Chapter 3

Elements combine to form compounds.

Bubbles and fizz. That is what you get when you drop an antacid tablet into a glass of water. Why the fizz? The tablet contains two chemicals that dissolve on contact with water. The chemicals react with each other to produce carbon dioxide, a gas that helps break down the tablet, and sodium citrate, a compound that neutralizes stomach acids. In just a few seconds, the two chemicals have been transformed into something new. Chemical change is happening all around you, as elements combine to produce compounds.

What You Will Learn

In this chapter, you will

- **distinguish** between covalent and ionic compounds
- **demonstrate** understanding of chemical names and formulas of ionic compounds
- **differentiate** between chemical and physical change
- **describe** applications of chemical technology

Why It Is Important

Almost everything in our world is made of compounds and mixtures of compounds. Our whole society depends on the production and wise use of compounds.

Skills You Will Use

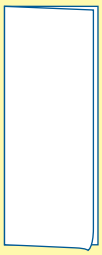
In this chapter, you will

- **write** chemical formulas given the names, and chemical names given the formulas
- **observe** changes in matter
- **communicate** your understanding of how substances are altered during chemical and physical changes

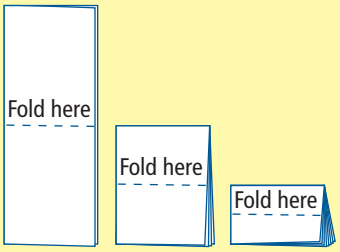
FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 3.

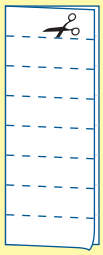
STEP 1 **Fold** a sheet of copy paper in half lengthwise (hot dog fold).



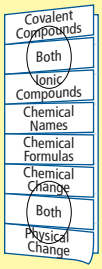
STEP 2 **Fold** in half to form two equal sections, fold in half again to form four equal sections, and in half again to form eight equal sections.



STEP 3 **Open** the folded paper and **cut** along the fold lines of one side only to form eight tabs.



STEP 4 **Label** the tabs as illustrated. Draw two circles as shown.



Similarities and Differences As you read this chapter, use your Foldable to find similarities and differences between covalent and ionic compounds and to differentiate between chemical and physical change.

3.1 Compounds

A compound is a pure substance made up of two or more kinds of elements that are chemically combined. When they combine, the atoms of one element make connections with the atoms of another element in very specific ways. Compounds are either covalent or ionic. In covalent compounds, atoms join together by sharing electrons. In ionic compounds, oppositely charged ions attract each other. Polyatomic ions are groups of atoms that are joined to each other by covalent bonds and, as a group, have an ion charge.

Words to Know

covalent compound
ionic compound
ionic lattice
molecule
polyatomic ion

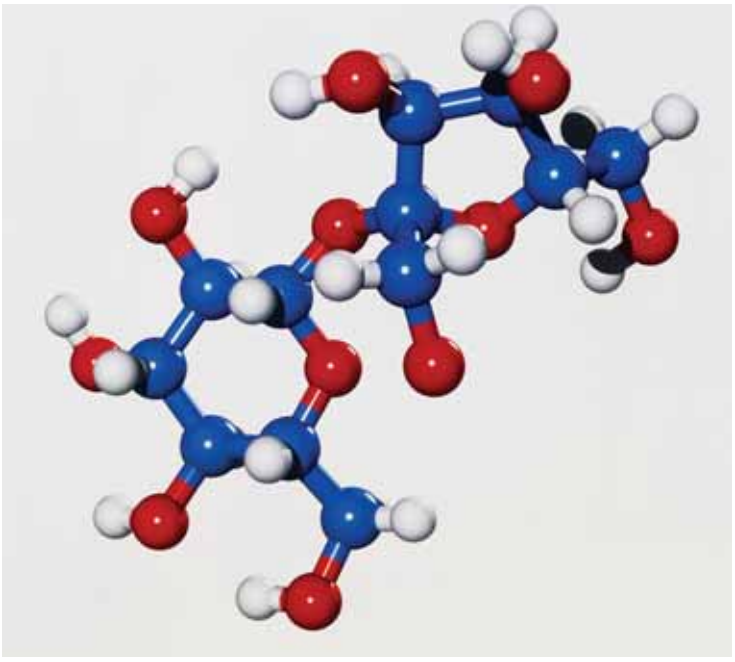


Figure 3.1 In this model of common table sugar ($C_{12}H_{22}O_{11}$), the carbon atoms are blue, oxygen atoms are red, and hydrogen atoms are white.

Imagine if you could see deep into the atomic structure of objects. You would see that a relatively simple substance, like table sugar, is composed of only one type of compound (Figure 3.1). A more complex example, such as a butterfly, might have between 100 000 and 1 million different kinds of compounds.

A compound is a pure substance made of more than one kind of element in which the atoms of the elements are joined together. By combining in compounds, elements can form more complex substances. Compounds form through **chemical bonds**, which are links between two or more atoms that hold the atoms together.

Although scientists have identified only some of the compounds that are found in nature, we do know that most compounds are one of two basic types: covalent compounds and ionic compounds.

Did You Know?

The elements magnesium and oxygen can combine to form a compound simply by being heated together. As they react, magnesium atoms give electrons to oxygen atoms. In the new compound, there is one ion of magnesium for every one ion of oxygen. As the photograph shows, this process releases a lot of light and heat.

3-1A The Synthesis of Oxygen

Find Out ACTIVITY

Hydrogen peroxide is a compound that can be made to quickly decompose into the element oxygen and another compound, water. In this activity, you will decompose hydrogen peroxide by adding a catalyst, which is a chemical that helps speed up the process.

Safety

- Hydrogen peroxide solution is corrosive.
- Be careful around open flames.
- Tie back long hair.

Materials

- liquid dish soap
- medium test tube in a test tube rack
- hydrogen peroxide (H_2O_2) solution
- candle and lighter
- scoopula
- potassium iodide (KI) crystals
- 2 wooden splints

What to Do

1. Put one drop of dish soap into the test tube.
2. Carefully pour hydrogen peroxide solution into the test tube until it is no more than $\frac{1}{3}$ full.
3. Light a candle.
4. Use a scoopula to obtain about 1 mL (the size of a pea) of potassium iodide (KI) crystals and drop them into the test tube. You should see bubbles appear, making a foam as oxygen collects in the soapy water.
5. Light a wooden splint and blow it out, leaving a few embers glowing.
6. Place the glowing splint in the soap bubbles, keeping it above the solution. Observe.
7. Repeat steps 5 and 6 several times.
8. Clean up and put away the equipment you have used.

What Did You Find Out?

1. What happens to a glowing splint when it is placed in pure oxygen?
2. If you have practised the burning splint test for hydrogen in a previous investigation, compare the test for oxygen with the test for hydrogen, using a lit splint for both.
   (a) How are the procedures different?
   (b) How do the observations differ?

Covalent Compounds

In **covalent compounds**, atoms combine by sharing electrons to form molecules. A **molecule** is a group of atoms in which the atoms are bound together by sharing one or more pairs of electrons. The shared pairs of electrons form covalent bonds that keep the atoms together. Carbon dioxide and water are examples of covalent compounds.

The smallest possible particle of water is a single molecule. A water molecule is composed of two hydrogen atoms and one oxygen atom. The formula for water shows this two-to-one relationship using element symbols and a subscript number: H_2O. Figure 3.2 on the next page shows three common ways of modelling a water molecule. In all three cases, the covalent bonds that hold the water molecule together are formed by the atoms of oxygen and hydrogen sharing pairs of electrons.

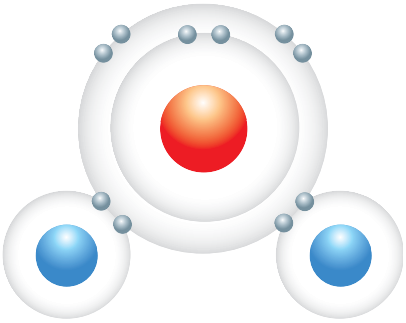


Figure 3.2A A Bohr model diagram of a water molecule. Notice how electrons in the valence shells of oxygen and hydrogen atoms are being shared.

Figure 3.2B A ball and stick model of a water molecule. The sticks represent covalent bonds.

Figure 3.2C A space-filling model of a water molecule. Each overlap represents one shared pair of electrons.

When a jar is filled with water, trillions and trillions of molecules bump into each other constantly, but the atoms in one molecule are not bonded to atoms in other water molecules. Each molecule is separate from the other. Liquid water flows because the water molecules can move past each other.

Ionic Compounds

In **ionic compounds**, atoms gain or lose electrons to form ions. For example, table salt is made from the elements sodium and chlorine. When the atoms of each element first come together, both are electrically neutral. When they get close enough, an electron transfers from the sodium to the chlorine. This makes a positive sodium ion, Na^+, and a negative chloride ion, Cl^-. The process is shown in Figure 3.3.

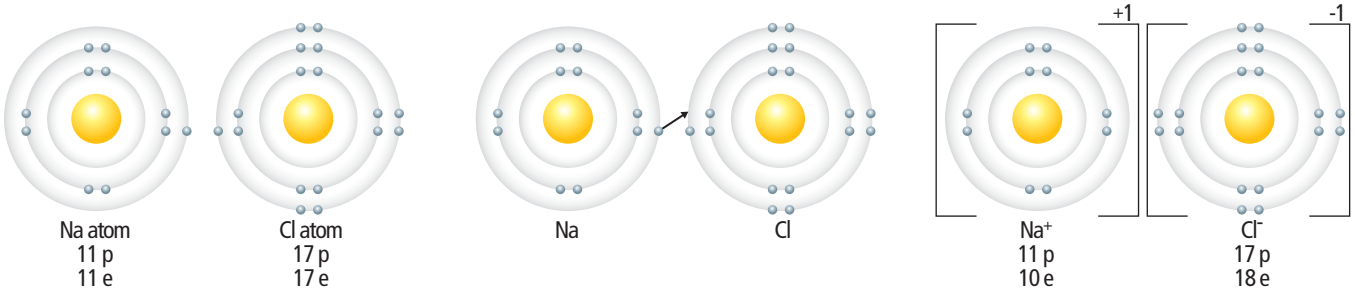


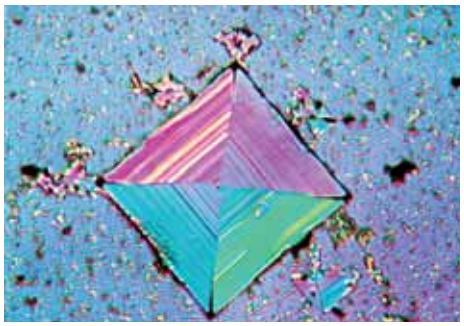
Figure 3.3 An ionic compound forms when an electron on a metal atom transfers to a non-metal atom, creating oppositely charged ions.

Figure 3.4 Striped and solid-coloured balls arranged alternately can model the arrangement of ions in an ionic compound.

Ionic compounds exist as a solid in the form of an ionic lattice. An **ionic lattice** is a repeating pattern of positive and negative ions. Ionic compounds can be modelled by arranging striped and solid-coloured balls. Striped balls would repel other striped balls. Solid-coloured balls would repel other solid-coloured balls. But striped balls and solid-coloured balls would strongly attract each other. What would happen to real balls if they had this property? They would assemble into a pattern that looks like Figure 3.4. This type of pattern happens when a crystal of table salt forms (Figure 3.5 on the next page). In an ionic compound, *all* the positive ions attract *all* the negative ions everywhere in the same crystal.

Reading Check

1. Name two ways in which elements can combine into compounds.
2. How are atoms connected to each other in covalent compounds?
3. Give one example of a covalent compound.
4. Give one example of an ionic compound.
5. What needs to happen to atoms of different elements to allow them to combine to form an ionic compound?



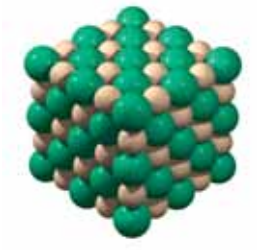


Figure 3.5 Table salt is an ionic crystal.

Molecules, Ions, and Polyatomic Ions

Covalent and ionic bonds can be found in the same compound. It is possible for some molecules to gain or lose one or more electrons as their atoms combine to form a molecule. In so doing, they become a molecular ion, usually called a **polyatomic ion**. The prefix "poly-" means many.

Figure 3.6A British Columbia's roadside CounterAttack uses chemical tests to detect alcohol.

Figure 3.6B The orange chemical contains the dichromate ion. It turns green in the presence of alcohol on a person's breath.

Police officers in British Columbia run a roadside CounterAttack program that checks drivers to ensure that they do not drink and drive (Figure 3.6A). In one of the checks, a test chemical turns from orange to green in response to alcohol on a driver's breath (Figure 3.6B). This test chemical is potassium dichromate. It contains potassium ions and an ion named dichromate. The dichromate ion has the formula $Cr_2O_7^{2-}$. This polyatomic ion is made from two atoms of chromium and seven atoms of oxygen and has a charge of 2− (Figure 3.7).

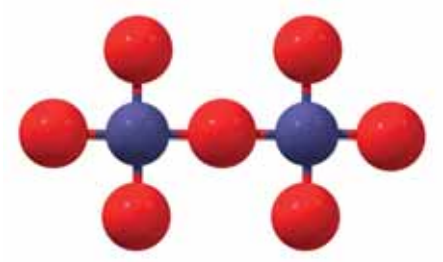


Figure 3.7A Ball and stick model of the dichromate ion

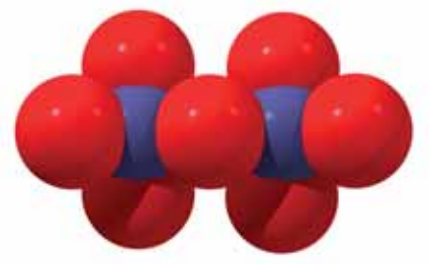


Figure 3.7B Space-filling model of the dichromate ion

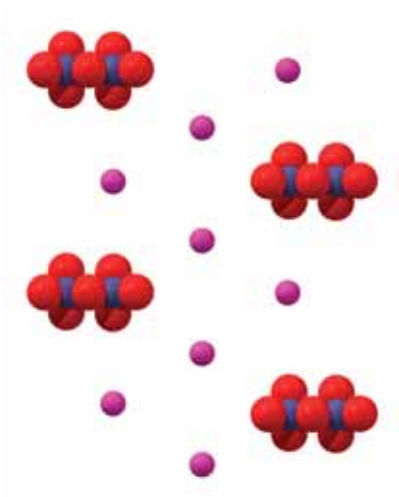


Figure 3.8 A model of the ionic lattice of potassium dichromate, which contains potassium ions and dichromate ions

In a polyatomic ion, the atoms are connected by covalent bonds, which involve the sharing of electrons. In the dichromate ion, the atoms are the elements oxygen and chromium. The negatively charged dichromate ion is connected by ionic bonds to positive potassium ions in the potassium dichromate that is used in breathalyzer tests (Figure 3.8).

Many Kinds of Polyatomic Ions

Polyatomic ions are an important part of many materials. One kind, carbonate (CO_3^{2-}), helps form the delicate shell of a robin's egg, as well as the enamel of your teeth, one of the hardest substances known. Another polyatomic ion, phosphate, is a major component in your bones and in your DNA, from which chromosomes are made. Ammonium nitrate is a compound made of two polyatomic ions: ammonium (NH_4^+) and nitrate (NO_3^-). This compound, ammonium nitrate, is one of the most important fertilizers in the world. Figure 3.9 shows diagrams of all four ions.

In the next section, you will learn to write names and formulas for a number of important ionic compounds.

