

Electrons and Chemical Bonding

BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- What is chemical bonding?
- What are valence electrons?
- How do valence electrons affect bonding?

National Science Education Standards

PS 1b, 1c

What Is a Chemical Bond?

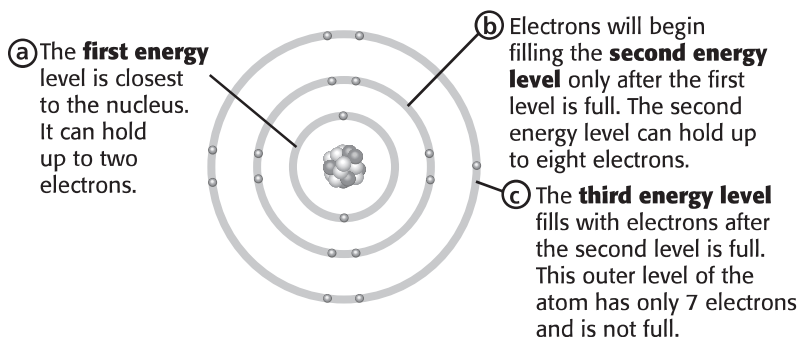
All things are made of atoms. A few substances are made of single atoms, but most are made of two or more atoms joined together. **Chemical bonding** is the joining of atoms to form a new substance. The bond that forms when two atoms join is called a **chemical bond**. Chemical bonds form when electrons in atoms interact. Atoms can gain, lose, or share electrons to form a chemical bond. ✓

In some cases, the atoms that join together are atoms of the same element. Oxygen gas, for example, is made of two oxygen atoms bonded together. In other cases, atoms of different elements bond. For example, hydrogen and oxygen atoms bond to form water.

ELECTRONS IN ATOMS

Remember that electrons are found outside the nucleus in layers called energy levels. Each energy level can hold a certain number of electrons. The first energy level is closest to the nucleus. It can hold up to two electrons. The second energy level can hold up to eight electrons. The third energy level can also hold up to eight electrons. ✓

Electron Arrangement in an Atom of Chlorine



STUDY TIP

Clarify Concepts Take turns reading this section out loud with a partner. Stop to discuss ideas that seem confusing.

READING CHECK

1. Explain What can happen to electrons in an atom when a chemical bond forms?

READING CHECK

2. Describe Where are electrons found in an atom?

SECTION 1 Electrons and Chemical Bonding *continued*

Which Electrons Affect Bonding?

Atoms form chemical bonds when their electrons interact with one another. However, not all of the electrons in an atom interact to form bonds. In most cases, only the electrons in the outermost energy level are able to form bonds. Electrons in the outermost energy level are called **valence electrons**. An atom can form different kinds of bonds depending on how many valence electrons it has. ✓

READING CHECK

3. Explain Where are the valence electrons found in an atom?

Math Focus

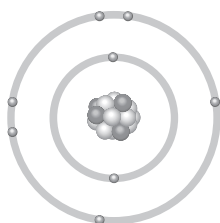
4. Determine The atomic number of carbon is 6. How many protons does an atom of carbon have? How many electrons?

DETERMINING THE NUMBER OF VALENCE ELECTRONS

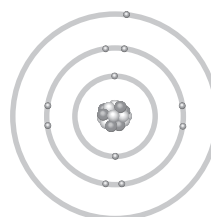
The *atomic number* of an element tells you how many protons are in an atom of the element. No two elements have the same number of protons in their atoms. As a result, no two elements have the same atomic number. The number of protons in an atom equals the number of electrons in the atom. Therefore, the atomic number also tells how many electrons are found in an atom of an element.

You can use an element's atomic number to learn how many valence electrons its atoms have. In order to do this, you need to draw a model of the atom. Remember that valence electrons are in the outermost level. For example, the figures below show models of two atoms.

Model of an Oxygen Atom



Model of a Sodium Atom



In the illustration above, the figure on the left shows a model of an atom of oxygen. Oxygen's atomic number is 8. Therefore, its atoms have 8 electrons in them. The first energy level holds 2 electrons. The second, outermost energy level has 6 electrons in it. Therefore, oxygen has 6 valence electrons.

