CHAPTER 8
LESSON 2

Elements and Chemical Bonds

Compounds, Chemical Formulas, and Covalent Bonds

Key Concepts

- How do elements differ from the compounds they form?
- What are some common properties of a covalent compound?
- Why is water a polar compound?

Before You Read

What do you think? Read the two statements below and decide whether you agree or disagree with them. Place an A in the Before column if you agree with the statement or a D if you disagree. After you've read this lesson, reread the statements to see if you have changed your mind.

Before	Statement	After
	3. The atoms in a water molecule are more chemically stable than they would be as individual atoms.	
	4. Many substances dissolve easily in water because opposite ends of a water molecule have opposite charges.	

Study Coach

Make an Outline
Outline the information in this lesson. Use the headings as the main divisions of your outline. Include important details under each heading. Use your outline to review the lesson.

Read to Learn

From Elements to Compounds

Have you ever baked cupcakes? The ingredients in the cupcakes—flour, baking soda, salt, sugar, eggs, vanilla, milk, and butter—all have unique physical and chemical properties. But when you mix the ingredients together and bake them, a new product results—cupcakes. The cupcakes have properties after being baked that are different from the original ingredients.

In some ways, compounds are like the cupcakes. Recall that a compound is a substance made up of two or more different elements. Just as cupcakes are different from their ingredients, compounds are different from their elements. An element is made of one type of atom. Compounds are chemical combinations of different types of atoms. Compounds and the elements that make them up often have different properties.

Chemical bonds join atoms together. Recall that a chemical bond is a force that holds atoms together in a compound. In this lesson, you will learn how atoms can form bonds by sharing valence electrons. You will also learn how to write and read a chemical formula.

Key Concept Check

1. Differentiate How is a compound different from the elements that make it up?

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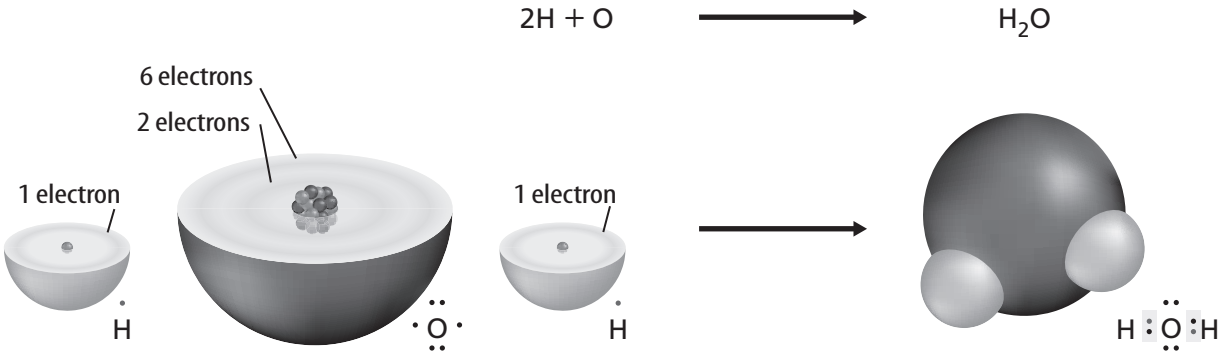
Covalent Bonds—Electron Sharing

Recall that atoms can become more chemically stable by sharing valence electrons. When unstable, nonmetal atoms bond, they do this by sharing valence electrons. *A* **covalent bond** *is a chemical bond formed when two atoms share one or more pairs of valence electrons*. The atoms then form a stable covalent compound.

A Noble Gas Electron Arrangement

Hydrogen and oxygen can react to form water (H_2O), as shown in the figure below. Before the reaction, the atoms are chemically unstable. Each hydrogen atom is unstable with one valence electron. The oxygen atom is unstable with six valence electrons.

Recall that most atoms are chemically stable with eight valence electrons. This is the same electron arrangement as a noble gas. An atom with less than eight valence electrons becomes stable by forming chemical bonds until it has eight valence electrons. Therefore, an oxygen atom forms two bonds to become stable. A hydrogen atom is stable with two valence electrons. It forms one bond to become stable.



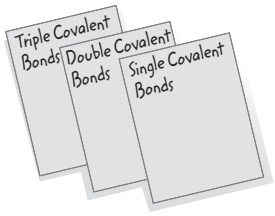
Shared Electrons

Look again at the figure above. How did the oxygen atom and the hydrogen atoms become chemically stable? They shared their unpaired valence electrons and formed a stable covalent compound. Each covalent bond has two valence electrons—one from the hydrogen atom and one from the oxygen atom. These electrons are shared in the bond. They count as valence electrons for both atoms.

Look at the dot diagram for water, on the right side of the figure. Each hydrogen atom now has two valence electrons. The oxygen atom bonded with two hydrogen atoms. As a result, oxygen now has eight valence electrons. All three atoms have the electron arrangement of a noble gas. The compound is stable.

FOLDABLES®

Make three quarter-sheet note cards to organize information about single, double, and triple covalent bonds.



Visual Check

2. State How many valence electrons did the oxygen atom have before bonding?

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Visual Check

3. Compare Is the bond stronger between atoms in hydrogen gas (H_2) or nitrogen gas (N_2)? Why?

Double and Triple Covalent Bonds

Look at the figure below. In a single covalent bond, two atoms share one pair of valence electrons. In a double covalent bond, two atoms share two pairs of valence electrons. In a triple covalent bond, two atoms share three pairs of valence electrons. The more electrons that two atoms share, the stronger the covalent bond is between them. Double bonds are stronger than single bonds. Triple bonds are stronger than double bonds.

Single Covalent Bond

Each hydrogen atom is chemically unstable with 1 unpaired valence electron.

In a hydrogen molecule, each hydrogen atom shares its valence electron with the other, forming a single covalent bond.

Double Covalent Bond

Each oxygen atom is chemically unstable with 2 unpaired valence electrons. A carbon atom is unstable with 4 unpaired valence electrons.

In a carbon dioxide molecule, the carbon atom shares 2 pairs of electrons with each oxygen atom, forming a double covalent bond.

Triple Covalent Bond

Each nitrogen atom is chemically unstable with 3 unpaired valence electrons.

In a nitrogen molecule, each nitrogen atom shares 3 valence electrons with the other, forming a triple covalent bond.

Covalent Compounds

When two or more atoms share valence electrons, they form a stable covalent compound. The covalent compound's carbon dioxide and water are different, but they share similar properties. They usually have low melting points and low boiling points. They are also usually gases or liquids at room temperature, but they can be solids. Covalent compounds are poor conductors of thermal energy and electricity.

Key Concept Check

4. Summarize What are some common properties of covalent compounds?

Molecules

The chemically stable unit of a covalent compound is a molecule. *A* **molecule** *is a group of atoms held together by covalent bonding that acts as an independent unit*. Table sugar is a covalent compound. The chemical formula for a molecule of table sugar is $C_{12}H_{22}O_{11}$. One molecule contains 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms. All these atoms are covalently bonded together. The only way to further break down the molecule would be to chemically separate the carbon, hydrogen, and oxygen atoms. Trillions of sugar molecules make up one grain of sugar.

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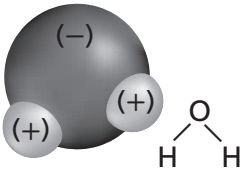
Water and Other Polar Molecules

In a covalent bond, one atom can attract the shared electrons more strongly than the other atom can. In a water molecule, shown in the model below on the left, the oxygen atom attracts the electrons more strongly than each hydrogen atom does. As a result, the shared electrons are pulled closer to the oxygen atom. Because electrons have a negative charge, the oxygen atom has a partial negative charge. The hydrogen atoms have a partial positive charge. As a result, a water molecule is polar. *A* **polar molecule** *is a molecule that has a partial positive end and a partial negative end because of unequal sharing of electrons.*

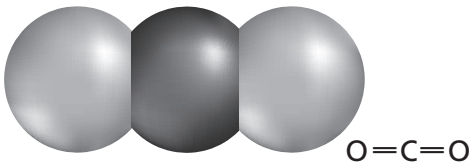
The charges on the ends of a polar molecule affect its properties. Sugar, for example, dissolves easily in water because both sugar and water are polar. The negative end of a water molecule pulls on the positive end of a sugar molecule. Also, the positive end of a water molecule pulls on the negative end of a sugar molecule. This causes the sugar molecules to separate from one another and mix with the water molecules.

Polar
(Partial negative charge)



(Partial positive charge)

Nonpolar



Nonpolar Molecules

A molecule is nonpolar if its atoms pull equally on the shared valence electrons. A hydrogen molecule, H_2, is a nonpolar molecule. Because the two hydrogen atoms are identical, their attraction for shared electrons is equal. A carbon dioxide molecule, CO_2, is shown in the model on the right above. This molecule is also nonpolar because the carbon atom and the oxygen atoms pull equally on the shared electrons.

A nonpolar compound will not easily dissolve in a polar compound. For example, oil is a nonpolar compound. It will not dissolve in water, which is a polar compound. However, "like dissolves like." Polar compounds dissolve in other polar compounds. Nonpolar compounds dissolve in other nonpolar compounds.

Key Concept Check

5. State Why is water a polar compound?

Visual Check

6. Identify Which atoms in a water molecule have a partial positive charge?

Think it Over

7. Infer Imagine that you mix table salt with water, and the salt dissolves. Are the molecules of table salt polar or nonpolar? How do you know?

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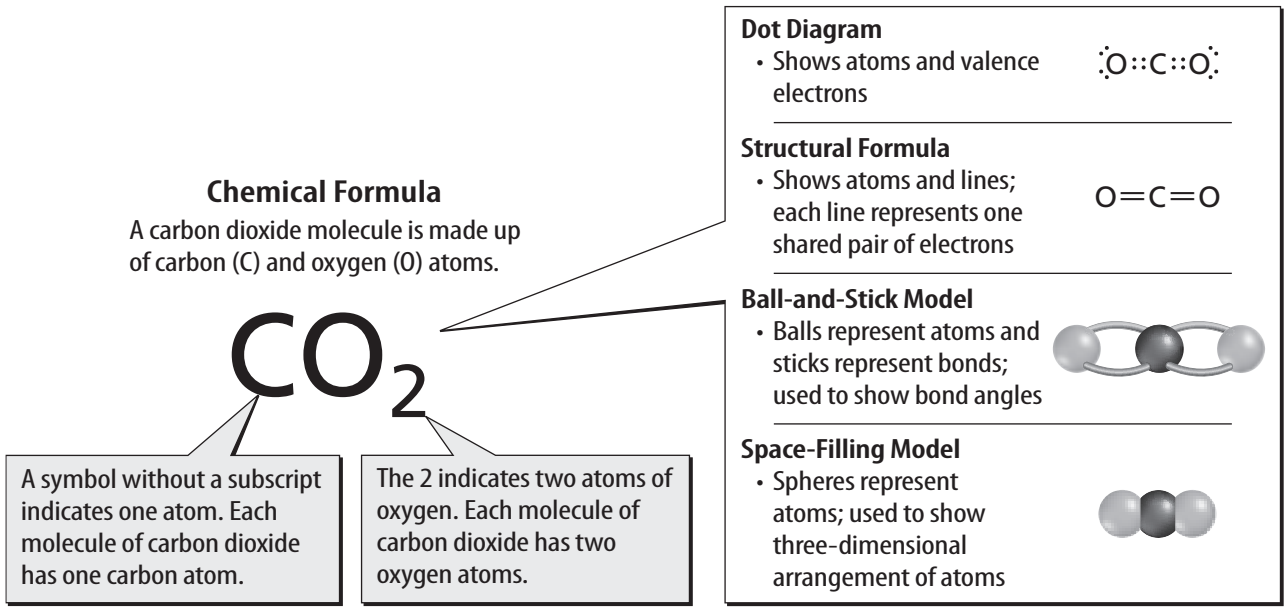
Chemical Formulas and Molecular Models

How do you know which elements make up a compound? *A* **chemical formula** *is a group of chemical symbols and numbers that represent the elements and the number of atoms of each element that make up a compound*. Just as a recipe lists the ingredients, a chemical formula lists the elements in a compound. For example, the chemical formula for carbon dioxide is CO_2. The formula uses chemical symbols to identify the elements in the compound. CO_2 is made up of carbon (C) and oxygen (O). The small number after a chemical symbol is a subscript. A subscript shows the number of atoms of that element in the compound. A symbol without a subscript means one atom. Carbon dioxide (CO_2) contains two atoms of oxygen bonded to one atom of carbon.

A chemical formula identifies the types of atoms in a compound or a molecule. However, a formula does not explain the shape or appearance of the molecule. Models can provide different information about a molecule. Each one can show the molecule in a different way. Common types of models for CO_2 are shown below.

Reading Check

8. Specify What information is given in a chemical formula?



Visual Check

9. Interpret According to the structural formula, how many pairs of shared electrons are in a molecule of carbon dioxide?

