molecules) × (2 H atoms per molecule) = 4 H atoms
		O	2 molecules of H_2O = (2 molecules) × (1 O atom per molecule) = 2 O atoms

Counting atoms shows that the numbers of hydrogen atoms (four) and oxygen atoms (two) are equal in the formula equation, just as they are in Figure 4.45.

Learning Checkpoint

1. State the law of conservation of mass.
2. How does the law of conservation of mass tell you that reacting zinc with hydrochloric acid can never produce aluminum oxide?
3. Suppose a solid substance with a mass of 10.0 g is heated in a chemical reaction that produces a different solid substance and a gas, which escapes. Suppose the new solid substance has a mass of 6.5 g. What mass of gas was produced?
4. What is a balanced chemical equation?
5. Count the number of each kind of atom on both sides of this equation:
   $4K + O_2 \rightarrow 2K_2O$

Writing Balanced Chemical Equations

A chemical equation that is complete except for coefficients is called an unbalanced equation or a **skeleton equation**. Example Problem 4.8 shows a "guess-and-check" method for writing and balancing a chemical equation. Example Problem 4.9 on page 179 shows a more detailed method for balancing an equation. (States are omitted in some examples and shown in others.)

Suggested Activity •
B12 Inquiry Activity on page 186

Example Problem 4.8

When methane (often called natural gas) burns in a gas fireplace, it reacts with oxygen in the air (Figure 4.46). The products of the chemical reaction are carbon dioxide and water. Write a word equation, skeleton equation, and balanced formula equation for this reaction.

1. Write the word equation by placing the reactants on the left side of the arrow and the products on the right side.
   methane + oxygen → carbon dioxide + water

2. To write the skeleton equation, write the symbols and chemical formulas for each of the reactants and products. You may need to use a periodic table, ion chart, or chart containing names and formulas of substances.
   $CH_4 + O_2 \rightarrow CO_2 + H_2O$

3. Write the balanced formula equation by adding coefficients in front of some or all of the substances in the equation, as needed.
   - Count the number of atoms of each element on the reactants side and on the products side of the skeleton equation. There are four hydrogen atoms on the reactants side but only two hydrogen atoms on the products side.
   - Guess what coefficient will balance the hydrogen atoms. For example, try placing a coefficient of 2 in front of H_2O.
     $CH_4 + O_2 \rightarrow CO_2 + 2H_2O$
   - Count the number of atoms of each element on the reactants side and the products side. There are two oxygen atoms on the reactants side, but there are four oxygen atoms on the products side. Try placing a coefficient of 2 in front of O_2.
     $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
   - Counting atoms again shows there are one carbon atom, four hydrogen atoms, and four oxygen atoms on each side of the formula equation.

The balanced formula equation is:
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Figure 4.46 Methane gas undergoes a chemical reaction when it burns.

Practice Problems

Balance the following skeleton equations.

1. $Na + O_2 \rightarrow Na_2O$
2. $HCl + Al \rightarrow AlCl_3 + H_2$
3. $KClO_3 \rightarrow KCl + O_2$

Example Problem 4.9

Balance the following skeleton equation.

$AlBr_3(s) + Cl_2(g) \rightarrow AlCl_3(s) + Br_2(g)$

1. Count the number of atoms of each element in the skeleton equation.

Reactants	Number of Atoms	Products	Number of Atoms
$AlBr_3(s)$	Al = 1 Br = 3	$AlCl_3(s)$	Al = 1 Cl = 3
$Cl_2(g)$	Cl = 2	$Br_2(g)$	Br = 2

2. Balance the number of bromine atoms by adding a coefficient of 2 in front of $AlBr_3$ and a coefficent of 3 in front of Br_2.
   - Count the atoms again. For substances with a coefficient, remember to multiply the coefficient by the number of atoms in the formula to get the total number of atoms.

Reactants	Number of Atoms	Products	Number of Atoms
$2AlBr_3(s)$	Al = $2 \times 1 = 2$ Br = $2 \times 3 = 6$	$AlCl_3(s)$	Al = 1 Cl = 3
$Cl_2(g)$	Cl = 2	$3Br_2(g)$	Br = $3 \times 2 = 6$

   - The number of aluminum atoms is no longer equal.

