CHAPTER 14 Chemical Bonding

Strange but True!

In 1987, pilots Richard Rutan and Jeana Yeager performed a record-breaking feat. They flew the *Voyager* aircraft, shown above, around the world without refueling. The trip lasted just over 9 days. In order to carry enough fuel for the trip, the plane had to be as lightweight as possible. The designers knew that using fewer bolts than usual to attach parts would make the airplane lighter. But without the bolts, what would hold the parts together? The designers decided to replace the bolts with glue!

Not just any glue would do. They used superglue. When superglue is applied, it combines with water from the air to form *chemical bonds.* A chemical bond is a force of attraction that holds atoms together. The particles of superglue squeeze into the materials being glued. The materials stick together as if they were one material. Superglue is so strong that the weight of a two-ton elephant cannot separate two metal plates glued together with just a few drops!

Along with hundreds of household uses, superglue also has many uses in industry and medicine. For example, to make shoes stronger and lighter, manufacturers can replace some of the stitching with superglue. To repair a cracked tooth, dentists can apply superglue to hold the tooth together.

Superglue was discovered by a scientist in the early 1950s who was trying to develop a new plastic for the cockpit bubble of a jet plane.

Chemical bonding is responsible for the ways all materials behave—the properties of materials. In this chapter, you will learn about the different types of bonds that hold atoms together and how those bonds affect the properties of the materials.

What Do You Think?

In your ScienceLog, try to answer the following questions based on what you already know:

1. What is a chemical bond?
2. How are ionic bonds different from covalent bonds?
3. How are the properties of metals related to the type of bonds in them?

Investigate!

From Glue to Goop

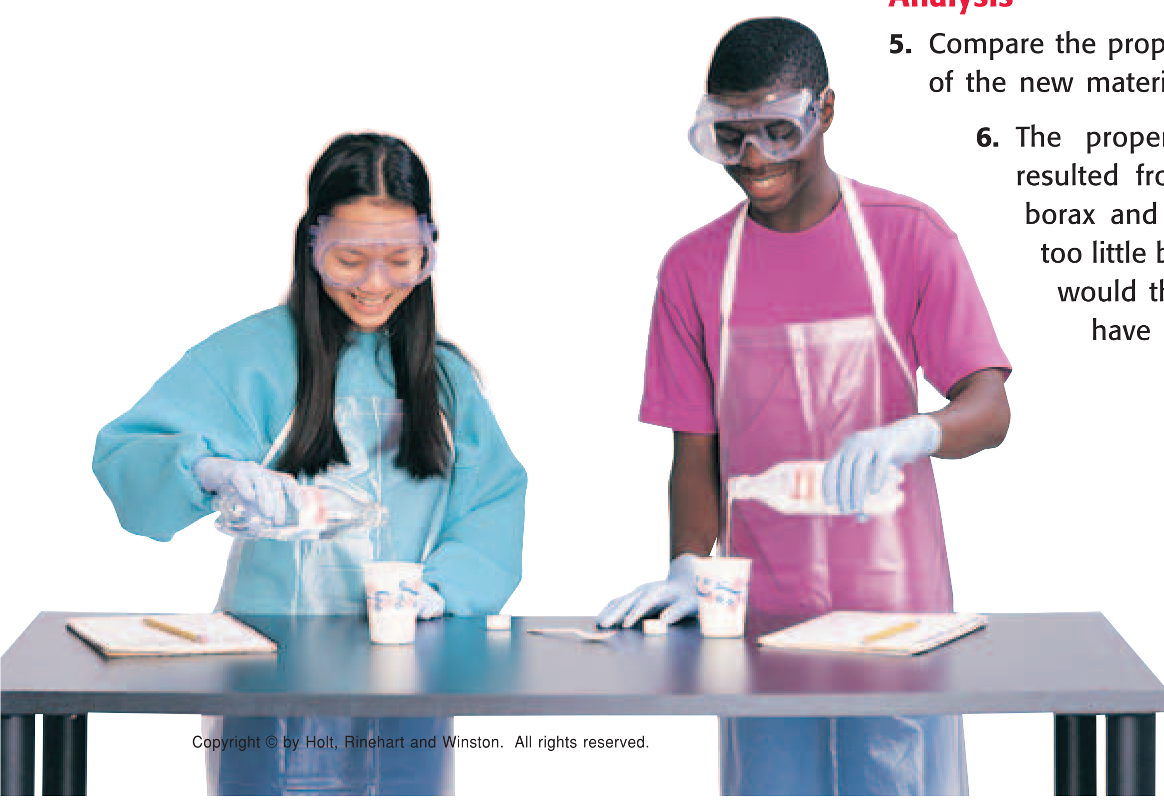
Particles of glue can bond to other particles and hold objects together. Different types of bonds create differences in the properties of substances. In this activity, you will see how the formation of bonds causes an interesting change in the properties of a very common material—white glue.

Procedure

1. Fill a **small paper cup** 1/4 full of **white glue.** Observe the properties of the glue, and record your observations in your ScienceLog.
2. Fill a second **small paper cup** 1/4 full of **borax solution.**
3. Pour the borax solution into the cup containing the white glue, and stir well using a **plastic spoon.**
4. When it becomes too thick to stir, remove the material from the cup and knead it with your fingers. Observe the properties of the material, and record your observations in your ScienceLog.

Analysis

5. Compare the properties of the glue with those of the new material.
6. The properties of the new material resulted from the bonds between the borax and the particles in the glue. If too little borax were used, in what way would the properties of the material have been different?



Section 1

Electrons and Chemical Bonding

NEW TERMS

chemical bonding
chemical bond
theory
valence electrons

OBJECTIVES

- Describe chemical bonding.
- Identify the number of valence electrons in an atom.
- Predict whether an atom is likely to form bonds.

Have you ever stopped to consider that by using just the 26 letters of the alphabet, you make all of the words you use every day? Even though the number of letters is limited, their ability to be combined in different ways allows you to make an enormous number of words.

Now look around the room. Everything around you—desks, chalk, paper, even your friends—is made of atoms of elements. How can so many substances be formed from about 100 elements? In the same way that words can be formed by combining letters, different substances can be formed by combining atoms.

Explore

In your ScienceLog, write down the term *chemical bonding.* Then write down as many different words as you can that are formed from the letters in these two words.

Atoms Combine Through Chemical Bonding

The atoms of just three elements—carbon, hydrogen, and oxygen—combine in different patterns to form the substances sugar, alcohol, and citric acid. **Chemical bonding** is the joining of atoms to form new substances. The properties of these new substances are different from those of the original elements. A force of attraction that holds two atoms together is called a **chemical bond.** As you will see, chemical bonds involve the electrons in the atoms.

Atoms and the chemical bonds that connect them cannot be observed with your eyes. During the past 150 years, scientists have performed many experiments that have led to the development of a theory of chemical bonding. Remember that a **theory** is a unifying explanation for a broad range of hypotheses and observations that have been supported by testing. The use of models helps people to discuss the theory of how and why atoms form chemical bonds.

across the sciences CONNECTION

Why are the amino acids that are chemically bonded together to form your proteins all left-handed? Read about one cosmic explanation on page 370.

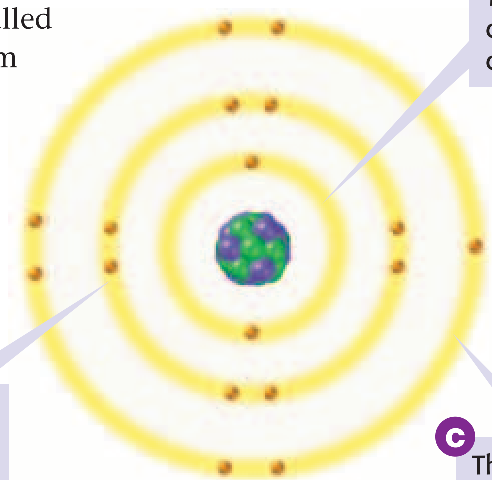
Electron Number and Organization

To understand how atoms form chemical bonds, you first need to know how many electrons are in a particular atom and how the electrons in an atom are organized.

