**Key Terms**
molecular compound
covalent bond
molecule

## 6.2 Molecular Compounds

Instead of throwing out that wrapper, eat it! Imagine if you could eat the protective wrapping on your food instead of throwing it out. Think of the amount of trash this would eliminate. Scientists are working on the development of edible films made from dairy products, like the one shown in **Figure 6.14**. Edible films are made from casein, a protein that is in milk and other dairy products. They are transparent and shiny, and they can extend the shelf life of food by preventing exposure to moisture and oxygen, just like plastic wrap. They are an example of another class of compounds, called molecular compounds. Like ionic compounds, molecular compounds have a specific type of chemical bond, which gives them characteristic properties.

**Figure 6.14** This food technologist is preparing an edible plastic film, similar to these green breath-freshening strips.

## Covalent Bonds

A **molecular compound** forms when atoms share a pair of electrons to form a **covalent bond**. In a covalent bond, the shared electrons are attracted to the nuclei of both atoms. The attraction of the nuclei for the shared electrons holds the atoms together. Unlike ionic compounds, electrons are not transferred between atoms, and the atoms remain uncharged. A covalent bond is like a tug-of-war game, as shown in **Figure 6.15**. Two teams are joined by their mutual pull on the rope.

**molecular compound** a compound formed when atoms of two or more different elements share electrons

**covalent bond** a chemical bond in which one or more pairs of electrons are shared by two atoms

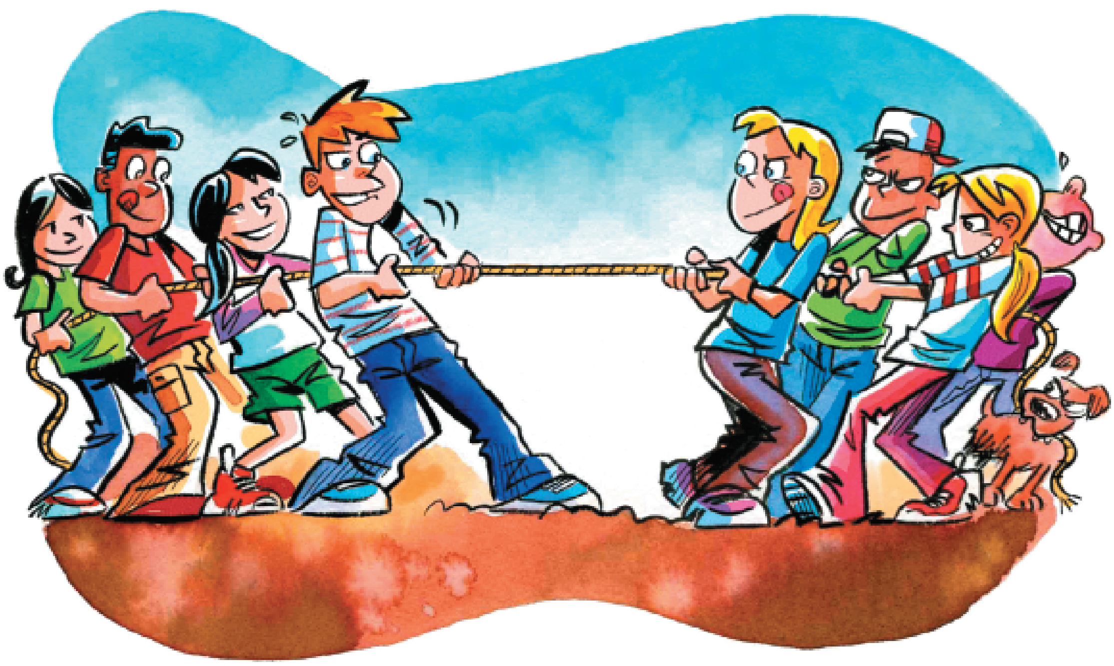


**Figure 6.15** The mutual pull of the two teams on the shared rope is an analogy for the attraction of two atoms on the electrons that are shared in a covalent bond.