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Mini Glossary

chemical formula: a group of chemical symbols and numbers that represent the elements and the number of atoms of each element that make up a compound

covalent bond: a chemical bond formed when two atoms share one or more pairs of valence electrons

molecule: a group of atoms held together by covalent bonding that acts as an independent unit

polar molecule: a molecule that has a partial positive end and a partial negative end because of unequal sharing of electrons

1. Review the terms and their definitions in the Mini Glossary. Write a sentence explaining what the chemical formula of glucose, a simple sugar, means. Glucose's chemical formula is $C_6H_{12}O_6$.

2. Complete the table below to compare the different types of covalent bonds.

	Single Bond	Double Bond	Triple Bond
Electrons shared			three pairs of electrons
Example	hydrogen gas		

3. How did making an outline of the lesson help you organize information about compounds, covalent bonds, and chemical formulas?

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What do you think NOW?

Reread the statements at the beginning of the lesson. Fill in the After column with an A if you agree with the statement or a D if you disagree. Did you change your mind?

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END OF LESSON

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Content Vocabulary

LESSON 2

Compounds, Chemical Formulas, and Covalent Bonds

Directions: *Complete this chart by providing an example for each term below. Then write a brief definition.*

Term	Example and Definition
Bond	**1.**
Chemical formula	**2.**
Covalent bond	**3.**
Molecule	**4.**
Polar molecule	**5.**

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Lesson Outline **LESSON 2**

Compounds, Chemical Formulas, and Covalent Bonds

A. From Elements to Compounds

1. Compounds are chemical combinations of two or more _____.

2. Compounds and the elements that form them often have very different chemical and physical _____.

3. Atoms can bond to form compounds by _____ valence electrons.

4. A(n) _____ is a group of chemical symbols and numbers that represent the elements and the numbers of atoms of each element in a compound.

5. The letters in a chemical formula represent _____.

6. _____ show the shape and appearance of the arrangement of atoms in a compound.

B. Covalent Bonds—Electron Sharing

1. A(n) _____ is a chemical bond formed when two or more atoms share one or more pairs of valence electrons.

2. When forming water, valence electrons are _____ between oxygen and hydrogen atoms, thereby forming covalent bonds to make three stable atoms.

C. Covalent Compounds

1. A(n) _____ is a group of atoms held together by covalent bonding that acts as an independent unit.

2. _____ generally have low melting points and low boiling points. They are _____ conductors of electricity.

a. In a hydrogen molecule, a(n) _____ covalent bond forms when each atom shares its valence electrons with the other.

b. In a carbon dioxide molecule, a double covalent bond forms when the carbon atom shares _____ pairs of valence electrons with each oxygen atom.

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Lesson Outline continued

c. In a(n) _____ covalent bond, three pairs of valence electrons are shared between two atoms.

d. _____ covalent bonds are stronger than _____ covalent bonds, which are stronger than single covalent bonds.

3. In a covalent bond, one atom can attract the shared electrons more _____ than the other atom can.

a. In a molecule of water, the _____ atom attracts the electrons more strongly than each hydrogen atom does.

b. Because the electrons have a slight negative charge, there is a slight negative charge near the _____ atom; there is a slight _____ charge near the hydrogen atoms.

c. A molecule that has a slight positive end and a slight negative end because of unequal sharing of electrons is a(n) _____.

d. Polar molecules, such as sugar and water, _____ easily in one another because of the attraction of opposite charges.

4. Molecules made up of atoms of the same element are _____ because the atoms are identical. So, they share electrons equally.

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Elements and Chemical Bonds

Ionic and Metallic Bonds

Key Concepts

- What is an ionic compound?
- How do metallic bonds differ from covalent and ionic bonds?

Before You Read

What do you think? Read the two statements below and decide whether you agree or disagree with them. Place an A in the Before column if you agree with the statement or a D if you disagree. After you've read this lesson, reread the statements to see if you have changed your mind.

Before	Statement	After
	5. Losing electrons can make some atoms more chemically stable.	
	6. Metals are good electrical conductors because they tend to hold onto their valence electrons very tightly.	

Study Coach

Write a Quiz As you read, write one question for each paragraph on one side of a sheet of paper. Write the answers on the back of the paper. Exchange quizzes with a partner and take each other's quiz.