The number of electrons in an atom can be determined from the atomic number of the element. Remember that the atomic number is the number of protons in an atom. Because atoms have no charge, the atomic number also represents the number of electrons in the atom. Equal numbers of positively charged protons and negatively charged electrons are needed to make the overall charge of the atom zero.

The electrons are organized in levels in an atom. These levels are usually called energy levels. The levels farther from the nucleus contain electrons that have more energy than levels closer to the nucleus. The arrangement of electrons within the energy levels of a chlorine atom is shown in **Figure 1.**

Figure 1 Electron Arrangement in an Atom



a The first energy level is closest to the nucleus and can hold up to 2 electrons.

b Electrons will enter the second energy level only after the first level is full. The second energy level can hold up to 8 electrons.

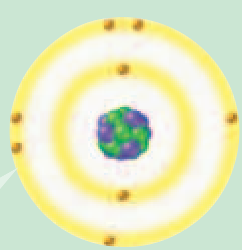
c The third energy level in this model of a chlorine atom contains only 7 electrons, for a total of 17 electrons in the atom. This outer level of the atom is not full.

Outer-Level Electrons Are the Key to Bonding As you just saw in Figure 1, a chlorine atom has a total of 17 electrons. When a chlorine atom bonds to another atom, not all of these electrons are used to create the bond. Most atoms form bonds using only the electrons in their outermost energy level. The electrons in the outermost energy level of an atom are called **valence** (VAY luhns) **electrons.** Thus, a chlorine atom has 7 valence electrons. You can see the valence electrons for atoms of some other elements in **Figure 2.**

Figure 2 *Valence electrons are the electrons in the outermost energy level of an atom.*

Oxygen

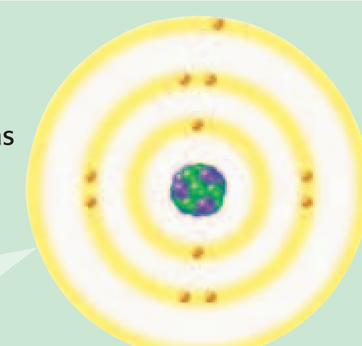
Electron total: 8
First level: 2 electrons
Second level: 6 electrons



The second energy level is the outermost level, so an oxygen atom has 6 valence electrons.

Sodium

Electron total: 11
First level: 2 electrons
Second level: 8 electrons
Third level: 1 electron

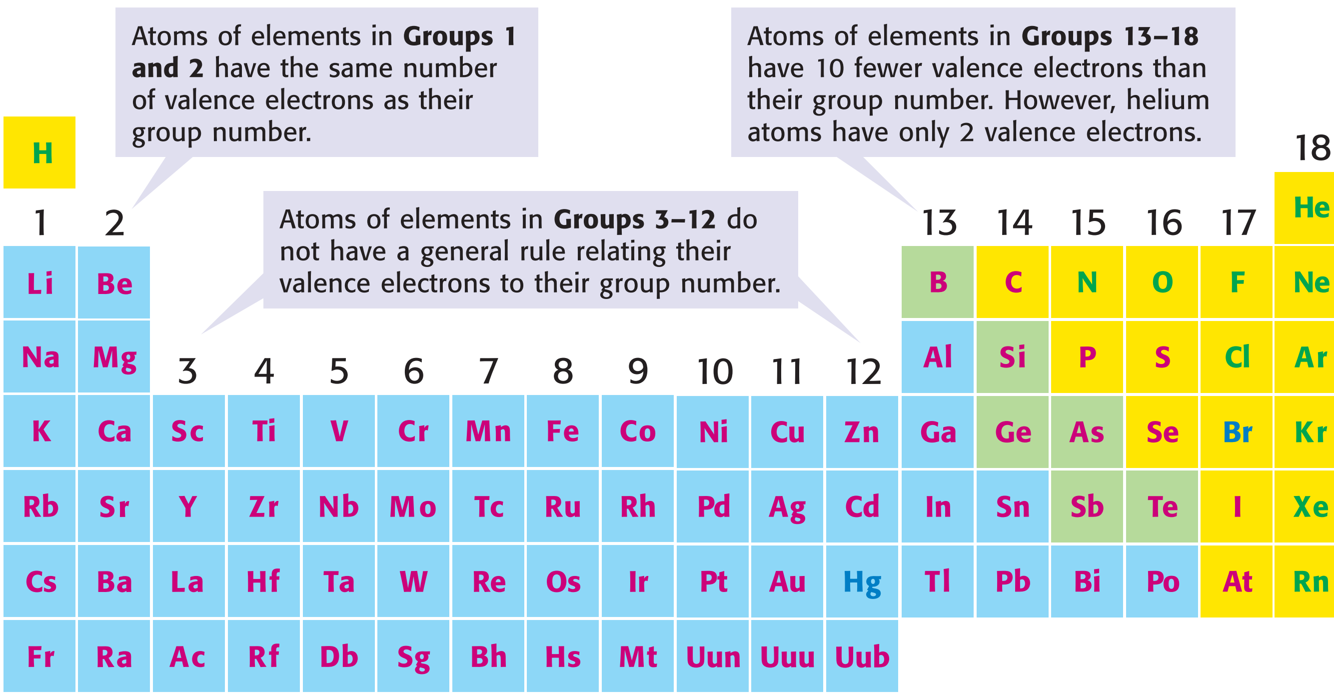


The third energy level is the outermost level, so a sodium atom has 1 valence electron.

Valence Electrons and the Periodic Table You can determine the number of valence electrons in Figure 2 because you have a model to look at. But what if you didn't have a model? You have a tool that helps you determine the number of valence electrons for some elements—the periodic table!

Remember that elements in a group often have similar properties, including the number of electrons in the outermost energy level of their atoms. The number of valence electrons for many elements is related to the group number, as shown in **Figure 3.**

Figure 3 **Determining the Number of Valence Electrons**



To Bond or Not to Bond

Atoms do not all bond in the same manner. In fact, some atoms rarely bond at all! The number of electrons in the outermost energy level of an atom determines whether an atom will form bonds.

Atoms of the noble, or inert, gases (Group 18) do not normally form chemical bonds. As you just learned, atoms of Group 18 elements (except helium) have 8 valence electrons. Therefore, having 8 valence electrons must be a special condition. In fact, atoms that have 8 electrons in their outermost energy level do not normally form new bonds. The outermost energy level of an atom is considered to be full if it contains 8 electrons.

Explore

Determine the number of valence electrons in each of the following atoms: lithium (Li), beryllium (Be), aluminum (Al), carbon (C), nitrogen (N), sulfur (S), bromine (Br), and krypton (Kr).

Atoms Bond to Have a Filled Outermost Level An atom that has fewer than 8 valence electrons is more reactive, or more likely to form bonds, than an atom with 8 valence electrons. Atoms bond by gaining, losing, or sharing electrons in order to have a filled outermost energy level with 8 valence electrons. **Figure 4** describes the ways in which atoms can achieve a filled outermost energy level.

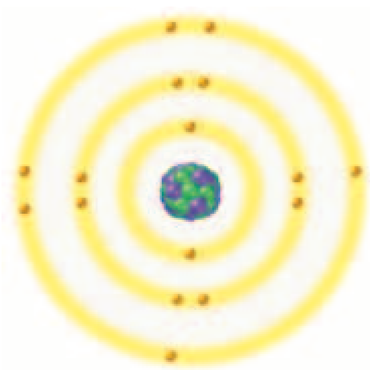
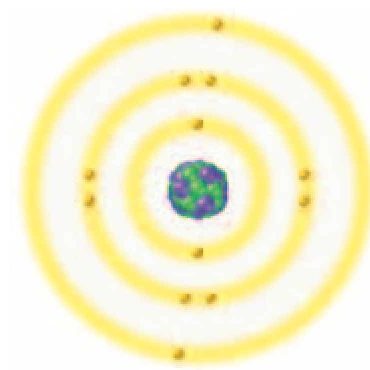


Figure 4 *These atoms achieve a full set of valence electrons in different ways.*



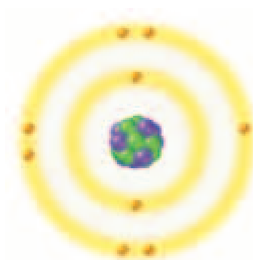
Sulfur
An atom of sulfur has 6 valence electrons. It can have 8 valence electrons by sharing 2 electrons with or gaining 2 electrons from other atoms to fill its outermost energy level.