3. Balance the number of aluminum atoms by adding a coefficient of 2 in front of $AlCl_3$. Count the atoms again.

Reactants	Number of Atoms	Products	Number of Atoms
$2AlBr_3(s)$	Al = $2 \times 1 = 2$ Br = $2 \times 3 = 6$	$2AlCl_3(s)$	Al = $2 \times 1 = 2$ Cl = $2 \times 3 = 6$
$Cl_2(g)$	Cl = 2	$3Br_2(g)$	Br = $3 \times 2 = 6$

   - The number of chlorine atoms is no longer balanced.

4. Balance the number of chlorine atoms by adding a coefficient of 3 in front of Cl_2. Count the atoms again.

Reactants	Number of Atoms	Products	Number of Atoms
$2AlBr_3(s)$	Al = $2 \times 1 = 2$ Br = $2 \times 3 = 6$	$2AlCl_3(s)$	Al = $2 \times 1 = 2$ Cl = $2 \times 3 = 6$
$3Cl_2(g)$	Cl = $3 \times 2 = 6$	$3Br_2(g)$	Br = $3 \times 2 = 6$

The balanced chemical equation is:

$2AlBr_3(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s) + 3Br_2(g)$

Practice Problems

Balance the following skeleton equations.

1. $HgO(s) \rightarrow Hg(l) + O_2(g)$
2. $Al(s) + Br_2(g) \rightarrow AlBr_3(s)$
3. $Ca(s) + H_2O(l) \rightarrow Ca(OH)_2(s) + H_2(g)$

Strategies for Writing Skeleton Equations

Writing the correct formula for certain elements and compounds when you are translating word equations into skeleton equations can sometimes be difficult. Here are some tips:

- When a metal element is not in a compound with other elements, write the symbol of the element from the periodic table. For example, if a word description were to state "an iron nail," it would be translated to Fe.
- Seven common non-metal elements occur as molecules containing two identical atoms. These are hydrogen (H_2), nitrogen (N_2), oxygen (O_2), fluorine (F_2), chlorine (Cl_2), bromine (Br_2), and iodine (I_2). One way to help to remember these elements is to think of them as the "-gens": hydrogen, nitrogen, oxygen, and the halogens (consisting of fluorine, chlorine, bromine, and iodine). For example, if a word equation were to state "oxygen reacts with fluorine," the skeleton equation should be written $O_2 + F_2$.
- Common compounds that contain hydrogen include water (H_2O), ammonia (NH_3), and methane (CH_4).
- Some common acids are hydrochloric acid (HCl), nitric acid (HNO_3), sulphuric acid (H_2SO_4), and phosphoric acid (H_3PO_4). (You will study acids in Chapter 5.)

Example Problem 4.10 uses some of the tips.

Practice Problems

For each of the following, translate the word equation into a skeleton equation, showing states. Then, balance the skeleton equation.

1. hydrogen gas + nitrogen gas → ammonia gas
2. nitrogen monoxide gas + oxygen gas → nitrogen dioxide gas
3. solid aluminum metal + aqueous nitric acid → aqueous aluminum nitrate + hydrogen gas
4. phosphorus trichloride gas + chlorine gas → phosphorus pentachloride gas

Example Problem 4.10

Iron(II) sulphate ($FeSO_4$) can be used to kill moss in lawns and as a nutritional supplement to treat and prevent iron deficiency. Write a formula equation, including states, in which an iron nail reacts with aqueous sulphuric acid to produce aqueous iron(II) sulphate and hydrogen gas.

1. Write the word equation by placing the reactants on the left side of the arrow and the products on the right side.
   - An iron nail consists of pure iron in the solid state: Fe(s).
   - Aqueous sulphuric acid is a common acid (listed above): $H_2SO_4(aq)$.
   - Iron(II) sulphate is composed of Fe^{2+} and SO_4^{2-}: $FeSO_4(aq)$.
   - Hydrogen gas exists as a molecule with two identical atoms: $H_2(g)$.