### Filling Outer Energy Levels by Sharing

The formation of a molecular compound is based on the same principle as the formation of an ionic compound: the stability that is associated with a full outer energy level of electrons. There is an important difference, however. The atoms that form a molecular compound achieve full outer energy levels, and therefore more stability, by sharing their valence electrons, as shown in **Figure 6.16**.

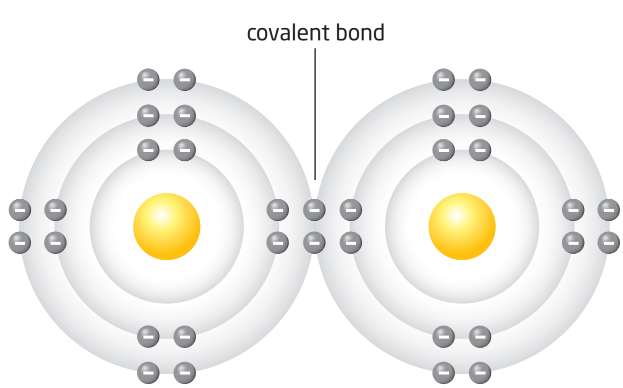



**Figure 6.16** Covalent bonds involve the sharing of valence electrons to form full outer energy levels of electrons.

## Recognizing Molecular Compounds

**molecule** the smallest discrete particle of a pure substance, which has one or more shared pairs of electrons

Simple covalent compounds are usually composed of two or more non-metals. One familiar molecular compound is water, shown in **Figure 6.17**. The smallest particle of water is a **molecule** of water. Each molecule of water is composed of two hydrogen atoms and one oxygen atom, represented as $H_2O$. The Bohr-Rutherford models for water in **Figure 6.18** show each hydrogen atom forming a covalent bond with the oxygen atom by sharing a pair of electrons. The covalent bonding of each hydrogen atom to the oxygen atom produces filled outer energy levels for all three atoms. In the Bohr-Rutherford model, the shared electrons are shown between the atoms.

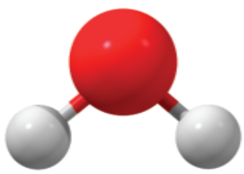


**Figure 6.17** A water molecule consists of two hydrogen atoms (shown in white) that are joined by covalent bonds to an oxygen atom (shown in red).

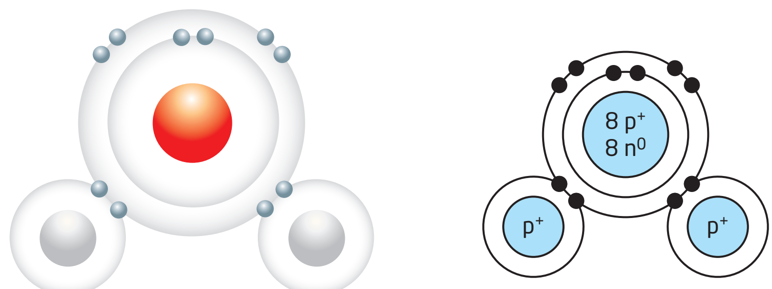



**Figure 6.18** These Bohr-Rutherford models for water show how the covalent bonds between hydrogen and oxygen involve sharing a pair of valence electrons.

### Molecules

Molecular compounds are so called because they exist as molecules. By definition, a molecule is the smallest unit of a pure substance that has two or more atoms covalently bonded. Not all molecules, however, are compounds. Recall, from Chapter 4, that compounds are defined as being composed of two or more *different* elements. Molecules can include two or more atoms of the *same* element that are covalently bonded. For example, the oxygen in the air you breathe exists as two oxygen atoms that are covalently bonded, shown in **Figure 6.19**. It is represented as $O_2$ and referred to as a molecule of oxygen, *not* a compound.

**Study Toolkit**

**Creating a Word Map**
To help you understand the meaning of the word *molecule*, draw a word map for it. Use the word map on page 220 as a guide to help you.

