Section 3.2

# Combining Matter

### Objectives

- **Describe** the chemical bonds that unite atoms to form compounds.
- **Relate** the nature of chemical bonds that hold compounds together to the physical structures of compounds.
- **Distinguish** among different types of mixtures and solutions.

### Review Vocabulary

**ion:** an electrically charged atom

### New Vocabulary

compound
chemical bond
covalent bond
molecule
ionic bond
metallic bond
chemical reaction
solution
acid
base

**MAIN Idea Atoms combine through electric forces, forming molecules and compounds.**

**Real-World Reading Link** Is there a rusty mailbox or bicycle on your street? Nearly everywhere you look, you can see iron objects that have become rusty. Rust forms when iron is exposed to water and oxygen in the air.

## Compounds

Can you identify the materials in **Figure 3.7?** The greenish gas in the flask is the element chlorine, which is poisonous. The solid, silvery metal is the element sodium, which is highly reactive. These two elements combine chemically to form the third material in the photograph—table salt. How can two dangerous elements combine to form a material that you sprinkle on your popcorn?

Table salt is a compound, not an element. A **compound** is a substance that is composed of atoms of two or more different elements that are chemically combined. Water is another example of a compound because it is composed of two elements—hydrogen and oxygen. Most compounds have different properties from the elements of which they are composed. For example, both oxygen and hydrogen are highly flammable gases at room temperature, but in combination they form water—a liquid.

**Chemical formulas** Compounds are represented by chemical formulas. These formulas include the symbol for each element followed by a subscript number that stands for the number of atoms of that element in the compound. If there is only one atom of an element, no subscript number follows the symbol. Thus, the chemical formula for table salt is NaCl. The chemical formula for water is $H_2O$.

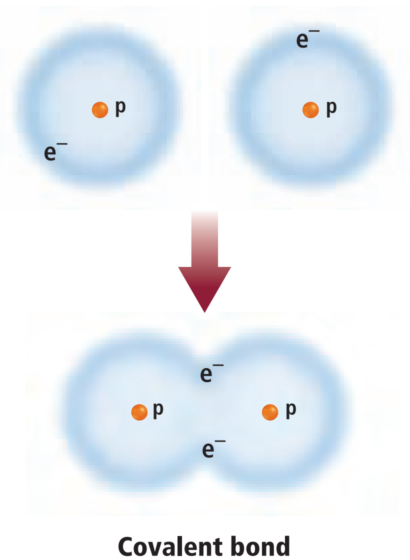
**Figure 3.7** Sodium is a silvery metal that is soft enough to cut with a knife. Chlorine is a green, poisonous gas. When they react, they produce sodium chloride, a white solid.



Stephen Frisch/Stock Boston

## Covalent Bonds

Recall that an atom is chemically stable when its outermost energy level is full. A state of stability is achieved by some elements by forming chemical bonds. A **chemical bond** is the force that holds together the elements in a compound. One way in which atoms fill their outermost energy levels is by sharing electrons. For example, individual atoms of hydrogen each have just one electron. Each atom becomes more stable when it shares its electron with another hydrogen atom so that each atom has two electrons in its outermost energy level. **Figure 3.8** shows an example of this bond. How do these two atoms stay together? The nucleus of each atom has one proton with a positive charge, and the two positively charged protons attract the two negatively charged electrons. This attraction of two atoms for a shared pair of electrons that holds the atoms together is called a **covalent bond.**