Magnesium
An atom of magnesium has 2 valence electrons. It can have a full outer level by losing 2 electrons. The second energy level becomes the outermost energy level and contains a full set of 8 electrons.

A Full Set—with Two? Not all atoms need 8 valence electrons for a filled outermost energy level. Helium atoms need only two valence electrons. With only two electrons in the entire atom, the first energy level (which is also the outermost energy level) is full. Atoms of the elements hydrogen and lithium form bonds with other atoms in order to have the same number of electrons as helium atoms have.

REVIEW

1. What is a chemical bond?
2. What are valence electrons?
3. How many valence electrons does a silicon atom have?
4. Predict how atoms with 5 valence electrons will achieve a full set of valence electrons.
5. **Interpreting Graphics** At right is a diagram of a fluorine atom. Will fluorine form bonds? Explain.



Fluorine

Section 2

Types of Chemical Bonds

NEW TERMS

ionic bond
ions
crystal lattice
covalent bond
molecule
metallic bond

OBJECTIVES

- Describe ionic, covalent, and metallic bonding.
- Describe the properties associated with substances containing each type of bond.

As you have learned, atoms bond by gaining, losing, or sharing electrons. Once bonded, most atoms have a filled outermost energy level containing eight valence electrons. Atoms are less reactive when they have a filled outermost energy level. The way in which atoms interact through their valence electrons determines the type of bond that forms. The three types of bonds are ionic (ie AHN ik), covalent (KOH VAY luhnt), and metallic. In this section, you will study each type of bond, starting with ionic bonds.

Ionic Bonds

Seashells, table salt, and plaster of Paris, shown in **Figure 5,** have much in common. They are all hard, brittle solids at room temperature, they all have high melting points, and they all contain ionic bonds. An **ionic bond** is the force of attraction between oppositely charged ions. **Ions** are charged particles that form during chemical changes when one or more valence electrons transfer from one atom to another.

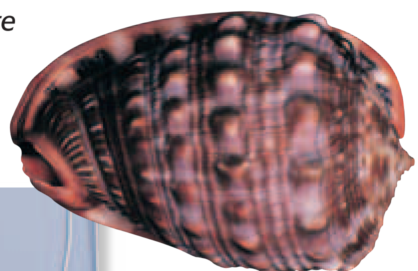


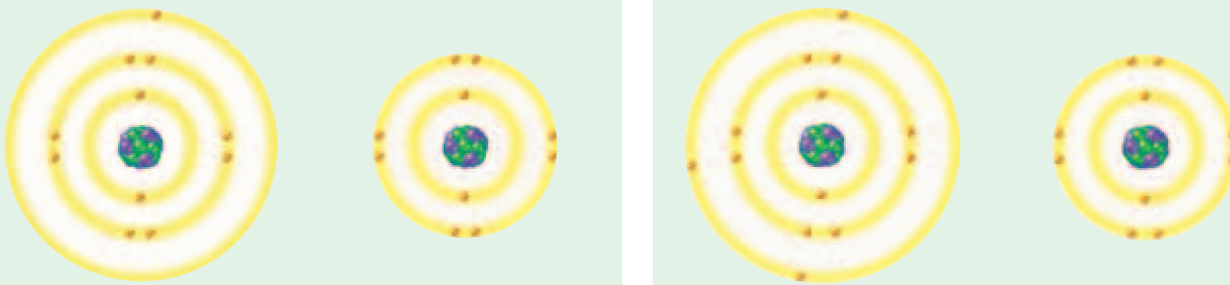
Figure 5 *Calcium carbonate in seashells, sodium chloride in table salt, and calcium sulfate used to make plaster of Paris casts all contain ionic bonds.*

Remember that in an atom, the number of electrons equals the number of protons, so the negative charges and positive charges cancel each other. Therefore, atoms are neutral. A transfer of electrons between atoms changes the number of electrons in each atom, while the number of protons stays the same. The negative charges and positive charges no longer cancel out, and the atoms become ions. Although an atom cannot gain (or lose) electrons without another atom nearby to lose (or gain) electrons, it is often easier to study the formation of ions one at a time.

Atoms That Lose Electrons Form Positive Ions Ionic bonds form during chemical reactions when atoms that have a stronger attraction for electrons pull electrons away from other atoms. The atoms that lose electrons form ions that have fewer electrons than protons. The positive charges outnumber the negative charges in the ions. Thus, the ions that are formed when atoms lose electrons have an overall positive charge.

Atoms of most metals have few electrons in their outer energy level. When metal atoms bond with other atoms, the metal atoms tend to lose these valence electrons and form positive ions. For example, look at the model in **Figure 6.** An atom of sodium has one valence electron. When a sodium atom loses this electron to another atom, it becomes a sodium ion. A sodium ion has a charge of 1+ because it contains 1 more proton than electrons. To show the difference between a sodium atom and a sodium ion, the chemical symbol for the ion is written as Na^+. Notice that the charge is written to the upper right of the chemical symbol. Figure 6 also shows a model for the formation of an aluminum ion.

Figure 6 Forming Positive Ions



Sodium atom (Na)
11+ protons
11− electrons
0 charge

Sodium ion (Na^+)
11+ protons
10− electrons
1+ charge

Aluminum atom (Al)
13+ protons
13− electrons
0 charge

Aluminum ion (Al^{3+})
13+ protons
10− electrons
3+ charge

Here's How It Works: During chemical reactions, a sodium atom can lose its 1 electron in the third energy level to another atom. The filled second level becomes the outermost level, so the resulting sodium ion has 8 valence electrons.

Here's How It Works: During chemical reactions, an aluminum atom can lose its 3 electrons in the third energy level to another atom. The filled second level becomes the outermost level, so the resulting aluminum ion has 8 valence electrons.

The Energy of Losing Electrons When an atom loses electrons, energy is needed to overcome the attraction between the electrons and the protons in the atom's nucleus. Removing electrons from atoms of metals requires only a small amount of energy, so metal atoms lose electrons easily. In fact, the energy needed to remove electrons from atoms of elements in Groups 1 and 2 is so low that these elements react very easily and can be found only as ions in nature. On the other hand, removing electrons from atoms of nonmetals requires a large amount of energy. Rather than give up electrons, these atoms gain electrons when they form ionic bonds.

Self-Check

Look at the periodic table, and determine which noble gas has the same electron arrangement as a sodium ion. *(See page 596 to check your answer.)*

MATH BREAK

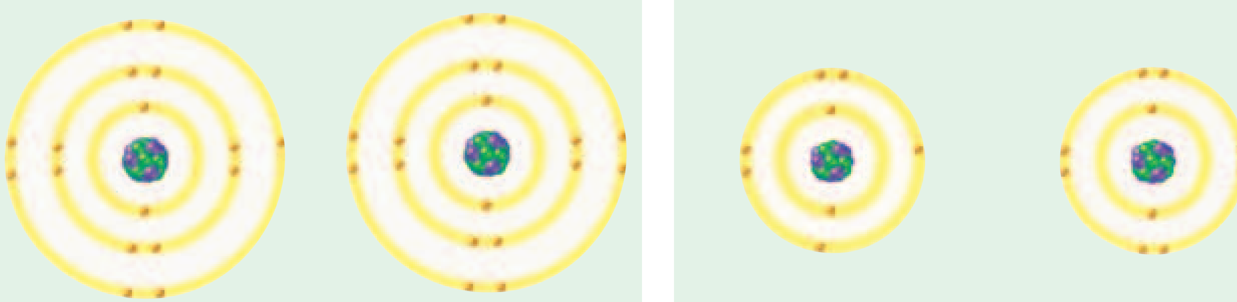
Charge!

