Section 4 Covalent Bonds

Objectives

After this lesson, students will be able to

L.1.4.1 State what holds covalently bonded atoms together.

L.1.4.2 Identify the properties of molecular compounds.

L.1.4.3 Explain how unequal sharing of electrons occurs and how it affects molecules.

Target Reading Skill

Asking Questions Explain that changing a head into a question helps students anticipate the ideas, facts, and events they are about to read.

Answers

Possible questions and answers:
How do covalent bonds form? *(Covalent bonds form when two atoms share electrons.)* **What are molecular compounds?** *(Molecular compounds are compounds that contain molecules bonded with covalent bonds.)* **How does unequal sharing of electrons affect the atoms in molecular compounds?** *(Unequal sharing of electrons causes the bonded atoms to have slight electrical charges.)*

All in One Teaching Resources

- Transparency L9

Preteach

Build Background Knowledge L2

How Atoms Form Bonds

Remind students that atoms form bonds in more than one way. Ask: **In addition to ionic bonding, in which atoms give up or gain electrons, what is another way atoms can form bonds?** *(By sharing electrons)* Tell students that in this section they will learn about bonds that form when atoms share electrons.

Section 4 Covalent Bonds

Reading Preview

Key Concepts

- What holds covalently bonded atoms together?
- What are the properties of molecular compounds?
- How does unequal sharing of electrons occur, and how does it affect molecules?

Key Terms

- covalent bond
- molecule
- double bond
- triple bond
- molecular compound
- polar bond
- nonpolar bond

Target Reading Skill

Asking Questions Before you read, preview the red headings. In a graphic organizer like the one below, ask a *what* or *how* question for each heading. As you read, answer your questions.

Covalent Bonds

Question	Answer
How do covalent bonds form?	Covalent bonds form when...

Lab zone Discover Activity

Can Water and Oil Mix?

1. Pour water into a small jar that has a tight-fitting lid until the jar is about a third full.
2. Add an equal amount of vegetable oil to the jar. Cover the jar tightly.
3. Shake the jar vigorously for 20 seconds. Observe the contents.
4. Allow the jar to sit undisturbed for 1 minute. Observe again.
5. Remove the top and add 3 drops of liquid detergent. Cover the jar and repeat Steps 3 and 4.

Think It Over
Forming Operational Definitions Based on your observations, write an operational definition of *detergent*. How might your observations relate to chemical bonds in the detergent, oil, and water molecules?

Uh oh, you have a big project due in English class next week! You need to write a story and illustrate it with colorful posters. Art has always been your best subject, but writing takes more effort. Luckily, you're working with a partner who writes well but doesn't feel confident in art. If you each contribute your skills, together you can produce a high-quality finished project.

FIGURE 21
Sharing Skills
One student is a skilled artist, while the other is a skilled writer. By pooling their skills, the students can complete their project.

Lab zone Discover Activity

Skills Focus Forming operational definitions L1

Materials small jar with tight-fitting top, water, vegetable oil, liquid detergent

Time 10 minutes

Tip Baby food jobs are good choices for this activity.

Expected Outcome Water and vegetable oil will not mix until liquid detergent is added.

Think It Over Sample definition: Detergent is a substance that allows oil and water to mix. Students might explain that bonds between oil molecules and bonds between water molecules do not break and allow the two substances to mix unless liquid detergent is added.

How Covalent Bonds Form

Just as you and your friend can work together by sharing your talents, atoms can become more stable by sharing electrons. The chemical bond formed when two atoms share electrons is called a **covalent bond.** Covalent bonds usually form between atoms of nonmetals. In contrast, ionic bonds usually form when a metal combines with a nonmetal.

Electron Sharing Recall that the noble gases are not very reactive. In contrast, all other nonmetals, including hydrogen, can bond to other nonmetals by sharing electrons. