Lesson 3

Ionic and Metallic Bonds

Reading Guide

Key Concepts

ESSENTIAL QUESTIONS

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

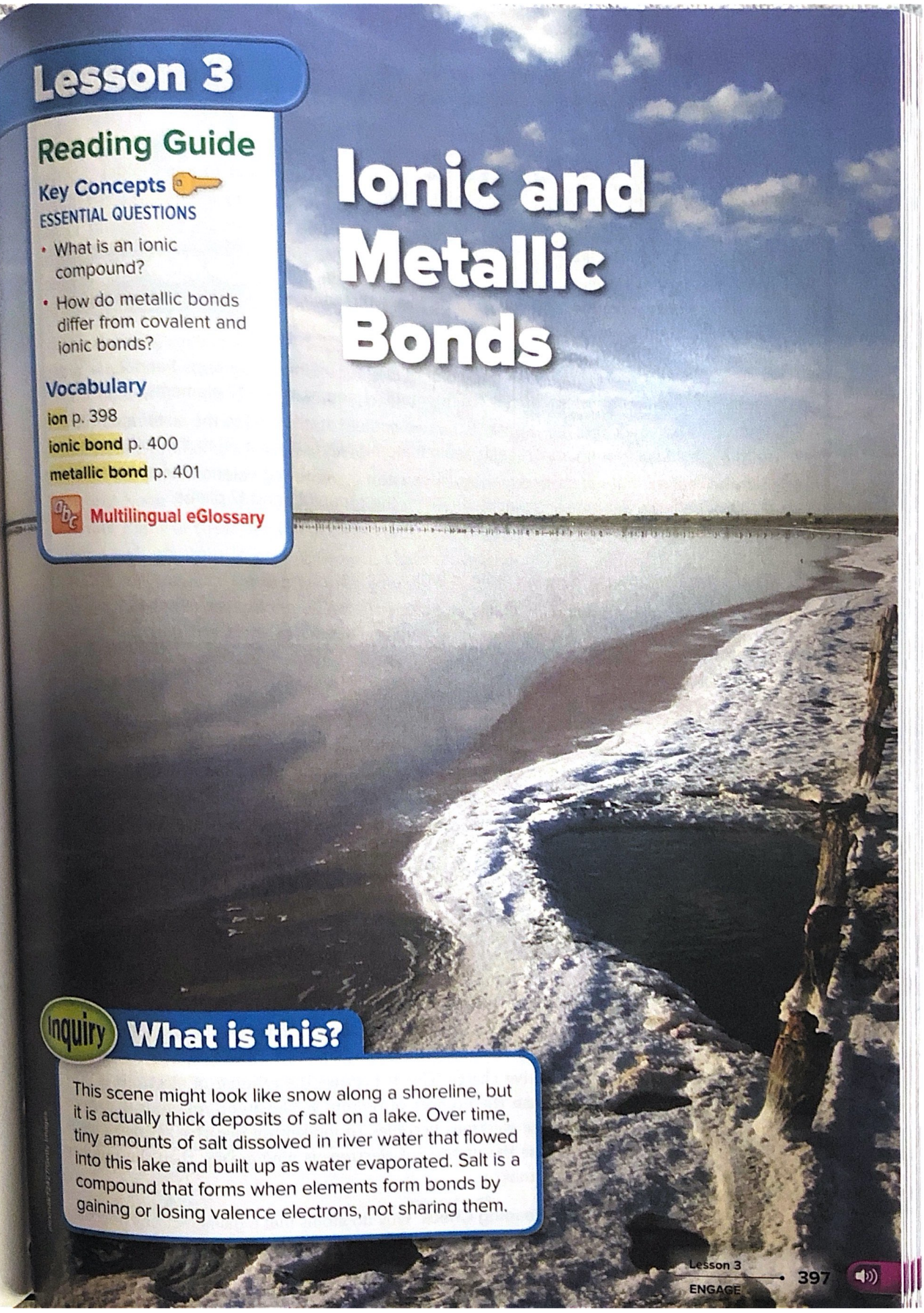
Vocabulary

ion p. 398

ionic bond p. 400

metallic bond p. 401

Multilingual eGlossary



Inquiry What is this?