In the illustration above, the figure on the right shows a model of a sodium atom. Sodium's atomic number is 11. Its atoms have 11 electrons in them. The first energy level holds 2 electrons. The second energy level holds 8 electrons. The third, outermost energy level holds 1 electron. Therefore, sodium has 1 valence electron.

STANDARDS CHECK

PS 1b Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristics. In chemical reactions, the total mass is conserved. Substances are often placed in categories or groups if they react in similar ways; metals is an example of such a group.

Word Help: chemical
of or having to do with properties or actions of substances

Word Help: reaction
a response or change

5. Determine When oxygen reacts, how many more electrons are needed to fill its outermost energy level?

SECTION 1 Electrons and Chemical Bonding *continued***USING THE PERIODIC TABLE TO FIND VALENCE ELECTRONS**

You can also use the periodic table to find the number of valence electrons in an atom. Each column in the table is a group. The atoms of all of the elements in a group have the same number of valence electrons. The only exception to this rule is helium. Helium has two valence electrons. All of the other atoms in its group have eight valence electrons.

Atoms of elements in **Groups 1 and 2** have the same number of valence electrons as their group number.

Atoms of elements in **Groups 3–12** do not have a rule relating their valence electrons to their group number.

Atoms of elements in **Groups 13–18** have 10 fewer valence electrons than their group number. However, helium atoms have only 2 valence electrons.

H																				18	He
1	2																				
Li	Be													B	C	N	O	F			Ne
Na	Mg	3	4	5	6	7	8	9	10	11	12		Al	Si	P	S	Cl			Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn		Ga	Ge	As	Se	Br			Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd		In	Sb	Sb	Te	I			Xe	
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg		Tl	Pb	Bi	Po	At			Rn	
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Uuu	Uub		Uut	Uuq	Uup						

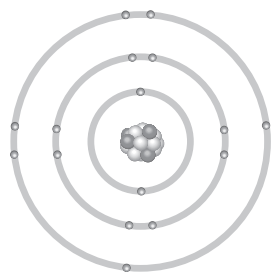
Math Focus

6. Analyze Data Use the periodic table to figure out how many valence electrons the elements in Group 16 have.

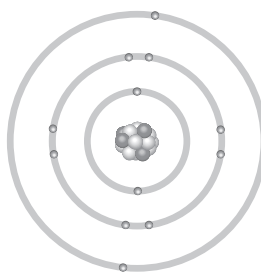
Why Do Atoms Bond?

Some atoms form bonds easily. Others don't. How an atom bonds depends on how many valence electrons it has. An atom forms a bond with another atom in order to complete, or fill, its outermost energy level. An atom is most stable when its outermost energy level is full. ✓

The atoms in Group 18 (at the far right) have full outermost energy levels. Therefore, they do not usually form bonds. However, atoms in the other groups have outermost energy levels that are not full. These atoms fill their outermost energy levels by forming bonds. For most atoms, eight electrons will fill the outermost energy level.

Filling Outermost Energy Levels

Sulfur An atom of sulfur has six valence electrons. It can have eight valence electrons by sharing two electrons with or gaining two electrons from other atoms.



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

READING CHECK

7. Explain Why do atoms bond with one another?

TAKE A LOOK

8. Apply Concepts Calcium (Ca) is in the same group as magnesium. Does it tend to gain or lose electrons when it bonds?

Section 1 Review

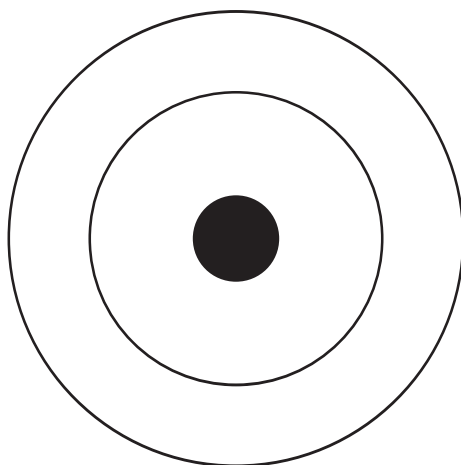
NSES PS 1b, 1c

SECTION VOCABULARY

<p>chemical bonding the combining of atoms to form molecules or ionic compounds</p> <p>chemical bond an interaction that holds atoms or ions together</p>	<p>valence electron an electron that is found in the outermost shell of an atom and that determines the atom's chemical properties</p>
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1. **Identify** How do atoms form chemical bonds?