The skeleton equation is:
$Fe(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2(g)$

Strategies for Writing Balanced Equations

Successfully balancing chemical equations can take some practice. Here are some strategies you might try:

- Balance atoms of elements in any complicated-looking formulas first, and balance atoms of pure elements last.
- Never change a subscript in a formula to help make atoms balance. Balance by placing coefficients in front of formulas only.
- Use guess-and-check to balance simple equations. Begin by placing a coefficient where you think it might work, or just take a guess and then count atoms.
- Hydrogen atoms and/or oxygen atoms often will appear in many or all of the formulas of the reactants and products. When this is the case, try to balance other elements first. Balance hydrogen second last, and oxygen last.
- You may be able to treat polyatomic ions as a unit. For example, if NO_3^- appears in the reactants and products of a skeleton equation, count the number of NO_3^- groups rather than the number of N atoms and O atoms separately.

Take It Further

Antoine Lavoisier and Marie-Anne Paulze developed the law of conservation of mass. Find out more about this pioneering couple and the story of how Antoine Lavoisier died. Begin your research at ***ScienceSource***.

Example Problem 4.11

Aluminum fluoride (AlF_3) is used in the production of aluminum for aluminum kitchen foil. Write a balanced equation for the reaction shown by the following word equation:
aluminum + fluorine → aluminum fluoride

1. Write the skeleton equation.
   $Al + F_2 \rightarrow AlF_3$
2. Apply some of the strategies for writing balanced equations.
   - Al is a pure substance, so balance it last.
   - Do not change the subscripts in F_2 or in AlF_3, since this will make these formulas incorrect.
   - Use guess-and-check. Place a coefficient of 3 in front of F_2 and a coefficient of 2 in front of AlF_3. There are now six F atoms on each side of the equation.
     $Al + 3F_2 \rightarrow 2AlF_3$

   The number of Al atoms is no longer balanced. Correct this by placing a coefficient of 2 in front of Al.
   $2Al + 3F_2 \rightarrow 2AlF_3$
3. Count the atoms of all the elements again to make sure the equation is balanced.

   The balanced formula equation is:
   $2Al + 3F_2 \rightarrow 2AlF_3$

Practice Problems

For each of the following, translate the word equation into a skeleton equation. Then, balance the skeleton equation.

1. iron + chlorine → iron(III) chloride
2. sodium + calcium hydroxide → sodium hydroxide + calcium
3. sodium phosphate + magnesium hydroxide → magnesium phosphate + sodium hydroxide
4. sulphuric acid + nickel(III) hydroxide → nickel(III) sulphate + water

Example Problem 4.12

Calcium phosphate is a solid called plaster of Paris and has been used to make casts to stabilize broken bones. It can be produced in the reaction between aqueous calcium chloride and aqueous sodium phosphate. A second product in the reaction is aqueous sodium chloride. Write a word equation and a balanced formula equation, showing states in the formula equation.

1. Write the word equation by placing the reactants on the left side of the arrow and the products on the right side.

   Word equation:
   calcium chloride + sodium phosphate → calcium phosphate + sodium chloride

2. Translate the word equation into a formula equation. Here are the formulas as well as states:
   calcium chloride: $CaCl_2(aq)$
   sodium phosphate: $Na_3PO_4(aq)$
   calcium phosphate: $Ca_3(PO_4)_2(s)$
   sodium chloride: $NaCl(aq)$

   Skeleton equation:
   $CaCl_2(aq) + Na_3PO_4(aq) \rightarrow Ca_3(PO_4)_2(s) + NaCl(aq)$

3. Apply some strategies from the previous page.
   - Do not change any subscripts. This would make the formulas incorrect.
   - Try guess-and-check.
   - Treat polyatomic ions as a unit. For example, balance PO_4^{3-} all at once.

   There are two PO_4^{3-} ions in the products and only one in the reactants, so balance PO_4^{3-} by placing a 2 in front of Na_3PO_4.

   $CaCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Ca_3(PO_4)_2(s) + NaCl(aq)$

4. Bring Na into balance by placing a 6 in front of NaCl.

   $CaCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Ca_3(PO_4)_2(s) + 6NaCl(aq)$

5. Finish balancing by placing a 3 in front of $CaCl_2$. This brings both Ca and Cl into balance in one step.

   Balanced formula equation:
   $3CaCl_2(aq) + 2Na_3PO_4(aq) \rightarrow Ca_3(PO_4)_2(s) + 6NaCl(aq)$

Practice Problems

For each of the following, write a word equation and a balanced formula equation, showing states in the formula equation.