This scene might look like snow along a shoreline, but it is actually thick deposits of salt on a lake. Over time, tiny amounts of salt dissolved in river water that flowed into this lake and built up as water evaporated. Salt is a compound that forms when elements form bonds by gaining or losing valence electrons, not sharing them.

Launch Lab

15 minutes

How can atoms form compounds by gaining and losing electrons?

Metals often lose electrons when forming stable compounds. Nonmetals often gain electrons.

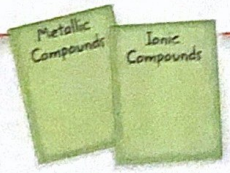
1. Read and complete a lab safety form.
2. Make two model atoms of sodium, and one model atom each of calcium, chlorine, and sulfur. To do this, write each element's chemical symbol with a **marker** on a **paper plate.** Surround the symbol with small balls of **clay** to represent valence electrons. Use one color of clay for the metals (groups 1 and 2 elements) and another color of clay for nonmetals (groups 16 and 17 elements).
3. To model sodium sulfide (Na_2S), place the two sodium atoms next to the sulfur atom. To form a stable compound, move each sodium atom's valence electron to the sulfur atom.
4. Form as many other compound models as you can by removing valence electrons from the groups 1 and 2 plates and placing them on the groups 16 and 17 plates.

Think About This

1. What other compounds were you able to form?
2. **Key Concept** How do you think your models are different from covalent compounds?

FOLDABLES

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



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, losing or gaining an electron changes the overall charge of an atom. An atom that loses valence electrons becomes an ion with a positive charge. This is because the number of electrons is now less than the number of protons in the atom. An atom that gains valence electrons becomes an ion with a negative charge. This is because the number of electrons is now greater than the number of protons.

WORD ORIGIN

ion
from Greek *ienai*, means "to go"

Reading Check Why do atoms that a gain electrons become an ion with a negative charge?

Losing Valence Electrons

Look at the periodic table on the inside back cover of this book. What information about sodium (Na) can you infer from the periodic table? Sodium 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 they are chemically unstable.

Metal atoms, such as sodium, become more stable when they lose valence electrons and form a chemical bond with a nonmetal. If a sodium atom loses its one valence electron, it would have a total of ten electrons. Which element on the periodic table has atoms with ten electrons? Neon (Ne) atoms have a total of ten electrons. Eight of these are valence electrons. When a sodium atom loses one valence electron, the electrons in the next lower energy level are now the new valence electrons. The sodium ion then has eight valence electrons, the same as the noble gas neon and is chemically stable.

Gaining Valence Electrons

In Lesson 2, you read 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. Find the nonmetal chlorine (Cl) on the periodic table. Its atomic number is 17. Atoms of chlorine have seven valence electrons. If a chlorine atom gains one valence electron, it will have eight valence electrons. It will also have the same electron arrangement as the noble gas argon (Ar).