2. **Use Models** Fluorine (F) is an atom with two electrons in its innermost energy level and seven in its outermost level. Draw the electrons around the nucleus. Color the valence electrons in a different color.



3. **Apply Concepts** How can an atom that has seven valence electrons complete its outermost level?

4. **Apply Concepts** Magnesium (Mg) has two electrons in its outermost energy level. Oxygen (O) has six. How can a Mg atom bond with an O atom?

5. **Interpret Graphics** Each box in the periodic table contains an element symbol and the element's atomic number. Using the box below, answer the questions about sulfur (S) next to the box.

16
S

How many protons does an atom of sulfur have? _____

How many electrons does an atom of sulfur have? _____

CHAPTER 13 Chemical Bonding

SECTION

2

Ionic Bonds

BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- What is ionic bonding?
- What happens to atoms that gain or lose electrons?
- What kinds of solids are formed from ionic bonds?

National Science Education Standards

PS 1b, 3a, 3e

How Do Ionic Bonds Form?

There are several types of chemical bonds. An ionic bond is one type. **Ionic bonds** form when valence electrons are transferred from one atom to another.

Like other bonds, ionic bonds form so that the outermost energy levels of the atoms are filled. To understand why ionic bonds form, you need to learn what happens when atoms gain or lose electrons. ✓

CHARGED PARTICLES

An electron has a negative electrical charge. A proton has a positive electrical charge. An atom is neutral, or not charged, when it has an equal number of electrons and protons. The electrical charges cancel out each other.

When atoms gain or lose electrons, the numbers of protons and electrons are no longer equal. When this happens, atoms become charged particles called **ions**. ✓

How Do Positive Ions Form?

Ions form when atoms gain or lose electrons. The atoms that lose electrons have more protons than electrons. That means they have positive charges as shown in the figure.

Forming a Positive Ion



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



Aluminum ion (Al³⁺)
 13+ protons
 10- electrons
 3+ charge

Here's How It Works:
 During chemical changes, 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.

STUDY TIP

Ask Questions As you read, make a list of things you don't understand. Talk about your questions in a small group.

READING CHECK

1. Explain How does an ionic bond form?

READING CHECK

2. Explain How are ions different from atoms?

SECTION 2 Ionic Bonds *continued*

Critical Thinking

3. Apply Concepts What is the charge of a nickel atom that has lost two electrons?

READING CHECK

4. Explain What has to happen in order for an atom to lose an electron?

STANDARDS CHECK

PS 3e In most chemical and nuclear reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might be involved in such transfers.

Word Help: chemical
of or having to do with the properties or actions of substances

Word Help: reaction
a response or change

Word Help: involve
to have as a part of

5. Identify Where does the energy needed to form positive ions come from during ionic bonding?

READING CHECK

6. Identify What kinds of atoms tend to gain electrons?

METAL ATOMS LOSE ELECTRONS

Most metal atoms have few valence electrons. As shown in the figure on the previous page, metal atoms form positive ions. Notice that the symbol for a metal ion has the charge at the upper right of the chemical symbol.

ENERGY AND LOSING ELECTRONS

For an atom to lose an electron, the attraction between the electron and the protons has to be broken. Breaking the attraction takes energy.

Compared with other elements, only a small amount of energy is needed for metals to lose their valence electrons. Therefore, metals are much more likely to form positive ions than nonmetals are. In the periodic table, the elements in Groups 1 and 2 are all metals. They need little energy to lose their valence electrons. Therefore, the metals in Groups 1 and 2 form ions very easily. The energy needed to make positive ions comes from forming negative ions during ionic bonding.

How Do Negative Ions Form?

What happens to the electrons that metal atoms lose? Atoms of nonmetals gain electrons during ionic bonding. This forms ions that have more electrons than protons. These ions have a negative charge.

Forming a Negative Ion

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



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



Oxide ion (O²⁻)
8+ protons
10- electrons
2- charge

NONMETAL ATOMS GAIN ELECTRONS

The outermost energy level of a nonmetal is almost full. It is easier for it to fill its outer energy level by gaining electrons than by losing electrons. As a result, atoms of nonmetals tend to gain electrons from other atoms. The name of a negative ion formed from an element ends with *-ide*.