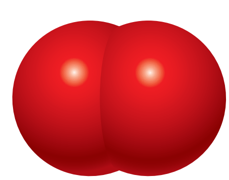
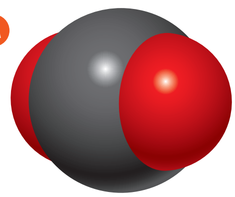


**Figure 6.19** Oxygen in the air you breathe exists as a molecule composed of two oxygen atoms that are covalently bonded.

## Naming Molecular Compounds

The names of most molecular compounds reflect the elements that are in the compounds, as well as the number of each element. Consider carbon monoxide and carbon dioxide, shown in **Figure 6.20**. Both compounds are composed of the elements carbon and oxygen. Notice, however, that their names include the prefixes *mono-* and *di-*, which are used to indicate the number of oxygen atoms present in a molecule of each compound. So, carbon *mono*xide has the formula CO because *monoxide* means one oxygen. Carbon *di*oxide has the formula $CO_2$ because *dioxide* means two oxygens.

A

carbon dioxide

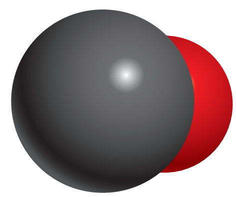
B

carbon monoxide


**Figure 6.20** **A** Carbon dioxide and **B** carbon monoxide are molecular compounds that differ in composition by one oxygen atom. Nevertheless, carbon monoxide is a toxic gas. Detectors, like the one shown here, are recommended in homes that are heated using fossil fuels to warn residents about unsafe levels of carbon monoxide.

Although the only difference between their names is a prefix, carbon dioxide and carbon monoxide are compounds with vastly different properties. Carbon dioxide is a gas that is exhaled every time you breathe. It is also used to carbonate drinks. Carbon monoxide, however, is a highly toxic gas that interferes with the body's ability to transport oxygen. Carbon monoxide is generated by burning fuels such as gasoline, wood, and natural gas.

**Table 6.1** lists some common prefixes and the number that each prefix represents. You will learn more about naming molecular compounds and determining their chemical formulas in Grade 10.

**Table 6.1 Prefixes Used for Molecular Compounds**

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

## The Properties of Molecular Compounds

There are many different types of molecular compounds. This makes it difficult to generalize about the properties of all molecular compounds. Nevertheless, there are some properties that are shared by a large number of molecular compounds and that are quite different from the properties of ionic compounds. A key reason for many of the differences in properties is the weaker attraction *between* molecules.

Recall that an ionic compound behaves like one large structure. Each ion is surrounded by ions of opposite charge, and the strong attractions between oppositely charged ions exist throughout the crystal. Although the strengths of ionic and covalent bonds are about the same, the attraction between molecules in a molecular compound are weak, as shown in **Figure 6.21**. These attractions are much weaker than the attraction between ions in an ionic crystal.

When a molecular compound is melted or vaporized, enough energy must be supplied to overcome the attraction between molecules. Because the attraction is weak, most molecular compounds have relatively low melting and boiling points. The weak attraction between molecules also explains the relative softness of molecular compounds. In addition, because molecular compounds do not have free electrons or ions, they are poor conductors of electricity and heat, compared with ionic compounds. **Figure 6.22** shows just one of many ways that the properties of molecular compounds can be taken advantage of, for practical applications.