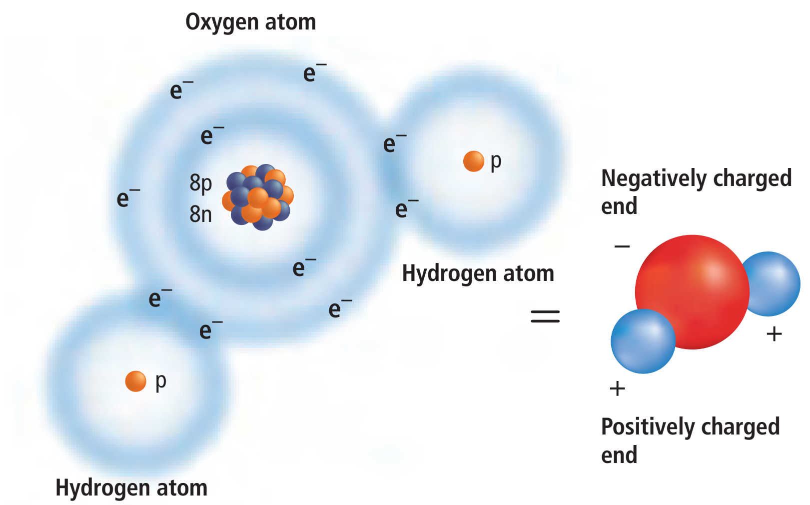

■ **Figure 3.8** In this covalent bond example, notice the positions of the electrons in the outermost energy levels. They can now be considered as part of each atom.

**Molecules** A **molecule** is composed of two or more atoms held together by covalent bonds. Molecules have no overall electric charge because the total number of electrons equals the total number of protons. Water is an example of a compound whose atoms are held together by covalent bonds, as illustrated in **Figure 3.9.** The chemical formula for a water molecule is $H_2O$ because, in this molecule, two atoms of hydrogen, each of which need to gain an electron to become stable, are combined with one atom of oxygen, which needs to gain two electrons to become stable. A compound comprised of molecules is called a molecular compound.

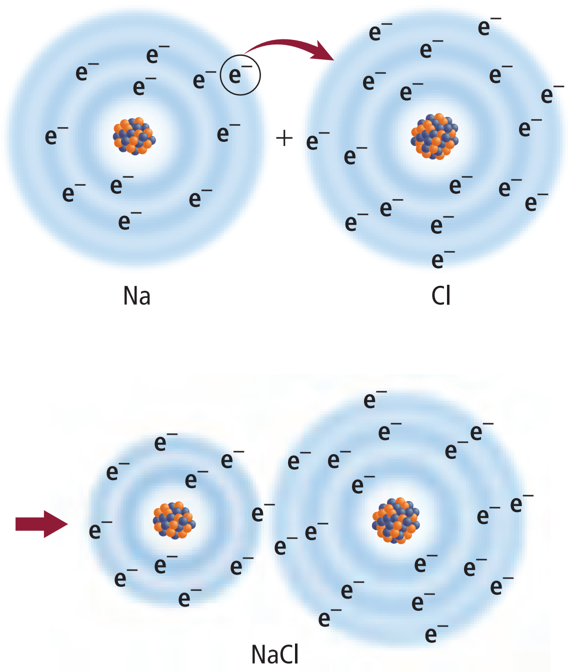
**Polar molecules** Although water molecules are held together by covalent bonds, the atoms do not share the electrons equally. As shown in **Figure 3.9,** the shared electrons in a water molecule are attracted more strongly by the oxygen atom than by the hydrogen atoms. As a result, the electrons spend more time near the oxygen atom than they do near the hydrogen atoms. This unequal sharing of electrons results in polar molecules. A polar molecule has a slightly positive end and a slightly negative end.

**VOCABULARY**
**SCIENCE USAGE V. COMMON USAGE**
**Polar**
***Science usage:*** the unequal sharing of electrons

***Common usage:*** locations of or near the north or south pole, or the ends of a magnet




■ **Figure 3.9** Polar molecules are similar to bar magnets. At one end of a water molecule, the hydrogen atoms have a positive charge, while at the opposite end, the oxygen atom has a negative charge.




■ **Figure 3.10** The single valence electron in a sodium atom is used to form an ionic bond with a chlorine atom. Once an ionic bond is formed, the negatively charged ion is slightly larger than the positively charged ion.

**Concepts In Motion**

**Interactive Figure** To see an animation of ionic bonds, visit glencoe.com.

## Ionic Bonds

As you might expect, positive and negative ions attract each other. An **ionic bond** is the attractive force between two ions of opposite charge. **Figure 3.10** illustrates an ionic bond between a positive ion of sodium and a negative ion of chlorine called chloride. The chemical formula for common table salt is NaCl, which consists of equal numbers of sodium ions ($Na^+$) and chloride ions ($Cl^-$) . Note that positive ions are always written first in chemical formulas.