Its charge is shown as at the upper right of the symbol. As shown in figure, an oxygen atom gains two electrons and becomes an oxide ion. The charge on an oxide ion is -2 because it has two more electrons than protons.

SECTION 2 Ionic Bonds *continued***ENERGY AND GAINING ELECTRONS**

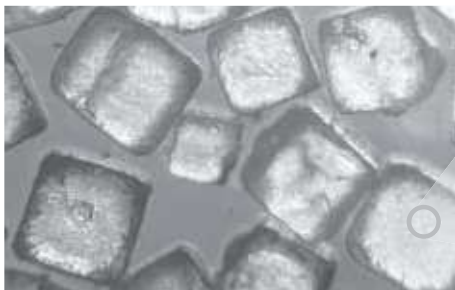
When atoms of most nonmetals gain electrons, they give off energy. The more easily an atom gains electrons, the more energy it releases. The elements in Group 17 (the halogens) are all nonmetals. Their atoms give off a lot of energy when they gain electrons. ✓

How Do Ionic Compounds Form?

Ionic bonds form because positive ions are attracted to negative ions. When ionic bonds form, the number of electrons lost by metal atoms equals the number of electrons gained by nonmetal atoms. ✓

The ions that form an ionic compound are charged, but the compound they form is neutral. That is because the charges of the two kinds of ions cancel out.

Ionic compounds form hard solids with flat faces and straight edges. These solids are called *crystals*. In a crystal, the positive and negative ions are found in a repeating three-dimensional pattern. This arrangement of ions is called a **crystal lattice**. The figure below shows an example of a crystal lattice in sodium chloride, or table salt.



This model shows a crystal lattice of sodium chloride. The sodium ions are dark gray and the chloride ions are light gray.

PROPERTIES OF IONIC COMPOUNDS

Ionic compounds form brittle solids. Something that is *brittle* breaks apart when it is hit with another object. They also have high melting points. This means they have to be heated to very high temperatures before they become liquids. Many ionic compounds also dissolve easily in water. For example, seawater tastes salty because sodium chloride and other ionic compounds are dissolved in it.

READING CHECK

7. Describe What does a halogen atom give off when it gains an electron?

READING CHECK

8. Explain Why do ionic bonds form?

 **Say It**

Share Observations Spread several grains of salt on a sheet of dark construction paper. Use a magnifying lens to examine the salt grains. Try to crush the grains with your fingers. Talk to your class about your observations.

Section 2 Review

NSES PS 1b, 3a, 3e

SECTION VOCABULARY

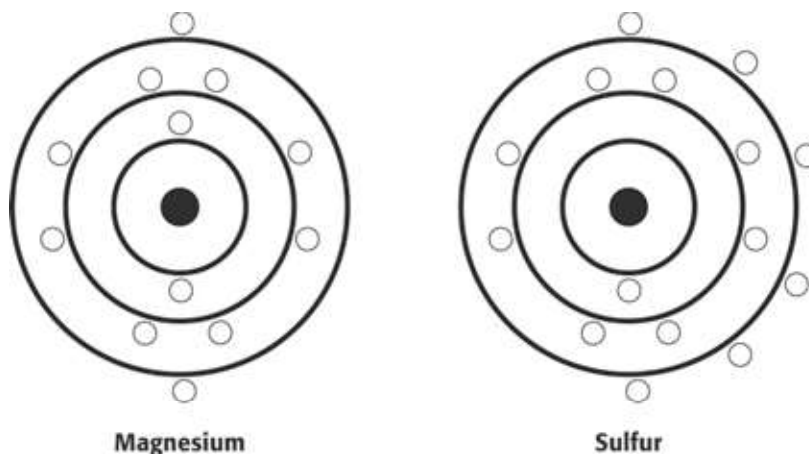
crystal lattice the regular pattern in which a crystal is arranged

ion a charged particle that forms when an atom or group of atoms gains or loses one or more electrons

ionic bond the attractive force between oppositely charged ions, which form when electrons are transferred from one atom to another

1. Apply Concepts Magnesium is a metal with two electrons in its outermost energy level. When it becomes an ion, what happens to its valence electrons? What happens to its charge?

2. Interpret Graphics Sulfur is a nonmetal that has six electrons in its outermost level. Using the models of a magnesium (Mg) atom and a sulfur (S) atom below, draw arrows to show the transfer of electrons.