Calculating the charge of an ion is the same as adding integers (positive or negative whole numbers or zero) with opposite signs. You write the number of protons as a positive integer and the number of electrons as a negative integer and then add the integers. Calculate the charge of an ion that contains 16 protons and 18 electrons. Write the ion's symbol and name.

Atoms That Gain Electrons Form Negative Ions Atoms that gain electrons from other atoms during chemical reactions form ions that have more electrons than protons. The negative charges outnumber the positive charges, giving each of these ions an overall negative charge.

The outermost energy level of nonmetal atoms is almost full. Only a few electrons are needed to fill the outer level, so atoms of nonmetals tend to gain electrons from other atoms. For example, look at the model in **Figure 7.** An atom of chlorine has 7 valence electrons. When a chlorine atom gains 1 electron to complete its outer level, it becomes an ion with a 1– charge called a chloride ion. The symbol for the chloride ion is Cl^-. Notice that the name of the negative ion formed from chlorine has the ending *-ide*. This ending is used for the names of the negative ions formed when atoms gain electrons. Figure 7 also shows a model of how an oxide ion is formed.

Figure 7 **Forming Negative Ions**



Chlorine atom (Cl)
17+ protons
17– electrons
0 charge

Chloride ion (Cl^-)
17+ protons
18– electrons
1– charge

Oxygen atom (O)
8+ protons
8– electrons
0 charge

Oxide ion (O^{2-})
8+ protons
10– electrons
2– charge

Here's How It Works: During chemical reactions, a chlorine atom gains 1 electron in the third energy level from another atom. A chloride ion is formed with 8 valence electrons. Thus, its outermost energy level is filled.

Here's How It Works: During chemical reactions, an oxygen atom gains 2 electrons in the second energy level from another atom. An oxide ion is formed with 8 valence electrons. Thus, its outermost energy level is filled.

The Energy of Gaining Electrons Atoms of most nonmetals fill their outermost energy level by gaining electrons. Energy is given off by most nonmetal atoms during this process. The more easily an atom gains an electron, the more energy an atom gives off. Atoms of the Group 17 elements (the halogens) give off the most energy when they gain an electron. The halogens, such as fluorine and chlorine, are extremely reactive nonmetals because they release a large amount of energy.

Ions Bond to Form a Crystal Lattice When a metal reacts with a nonmetal, the same number of electrons is lost by the metal atoms as is gained by the nonmetal atoms. Even though the ions that bond are charged, the compound formed is neutral. The charges of the positive ions and the negative ions cancel each other through ionic bonding. An ionic bond is an example of a special kind of attraction, called electrostatic attraction, that causes opposite electrical charges to stick together. Another example is static cling, as shown in **Figure 8.**

The ions that make up an ionic compound are bonded in a repeating three-dimensional pattern called a **crystal lattice** (KRI stuhl LAT is). In ionic compounds, such as table salt, the ions in the crystal lattice are arranged as alternating positive and negative ions, forming a solid. Each ion is bordered on every side by an ion with the opposite charge. The model in **Figure 9** shows a small part of a crystal lattice. The arrangement of bonded ions in a crystal lattice determines the shape of the crystals of an ionic compound.

The strong force of attraction between bonded ions in a crystal lattice gives ionic compounds certain properties, including a high melting point and boiling point. Ionic compounds tend to be brittle solids at room temperature. Ionic compounds usually break apart when hit with a hammer because as the ions move, ions with like charges line up and repel one another.

Figure 8 *Like ionic bonds, static cling is the result of the attraction between opposite charges.*

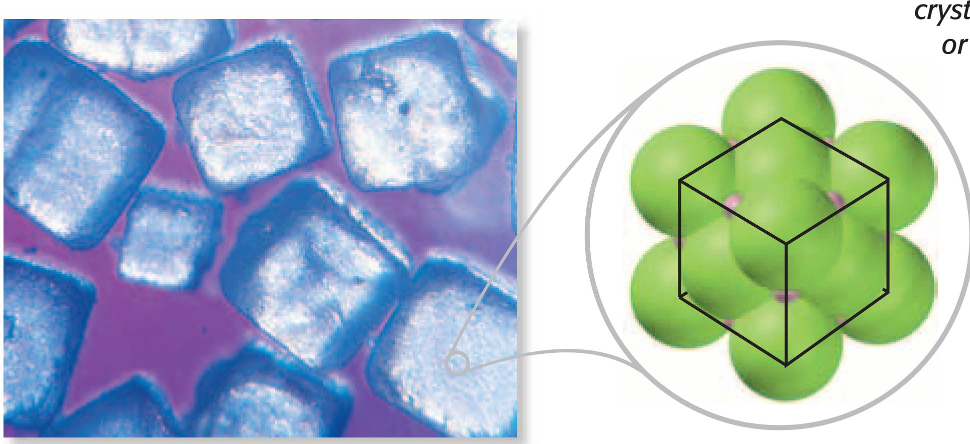


Figure 9 *This model of the crystal lattice of sodium chloride, or table salt, shows a three-dimensional view of the bonded ions.*

REVIEW

1. How does an atom become a negative ion?
2. What are two properties of ionic compounds?
3. **Applying Concepts** Which group of elements lose 2 valence electrons when their atoms form ionic bonds? What charge would the ions formed have?

Covalent Bonds

Most materials you encounter every day, such as water, sugar, and carbon dioxide, are held together by bonds that do not involve ions. These substances tend to have low melting and boiling points, and some of these substances are brittle in the solid state. The type of bonds found in these substances, including the substances shown in **Figure 10,** are covalent bonds.

Figure 10 *Covalent bonds join the atoms that make up this plastic ball, the rubber covering on the paddle, the cotton fibers in clothes, and even many of the substances that make up the human body!*

A **covalent bond** is the force of attraction between the nuclei of atoms and the electrons shared by the atoms. Based on experiments and observations, the current theory about covalent bonding is that it occurs between atoms that require a large amount of energy to remove an electron. When two atoms of nonmetals bond, too much energy is required for either atom to lose an electron, so no ions are formed. Rather than transferring electrons to complete their outermost energy levels, two nonmetal atoms bond by sharing electrons with one another, as shown in the model in **Figure 11.**

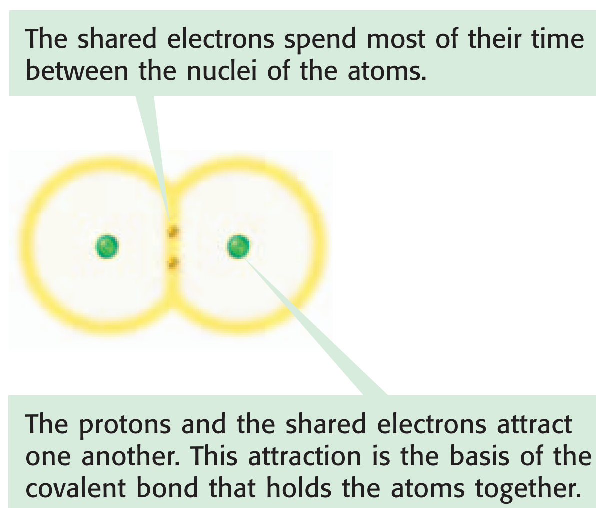


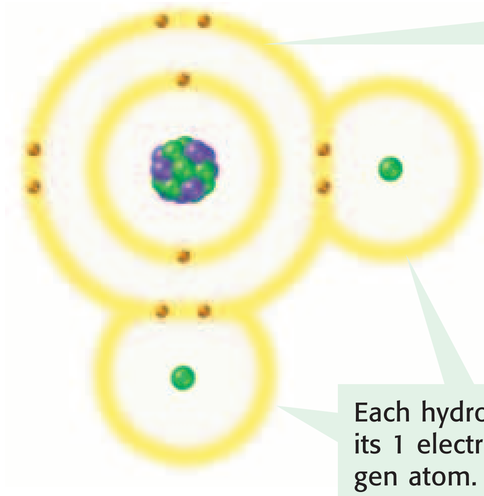
Figure 11 *By sharing electrons in a covalent bond, each hydrogen atom (the smallest atom known) has a full outermost energy level containing two electrons.*

LabBook

Make models of molecules out of marshmallows on page 574 of the LabBook.