1. Aqueous silver nitrate and copper metal react to produce aqueous copper(II) nitrate and silver metal.
2. Solid magnesium chloride and aqueous potassium phosphate react to produce aqueous potassium chloride and solid magnesium phosphate.
3. Hydrogen gas and carbon dioxide gas react to produce carbon monoxide gas and liquid water.
4. Solid potassium reacts with oxygen gas to produce solid potassium oxide.

B9 STSE Science, Technology, Society, and the Environment

Everyday Chemistry

When you start your day, you probably take a shower, brush your teeth, get dressed, and fix your hair. Maybe you listen to music on your way to school. These are some of the many activities in your daily life that involve products that were made using chemical reactions.

For example, you might wear a shirt that does not need to be ironed. The shirt does not wrinkle because a chemical called a resin was applied to the fabric or because a chemical called a polyester was blended with other fibres that make up the fabric. The casing of a music player is made using chemicals known as plastics. Plastics are manufactured using a number of chemical reactions.

1. In your group, brainstorm ways that you use chemicals or products made using chemical reactions. Think of and list as many ways as you can.
2. Choose at least five items from your list. For each item, provide further information or examples. You might need to do some research. You can start your research at ***ScienceSource***.
3. Organize and display your work using a method of your choice or as directed by your teacher.

B10 Quick Lab

The Flame Test (Teacher Demonstration)

The flame test can be used to determine the presence of hydrogen gas ($H_2(g)$).

Purpose

To use the flame test to determine if hydrogen gas is produced when solid zinc is combined with hydrochloric acid solution

Materials & Equipment

- 0.5 g of granulated zinc, Zn(s)
- 1 test tube
- 1 test-tube rack
- test-tube clamp
- 5 mL of 3M hydrochloric acid, HCl(aq)
- matches
- wooden splint

CAUTION
- Tie back loose hair or clothing.

Procedure

1. Your teacher will add 0.5 g of granulated zinc to a test tube, then place the test tube in the test-tube rack.
2. Your teacher will add enough HCl(aq) to the test tube to cover the zinc. Record your observations.
3. Your teacher will light a wooden splint. Holding the test tube with a test-tube clamp, he or she will then insert the burning splint into the mouth of the test tube. This is the flame test. Record your observations.

Questions

4. When hydrogen gas is present during the flame test, you will hear a popping sound. Was hydrogen gas produced?
5. The other product of the reaction is zinc chloride. Write a word equation and a balanced chemical equation for this reaction.

DI Key Activity

B11 *Inquiry Activity*

Skills References 1, 2, 6, 9

SKILLS YOU WILL USE
- Evaluating reliability of data and information
- Identifying sources of error

Does Mass Change During Chemical Reactions?

In 1789, Antoine and Marie-Anne Lavoisier performed a series of chemical experiments in a container designed to keep all the products of a chemical reaction inside. These experiments led to the discovery of the law of conservation of mass. In this activity, you will make a prediction and then observe what happens to mass during two chemical reactions, one that takes place in a sealed system and one that takes place in an open system.

Question

Does the total mass change during a chemical reaction?

Materials & Equipment

- Erlenmeyer flask with tight-fitting stopper
- small test tube
- test-tube rack
- balance
- 25-mL graduated cylinder
- calcium chloride solution, $CaCl_2(aq)$
- sodium carbonate solution, $Na_2CO_3(aq)$
- scoopula
- sodium hydrogen carbonate, $NaHCO_3(s)$
- 50-mL beaker
- hydrochloric acid solution, $HCl(aq)$

Procedure

Part 1 — A Chemical Reaction Inside a Sealed System

1. Read steps 2 to 8, and then write a prediction about what will happen to the total mass of the flask and its contents when the chemicals react.
2. Test that the equipment fits together. Carefully slide a small test tube into the Erlenmeyer flask. Seal the flask with a rubber stopper. Check that the stopper does not fall out when you turn the apparatus upside down (Figure 4.47).
3. Take the test tube out, and place it in the test-tube rack for safekeeping.
4. With the graduated cylinder, measure 25 mL of calcium chloride solution and then pour it into the Erlenmeyer flask. Wipe the outside of the flask to make sure it is dry. Set it aside.
5. Fill the test tube about half full with sodium carbonate solution. Wipe the outside of the test tube to make sure it is dry. Place the test tube in the 50-mL beaker
6. Carefully slide the filled test tube into the Erlenmeyer flask. Seal the flask with the rubber stopper, ensuring that the two solutions do not mix. Measure and record the total mass of the sealed assembly.
7. Tip the assembly so that the two liquids mix. Keep your thumb on the rubber stopper so that it remains in place and does not leak. Observe the chemical reaction. Record your observations.
8. Measure the mass of the total assembly again, and record it.
9. Check your results against your prediction. If necessary, revise your prediction.
10. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Figure 4.47 Ensure the test tube is sealed in the flask.