3. Predict Consequences Potassium (K) is found in Group 1. Fluorine (F) is found in Group 17. When these atoms bind, which will form the positive ion, and which will form the negative ion? Why? Hint: Refer back to the periodic table.

4. Name What is the name given to the regular pattern in which an ionic compound is arranged?

CHAPTER 13 Chemical Bonding

SECTION

3

Covalent and Metallic Bonds

BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- What are covalent bonds?
- What are molecules?
- What are metallic bonds?
- How does bonding affect a metal's properties?

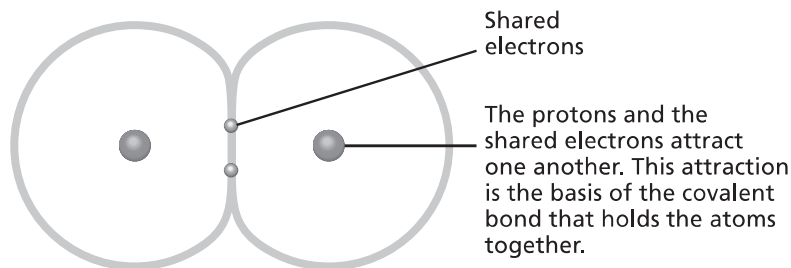
National Science Education Standards

PS 1b

What Are Covalent Bonds?

Another type of bond is a covalent bond. A **covalent bond** forms when atoms share electrons. Covalent bonds most often form between atoms of nonmetals. Remember that most nonmetals can fill the outermost energy level by gaining an electron. When a covalent bond forms, both atoms are able to fill their outermost energy level. They do this by sharing electrons between the two atoms. ✓

Hydrogen is one example of an atom that bonds covalently. A hydrogen atom has one electron in its outermost level. Two hydrogen atoms can come together and share their electrons. This fills the first energy level of both atoms. The electrons move around both hydrogen nuclei. The protons and the shared electrons attract one another. This attraction holds the atoms together.



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

What Are Molecules?

Atoms that join with each other by covalent bonds form particles called **molecules**. Most molecules are made of atoms of two or more elements. The atoms share electrons. In the figure above, two hydrogen atoms have formed a covalent bond. The result is a hydrogen molecule. ✓

STUDY TIP

Compare As you read, make a chart comparing covalent bonds and metallic bonds.

READING CHECK

1. Explain How do electrons behave in covalent bonds?

READING CHECK

2. Identify What type of bond joins the atoms in molecules?

SECTION 3 Covalent and Metallic Bonds *continued***PROPERTIES OF MOLECULES**

Remember that an atom is the smallest piece of an element that still has the properties of that element. In the same way, a molecule is the smallest piece of a covalent compound that has the properties of that compound. This means that if a molecule is broken down, it will no longer have the properties of that compound.

Most covalently bonded substances have low melting and boiling points (water is an exception to this). Many are gases at room temperature. When a substance with covalent bonds forms a solid, the solid tends to be soft.

How Can You Model a Covalent Bond?

An *electron-dot diagram* is a model that shows only the valence electrons of an atom. The figure below shows the electron-dot diagrams for the elements in the second row of the periodic table.

Electron-Dot Diagrams	Li·	Be·	·B·	·C·	:N·	:O·	:F·	:Ne:

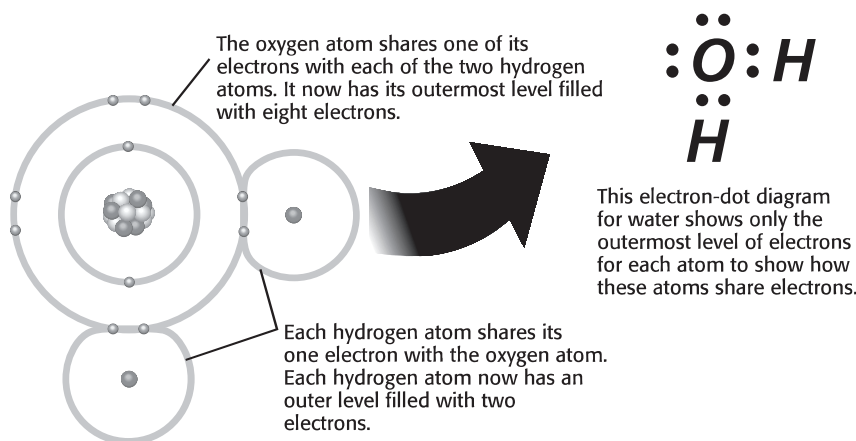
Electron-dot diagrams are used to show how atoms bond in molecules. In the diagram below, you can see the pairs of electrons that form the covalent bonds in a water molecule.

