Name _____ Class _____ Date _____

CHAPTER 6 The Structure of Matter

SECTION 2

Ionic and Covalent Bonding

KEY IDEAS

As you read this section, keep these questions in mind:

- Why do atoms form bonds?
- How do ionic bonds and covalent bonds differ?
- What gives metals their distinctive properties?
- What makes a polyatomic ion different from other ions?

Why Do Chemical Bonds Form?

Atoms form bonds when their valence electrons interact. Recall that atoms with filled outermost energy levels are more stable than atoms with partially filled energy levels. In general, atoms join to form bonds so that each atom has a stable electron configuration. In other words, each atom binds in order to fill its outermost energy levels. ☑

There are two basic kinds of chemical bonding: ionic bonding and covalent bonding. The type of bonding in a compound determines many of the properties of the compound.

A Comparison of Ionic and Covalent Compounds

	Ionic compounds	Covalent compounds
Structure	network of bonded ions	molecules
Valence electrons	transferred	shared
Electrical conductivity	good (when melted or dissolved)	poor
State at room temperature	solid	solid, liquid, or gas
Melting and boiling points	generally high	generally low

READING TOOLBOX

Compare As you read, make a chart that describes and compares the different types of bonds.

READING CHECK

1. Explain Why do atoms join to form bonds?

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LOOKING CLOSER

2. Compare How do the structures of ionic and covalent compounds differ?

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What Are the Properties of Ionic Bonds?

Ionic bonds form between oppositely charged ions. In general, atoms of metals, such as sodium and calcium, form positively charged ions. Atoms of nonmetals, such as chlorine and oxygen, form negatively charged ions. The attraction between ions with opposite charges holds ionic compounds together. ☑

READING CHECK

3. Identify What holds ionic compounds together?

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TRANSFER OF ELECTRONS

Ionic bonds form when one atom transfers electrons to another atom. The atom that lost the electron has a positive charge. The atom that gained the electron has a negative charge. The figure below shows the transfer of an electron from a sodium atom to a chlorine atom. Chlorine attracts electrons more strongly than sodium does. Two atoms tend to form an ionic bond when one atom attracts electrons more strongly than the other atom.

LOOKING CLOSER

4. Identify In sodium chloride, which ion is negatively charged and which is positively charged?

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5. Compare Describe the outermost orbitals of Na^+ and Cl^-.

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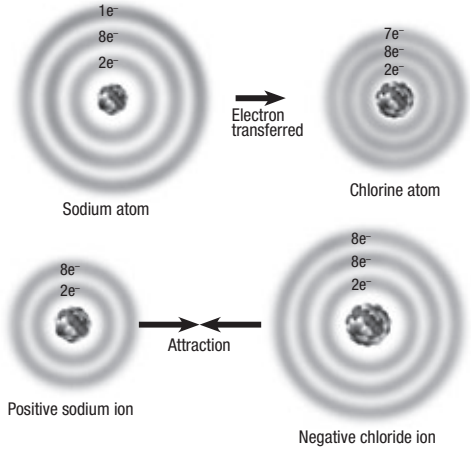

Ionic bonds form when one atom transfers electrons to another. The result is two ions with opposite charges. The oppositely charged ions attract each other.

NETWORKS OF IONIC COMPOUNDS

There is no such thing as "a molecule of NaCl." Sodium chloride is made up of a network of ions. In the network, each sodium ion is surrounded by six chloride ions. Why, then, is the chemical formula for sodium chloride not $NaCl_6$? In sodium chloride, each chloride ion is also surrounded by six sodium ions. Thus, in a sample of sodium chloride, there is one sodium ion for every chloride ion. ☑

READING CHECK

6. Explain Why is the chemical formula for sodium chloride NaCl, and not $NaCl_6$ or Na_6Cl?

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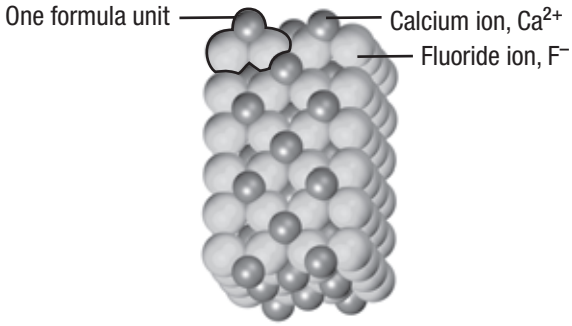
Different ionic compounds have different ratios of ions. For example, in calcium fluoride, the ratio of calcium ions to fluoride ions is 1:2. That is, there are twice as many fluoride ions in a sample as calcium ions. Why?