B11 *Inquiry Activity (continued)*

Part 2 — A Chemical Reaction Inside an Open System

11. Read steps 12 to 16, and then write a prediction about what will happen to the total mass of the flask and its contents when the chemicals react.

12. Using the balance and the scoopula, measure 5 g of sodium hydrogen carbonate powder into a dry 50-mL beaker.

13. Fill a small test tube about half full with hydrochloric acid solution. Wipe the outside of the test tube to make sure it is dry.

14. Carefully slide the test tube into the beaker, ensuring that the sodium hydrogen carbonate powder does not mix with the hydrochloric acid solution. Measure and record the total mass of the assembly.

15. Empty the contents of the test tube into the beaker. Record your observations.

16. Measure and record the mass of the beaker, test tube, and mixed solutions.

17. Check your results against your prediction. If necessary, revise your prediction.

18. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

19. In your notebook, draw a table using the headings shown in Table 4.18. Collect and record the class data for Parts 1 and 2 in your table.

Analyzing and Interpreting

20. What evidence was there that a chemical reaction occurred in Part 1 and/or Part 2?

21. For your group, how did the total mass after mixing compare with the total mass before mixing, in both Part 1 and Part 2?

22. How did your observations of the overall changes in mass compare with your predictions?

23. Using the data for Part 1 and Part 2 from the entire class, compare the total mass after the chemical reactions had occurred with the total mass before mixing.

Skill Practice

24. How precisely were you able to measure mass each time (i.e., to how many places after the decimal point were you able to read your mass measurements)?

25. Suggest some possible causes for errors in measurement for this activity.

Forming Conclusions

26. Using the class results for both parts of this activity, state a conclusion about changes in mass in a sealed system versus an open system. For example, you might calculate the average change in mass for all groups for each part.

27. Do the results of this activity support the law of conservation of mass? Provide reasons for your answer.

Table 4.18 Does Mass Change During Chemical Reactions?

Group #	Part 1 — Sealed System			Part 2 — Open System		
	Total Mass Before (g)	Total Mass After (g)	Change in Mass (g)	Total Mass Before (g)	Total Mass After (g)	Change in Mass (g)

B12 *Inquiry Activity* Skills References 1, 2, 6, 9

SKILLS YOU WILL USE

- Observing and recording observations
- Drawing conclusions

Observing Chemical Change

Question

What kinds of changes can be observed to occur during chemical reactions?

Materials & Equipment

- 50-mL beaker
- 1 M copper(II) chloride solution, $CuCl_2(aq)$
- iron nail, Fe(s)
- 3 test tubes
- 1 M calcium chloride solution, $CaCl_2(aq)$
- 1 M sodium carbonate solution, $Na_2CO_3(aq)$
- test-tube rack
- 6% hydrogen peroxide solution, $H_2O_2(aq)$
- liquid dish soap
- scoopula
- potassium iodide, KI(s)
- wooden splints
- matches

CAUTION
- Tie back loose hair or clothing.

Procedure

Part 1 — Iron and Copper(II) Chloride

1. Fill a 50-mL beaker half full with 1 M copper(II) chloride solution. Observe the solution.
2. Gently place a clean iron nail into the copper(II) chloride solution, making sure the head of the nail remains dry and out of the solution. Every few minutes, lift the nail partly out of the solution and observe. Gently replace the nail to allow it to continue to react.
3. After 15 min, record all your observations.

Part 2 — Calcium Chloride and Sodium Carbonate

4. Fill a test tube one-third full with 1 M calcium chloride solution. Fill a second test tube one-third full with 1 M sodium carbonate solution.
5. Pour the contents of one test tube into the other, and observe.
6. Set the test tube in the test-tube rack, and observe again after 10 min. Record your observations.