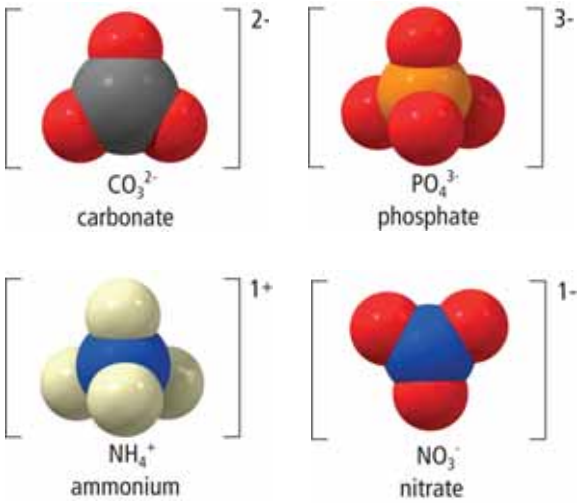


Figure 3.9 There are many kinds of polyatomic ions but only a few basic shapes.

Suggested Activity

Conduction an Investigation 3-1B on page 81

Explore More

Sodium hydroxide is a substance that contains the polyatomic ion hydroxide (OH^-). Find out about the uses of substances containing hydroxide. Begin your search at **www.bcscience9.ca**.

Reading Check

1. What is the meaning of the prefix "poly-" in the term "polyatomic ion"?
2. How are the atoms in a polyatomic ion connected together?
3. What kind of bond can a polyatomic ion form in a compound?
4. Give the name and formula of the polyatomic ion used in some roadside-check equipment that tests for alcohol on drivers' breath.
5. Give one example of how the polyatomic ion ammonium is used.

3-1B The Synthesis and Detection of Copper

Conduct an INVESTIGATION

Inquiry Focus

SkillCheck

- Observing
- Predicting
- Evaluating information
- Working co-operatively

In this activity, you will transform copper(II) chloride into pure copper metal. This is similar to how copper ore is processed into metallic copper in smelting operations.

Question

How can copper be extracted from a compound of copper, purified, and then tested to verify success?

Safety

- Wear protective clothing and safety goggles.
- Hydrochloric acid is corrosive.
- Be careful around open flames.

Materials

- copper(II) chloride solution
- two 400 mL beakers
- aluminum foil
- crucible tongs
- waste container
- dilute hydrochloric acid solution (HCl)
- wooden splint
- paper towel
- Bunsen burner

Procedure

1. Carefully pour 100 mL of copper(II) chloride solution into a 400 mL beaker.
2. Roll a 10 cm by 10 cm piece of aluminum foil into a small cylinder (try rolling it around a pencil). Place it in the solution. Wait and observe.
3. After the reaction has slowed down, or no longer than 5 min later, pick out the larger pieces of aluminum foil, using crucible tongs.
4. Add about 30 mL of water to the solution and let the brown solid settle for about 1 min. Pour the top part of the liquid into the other 400 mL beaker.
5. Pour the contents of the second beaker and all waste materials into the waste container provided by your teacher. Do not pour it down the sink.
6. Fill the first beaker again with water until it nearly reaches the top. Let the solids settle again for 1 to 2 min. Be patient. Then pour out the top part of the water. This process washes the copper, which is collecting at the bottom of the first beaker. Repeat until your copper product appears clean.
7. Add about 25 mL of hydrochloric acid solution (HCl) to the copper in the first beaker, and let it sit for about 1 min. Then begin rinsing again with water, as in steps 4 and 6. The hydrochloric acid helps to clean the copper.
8. Pour out as much water as you can, then pour your copper product onto a paper towel, using a wooden splint as needed to make the transfer.
9. Light a Bunsen burner. Pick up a piece of copper with crucible tongs and place it in the Bunsen burner flame. Observe the colour of the flame.
10. Wash all materials into the waste container provided.
11. Clean up and put away the equipment you have used.

Analyze

1. What colour changes showed that a chemical change took place when aluminum was placed in the copper(II) chloride solution?
2. Describe what happens when copper is placed in a Bunsen burner flame.