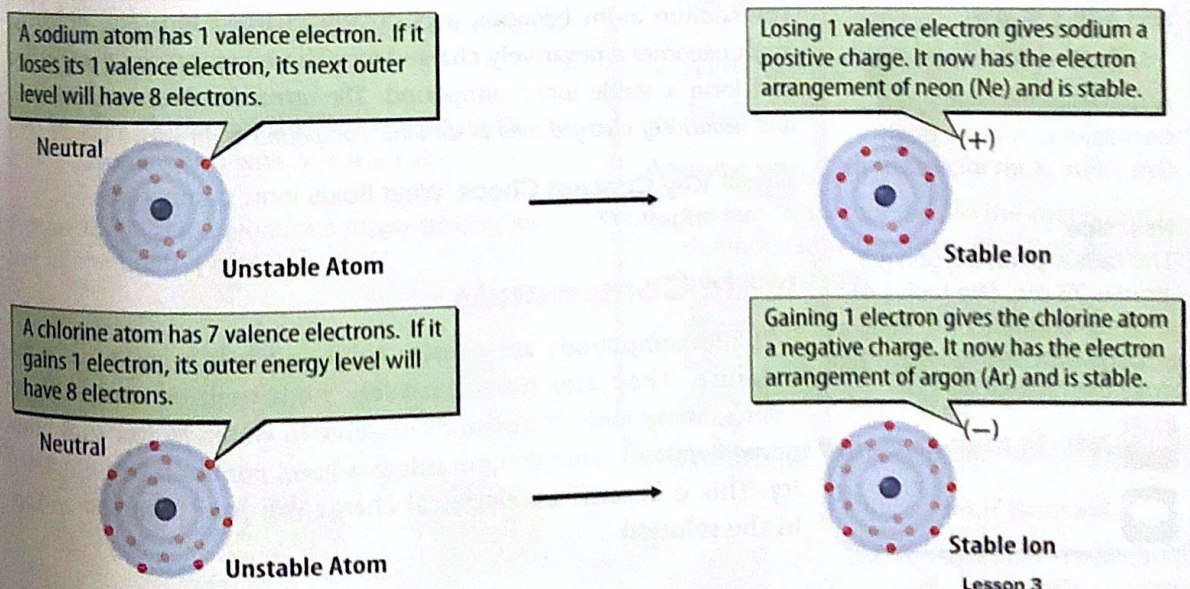
When a sodium atom loses a valence electron, it becomes a positively charged ion. This is shown by a plus (+) sign. When a chlorine atom gains a valence electron, it becomes a negatively charged ion. This is shown by a negative (−) sign. **Figure 11** illustrates the process of a sodium atom losing an electron and a chlorine atom gaining an electron.

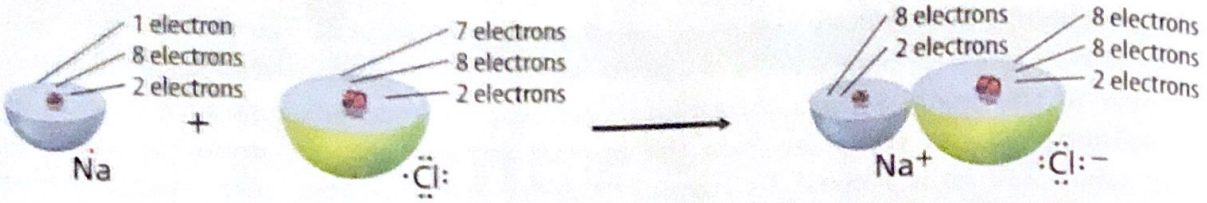
Reading Check Are atoms of a group 16 element more likely to gain or lose valence electrons?

Losing and Gaining Electrons

Animation

Figure 11 Sodium atoms have a tendency to lose a valence electron. Chlorine atoms have a tendency to gain a valence electron.





Sodium and chlorine atoms are stable when they have eight valence electrons. A sodium atoms loses one valence electron and becomes stable. A chlorine atom gains one valence electron and becomes stable.

The positively charged sodium ion and the negatively charged chlorine ion attract each other. Together they form a strong ionic bond.

Figure 12 An ionic bond forms between Na and Cl when an electron transfers from Na to Cl.

Animation

Math Skills

Use Percentage

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

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

102 pm − **186 pm** = −84 pm

Divide the difference by the atom's radius.

−84 pm ÷ **186 pm** = −0.45

Multiply the answer by 100 and add a % sign.

−0.45 × 100 = −45%

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

Practice

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?

Math Practice

Personal Tutor

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. Each N atom has 7 protons and 7 electrons and is electrically neutral. However, an N atom often gains 3 electrons when forming an ion. The N ion then has 10 electrons. To determine the charge, 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 typically lose valence electrons and nonmetal atoms typically gain valence electrons. When forming a chemical bond, the nonmetal atoms gain the electrons lost by the metal atoms. Take a look at **Figure 12**. In NaCl, or table salt, a sodium atom loses a valence electron. The electron is transferred to a chlorine atom. The sodium atom becomes a positively charged ion. The chlorine atom becomes a negatively charged ion. These ions attract each other and form a stable ionic compound. *The attraction between positively and negatively charged ions in an ionic compound is an* **ionic bond.**

Key Concept Check What holds ionic compounds together?