Recall that calcium forms ions with +2 charges and fluorine forms ions with −1 charges. The total charge of an ionic compound is zero. For the total charge to be zero, the positive and negative charges must cancel each other.



The ionic compound calcium fluoride has twice as many fluoride ions as calcium ions. Thus, the chemical formula for the compound is CaF_2.

CONDUCTING ELECTRICITY

Electrical current is moving charges. The ions in a solid ionic compound are locked into place. Thus, the charges are not free to move, and the compound cannot conduct electricity. However, when an ionic compound dissolves or melts, the ions are no longer locked in place. The ions are free to move. Thus, dissolved or melted ionic compounds can conduct electricity. ☑

READING CHECK

7. Explain Why can a melted ionic compound conduct electricity, but a solid ionic compound cannot?

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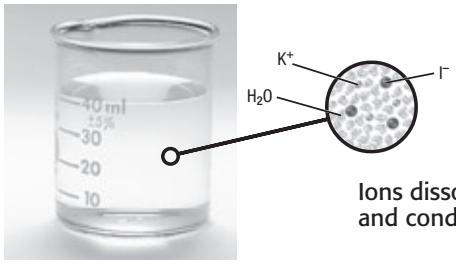
When an ionic compound is solid, the ions are locked in place.

When the solid melts, ions can move more freely and conduct electricity.



Ions dissolved in a solvent can move freely and conduct electricity.

What Are the Properties of Covalent Bonds?

A **covalent bond** forms when electrons are shared between two atoms. Compounds that are made of molecules, such as water and sugar, have covalent bonds. Compounds that exist as networks of bonded atoms, such as silicon dioxide, are also held together by covalent bonds. In general, covalent bonds form between atoms of nonmetals. ☑

READING CHECK

8. Define What is a covalent bond?

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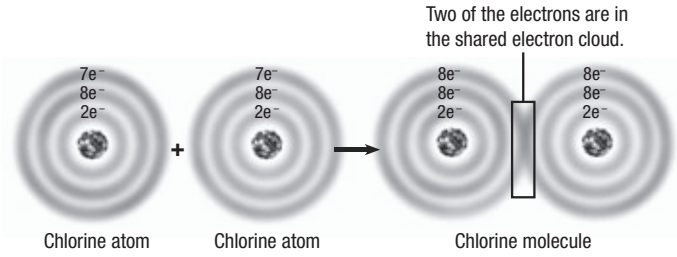
The figure below shows electrons shared by two chlorine atoms. Before the chlorine atoms bond, each atom has seven electrons in its outermost energy level. By sharing a pair of electrons, both atoms can have full outermost energy levels.

A single line between two atoms in a structural formula represents a covalent bond. Each covalent bond indicates that two electrons are shared between the atoms.



LOOKING CLOSER

9. Identify How many electrons does each line between atoms represent?

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10. Identify From where did the electrons that form the covalent bond between chlorine atoms come?

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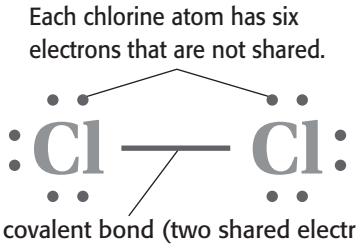