TAKE A LOOK**3. Apply Concepts**

Hydrogen has one valence electron. Draw an electron-dot diagram of a hydrogen atom.

Critical Thinking

4. Apply Concepts Draw the electron-dot diagram that shows how two hydrogen atoms bond with a covalent bond.



SECTION 3 Covalent and Metallic Bonds *continued***What Kinds of Molecules Can Form?**

Molecules contain at least two atoms bonded by covalent bonds. The simplest molecules are made up of only two bonded atoms. They are called *diatomic molecules*. If the two atoms are of the same element, the substance is known as a *diatomic element*. The oxygen and nitrogen in the air that we breathe are both diatomic elements. ✓

In any diatomic molecule, each of the shared electrons is counted as a valence electron for both atoms. As a result, both atoms of the molecule have filled outermost energy levels.

Electron-Dot Diagrams for Chlorine, Oxygen, and Nitrogen Gas**COUNTING COVALENT BONDS**

We have seen how atoms can share one or more pairs of electrons. The oxygen atom in water shares two pairs of electrons, one pair with each hydrogen atom. This means that the oxygen atom in a water molecule forms two covalent bonds.

The number of shared pairs of electrons tells you the number of covalent bonds in a molecule. In the figure above, you counted the number of electron pairs shared in molecules of chlorine, oxygen, and nitrogen. In a chlorine molecule, there is one covalent bond. There are two covalent bonds in an oxygen molecule and three in a nitrogen molecule.

Many molecules are more complex than the molecules in the figure. As you may suspect, some molecules have many covalent bonds.

READING CHECK

5. Identify What type of molecule is made of only two bonded atoms?

TAKE A LOOK

6. Count How many electrons are around each chlorine atom, each oxygen atom, and each nitrogen atom? (Remember, the electrons that are shared count for each atom.)

Chlorine: _____

Oxygen: _____

Nitrogen: _____

7. Count How many pairs of electrons are shared in each molecule?

Chlorine: _____

Oxygen: _____

Nitrogen: _____

Critical Thinking

8. Apply Concepts How many covalent bonds does phosphorus (P) form in the molecule shown below:



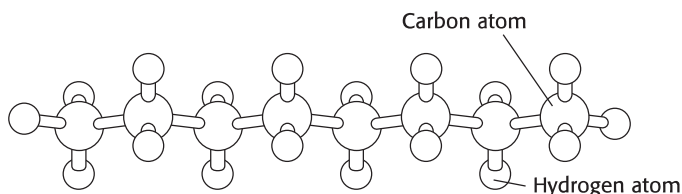
SECTION 3 Covalent and Metallic Bonds *continued*

MORE COMPLEX MOLECULES

Many molecules are much larger and more complex than diatomic molecules or water. Complex molecules have many atoms joined by covalent bonds. Complex molecules make up many important and familiar substances, such as gasoline, soap, plastics, proteins, and sugars. In fact, most of the substances that make up your body are complex molecules!

Carbon (C) atoms are the basis of many complex molecules. Carbon has four valence electrons. To fill its outer energy level, a carbon atom needs to gain four electrons. Therefore, carbon atoms can form four covalent bonds. Carbon atoms can form bonds with other carbon atoms. They also can bond to atoms of other elements, such as oxygen, hydrogen, and nitrogen. Most of the molecules that carbon forms are very complex.

Model of an Octane Molecule Found in Gasoline



TAKE A LOOK

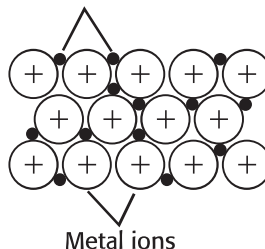
9. Count How many covalent bonds does an atom of carbon form in this molecule?

What Are Metallic Bonds?