Read to Learn

Understanding Ions

As you read in Lesson 2, the atoms of two or more nonmetals form compounds by sharing valence electrons. However, when a metal and a nonmetal bond, they do not share electrons. Instead, one or more valence electrons transfers from the metal atom to the nonmetal atom. After electrons transfer, the atoms bond and form a chemically stable compound. Transferring valence electrons results in atoms with the same number of valence electrons as a noble gas.

When an atom loses or gains a valence electron, it becomes an ion. *An* **ion** *is an atom that is no longer electrically neutral because it has lost or gained valence electrons*. Because electrons have a negative charge, gaining or losing an electron changes the overall charge of the atom. An atom that loses valence electrons becomes an ion with a positive charge. This is because after an atom loses an electron, the atom has more protons than electrons. The atom is now an ion with a positive charge. An atom that gains valence electrons becomes an ion with a negative charge. This is because the number of protons is now less than the number of electrons.

Reading Check

1. Explain Why does an atom that gains an electron become an ion with a negative charge?

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Losing Valence Electrons

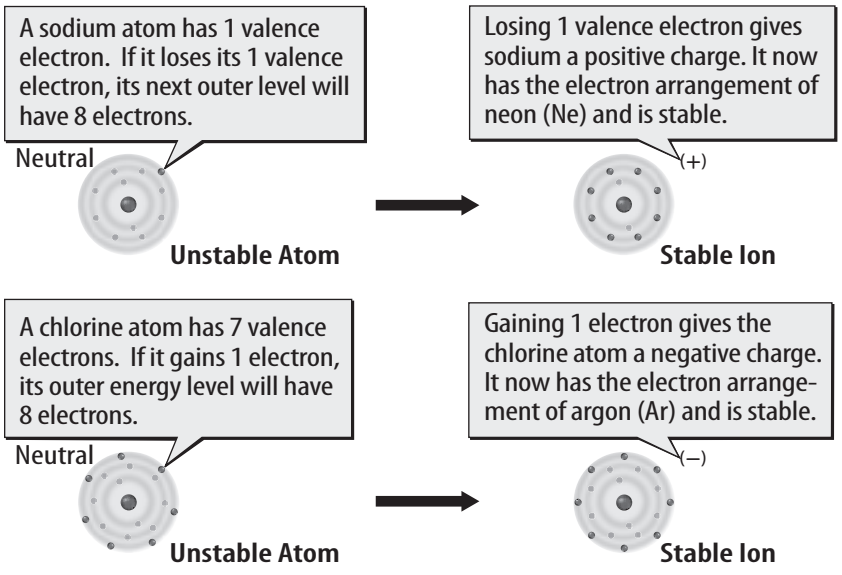
Sodium (Na) is a metal. Its atomic number is 11. This means each sodium atom has 11 protons and 11 electrons. Sodium is in group 1 on the periodic table. Therefore, sodium atoms have one valence electron and are chemically unstable.

Metal atoms, such as sodium, become more stable when they lose valence electrons and form a chemical bond with a nonmetal. The figure below describes the process of losing and gaining valance electrons. When a sodium atom loses one valence electron, the electrons in the next-lower energy level become the new valence electrons. The sodium atom then has eight valence electrons, the same as the noble gas neon (Ne). The sodium atom is chemically stable.

Gaining Valence Electrons

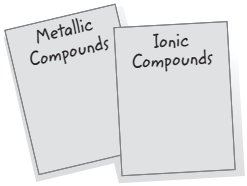
In Lesson 2, you learned that nonmetal atoms can share valence electrons with other nonmetal atoms. Nonmetal atoms can also gain valence electrons from metal atoms. Either way, they achieve the electron arrangement of a noble gas. The nonmetal chlorine (Cl) has an atomic number of 17. Chlorine atoms have seven valence electrons, as shown in the figure below. If a chlorine atom gains one valence electron, it will have eight valence electrons. It will then have the same electron arrangement as the stable noble gas argon (Ar).

When a sodium atom loses a valence electron, it becomes a positively charged ion. This is shown by a plus (+) sign. When a chlorine atom gains a valence electron, it becomes a negatively charged ion. This is shown by a negative (−) sign.



FOLDABLES®

Make two quarter-sheet note cards to summarize information about ionic and metallic compounds.



Reading Check

2. Predict Are atoms of a group 16 element more likely to gain or lose valence electrons?

Visual Check

3. Identify What would an ion's charge be if the atom gained two electrons?

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Math Skills

An atom's radius is measured in picometers (pm), 1 trillion times smaller than a meter. When an atom becomes an ion, its radius either increases or decreases. For example, the radius of a sodium (Na) atom is 186 pm. The radius of a Na^+ ion is 102 pm. By what percentage does the radius change as the ion forms?

a. Subtract the ion's radius from the atom's radius.