Conclude and Apply

1. List several properties of copper that distinguish it from another metal, such as iron.

Career Connect

Avalanche Technician

Tony Moore

Q. How did you become an avalanche technician?

A. I was employed as a surveyor when I had the opportunity to spend a day skiing and taking snow profiles with the local avalanche technician. I thought it was a pretty interesting line of work. I took courses from the Canadian Avalanche Association, earned a blasting certificate and a first aid certificate, and learned about weather and weather forecasting.

Q. What does an avalanche technician do?

A. We provide safety from avalanches for people. We forecast avalanche activity, implement closures, and do control work to make the slopes safe. By watching the weather and looking for weak layers of snow, we can recognize when we need to close a road and trigger an avalanche.

Q. How do you trigger an avalanche?

A. For my crew, the most common method is by dropping explosives out of a helicopter. However, helicopter work depends on good weather and daylight. On some of our roads, we have the option of launching explosives from the roadside. For shorter slopes, we detonate large charges at the side of the road that send a concussion wave through the air.

Q. Why is it important to know about chemistry?

A. We assemble the charges using ANFO (ammonium nitrate fuel oil) explosives just before we go up in the helicopter. The ANFO is detonated by a booster made of PETN (pentaerythritoltetranitrate). The booster is detonated by a safety fuse assembly that has a high strength blasting cap. The helicopters we use are capable of carrying up to 10 charges. We use up to 30 charges per mission.

Q. How long does it take to prepare once you have determined a need for avalanche control?

A. It can take up to a couple of hours to get the entire crew in place and ready. We have the pilot, the avalanche technician, and an assistant in the helicopter. On the ground, we have a flag person at each end of the closure area stopping traffic, a person to check the closure area to make sure no one is on the road, and an equipment operator to clean avalanche debris from the road.

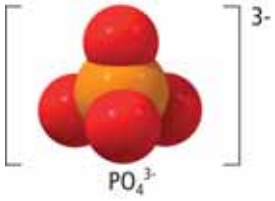
Questions

1. What are the three ways avalanches are controlled?
2. What are four things that avalanche technicians do?
3. Why would learning about compounds and chemical reactions be important to an avalanche technician?

Check Your Understanding

Checking Concepts

1. What is a chemical bond?
2. What are the two kinds of compounds?
3. How are two atoms held together in a covalent bond?
4. What causes ions to come together in an ionic compound?
5. When sodium and chlorine combine, one electron transfers from each sodium atom onto each chlorine atom. Explain why the new ions of sodium and chlorine will arrange themselves into an alternating fashion inside a crystal lattice.
6. (a) When lithium reacts with fluorine, one electron from a lithium atom transfers onto a fluorine atom, forming ions. Which ion has a positive charge, and which ion has a negative charge?
   (b) Write the symbol for each ion.
7. In a water molecule, how many atoms are connected to each
   (a) oxygen atom?
   (b) hydrogen atom?
8. Give the name and the formula of each of the following:
   (a) a polyatomic ion present in eggshells as well as in teeth
   (b) a polyatomic ion present in your bones
   (c) two polyatomic ions that contain the element nitrogen, one positive and one negative
9. Use the diagram of the phosphate ion shown below to answer the following questions.
   (a) What kind of chemical bond holds each oxygen atom to the phosphorus atom?
   (b) How many atoms does the phosphorus atom connect to?
   (c) What is the general term for an ion such as phosphate, which is a molecule that has an overall electric charge?



Understanding Key Ideas

10. Ionic compounds melt at high temperatures. For example, table salt is an ionic compound that melts at 800°C. Why is it so difficult to melt ionic compounds?
11. In a compound that contains a polyatomic ion, there are both covalent bonds and ionic bonds. Where are the covalent bonds, and where are the ionic bonds?
12. How many oxygen atoms are connected to each chromium atom in the dichromate ion?

Pause and Reflect

Many compounds are composed of just two elements. Below is a list of pairs of elements and the type of compounds they form. Suggest a pattern that could be used to determine whether lead and chlorine combine to form a molecular compound or an ionic compound.

First Element	Second Element	Type of Compound
sodium	oxygen	ionic
magnesium	sulphur	ionic
carbon	fluorine	covalent
sulphur	oxygen	covalent
iron	iodine	ionic
phosphorus	bromine	covalent