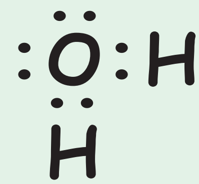
Covalently Bonded Atoms Make Up Molecules The particles of substances containing covalent bonds differ from those containing ionic bonds. Ionic compounds consist of ions organized in a crystal. Covalent compounds consist of individual particles called molecules (MAHL i KYOOLZ). A **molecule** is a neutral group of atoms held together by covalent bonds. Each molecule is separate from other molecules of the substance. In Figure 11, you saw a model of a hydrogen molecule, which is composed of two hydrogen atoms covalently bonded. However, most molecules are composed of atoms of two or more elements. The models in **Figure 12** show two ways to represent the covalent bonds in a molecule.

Figure 12 Covalent Bonds in a Water Molecule



Through covalent bonding, the oxygen atom shares one of its electrons with each of the two hydrogen atoms. As a result, it has a filled outermost energy level with 8 electrons.

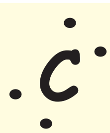
Each hydrogen atom shares its 1 electron with the oxygen atom. This allows each hydrogen to have a filled outer level with 2 electrons.



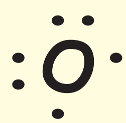
Another way to show covalent bonds is to draw an electron-dot diagram. An electron-dot diagram shows only the outermost level of electrons for each atom. But you can still see how electrons are shared between the atoms.

Making Electron-Dot Diagrams

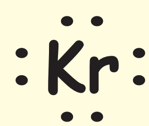
An electron-dot diagram is a model that shows only the valence electrons in an atom. Electron-dot diagrams are helpful when predicting how atoms might bond. You draw an electron-dot diagram by writing the symbol of the element and placing the correct number of dots around it. This type of model can help you to better understand bonding by showing the number of valence electrons and how atoms share electrons to fill their outermost energy levels, as shown below.



Carbon atoms have 4 valence electrons, so 4 dots are placed around the symbol. A carbon atom needs 4 more electrons for a filled outermost energy level.



Oxygen atoms have 6 valence electrons, so 6 dots are placed around the symbol. An oxygen atom needs only 2 more electrons for a filled outermost energy level.



The noble gas krypton has a full set of 8 valence electrons in its atoms. Thus, krypton is nonreactive because its atoms do not need any more electrons.

This electron-dot diagram represents hydrogen gas, the same substance shown in the model in Figure 11.

Self-Check

1. How many dots does the electron-dot diagram of a sulfur atom have?
2. How is a covalent bond different from an ionic bond?

(See page 596 to check your answers.)

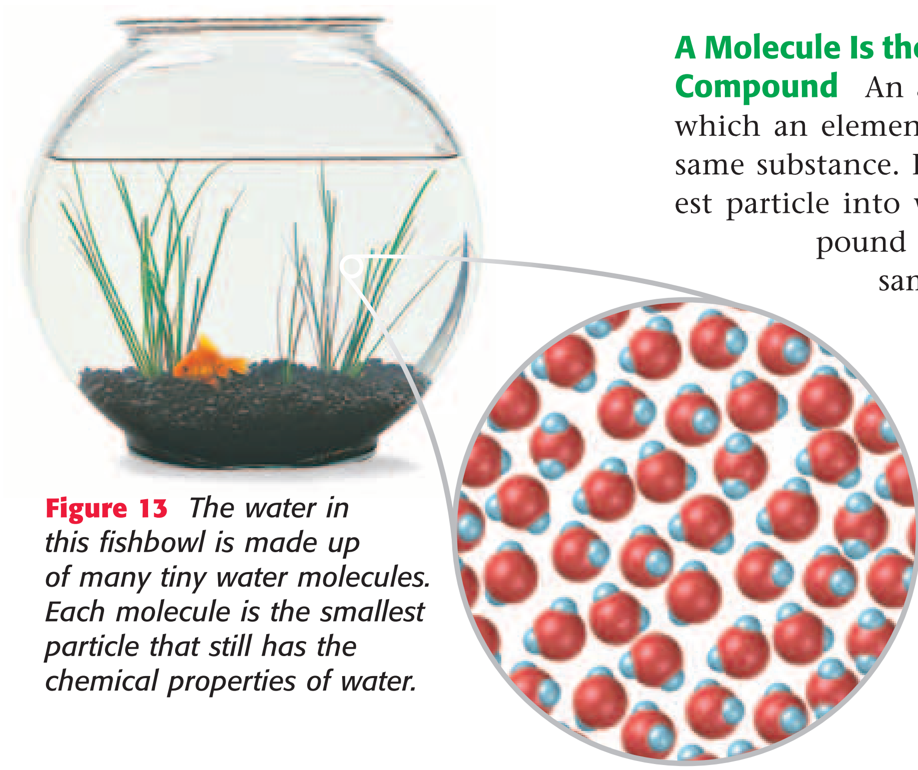


Figure 13 *The water in this fishbowl is made up of many tiny water molecules. Each molecule is the smallest particle that still has the chemical properties of water.*

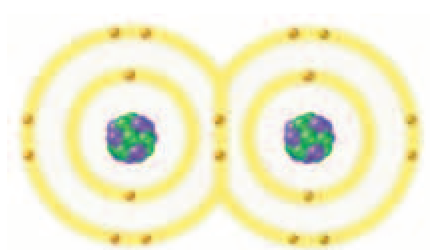
A Molecule Is the Smallest Particle of a Covalent Compound An atom is the smallest particle into which an element can be divided and still be the same substance. Likewise, a molecule is the smallest particle into which a covalently bonded compound can be divided and still be the same compound. **Figure 13** illustrates how a sample of water is made up of many individual molecules of water (shown as three-dimensional models). If you could divide water over and over, you would eventually end up with a single molecule of water. However, if you separated the hydrogen and oxygen atoms that make up a water molecule, you would no longer have water.

Explore

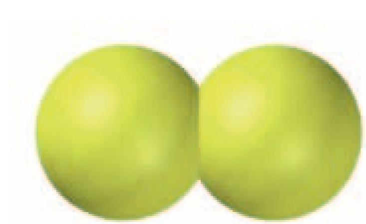
Try your hand at drawing electron-dot diagrams for a molecule of chlorine (a diatomic molecule) and a molecule of ammonia (one nitrogen atom bonded with three hydrogen atoms).

The Simplest Molecules All molecules are composed of at least two covalently bonded atoms. The simplest molecules, known as *diatomic molecules,* consist of two atoms bonded together. Some elements are called diatomic elements because they are found in nature as diatomic molecules composed of two atoms of the element. Hydrogen is a diatomic element, as you saw in Figure 11. Oxygen, nitrogen, and the halogens fluorine, chlorine, bromine, and iodine are also diatomic. By sharing electrons, both atoms of a diatomic molecule can fill their outer energy level, as shown in **Figure 14.**

Figure 14 **Models of a Diatomic Fluorine Molecule**



Two covalently bonded fluorine atoms have filled outermost energy levels. The pair of electrons shared by the atoms are counted as valence electrons for each atom.



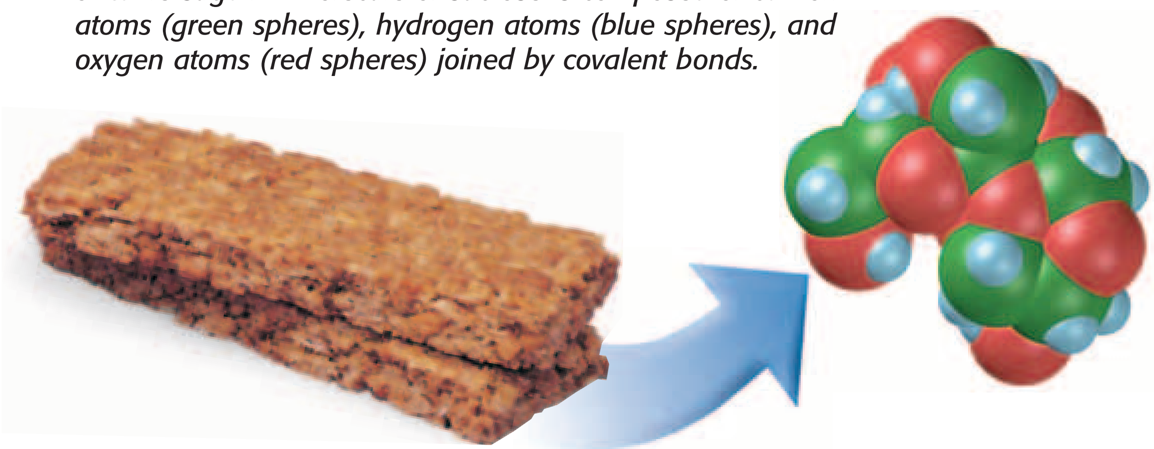
This is a three-dimensional model of a fluorine molecule.