Part 3 — Hydrogen Peroxide Decomposition

7. Carefully pour 6% hydrogen peroxide solution into a test tube to a depth of about 2 cm. Add 2 drops of liquid dish soap to the solution. Set the test tube into the test-tube rack.
8. Using a scoopula, get a pea-sized amount of potassium iodide powder and drop it into the test tube. Observe. (Note: KI helps this reaction go quickly but is NOT considered a reactant.)
9. Light a wooden splint with a match, and blow out the flame, leaving only a glowing ember. Place the glowing splint into the top of the test tube and also into some soap bubbles that are present. Observe. Repeat several times. Record your observations.
10. Clean up your work area. Make sure to follow your teacher's directions for safe disposal of materials. Wash your hands thoroughly.

Analyzing and Interpreting

11. Write a skeleton equation for each of the three chemical reactions in this activity. The products of the chemical reactions are as follows:

    Part 1: iron(II) chloride and copper
    Part 2: sodium chloride and calcium carbonate
    Part 3: oxygen gas and water

Skill Practice

12. Many furnaces burn natural gas. Is burning natural gas a physical change or a chemical change? Justify your conclusion.

Forming Conclusions

13. Write a summary that answers the question at the beginning of this activity.

4.3 CHECK and REFLECT

Key Concept Review

1. State the law of conservation of mass.
2. Use the following chemical equation to explain these terms: reactants, products, state of matter, symbols, formulas, subscripts, coefficients.
$Zn(s) + 2HCl(s) \rightarrow ZnCl_2(aq) + H_2(g)$
3. During a forest fire, like the one shown in the photo, large trees weighing thousands of kilograms were reduced to only a few kilograms of ash. What happened to the mass of the trees when they burned?

Question 3

Connect Your Understanding

4. Write a word equation and a balanced formula equation, including states, for each of the following reactions. Hint: Remember to use the correct formula for elements that form a diatomic molecule.
   (a) Solid aluminum metal combines with fluorine gas to produce solid aluminum fluoride.
   (b) Potassium metal combines with oxygen gas to produce solid potassium oxide.
   (c) Lithium sulphate combines with barium chloride and yields solid barium sulphate and aqueous lithium chloride. Both of the reactants are dissolved in water.
   (d) Aluminum chloride combines with sodium carbonate to produce aluminum carbonate and sodium chloride. The aluminum carbonate is a solid at the bottom of the container. The other three compounds are all aqueous.
5. Balance the following skeleton equations.
   (a) $Al(s) + F_2(g) \rightarrow AlF_3(s)$
   (b) $K(s) + O_2(g) \rightarrow K_2O(s)$
   (c) $C_6H_{12}O_6(s) + O_2(g) \rightarrow CO_2(g) + H_2O(l)$
   (d) $H_2SO_4(aq) + NaOH(s) \rightarrow Na_2SO_4(aq) + H_2O(l)$
   (e) $Mg(CH_3COO)_2(aq) + AgNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + AgCH_3COO(s)$
   (f) $H_2O_2(aq) \rightarrow O_2(g) + H_2O(l)$
   (g) $HCl(aq) + Ba(OH)_2(aq) \rightarrow BaCl_2(aq) + H_2O(l)$
6. For each of the following, write a word equation and a balanced formula equation. Hint: Remember to use the correct formula for diatomic elements.
   (a) Solid calcium metal combines with oxygen gas in the air to produce solid calcium oxide.
   (b) Propane gas (C_3H_8) combines with oxygen gas in the air to produce carbon dioxide gas and water vapour.
   (c) Fluorine gas combines with aqueous potassium chloride. The chemical reaction produces aqueous potassium fluoride and chlorine gas.

Reflection

7. Using a poster, Web page, or another method of your choosing, summarize what you have learned about balancing chemical equations.

For more questions, go to ***ScienceSource***.

Investigating CAREERS in Science

Great CANADIANS in Science Dr. Robert D. Singer

Dr. Robert D. Singer is a professor in and chair of the chemistry department at St. Mary's University in Halifax, Nova Scotia (Figure 4.48). One of his research interests is in the area of green chemistry.

Green chemistry is a new area of research. The goal of green chemistry is to protect the environment by inventing chemicals and chemical processes that do not pollute. This is a lot less harmful to our environment than cleaning up pollution after it has already occurred. Green chemistry also looks for ways to use renewable starting materials and to reuse any wastes.

Dr. Singer is a member of a group of scientists, industrial leaders, and environmentalists called the Green Chemistry Network. Members of this group promote and teach green chemistry in industry, business, universities, and schools.