Within the compound NaCl, there are as many positive ions as negative ions; therefore, the positive charge on the sodium ion equals the negative charge on the chloride ion, and the net electric charge of the compound NaCl is zero. Magnesium and oxygen ions combine in a similar manner to form the compound magnesium oxide (MgO)—one of the most common compounds on Earth. Compounds formed by ionic bonding are called ionic compounds. Other ionic compounds have different proportions of ions. For example, oxygen and sodium ions combine in the ratio shown by the chemical formula for sodium oxide ($Na_2O$), in which there are two sodium ions to each oxygen ion.

**Reading Check** **Describe** how ionic bonds form.

## Metallic Bonding

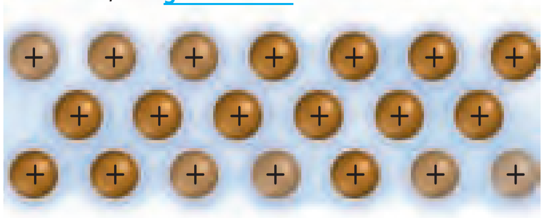
Most compounds on Earth are held together by ionic or covalent bonds, or by a combination of these bonds. Another type of bond is shown in **Figure 3.11.** In metals, the valence electrons are shared by all the atoms, not just by adjacent atoms as they are in covalent compounds. You could think of a metal as a group of positive ions surrounded by a sea of freely moving negative electrons. The positive ions of the metal are held together by the attraction to the negative electrons between them. This type of bond, known as a **metallic bond,** allows metals to conduct electricity because the electrons can move freely throughout the entire solid metal.

Metallic bonding also explains why metals are so easily deformed. When a force is applied to a metal, such as the blow of a hammer, the electrons are pushed aside. This allows the metal ions to move past each other, thus deforming or changing the shape of the metal. **Figure 3.12** summarizes how valence electrons are used to form the three different types of bonds.

■ **Figure 3.11** Metallic bonds are formed when valence electrons are shared equally among all the positively charged atoms. Because the electrons flow freely among the positively charged ions, you can visualize electricity flowing through electrical wires.

**Concepts In Motion**

**Interactive Figure** To see an animation of electron flow, visit glencoe.com.

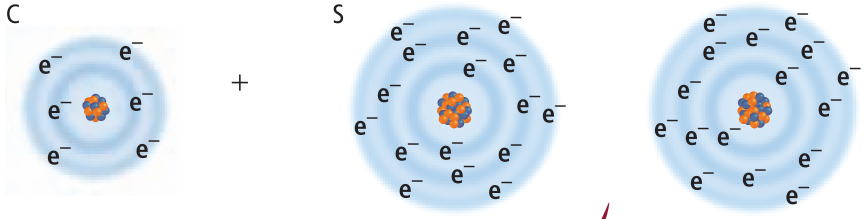


**Metallic bond**

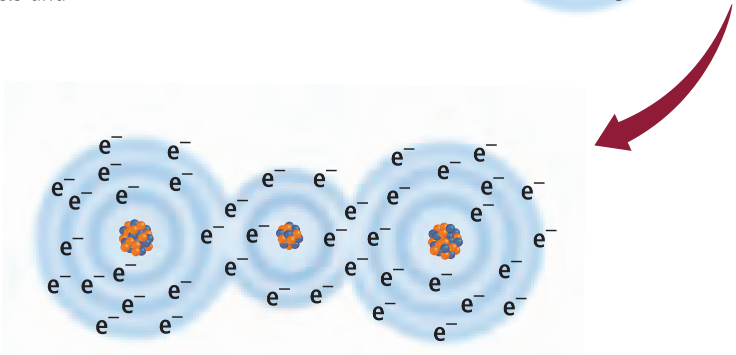
# Visualizing Bonds

NATIONAL GEOGRAPHIC

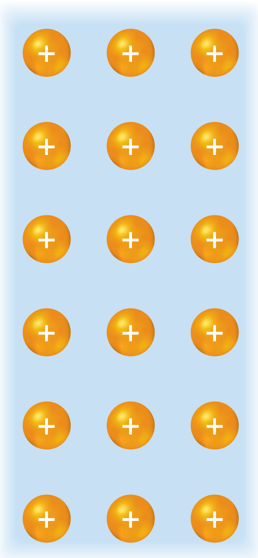
**Figure 3.12** Atoms gain stability by sharing, gaining, or losing electrons to form ions and molecules. The properties of metals can be explained by metallic bonds.