Ionic Compounds

Ionic compounds are usually solid and brittle at room temperature. They also have relatively high melting and boiling points. Many ionic compounds dissolve in water. 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, such as water, 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 oppositely charged ions. All of the ions attract each other and are held together by ionic bonds.

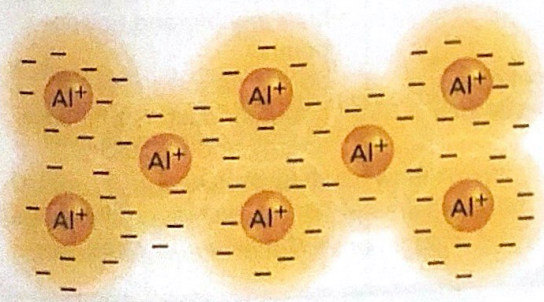
Metallic Bonds—Electron Pooling

Recall that metal atoms typically lose valence electrons when forming compounds. What happens when metal atoms bond to other metal atoms? Metal atoms form compounds with one another by combining, or pooling, their valence electrons. *A* **metallic bond** *is a bond formed when many metal atoms share their pooled valence electrons.*

The pooling of valence electrons in aluminum is shown in **Figure 13.** The aluminum atoms lose their valence electrons and become positive ions, indicated by the plus (+) signs. The negative (-) signs indicate the valence electrons, which move from ion to ion. Valence electrons in metals are not bonded to one atom. Instead, a "sea of electrons" surrounds the positive ions.

Key Concept Check How do metal atoms bond with one another?

Figure 13 Valence electrons move among all the aluminum (Al) ions.



MiniLab 20 minutes

How many ionic compounds can you make?

You have read that in ionic bonding, metal atoms transfer electrons to nonmetal atoms.

1. Copy the table below into your Science Journal.

Group	Elements	Type	Dot Diagram
1	Li, Na, K	Metal	$\dot{X}$
2	Be, Mg, Ca	Metal	
14	C	Nonmetal	
15	N, P	Nonmetal	
16	O, S	Nonmetal	
17	F, Cl	Nonmetal	

2. Fill in the last column with the correct dot diagram for each group. Color the dots of the metal atoms with a **red marker** and the dots of the nonmetal atoms with a **blue marker.**
3. Using the information in your table, create five different ionic bonds. Write (a) the equation for the electron transfer and (b) the formula for each compound. For example:

a. $\dot{N}a + \dot{N}a + \cdot\ddot{O}: \longrightarrow Na^+ + Na^+ + :\ddot{O}:^{2-}$

b. Na_2O

Analyze and Conclude

1. **Explain** What happens to the metal and nonmetal ions after the electrons have been transferred?
2. **Key Concept** Describe the ionic bonds that hold the ions together in your compounds.

ACADEMIC VOCABULARY

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

Interactive Table

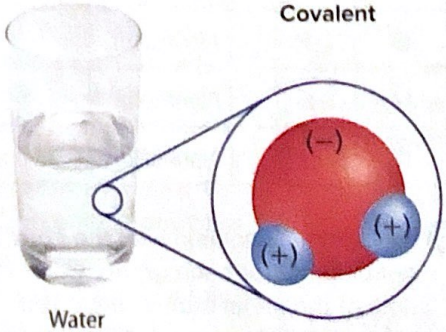
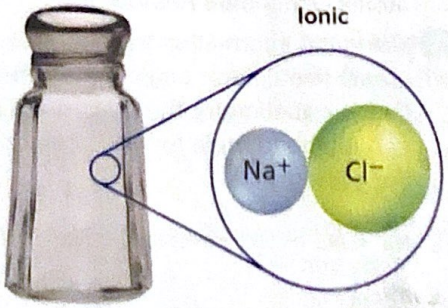
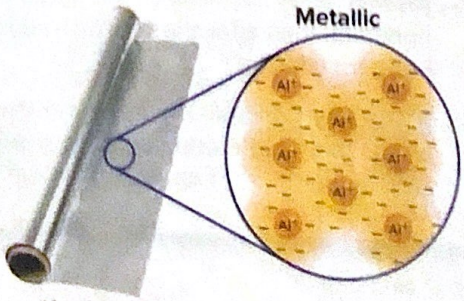
Table 1 Bonds can form when atoms share valence electrons, transfer valence electrons, or pool valence electrons.