Dr. Singer and the members of his research group are looking for ways to replace the use of chemicals called volatile organic compounds (VOCs) in certain industrial processes. VOCs produce harmful fumes and can easily catch fire. You may have heard about low-VOC or no-VOC paints (Figure 4.49). These are an example of a green chemistry success story.

Dr. Singer has found that some VOCs can be replaced with ionic liquids. Ionic liquids do not produce fumes and will not burn. Since they do not release harmful fumes, they could make workplaces safer for people who handle and use chemicals.

Figure 4.48 Dr. Singer and his research group focus on many aspects of green chemistry.

Figure 4.49 Low-VOC and no-VOC paints are safer to use and better for the environment.

Questions

1. What is Dr. Singer's contribution to the health of our environment?
2. *ScienceSource* The Green Chemistry Network has outlined 12 principles of green chemistry. Conduct research to find out what these 12 principles of green chemistry are.

Science in My FUTURE Polymer Chemist

Figure 4.50 Polymers are used in the materials that make up the soles and tops of many sneakers and other sports shoes.

What do plastic food wrap, automobile parts, and sneakers have in common (Figure 4.50)? All these products, and many others that you use every day, are made with a type of chemical called a polymer. Polymer chemists are scientists who study and create new polymers.

A polymer is a chemical compound that is composed of a large number of smaller, identical units that are joined together to form one large molecule. Polymers may be natural or synthetic. For example, starch is a natural polymer made up of many sucrose molecules joined together. Vinyl is an example of a synthetic polymer is found in many products, including home siding, electrical components, and medical products.

Polymer chemists are involved in creating new polymers and/or finding new uses for the polymers we already have. Therefore, a polymer chemist's job involves some aspect of analyzing, synthesizing, purifying, modifying, and characterizing different polymers. She or he may be involved in ensuring that some or all of the stages of production of polymers meet quality control standards. A polymer chemist also might investigate the physical and chemical properties of polymers. Some polymer chemists are employed as technical consultants.

Most polymer chemists are employees who work for a private company or in a university or a government laboratory. Depending on their training and experience, they may supervise other chemists and/or technicians and technologists. Polymer chemists often work in collaboration with other experts, such as engineers. Working as a polymer chemist involves a higher-than-average danger of exposure to dangerous chemicals, but these dangers are reduced by following good safety practices.

At a minimum, a bachelor's degree in chemistry is needed to work in this field. To be able to enter into a bachelor's degree program in chemistry, a person must have successfully completed at least two grade 12 mathematics courses, a grade 12 chemistry course, at least two other grade 12 science courses, and a grade 12 English course. Universities often require specific courses and final grades. A person with a bachelor's degree in chemistry is likely to be a teacher or to work in the polymer industry as a technician or a sales person. You will need a master's or a doctorate degree to find work conducting research in industry or at a university or government laboratory. Anyone who works in this field should love learning, since he or she must always keep up with new advances in polymer chemistry.

Questions

1. Write a job description for a polymer chemist in the form of an advertisement for a position at a chemical company.
2. ***ScienceSource*** Research what university courses you would need to take to become a polymer chemist.

4 CHAPTER REVIEW

ACHIEVEMENT CHART CATEGORIES

k Knowledge and understanding
t Thinking and investigation
c Communication
a Application

Key Concept Review

1. Name two properties possessed by all forms of matter. k

2. Identify two kinds of pure substances and three kinds of mixtures. k

3. Explain the difference between a homogeneous mixture and a heterogeneous mixture, giving an example of each. k

4. Identify the three subatomic particles, their electric charge, and location in an atom. k

5. What are the two main types of compounds, and what are the names of the chemical bonds involved in each? k

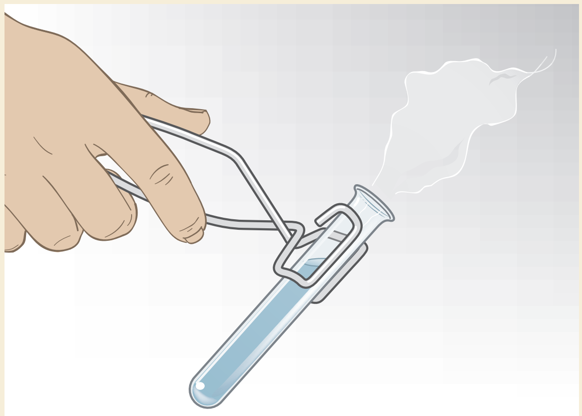
6. Name each of the following ions: a
(a) Na^+ (b) Ca^{2+} (c) Fe^{3+} (d) F^- (e) O^{2-}