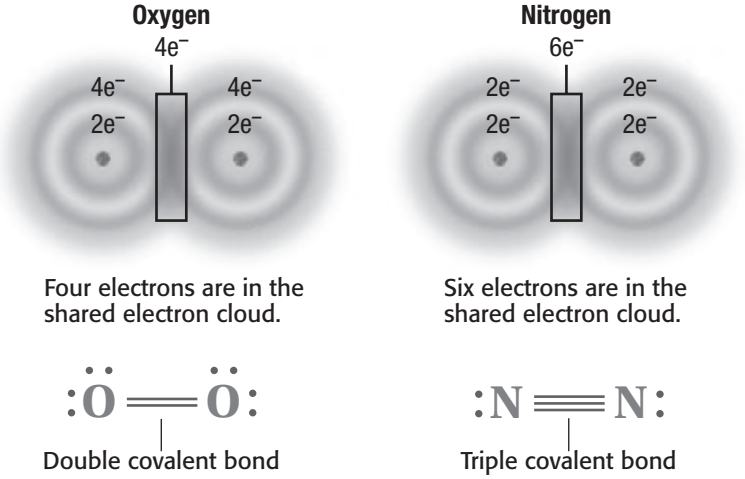
Two chlorine atoms share electrons equally to form a nonpolar covalent bond.

MOLECULAR COMPOUNDS

Covalent compounds made up of molecules are called molecular compounds. Molecular compounds can be solids, liquids, or gases. Most molecular compounds have low melting points—generally below 300 °C. When a molecular compound dissolves or melts, the molecules can move more freely than they do in solids. However, unlike melted or dissolved ions, molecules cannot conduct electricity. This is because molecules are not charged.

MULTIPLE BONDS

Some atoms need to share more than one pair of electrons to fill their outermost energy levels.



Notice that the covalent bond that joins the two oxygen atoms in the figure is shown as two lines. These two lines represent two pairs of electrons, or a total of four electrons. Two pairs of electrons shared between atoms are called a *double bond*.

The covalent bond that joins the two nitrogen atoms above is shown as three lines. These three lines represent three pairs of electrons. Three pairs of electrons shared between atoms are called a *triple bond*.

More energy is needed to break double and triple bonds than to break single bonds. A double bond is stronger than a single bond. A triple bond is stronger than both single and double bonds. Double and triple bonds are also shorter than single bonds. ☑

EQUAL SHARING

When two atoms of the same element share electrons, they share the electrons equally. That is, the electrons spend equal amounts of time near the nuclei of both atoms. For example, two chlorine atoms are exactly alike. When they bond, electrons are equally attracted to the positive nucleus of each atom. Bonds in which the electrons are shared equally are called *nonpolar covalent bonds*.

LOOKING CLOSER

11. Identify How many pairs of electrons are shared between oxygen atoms in O_2?

12. Identify How many unshared valence electrons does each oxygen atom have?

READING CHECK

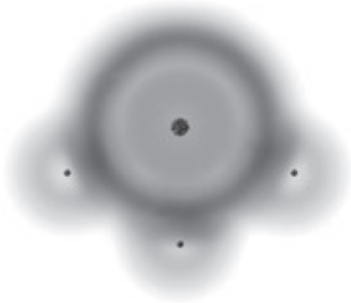
13. Identify Which bond is strongest—a single, double, or triple bond?

UNEQUAL SHARING

When two atoms of different elements share electrons, they do not share them equally. The shared electrons are attracted to the nucleus of one atom more than to the other. Bonds in which electrons are not shared equally are called *polar covalent bonds*.

Critical Thinking

14. Explain In a molecule of ammonia, NH_3, three hydrogen atoms are attached to one nitrogen atom. Are the bonds in ammonia polar covalent or nonpolar covalent? Explain your answer.



In a molecule of ammonia, NH_3, electrons are not shared equally.

In general, electrons are more attracted to elements located farther to the right and closer to the top of the periodic table. For example, within a molecule of ammonia, NH_3, the shared electrons are more attracted to the nitrogen atom than to the hydrogen atoms.

What Are the Properties of Metallic Bonds?

Critical Thinking

15. Infer Which element will attract electrons more strongly—fluorine or carbon? Explain your answer.

Metals, such as copper, can conduct electricity when they are solids. Metals are also flexible, so they can bend and stretch.

Atoms in metals pack tightly together. This happens because the nucleus of each atom strongly attracts the electrons from a neighboring atom. These strong attractions are called **metallic bonds**. Because the atoms are packed so tightly, the outermost energy levels of neighboring atoms overlap. Therefore, electrons are free to move from atom to atom.