More-Complex Molecules Diatomic molecules are the simplest—and some of the most important—of all molecules. You could not live without diatomic oxygen molecules. But other important molecules are much more complex. Gasoline, plastic, and even proteins in the cells of your body are examples of complex molecules. Carbon atoms are the basis of many of these complex molecules. Each carbon atom needs to make 4 covalent bonds to have 8 valence electrons. These bonds can be with atoms of other elements or with other carbon atoms, as shown in the model in **Figure 15.**

life science CONNECTION

Proteins perform many functions throughout your body, such as digesting your food, building components of your cells, and transporting nutrients to each cell. A single protein can have a chain of 7,000 atoms of carbon and nitrogen with atoms of other elements covalently bonded to it.

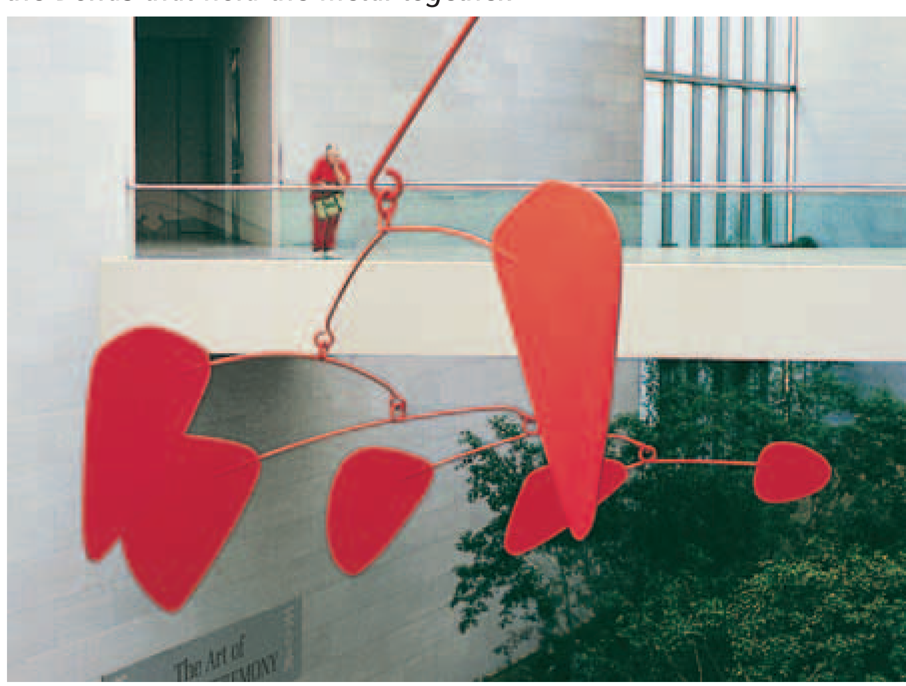
Figure 15 *A granola bar contains the covalent compound sucrose, or table sugar. A molecule of sucrose is composed of carbon atoms (green spheres), hydrogen atoms (blue spheres), and oxygen atoms (red spheres) joined by covalent bonds.*



Metallic Bonds

Look at the unusual metal sculpture shown in **Figure 16.** Notice that some metal pieces have been flattened, while other metal pieces have been shaped into wires. How could the artist change the shape of the metal into all of these different forms without breaking the metal into pieces? A metal can be shaped because of the presence of a special type of bond called a metallic bond. A **metallic bond** is the force of attraction between a positively charged metal ion and the electrons in a metal. (Remember that metal atoms tend to lose electrons and form positively charged ions.)

Figure 16 *The different shapes of metal in this sculpture are possible because of the bonds that hold the metal together.*



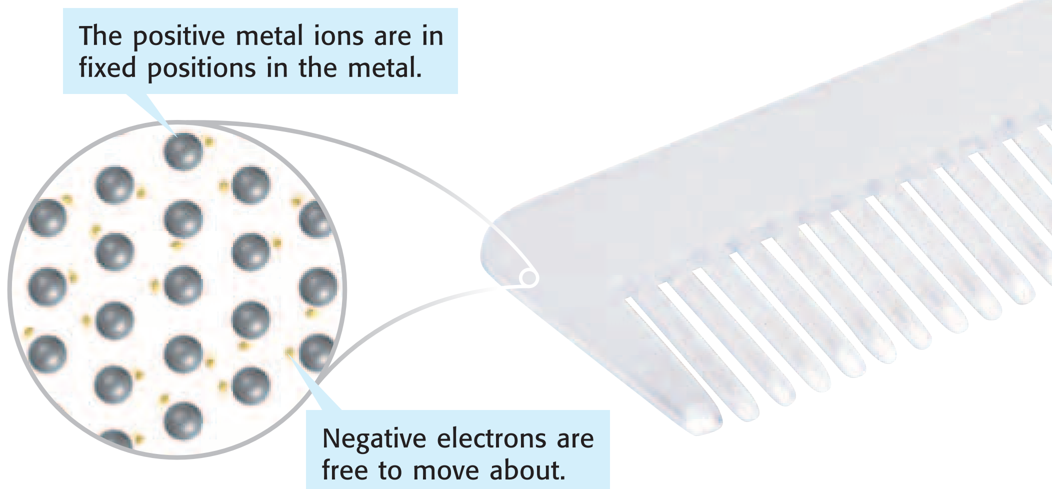
QuickLab

Bending with Bonds

1. Straighten out a **wire paper clip.** Record the result in your ScienceLog.
2. Bend a **piece of chalk.** Record the result in your ScienceLog.
3. Chalk is composed of calcium carbonate, a compound containing ionic bonds. What type of bonds are present in the paper clip?
4. In your ScienceLog, explain why you could change the shape of the paper clip but could not bend the chalk without breaking it.

Electrons Move Throughout a Metal Our scientific understanding of the bonding in metals is that the metal atoms get so close to one another that their outermost energy levels overlap. This allows their valence electrons to move throughout the metal from the energy level of one atom to the energy levels of the atoms nearby. The atoms form a crystal much like the ions associated with ionic bonding. However, the negative charges (electrons) in the metal are free to move about. You can think of a metal as being made up of positive metal ions with enough valence electrons "swimming" about to keep the ions together and to cancel the charge of the ions, as shown in **Figure 17.** The ions are held together because metallic bonds extend throughout the metal in all directions.

Figure 17 *The moving electrons are attracted to the metal ions, forming metallic bonds.*



Explaining Metallic Properties You encounter metallic properties every day, such as when you turn on a lamp or wrap leftovers in aluminum foil. The abilities to conduct electrical energy and to be flattened and shaped without breaking are two properties of metals that result from metallic bonding.

When you turn on a lamp, electrons move within the wire. These moving electrons are the valence electrons in the metal. Because these electrons are not connected to any one atom in the wire, they can move freely within the wire.

Metals have a fairly high density because the metal atoms are closely packed. But because the atoms can be rearranged, metals can be shaped into useful forms. The properties of *ductility* (the ability to be drawn into wires) and *malleability* (the ability to be hammered into sheets) describe a metal's ability to be reshaped. For example, copper is made into wires for use in electrical cords. Aluminum can be pounded into thin sheets and made into aluminum foil and cans.

BRAIN FOOD

Gold can be pounded out to make a foil only a few atoms thick. A piece of gold the size of the head of a pin can be beaten into a thin "leaf" that would cover this page!