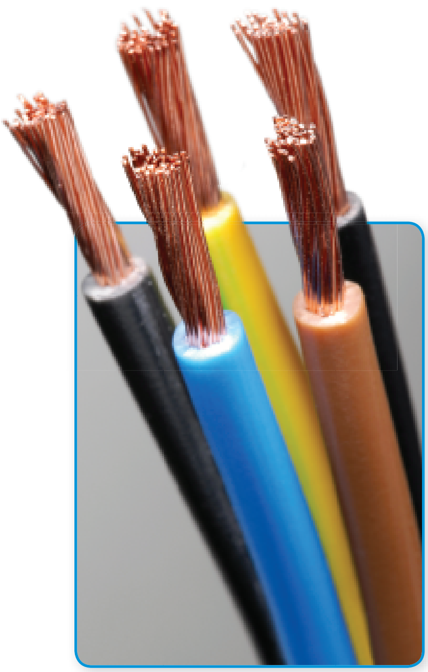


**Figure 6.22** Molecular compounds are poor conductors of electricity. This makes them useful as insulating covers over electrical wires.

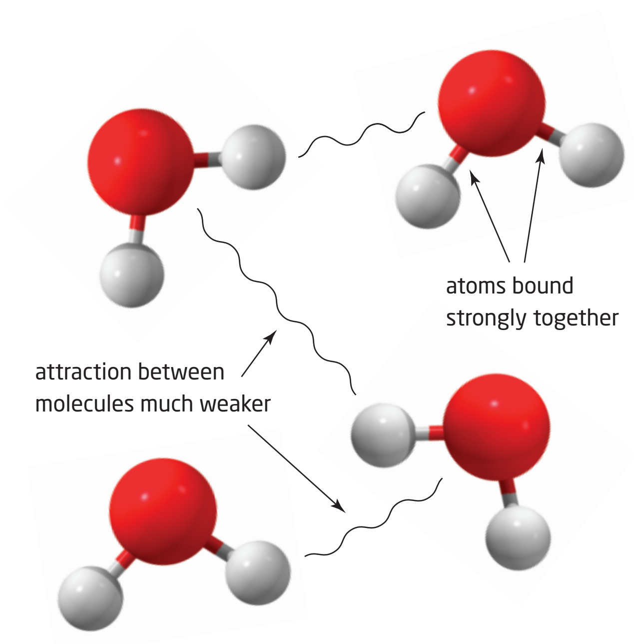



**Figure 6.21** In molecular compounds, such as water, the attraction between the molecules is much weaker than the strength of the covalent bonds between the atoms.

### Solubility

Another general difference between ionic and molecular compounds is solubility. Many molecular compounds do not dissolve as well as ionic compounds in water. For example, carbon dioxide is a molecular compound that gives soft drinks their fizz, as shown in **Figure 6.23**. Only very small amounts of carbon dioxide gas, however, can dissolve in water. To make the carbon dioxide gas dissolve better, soft drinks are packed under high pressure. When you open a bottle or can, and consequently reduce the pressure inside, the carbon dioxide begins to come out of solution and the soft drink starts to go flat.

**Suggested Investigation**

Inquiry Investigation 6-B, Properties of Ionic and Molecular Compounds, on page 250

**Figure 6.23** The bubbles that you see in a soft drink are carbon dioxide gas that is coming out of solution.

**Learning Check**

1. Which type of elements are molecular compounds composed of?
2. What happens to electrons in a covalent bond?
3. Identify the elements in each covalent molecular, and state the number of atoms of each element.
   a. silicon tetrachloride
   b. sulfur hexafluoride
4. Why would wearing gloves made from a molecular compound, such as rubber, help to prevent an electrician from being electrocuted?

**Figure 6.24** This milk jug is made of high-density polyethylene.

## Plastics

Plastics are made of molecular compounds called *polymers*. If you think about all the different things that are made from plastic, it becomes obvious that there are a large number of different types of plastic.

Ethylene, a molecular compound composed of the elements hydrogen and carbon, is a common starting material for a class of plastics called polyethylenes. Numerous items, such as shopping bags, toys, bottles, and containers, are made with this class of plastics. The different types of polyethylene plastic are grouped based on their density and how many ethylene molecules are joined together. If you look on the bottom of a plastic milk jug, such as the one shown in **Figure 6.24**, you will probably see the letters *HDPE*, which stand for high-density polyethylene.