The bonding in metals is different from the bonding we have discussed. Metals are substances like copper, iron, silver, and nickel. A **metallic bond** is formed by the attraction between positively charged metal ions and the electrons around the ions. ✓

Model Showing Metallic Bonding

Valence electrons from outer shells of metal atoms



The bonding in metals is a result of the closeness of many metal atoms. Their outermost energy levels overlap. Because of the overlapping, metallic bonds form and extend throughout the metal in all directions. The valence electrons can move throughout the metal. The electrons keep the ions together and cancel the positive charge of the ions. ✓

READING CHECK

10. Describe How is a metallic bond formed?

READING CHECK

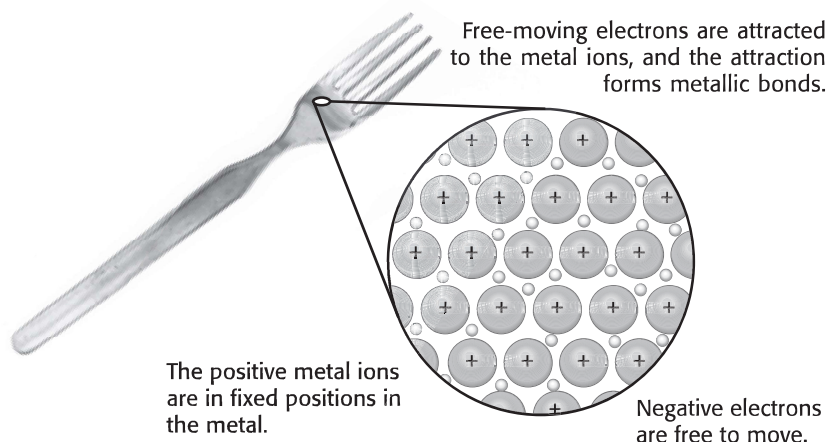
11. Explain What can valence electrons do in a metallic bond?

SECTION 3 Covalent and Metallic Bonds *continued***What Are the Properties of Metals?**

You probably know if something is metal as soon as you look at it. Most metals are very shiny, like gold, silver, copper, nickel, and platinum. Metals have other properties that identify a substance as a metal.

CONDUCTING ELECTRIC CURRENT

Metallic bonding allows metals to conduct electricity. Metals are used to make wires. When the wire is attached to an electrical source, the valence electrons are free to move throughout the wire. They can light a bulb or power a radio. ✓

**RESHAPING METALS**

The atoms in metals can be rearranged easily because the electrons move around freely. The valence electrons of metals are constantly moving around the metal ions. This movement maintains the metallic bonds. As a result, no matter how the shape of the metal is altered, it won't break. This is why metals can so easily change their shape. Two properties describe a metal's ability to be reshaped:

- *Ductility* is the ability to be shaped into long, thin wires.
- *Malleability* is the ability to be hammered into thin sheets. ✓

Ductility and malleability are the properties that make many metals useful for people. Copper can be stretched to make electrical wires. Aluminum can be pounded to form sheets of foil. Silver and gold can be mixed with other metals and bent to form jewelry or fill cavities in teeth.

READING CHECK

12. Explain Why can a wire conduct an electric current when it is connected to an electrical source?

READING CHECK

13. Define What does ductility mean? What does malleability mean?

Section 3 Review

SECTION VOCABULARY

<p>covalent bond a bond formed when atoms share one or more pairs of electrons</p> <p>metallic bond a bond formed by the attraction between positively charged metal ions and the electrons around them</p>	<p>molecule a group of atoms that are held together by chemical forces; a molecule is the smallest unit of matter that can exist by itself and retain all of a substance's chemical properties</p>
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1. Apply Ideas The following is a list of elements: gold, carbon, oxygen, aluminum, copper, and fluorine. In the table below, list each under the correct heading.

Forms covalent bonds	Forms metallic bonds

2. Apply Concepts Nitrogen has five valence electrons, and hydrogen has one. An ammonia molecule has one nitrogen atom and three hydrogen atoms. Draw an electron-dot diagram for a molecule of ammonia.

3. Apply Concepts In addition to conducting electricity, metals conduct heat quickly. Substances with covalent bonds are not good conductors of heat or electricity. Which type of substance would you use as insulating material for a hot mitt?

Which type of substance would you use as a heating coil in an electric toaster?

4. Make Inferences What happens to the properties of oxygen when oxygen bonds with hydrogen to form water?

5. Identify List three properties of metals that are caused by metallic bonding.