$102 \text{ pm} - 186 \text{ pm} = -84 \text{ pm}$

b. Divide the difference by the atom's radius.

$-84 \text{ pm} \div 186 \text{ pm} = -0.45$

c. Multiply the answer by 100 and add a % sign.

$-0.45 \times 100 = -45\%$

A negative value means a decrease in size. A positive value means an increase.

4. Calculate Percentage The radius of an oxygen (O) atom is 73 pm. The radius of an oxygen ion (O^{2-}) is 140 pm. By what percentage does the radius change? Show your work.

_____

_____

_____

Key Concept Check

5. Explain What holds ionic compounds together?

_____

_____

_____

Determining an Ion's Charge

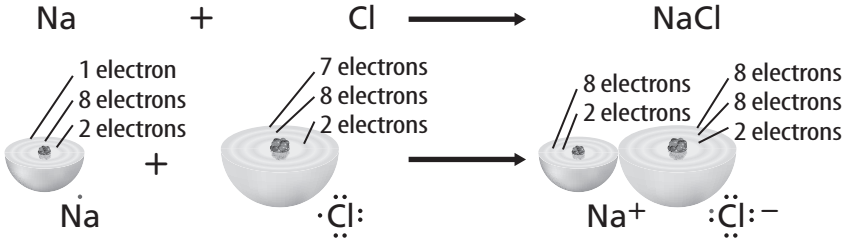
Atoms are electrically neutral because they have the same number of protons (+) and electrons (−). Once an atom gains or loses electrons, it becomes a charged ion. For example, the atomic number for nitrogen (N) is 7. This means that each N atom has 7 protons and 7 electrons. It is electrically neutral. When forming an ionic bond, N atoms gain 3 electrons. The N ion then has 10 electrons. To determine the charge of the ion, subtract the number of electrons in the ion from the number of protons.

7 protons − 10 electrons = −3 charge

A nitrogen ion has a −3 charge. This is written as N^{3-}.

Ionic Bonds—Electron Transferring

Recall that metal atoms lose valence electrons and nonmetal atoms gain valence electrons. When forming a chemical bond, the nonmetal atoms gain the electrons lost by the metal atoms. In (NaCl), or table salt, a sodium atom loses one valence electron. The electron is transferred to a chlorine atom. The sodium atom is now a positively charged ion. The chlorine atom is now a negatively charged ion. These ions attract each other and form a stable ionic compound, as shown below. *The attraction between positively and negatively charged ions in an ionic compound is an* **ionic bond.**



Ionic Compounds

The ions of ionic compounds are strongly attracted to each other. As a result, ionic compounds are usually solid and brittle at room temperature. They have relatively high melting and boiling points. Water that contains dissolved ionic compounds is a good conductor of electricity. This is because an electrical charge can pass from ion to ion in the solution.

Comparing Ionic and Covalent Compounds

Recall that in a covalent bond, two or more nonmetal atoms share electrons and form a unit, or molecule. Covalent compounds are made up of many molecules. However, when nonmetal ions bond to metal ions in an ionic compound, there are no molecules. Instead, there is a large collection of ions with opposite charges. The ions are all attracted to each other and are held together by ionic bonds.

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Metallic Bonds—Electron Pooling

Recall that metal atoms typically lose valence electrons when forming compounds. Metal atoms form compounds with one another by combining, or pooling, their valence electrons, as shown in the table below. *A* **metallic bond** *is a bond formed when many metal atoms share their pooled valence electrons*. In aluminum (Al), atoms lose their valence electrons and become positive ions. The negatively charged valence electrons move from ion to ion. Valence electrons in metals do not bond to one atom. Instead, a "sea of electrons" surrounds the positive ions.

Properties of Metallic Compounds

Metals are good conductors of thermal energy and electricity. Because the valence electrons can move from ion to ion, they can easily conduct an electric charge. When a metal is hammered into a sheet or drawn into a wire, it does not break. The metal ions can slide past one another in the electron sea and move to new positions. Metals are shiny because the valence electrons at the surface interact with light. The table below compares the covalent, ionic, and metallic bonds that you studied in this chapter.