When the shape of a piece of metal is changed, the metal ions shift position in the crystal. You might expect the metal to break apart as the ions push away from one another. However, even in their new positions, the positive ions are surrounded by and attracted to the electrons, as shown in **Figure 18.** On the other hand, ionic compounds do break apart when hit with a hammer because neither the positive ions nor the negative ions are free to move.

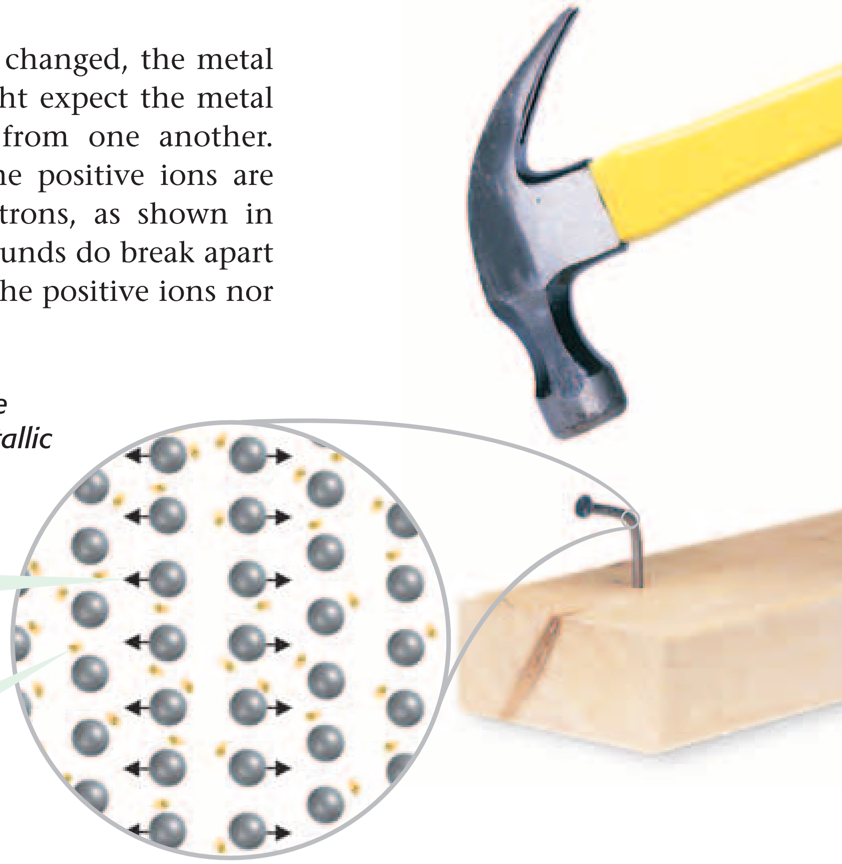


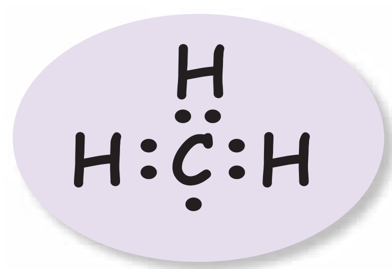
Figure 18 *The shape of a metal can be changed without breaking because metallic bonds occur in many directions.*

APPLY

Although they are not very glamorous, metal staples are very useful in holding things such as sheets of paper together. Explain how the metallic bonds in a staple allow it to change shape so that it can function properly.

REVIEW

1. What happens to electrons in covalent bonding?
2. What type of element is most likely to form covalent bonds?
3. What is a metallic bond?
4. What is one difference between a metallic bond and a covalent bond?
5. **Interpreting Graphics** The electron-dot diagram at right is not yet complete. Which atom needs to form another covalent bond? How do you know?



Chapter Highlights

SECTION 1

Vocabulary

chemical bonding *(p. 352)*
chemical bond *(p. 352)*
theory *(p. 352)*
valence electrons *(p. 353)*

Section Notes

- Chemical bonding is the joining of atoms to form new substances. A chemical bond is a force of attraction that holds two atoms together.
- Valence electrons are the electrons in the outermost energy level of an atom. These electrons are used to form bonds.
- Most atoms form bonds by gaining, losing, or sharing electrons until they have 8 valence electrons. Atoms of hydrogen, lithium, and helium need only 2 electrons to fill their outermost level.

SECTION 2

Vocabulary

ionic bond *(p. 356)*
ions *(p. 356)*
crystal lattice *(p. 359)*
covalent bond *(p. 360)*
molecule *(p. 360)*
metallic bond *(p. 363)*

Section Notes

- In ionic bonding, electrons are transferred between two atoms. The atom that loses electrons becomes a positive ion. The atom that gains electrons becomes a negative ion. The force of attraction between these oppositely charged ions is an ionic bond.
- Ionic bonding usually occurs between atoms of metals and atoms of nonmetals.

Skills Check

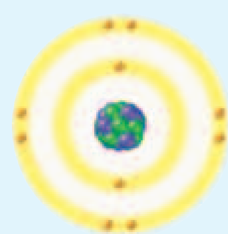
Math Concepts

CALCULATING CHARGE To calculate the charge of an ion, you must add integers with opposite signs. The total positive charge of the ion (the number of protons) is written as a positive integer. The total negative charge of the ion (the number of electrons) is written as a negative integer. For example, the charge of an ion containing 11 protons and 10 electrons would be calculated as follows:

$$(11+) + (10-) = 1+$$

Visual Understanding

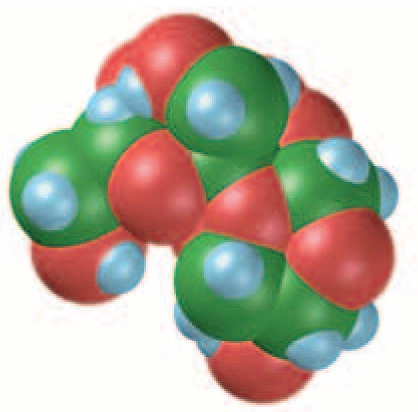
DETERMINING VALENCE ELECTRONS Knowing the number of valence electrons in an atom is important in predicting how it will bond with other atoms. Review Figure 3 on page 354 to learn how an element's location on the periodic table helps you determine the number of valence electrons in an atom.



FORMING IONS Turn back to Figures 6 and 7 on pages 357–358 to review how ions are formed when atoms lose or gain electrons.

SECTION 2

- Energy is needed to remove electrons from metal atoms to form positive ions. Energy is released when most nonmetal atoms gain electrons to form negative ions.
- In covalent bonding, electrons are shared by two atoms. The force of attraction between the nuclei of the atoms and the shared electrons is a covalent bond.
- Covalent bonding usually occurs between atoms of nonmetals.
- Electron-dot diagrams are a simple way to represent the valence electrons in an atom.
- Covalently bonded atoms form a particle called a molecule. A molecule is the smallest particle of a compound with the chemical properties of the compound.
- Diatomic elements are the only elements found in nature as diatomic molecules consisting of two atoms of the same element covalently bonded together.



- In metallic bonding, the outermost energy levels of metal atoms overlap, allowing the valence electrons to move throughout the metal. The force of attraction between a positive metal ion and the electrons in the metal is a metallic bond.
- Many properties of metals, such as conductivity, ductility, and malleability, result from the freely moving electrons in the metal.

Labs

Covalent Marshmallows *(p. 574)*

internetconnect

GO TO: go.hrw.com

Visit the **HRW** Web site for a variety of learning tools related to this chapter. Just type in the keyword:

KEYWORD: HSTBND

GO TO: www.scilinks.org

Visit the **National Science Teachers Association** on-line Web site for Internet resources related to this chapter. Just type in the ***sci*LINKS** number for more information about the topic:

TOPIC: The Electron	***sci*LINKS NUMBER:** HSTP305
TOPIC: The Periodic Table	***sci*LINKS NUMBER:** HSTP310
TOPIC: Types of Chemical Bonds	***sci*LINKS NUMBER:** HSTP315
TOPIC: Properties of Metals	***sci*LINKS NUMBER:** HSTP320

Chapter Review

USING VOCABULARY

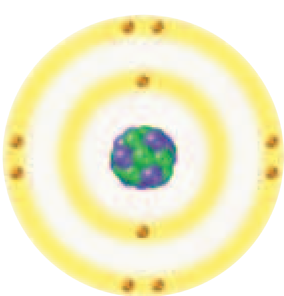
To complete the following sentences, choose the correct term from each pair of terms listed below.