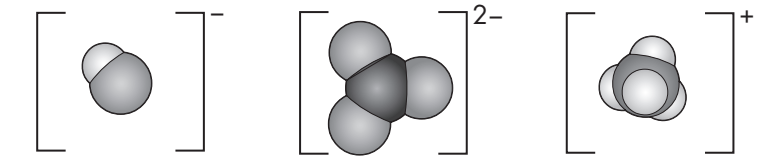
What Are Polyatomic Ions?

READING CHECK

16. Identify What kind of bond exists between atoms in a polyatomic ion?

The ions we have looked at so far are monatomic. That is, each is a single atom that has gained or lost an electron. However, some ions are made of groups of atoms that are covalently bonded. This kind of ion is a **polyatomic ion**. In a compound, a polyatomic ion acts as a single unit. A polyatomic ion can form ionic bonds with other polyatomic ions or with monatomic ions. ☑

Some Polyatomic Ions



Hydroxide ion, OH^- Carbonate ion, CO_3^{2-} Ammonium ion, NH_4^+

Many compounds you may use contain polyatomic ions. For example, baking soda, $NaHCO_3$, contains the polyatomic ion hydrogen carbonate, HCO_3^-. Sodium carbonate, Na_2CO_3, which is used to make soaps and other cleaners, contains the carbonate ion, CO_3^{2-}.

Like other ions, polyatomic ions with opposite charges can bind to form compounds. For example, ammonium nitrate, NH_4NO_3, is made up of positively charged ammonium ions, NH_4^+, and negatively charged nitrate ions, NO_3^-.

PARENTHESES AND POLYATOMIC IONS

Why is the chemical formula for ammonium sulfate written as $(NH_4)_2SO_4$ instead of $N_2H_8SO_4$? Parentheses show you that the ammonium ion, NH_4^+, acts as a single ion. The subscript outside the parentheses tells you how many of that particular polyatomic ion are in the compound. ☑

Remember that the charge on a polyatomic ion applies to the whole ion, not just the last atom of the formula. The ammonium ion, NH_4^+, has a 1+ charge. This means that NH_4, not just the hydrogen atom, has a positive charge. This is why a polyatomic ion acts as a single unit.

OXYGEN-CONTAINING POLYATOMIC IONS

Many polyatomic ions contain oxygen. The names of many polyatomic ions that contain oxygen end with *-ite* or *-ate*. A polyatomic ion with a name that ends in *-ate* has one more oxygen atom than one with a name that ends in *-ite*. For example, the chlorite ion has one fewer oxygen atoms than the chlorate ion.

Notice that the hydroxide ion, OH^-, and the cyanide ion, CN^-, have unique names. These ions are not named according to any general rule.

READING CHECK

17. Identify What do parentheses around a group of atoms in a chemical formula indicate?

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Critical Thinking

18. Apply Concepts The chemical formula for the chlorate ion is ClO_3^-. What is the chemical formula for the chlorite ion?

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Name _____ Class _____ Date _____

Section 2 Review

SECTION VOCABULARY

covalent bond a bond formed when atoms share one or more pairs of electrons

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

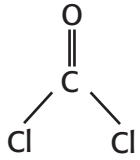
metallic bond a bond formed by the attraction between positively charged metal ions and the electrons around them

polyatomic ion an ion made of two or more atoms

1. **Predict** Would an atom of sodium and an atom of potassium join to form an ionic compound? Explain your answer.

2. **Explain** Why are electrons shared equally in oxygen, O_2, but not in carbon monoxide, CO?

3. **Describe** Examine the structural formula below. Complete the table to describe the bonds between atoms in the compound.



Bonded atoms	Number of shared electrons	Single, double, or triple bond?	Polar or nonpolar?
C—O			
C—Cl			

4. **Identify** Which of the bonds in calcium hydroxide, $Ca(OH)_2$, are ionic and which are covalent?

5. **Identify** Which of the following substances will conduct electric current: aluminum foil, sugar ($C_{12}H_{22}O_{11}$), or potassium hydroxide (KOH) dissolved in water? Explain your answer.