Key Concept Check

6. Specify How do metal atoms bond with one another?

_____

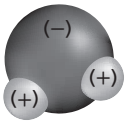
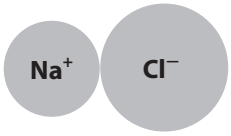
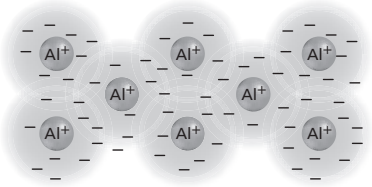
_____

ACADEMIC VOCABULARY

conduct
(verb) to serve as a medium through which something can flow

Visual Check

7. Identify Circle the bond that results in a compound that conducts thermal energy well.

Type of Bond	What is bonding?	Properties of Compounds
Covalent—share valence electrons  Water	nonmetal atoms; nonmetal atoms	• gas, liquid, or solid • low melting and boiling points • often not able to dissolve in water • poor conductors of thermal energy and electricity • dull appearance
Ionic—transfer valence electrons  Salt	nonmetal ions; metal ions	• solid crystals • high melting and boiling points • dissolves in water • solids are poor conductors of thermal energy and electricity • ionic compounds in water solutions conduct electricity
Metallic—pool valence electrons  Aluminum	metal ions; metal ions	• usually solid at room temperature • high melting and boiling points • do not dissolve in water • good conductors of thermal energy and electricity • shiny surface • can be hammered into sheets and pulled into wires

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Mini Glossary

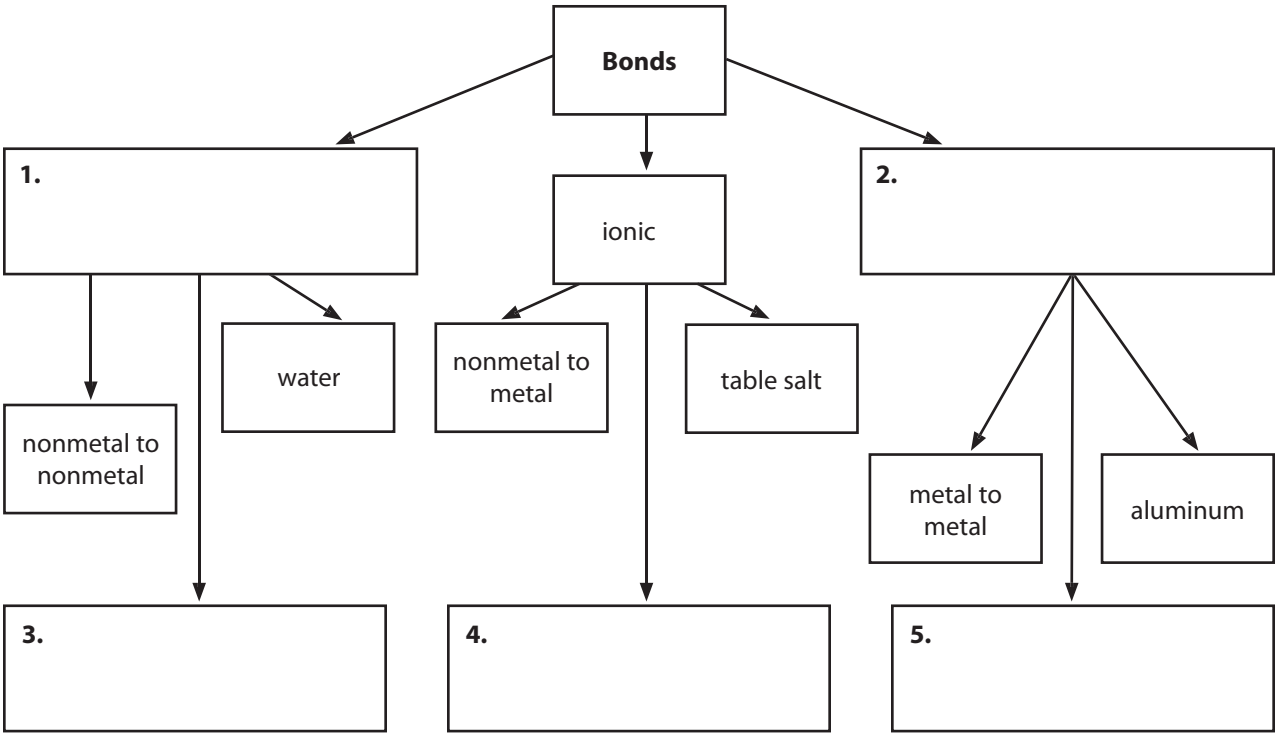
ion: an atom that is no longer electrically neutral because it has lost or gained valence electrons

ionic bond: the attraction between positively and negatively charged ions in an ionic compound

metallic bond: a bond formed when many metal atoms share their pooled valence electrons

1. Review the terms and their definitions in the Mini Glossary. Write two sentences that describe the difference between a positively charged ion and a negatively charged ion.