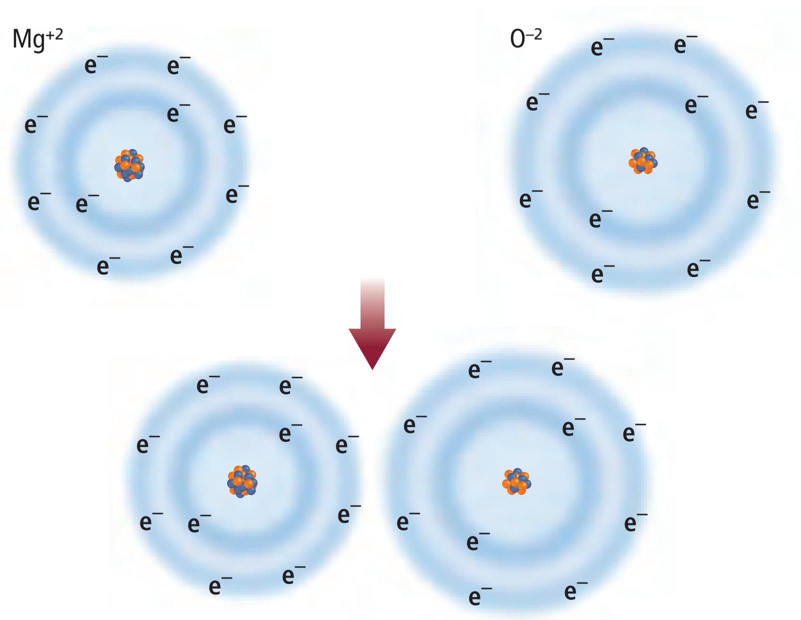

**Covalent bond** Shared electrons fill outermost energy levels and make stable molecular compounds.




**Metallic bond** Within metals, valence electrons move freely around positively charged protons.



**Ionic bond** Once valence electrons are gained or lost to fill outermost energy levels and form stable ions, the oppositely charged ions are attracted to each other.




Concepts In Motion To explore more about chemical bonding, visit glencoe.com.

Earth Science Online

■ **Figure 3.13** When a copper wire is placed in the solution of silver nitrate in the beaker, a chemical reaction occurs in which silver replaces copper in the wire and an aqua-colored copper nitrate solution forms.

Tim Courlas

## Chemical Reactions

You have learned that atoms gain, lose, or share electrons to become more stable and that these atoms form compounds. Sometimes, compounds break down into simpler substances. The change of one or more substances into other substances, such as those in **Figure 3.13,** is called a **chemical reaction.** Chemical reactions are described by chemical equations. For example, water ($H_2O$) is formed by the chemical reaction between hydrogen gas ($H_2$) and oxygen gas ($O_2$). The formation of water can be described by the following chemical equation.

$$2H_2 + O_2 \rightarrow 2H_2O$$

You can read this chemical equation as "two molecules of hydrogen and one molecule of oxygen react to yield two molecules of water." In this reaction, hydrogen and oxygen are the reactants and water is the product. When you write a chemical equation, you must balance the equation by showing an equal number of atoms for each element on each side of the equation. Therefore, the same amount of matter is present both before and after the reaction. Note that there are four hydrogen atoms on each side of the above equation ($2 \times 2 = 4$). There are also two oxygen atoms on each side of the equation.

Another example of a chemical reaction, one that takes place between iron (Fe) and oxygen (O), is represented by the following chemical equation.