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 of a metal interact with light. **Table 1** compares the covalent, ionic, and metallic bonds that you studied in this chapter.

Reading Check How does valence electron pooling explain why metals can be hammered into a sheet?

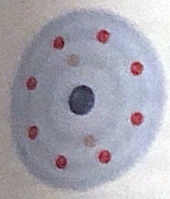
Table 1 Covalent, Ionic, and Metallic Bonds

Type of Bond	What is bonding?	Properties of Compounds
Covalent  Water	nonmetal atoms; nonmetal atoms	• gas, liquid, or solid • low melting and boiling points • dissolves in water if covalent bonds are polar • do not dissolve in water if covalent bonds are nonpolar • poor conductors of thermal energy and electricity • dull appearance
Ionic  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  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

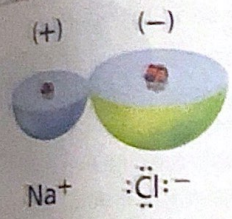
Lesson 3 Review

Online Quiz

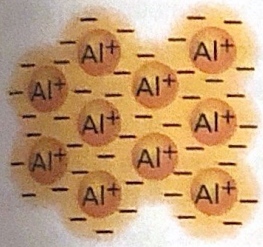
Visual Summary



Metal atoms lose electrons and non-metal atoms gain electrons and form stable compounds. An atom that has gained or lost an electron is an ion.



An ionic bond forms between positively and negatively charged ions.



A metallic bond forms when many metal atoms share their pooled valence electrons.

FOLDABLES

Use your lesson Foldable to review the lesson. Save your Foldable for the project at the end of the chapter.

What do you think NOW?

You first read the statements below at the beginning of the chapter.

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.

Did you change your mind about whether you agree or disagree with the statements? Rewrite any false statements to make them true.

Use Vocabulary

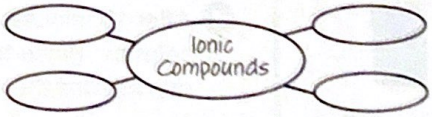
1. **Define** *ionic bond* in your own words.
2. An atom that changes so that it has an electrical charge is a(n) _____.
3. **Use the term** *metallic bond* in a sentence.

Understand Key Concepts

4. **Recall** What holds ionic compounds together?
5. Which element would most likely bond with lithium and form an ionic compound?
   - **A.** beryllium
   - **B.** calcium
   - **C.** fluorine
   - **D.** sodium
6. **Contrast** Why are metals good conductors of electricity while covalent compounds are poor conductors?

Interpret Graphics

7. **Organize** Copy and fill in the graphic organizer below. In each oval, list a common property of an ionic compound.



Critical Thinking

8. **Design** a poster to illustrate how ionic compounds form.
9. **Evaluate** What type of bonding does a material most likely have if it has a high melting point, is solid at room temperature, and easily dissolves in water?

Math Skills

Math Practice

10. The radius of the aluminum (Al) atom is 143 pm. The radius of the aluminum ion (Al^{3+}) is 54 pm. By what percentage did the radius change as the ion formed?

Lab

45 minutes

Ions in Solution

Materials

250-mL beaker

plastic spoon

dull pennies (20)

stopwatch

white vinegar

table salt

iron nails (2)

sandpaper

Safety

You know that ions can combine and form stable ionic compounds. Ions can also separate in a compound and dissolve in solution. For example, pennies become dull over time because the copper ions on the surface of the pennies react with oxygen in the air and form copper(II) oxide. When you place dull pennies in a vinegar-salt solution, the copper ions separate from the oxygen ions. These ions dissolve in the solution.