# STSE Case Study

## Taking a Stand on Plastic Bags

Leaf Rapids, Manitoba, a community of about 550 people, had a problem with plastic bags. The discarded bags were scattered all along the lakeshore, trails, and roads, and some bags were even left dangling from trees. The litter was an eyesore in the community, and it cost the community nearly $5000 a year to clean up. The problems with the plastic bags did not end, however, when they were cleaned up.

Plastic bags are not biodegradable. The plastic simply changes into smaller pieces over time. The small, broken-down particles contain toxic materials that can leach into water and soil. The toxic materials are found not only in landfill sites, but also anywhere that plastic ends up as litter.

### A Plan of Action

In May 2006, the Leaf Rapids town council began a program to reduce the use of plastic bags. Consumers were charged three cents for each single-use plastic shopping bag they took home from a store. To help consumers stop using plastic bags, the town gave each household five reusable cloth bags.

Then, in April 2007, Leaf Rapids became the first community in Canada to ban most plastic bags in retail stores. According to By-Law 462, “retailers in the Town of Leaf Rapids will not be permitted to give away or sell plastic shopping bags that are intended for single use.” Breaking this by-law could mean a fine of $1000.

Leaf Rapids officials estimated that the ban would mean preventing 50 000 to 100 000 bags from ending up in landfills each year. The ban had almost full support from town residents. A year after the ban, the mayor announced that the program was a success. The town was much tidier.

Consumers in Ontario use an estimated 2.5 billion plastic bags each year.

### Environmental Concerns

Plastics provide a wide range of products that have many benefits, from convenient food packaging to bottles that keep medicines safe. Each year, millions of tonnes of plastics are produced. The durability of most plastics, however, poses problems for the environment because plastics do not easily degrade. Recycling efforts have reduced the amount of plastics entering landfills, but only some plastics are able to be recycled at this time. For example, many products made from polyethylene plastics are not biodegradable—they are not broken down naturally by living organisms. Chemicals in the plastics slowly leach out over time in landfills. As well, discarded plastics are hazardous to wildlife on land and in the ocean, as shown in **Figure 6.25**.

**Suggested Investigation**

Data Analysis Investigation 6-C, Classification of Household Substances, on page 252

**Figure 6.25** Animals can be harmed if they eat discarded plastic or if they become trapped in pieces of plastic, such as plastic rings.

### Alternatives to Plastic

Are paper bags an eco-friendly alternative to plastic bags? Not necessarily. According to the David Suzuki Foundation, one paper bag uses more energy to make and produces more waste than two plastic bags. The Foundation suggests using reusable cloth bags instead of either plastic or paper bags.

The next time you go shopping, you have a choice. You can bring a cloth bag for your purchase, you can carry your purchase without a bag, or you can accept your purchase in a plastic or paper bag. What will you do? Will you take a stand on plastic bags?

### Your Turn

1. According to this case study, why might a community consider imposing a charge or a ban on plastic bags?
2. Banning plastic bags is one way to reduce the amount of plastic that is tossed into the garbage. With a partner, brainstorm a list of other solutions.
3. Research what other communities are doing to help reduce the use of plastic bags. Based on your research, write a proposal that describes what could be done in your community.

### Not for Everyone

In May 2007, The *Toronto Star* newspaper asked its readers if they thought that plastic shopping bags should be banned. Only about 18 percent of the people who responded agreed with a ban. Other responses included

- concern about not being able to use plastic shopping bags as garbage-bin liners or “stoop and scoop” bags for dog walking
- concern about why plastic bags were being targeted instead of other single-use disposable items
- support for a voluntary reduction instead of a ban

Many people are now using alternatives to plastic shopping bags.

# Activity 6-3

## Cornstarch Plastic

Starch particles are very long chains of sugar molecules. Starch, therefore, is a natural polymer. Under certain conditions, the long chains become tangled with each other, to form a solid material. How do you think it could be useful?