7. Suppose that a friend tells you that a balanced chemical equation involves only coefficients and chemical symbols. Would your friend be correct? If not, what else is needed? k

8. Name all seven elements that form diatomic molecules. Provide the correct symbol for each molecule. k

Connect Your Understanding

9. A group of students wanted to test the law of conservation of mass. They carefully weighed a test tube and two dissolved compounds provided by their teacher. They then carefully poured both solutions into a test tube. After several minutes, the chemical reaction was complete (pictured in the next column). The students then weighed the test tube and its contents and found that the mass had decreased by 0.27 g. The students concluded the chemical reaction caused a loss of mass.
   (a) Do you agree with the students' conclusion? Explain your answer. t
   (b) Suggest how the students could revise their procedure in doing another trial. a



Question 9

10. A friend tells you that only one possible compound can be made from the elements hydrogen and oxygen. Use the chemical formulas provided in this chapter to respond to your friend's statement. t

11. State the similarities and differences between: t
   (a) an element and a compound
   (b) an atom and an ion

12. What are the differences between hydrogen (H) and hydrogen gas (H_2)? k

13. What is the total number of atoms in one molecule of white sugar (sucrose), $C_{12}H_{22}O_{11}$? Show how you calculated this answer. a

14. Write the symbol for the ion formed by each of following elements. a
   (a) oxygen
   (b) bromine
   (c) sulphur
   (d) calcium
   (e) copper(I)

15. Write the symbol for the following polyatomic ions.

(a) ammonium
(b) carbonate
(c) hydrogen carbonate
(d) phosphate

16. Name each ionic compound.

(a) Na_3N
(b) CaF_2
(c) $Al(OH)_3$
(d) $FeCl_2$
(e) PdO_2
(f) $KMnO_4$
(g) $(NH_4)_3PO_4$
(h) $Cr(NO_3)_2$

17. Write the formula of each ionic compound.

(a) potassium iodide
(b) strontium nitride
(c) manganese(IV) chloride
(d) tin(II) sulphide
(e) magnesium hydroxide
(f) zinc phosphate
(g) silver oxide
(h) ammonium nitrate

18. Suppose that Canadian scientists discovered a new metal element, called ontarium (symbol On). Ontarium has two valence electrons. Write the chemical formula for the following compounds of ontarium:

(a) ontarium oxide
(b) ontarium chloride
(c) ontarium phosphate

19. Write the formula or name for each molecular compound.

(a) dinitrogen trioxide
(b) carbon monoxide
(c) sulphur hexafluoride
(d) PBr_5
(e) CCl_4
(f) NBr_3

20. Balance the following skeleton equations.

(a) $Li(s) + F_2(g) \rightarrow LiF(s)$
(b) $Be(s) + O_2(g) \rightarrow BeO(s)$
(c) $HCl(aq) + NaOH(s) \rightarrow NaCl(aq) + H_2O(l)$
(d) $Ca(CH_3COO)_2(aq) + AgNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + AgCH_3COO(s)$
(e) $NBr_3(l) \rightarrow N_2(g) + Br_2(g)$
(f) $HF(aq) + Ba(OH)_2(aq) \rightarrow BaF_2(aq) + H_2O(l)$

Reflection

21. Describe three or more new ideas about elements that you have learned in this chapter. Then, list three or more questions you have about these new ideas or any related topic.

After Reading

Thinking Literacy

Reflect and Evaluate

Use a two-column chart to summarize how you were able to determine important ideas in this chapter. In the first column, list words, text features, and purpose, leaving several lines between each item. In the second column, record examples from the text. With a partner, compare charts and explain how each feature helped you to understand important ideas.

Unit Task Link

In the Unit Task, you will be using the following substances in order to produce and observe chemical reactions. Classify each of the following as an element, an ionic compound, or a molecular compound, and name each one: Mg, $MgSO_4$, $CuCl_2$, Na_2CO_3, HCl(aq), Fe.