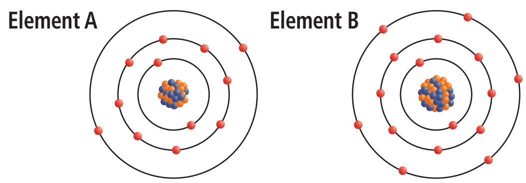
$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

You will examine how compounds form in the Problem-Solving Lab on this page.

# PROBLEM-SOLVING LAB

## Interpret Scientific Illustrations

**How do compounds form?** Many atoms gain or lose electrons in order to have eight electrons in the outermost energy level. In the diagram, energy levels are indicated by the circles around the nucleus of each element. The colored spheres in the energy levels represent electrons, and the spheres in the nucleus represent protons and neutrons.




### Analysis

1. How many electrons are present in atoms of Element A? Element B?
2. How many protons are present in the nuclei of these atoms?
3. Use the periodic table on page 61 to determine the name and symbol of Element A and Element B.

### Think Critically

4. **Decide** if these elements can form ions. If so, what would be the electric charges (magnitude and sign) and chemical symbols of these ions?
5. **Formulate** a compound from these two elements. What is the chemical formula of the compound?

## Mixtures and Solutions

Unlike a compound, in which the atoms combine and lose their identities, a mixture is a combination of two or more components that retain their identities. When a mixture's components are easily recognizable, it is called a heterogeneous mixture. For example, beach sand, shown in **Figure 3.14,** is a heterogeneous mixture because its components are still recognizable—shells, small pieces of broken shells, grains of minerals, and so on. In a homogeneous mixture, which is also called a **solution,** the component particles cannot be distinguished, even though they still retain their original properties.

A solution can be liquid, gaseous, or solid. Seawater is a solution consisting of water molecules and ions of many elements that exist on Earth. Molten rock is also a liquid solution; it is composed of ions representing all atoms that were present in the crystals of the rock before it melted. Air is a solution of gases, mostly nitrogen and oxygen molecules together with other atoms and molecules. Metal alloys, such as bronze and brass, are also solutions. Bronze is a homogeneous mixture of copper and tin atoms; brass is a similar mixture of copper and zinc atoms. Such solid homogeneous mixtures are called solid solutions. You will learn more about solid solutions in Chapters 4 and 5.

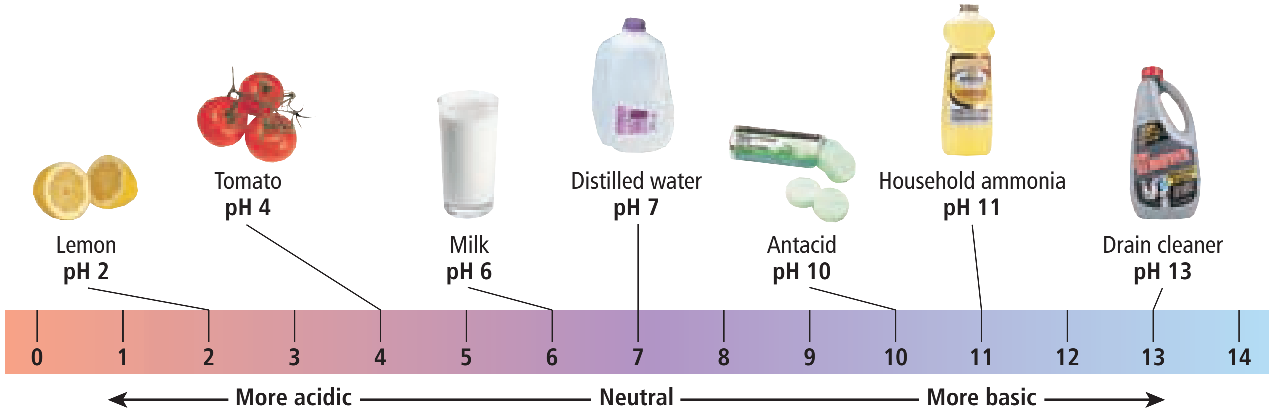
**Reading Check** **Describe** three examples of solutions.