1. The force of attraction that holds two atoms together is a ____. (*crystal lattice* or *chemical bond*)
2. Charged particles that form when atoms transfer electrons are ____. (*molecules* or *ions*)
3. The force of attraction between the nuclei of atoms and shared electrons is a(n) ____. (*ionic bond* or *covalent bond*)
4. Electrons free to move throughout a material are associated with a(n) ____. (*ionic bond* or *metallic bond*)
5. Shared electrons are associated with a ____. (*covalent bond* or *metallic bond*)

UNDERSTANDING CONCEPTS

Multiple Choice

6. Which element has a full outermost energy level containing only two electrons?
   - **a.** oxygen (O)
   - **b.** hydrogen (H)
   - **c.** fluorine (F)
   - **d.** helium (He)
7. Which of the following describes what happens when an atom becomes an ion with a 2– charge?
   - **a.** The atom gains 2 protons.
   - **b.** The atom loses 2 protons.
   - **c.** The atom gains 2 electrons.
   - **d.** The atom loses 2 electrons.



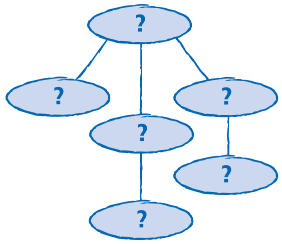
8. The properties of ductility and malleability are associated with which type of bonds?
   - **a.** ionic
   - **b.** covalent
   - **c.** metallic
   - **d.** none of the above
9. In which area of the periodic table do you find elements whose atoms easily gain electrons?
   - **a.** across the top two rows
   - **b.** across the bottom row
   - **c.** on the right side
   - **d.** on the left side
10. What type of element tends to lose electrons when it forms bonds?
    - **a.** metal
    - **b.** metalloid
    - **c.** nonmetal
    - **d.** noble gas
11. Which pair of atoms can form an ionic bond?
    - **a.** sodium (Na) and potassium (K)
    - **b.** potassium (K) and fluorine (F)
    - **c.** fluorine (F) and chlorine (Cl)
    - **d.** sodium (Na) and neon (Ne)

Short Answer

12. List two properties of covalent compounds.
13. Explain why an iron ion is attracted to a sulfide ion but not to a zinc ion.
14. Using your knowledge of valence electrons, explain the main reason so many different molecules are made from carbon atoms.
15. Compare the three types of bonds based on what happens to the valence electrons of the atoms.

Concept Mapping

16. Use the following terms to create a concept map: chemical bonds, ionic bonds, covalent bonds, metallic bonds, molecule, ions.



CRITICAL THINKING AND PROBLEM SOLVING

17. Predict the type of bond each of the following pairs of atoms would form:
    - **a.** zinc (Zn) and zinc (Zn)
    - **b.** oxygen (O) and nitrogen (N)
    - **c.** phosphorus (P) and oxygen (O)
    - **d.** magnesium (Mg) and chlorine (Cl)

18. Draw electron-dot diagrams for each of the following atoms, and state how many bonds it will have to make to fill its outer energy level.
    - **a.** sulfur (S)
    - **b.** nitrogen (N)
    - **c.** neon (Ne)
    - **d.** iodine (I)
    - **e.** silicon (Si)

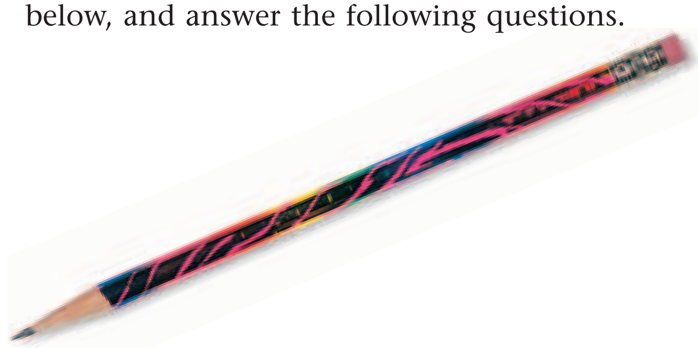
19. Does the substance being hit in the photo below contain ionic or metallic bonds? Explain.

MATH IN SCIENCE

20. For each atom below, write the number of electrons it must gain or lose to have 8 valence electrons. Then calculate the charge of the ion that would form.
    - **a.** calcium (Ca)
    - **b.** phosphorus (P)
    - **c.** bromine (Br)
    - **d.** sulfur (S)

INTERPRETING GRAPHICS

Look at the picture of the wooden pencil below, and answer the following questions.



21. In which part of the pencil are metallic bonds found?

22. List three materials composed of molecules with covalent bonds.

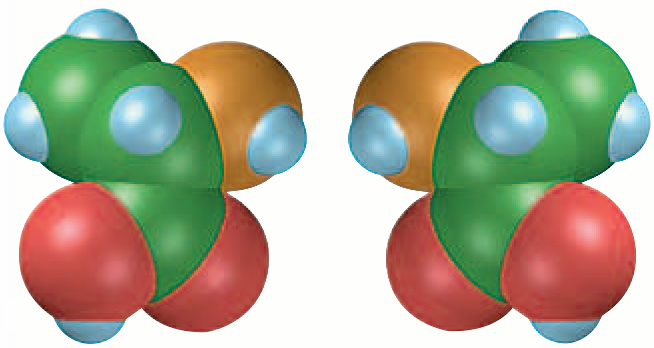
23. Identify two differences between the properties of the metallically bonded material and one of the covalently bonded materials.

NOW What Do You Think?

Take a minute to review your answers to the ScienceLog questions on page 351. Have your answers changed? If necessary, revise your answers based on what you have learned since you began this chapter.

Left-Handed Molecules

Some researchers think that light from a newly forming star 1,500 light-years away (1 light-year is equal to about 9.6 trillion kilometers) may hold the answer to an Earthly riddle that has been puzzling scientists for over 100 years!



▲ *Molecules, such as the carbon molecules shown above, often come in two mirror-image forms, just as hands do.*

We Are All Lefties!

In 1848, Louis Pasteur discovered that carbon-containing molecules come in left-handed and right-handed forms. Each of the molecules is an exact mirror image of the other, just as each of your hands is a mirror image of the other. These molecules are made of the same elements, but they differ in the elements' arrangement in space.

Shortly after Pasteur's discovery, researchers stumbled across an interesting but unexplained phenomenon—all organisms, including humans, are made almost entirely of left-handed molecules! Chemists were puzzled by this observation because when they made amino acids in the laboratory, the amino acids came out in equal numbers of right- and left-handed forms. Scientists also found that organisms cannot even use the right-handed form of the amino acids to make proteins! For years, scientists have tried to explain this. Why are biological molecules usually left-handed and not right-handed?

Cosmic Explanation

Astronomers recently discovered that a newly forming star in the constellation Orion emits a unique type of infrared light. Infrared light has a wavelength longer than the wavelenth of visible light. The wave particles of this light spiral through space like a corkscrew. This light spirals in only one direction. Researchers suspect that this light might give clues to why all organisms are lefties.

Laboratory experiments show that depending on the direction of the ultraviolet light spirals, either left-handed or right-handed molecules are destroyed. Scientists wonder if a similar type of light may have been present when life was beginning on Earth. Such light may have destroyed most right-handed molecules, which explains why life's molecules are left-handed.

Skeptics argue that the infrared light has less energy than the ultraviolet light used in the laboratory experiments and thus is not a valid comparison. Some researchers, however, hypothesize that both infrared and ultraviolet light may be emitted from the newly forming star that is 1,500 light-years away.

Find Out More

▶ The French chemist Pasteur discovered left-handed and right-handed molecules in tartaric acid. Do some research to find out more about Pasteur and his discovery. Share your findings with the class.