2. Fill in the organizer below with the following terms to compare the three types of bonding that you learned about in this chapter: *ionic, metallic,* and *covalent*. In each bottom box, identify the type of bond by writing *transfer valence electrons, pool valence electrons,* or *share valence electrons*.



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Content Vocabulary

LESSON 3

Ionic and Metallic Bonds

Directions: *In this word search puzzle, find and circle the four terms listed below. Then write each term on the line before its definition.*

conduct **ion** **ionic bond** **metallic bond**

U	U	K	N	O	M	V	M	H	R	R
T	C	Z	E	Y	E	X	O	T	O	C
Z	V	C	H	G	T	P	C	N	C	I
E	R	F	L	N	A	R	A	I	O	G
U	Q	J	T	P	L	Y	O	M	N	I
Z	K	Z	N	A	L	N	K	Z	T	C
K	R	U	P	F	I	Z	U	F	V	O
F	J	C	H	C	C	X	U	U	S	N
H	E	C	B	A	B	X	F	T	E	D
F	A	O	R	G	O	Z	V	Y	O	U
S	N	P	I	J	N	E	T	H	K	C
D	Y	S	C	Q	D	I	S	S	J	T

_____ **1.** to serve as a medium through which something can flow

_____ **2.** a chemical bond between positively and negatively charged ions

_____ **3.** a chemical bond between metal atoms

_____ **4.** an atom that has lost or gained valence electrons

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Lesson Outline **LESSON 3**

Ionic and Metallic Bonds

A. Understanding Ions

1. When a metal and a(n) _____ bond, they do not share electrons.

2. The _____ atom transfers one or more valence electrons to the _____ atom, forming a chemically stable compound.

3. A(n) _____ is an atom that is no longer electrically neutral because it has lost or gained one or more valence electrons.

a. An atom that loses one or more valence electrons becomes an ion with a(n) _____ charge.

b. An atom that gains one or more valence electrons becomes and ion with a(n) _____ charge.

4. Sodium is a metal that has _____ valence electron(s).

a. To become stable, sodium has to _____ a valence electron.

b. When a sodium atom loses a valence electron, it becomes a(n) _____ charged ion.

5. Chlorine is a nonmetal that has _____ valence electron(s).

a. To become stable, chlorine has to _____ a valence electron.

b. When a chlorine atom gains a valence electron, it becomes a(n) _____ charged ion.

6. To figure out the charge of an ion, _____ the number of electrons in the ion from the number of _____.

B. Ionic Bonds—Electron Transferring

1. When forming a chemical compound, the nonmetal atoms _____ the electrons _____ by the metal atoms.

2. Due to the change in the number of electrons, the metal and nonmetal atoms both become _____.

3. The attraction between positively and negatively charged ions in an ionic compound is a(n) _____.

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Lesson Outline continued

C. Ionic Compounds

1. Most ionic compounds are _____ and _____ at room temperature.

a. Ionic compounds usually have _____ melting points and boiling points.

b. Ionic compounds are _____ conductors of electricity because electric charge passes easily from one ion to another.

2. Covalent compounds form when atoms of different nonmetals _____ electrons, forming _____ bonds.

a. Covalent compounds are made up of many _____.

b. In contrast, _____ compounds are composed of a large collection of _____, all of which attract each other and are held together by _____ bonds.

D. Metallic Bonds—Electron Pooling

1. Metal atoms form compounds with other _____ by combining, or pooling, their valence electrons.

2. A(n) _____ is a bond formed when many metal atoms share their pooled valence electrons.

a. When metal atoms lose their _____, they become _____ ions.

b. Valence electrons in metals are not bonded to any particular atom; instead, _____ metal ions are surrounded by a sea of _____.

3. Metals are _____ conductors of electricity because their valence electrons can easily move from ion to ion, transferring electric charge.

4. Metals can _____ be hammered into a sheet or drawn into a wire because the ions slide past one another through the electron pool.

5. Metals are shiny because the _____ at their surface interact with light.

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