**Figure 3.14** Not all mixtures of beach sand and shells are alike. Mixtures from the Atlantic Ocean will contain components that are different from mixtures that form in the Pacific Ocean.

**Acids** Many chemical reactions that occur on Earth involve solutions called acids and bases. An **acid** is a solution containing a substance that produces hydrogen ions ($H^+$) in water. Recall that a hydrogen atom consists of one proton and one electron. When a hydrogen atom loses its electron, it becomes a hydrogen ion ($H^+$). The pH scale, shown in **Figure 3.15,** is based on the amount of hydrogen ions in a solution. This amount is referred to as the concentration. A value of 7 is considered neutral. A solution with a pH reading below 7 is considered to be acidic. The lower the number, the more acidic the solution.

Concepts In Motion
**Interactive Figure** To see an animation of the pH scale, visit glencoe.com.

**Figure 3.15** The pH scale is not only reserved for science class. All substances have a pH value, as you can see by the common household substances shown here.






(tr)Gregor Schuster/zefa/CORBIS, (l to r)Studiohio, (2)Mark Burnett, (3)Studiohio, (4)Matt Meadows, (5)Amanita Pictures, (6)Studiohio, (7)Aaron Haupt

## CAREERS IN EARTH SCIENCE

**Geochemistry** Some geochemists study the interaction of rocks, minerals and the environment. They can help mining companies reduce the amount of contamination from waste piles by understanding how the rocks and minerals break down and how toxic the byproducts might be. For more information on Earth science careers, visit glencoe.com.

The most common acid in Earth's environment is carbonic acid ($H_2CO_3$), which is produced when carbon dioxide ($CO_2$) is dissolved in water ($H_2O$) by the following reaction.

$$H_2O + CO_2 \rightarrow H_2CO_3$$

Some of the carbonic acid ($H_2CO_3$) in the water ionizes, or breaks apart, into hydrogen ions ($H^+$) and bicarbonate ions ($HCO_3$), as represented by the following equation.

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

These two equations play a major role in the dissolution and precipitation of limestone and the formation of caves, discussed in Chapter 10. Many of the reaction rates involved in geological processes are very slow. For example, it might take thousands of years for enough carbonic acid in limestone to dissolve in groundwater and produce a cave.

**Bases** When a solution contains hydroxide ions ($OH^-$), the solution is called a **base.** A base can neutralize an acid because hydrogen ions ($H^+$) from the acid react with the hydroxide ions ($OH^-$) from the base to form water through the following reaction.

$$H^+ + OH^- \rightarrow H_2O$$

Refer again to **Figure 3.15.** A solution with a reading above 7 is considered to be basic. The higher the number, the more basic the solution. Distilled water usually has a pH of 7, but rainwater is slightly acidic, with a pH of 5.0 to 5.6. The pH values of some common substances are shown in **Figure 3.15.**

# Section 3.2 Assessment

### Section Summary

- Atoms of different elements combine to form compounds.
- Covalent bonds form from shared electrons between atoms.
- Ionic compounds form from the attraction of positive and negative ions.
- There are two types of mixtures—heterogeneous and homogeneous.
- Acids are solutions containing hydrogen ions. Bases are solutions containing hydroxide ions.

### Understand Main Ideas

1. MAIN Idea **Explain** why molecules do not have electric charges.
2. **Differentiate** between molecules and compounds.
3. **Calculate** the number of atoms needed to balance the following equation:
   $CaCO + HCl \rightarrow CO_2 + H_2O + CaCl$
4. **Diagram** how an acid can be neutralized.
5. **Compare and contrast** mixtures and solutions by using specific examples of each.

### Think Critically

6. **Design** a procedure to demonstrate whether whole milk, which consists of microscopic fat globules suspended in a solution of nutrients, is a homogeneous or heterogeneous mixture.
7. **Predict** what kind of chemical bond forms between nitrogen and hydrogen atoms in ammonia ($NH_3$). Sketch this molecule.

### WRITING in Earth Science

8. Antacids are used to relieve indigestion and upset stomachs. Write an advertisement for a new antacid product. Explain how the product works in terms that people who are not taking a science class will understand.



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