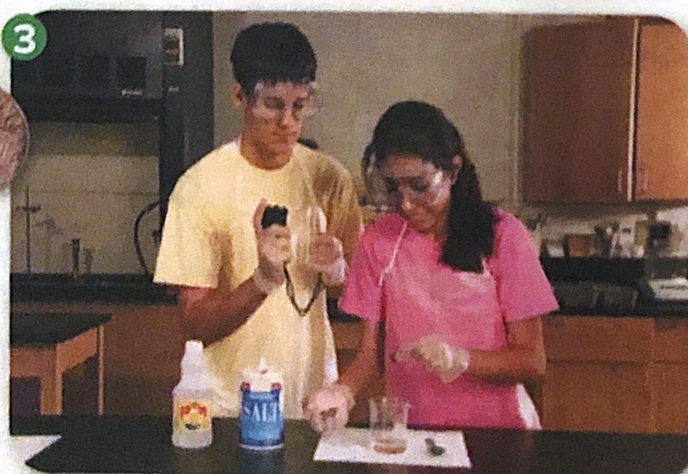
Question

How do elements join together to make chemical compounds?

Procedure

1. Read and complete a lab safety form.
2. Pour 50 mL of white vinegar into a 250-mL beaker. Using a plastic spoon, add a spoonful of table salt to the vinegar. Stir the mixture with the spoon until the salt dissolves.
3. Add 20 dull pennies to the vinegar-salt solution. Leave the pennies in the solution for 10 minutes. Use a stopwatch or a clock with a second hand to measure the time.
4. After 10 minutes, use the plastic spoon to remove the pennies from the solution. Rinse the pennies in tap water. Place them on paper towels to dry. Record the change to the pennies in your Science Journal.

3



Form a Hypothesis

5 If you place an iron nail in the vinegar-salt solution, predict what changes will occur to the nail.

Test Your Hypothesis

6 Use sandpaper to clean two nails. Place one nail in the vinegar-salt solution, and place the other nail on a clean paper towel. You will compare the dry nail to the one in the solution and observe changes as they occur.

7 Every 5 minutes observe the nail in the solution and record your observations in your Science Journal. Remember to use the dry nail to help detect changes in the wet nail. Use a stopwatch or a clock with a second hand to measure the time. Keep the nail in the solution for 25 minutes.

8 After 25 minutes, use a plastic spoon to remove the nail from the solution. Dispose of all materials as directed by your teacher.

Analyze and Conclude

9 **Compare and Contrast** What changes occurred when you placed the dull pennies in the vinegar-salt solution?

10 **Recognize Cause and Effect** What changes occurred to the nail in the leftover solution? Infer why these changes occurred.

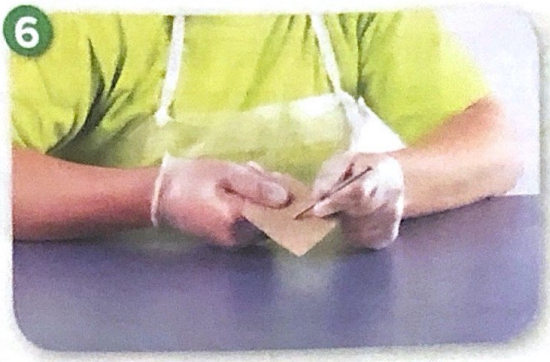
11 **The Big Idea** Give two examples of how elements chemically combine and form compounds in this lab.

Communicate Your Results

Create a chart suitable for display summarizing this lab and your results.

Inquiry Extension

The Statue of Liberty is made of copper. Research why the statue is green.



Lab Tips

- ☑ Be sure the pennies are separated when they are in the vinegar-salt solution. You may need to stir them with the plastic spoon.
- ☑ Use the plastic spoon to bring the nail out of the solution when checking for changes.