### Safety Precautions

- Wear safety goggles and a lab apron.
- Do not eat anything you use or produce in this activity.
- Make sure that you dispose of any waste materials according to your teacher's instructions.

### Materials

- 75 mL of cornstarch
- 250 mL beaker
- 45 mL of water
- sturdy spoon or stir stick
- graduated cylinder

### Procedure

1. Read over the procedure, and then make a table to record your observations. Give your table a title.
2. Place the cornstarch in the beaker. Add the water, and stir. When the water and cornstarch are completely mixed, the mixture should be difficult to stir.
3. Shape the mixture into a ball. Observe what happens when you let the ball just sit in your open hand. Record your observations.
4. Apply a small but sudden force to the ball, using your fingers or an object such as a spoon. How does the mixture respond to the sudden application of force? Record your observations.
5. Dispose of the materials as directed by your teacher.

### Questions

1. How does the mixture behave if it is allowed to sit undisturbed?
2. What does the mixture do when a sudden force is applied?
3. How do you think a mixture, like the one you made, could be useful?

## Making a Difference

As captain of her high school's 2007 Envirothon team, Dayna Corelli helped to develop an award-winning proposal that was reviewed by the city of Sudbury. Dayna's team was concerned that watering lawns and cleaning streets was wasting water. They were also concerned that the city's infrastructure could not handle heavy rainfall, which was causing storm sewers to overflow and dump raw sewage into the Great Lakes. Since reviewing the proposal, as well as recommendations from other groups, Sudbury has restricted lawn watering, made street cleaning more efficient, and improved infrastructure. The Envirothon team's proposal also recommended that the city develop a plan to capture methane, which is produced in landfills, and explore its potential as an energy source.

Dayna has worked on other campaigns to promote recycling, energy efficiency, water conservation, and anti-idling. In 2008, she received a Toyota Earth Day scholarship. Dayna is now studying chemical engineering at Laurentian University.

**What changes could your municipality make to improve water quality and energy conservation?**

# Section 6.2 Review

## Section Summary

- Most simple molecular compounds are composed of two or more atoms of different elements. These elements are usually two or more non-metals.
- The attraction between molecules is much weaker than the attraction between oppositely charged ions in an ionic crystal. This contributes to the differences in the properties of ionic compounds and some molecular compounds.
- Many molecular compounds tend to have low melting points and low solubility in water, compared with ionic compounds. Many molecular compounds are also poor conductors of heat and electricity.
- Plastics are a large class of human-made molecular compounds. Their numerous uses include shopping bags, containers, and fabrics. There are, however, many environmental concerns associated with the use of plastics.

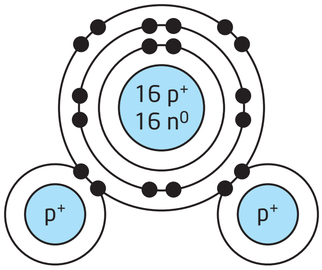
## Review Questions

K/U **1.** Identify each of the following compounds as molecular or ionic.
  **a.** carbon disulfide
  **b.** lithium carbonate
  **c.** $OCl_2$
  **d.** $P_2O_5$

T/I **2.** Is a molecular compound likely to form from two metals? Explain your reasoning.

T/I **3.** Why is the term "covalent" appropriate for describing the bonds in a molecular compound?

K/U **4.** Does the model on the right correctly represent a molecular compound? Why or why not?



This is a Bohr-Rutherford model.

A **5.** The prefixes that are used for naming molecular compounds are also used in many common everyday words. List three everyday words that contain one of the prefixes in **Table 6.1**, and explain why the prefix is used.

K/U **6.** What is an important difference between how molecules interact and how ions in a crystal lattice interact? How does this contribute to making the properties of ionic compounds and molecular compounds very different?

K/U **7.** Why are most molecular compounds poor electrical conductors?

C **8.** Suppose that you are given a pamphlet about polymers. The pamphlet claims that polymers are destructive and will ruin the environment. Write a short response, based on your study of molecular compounds.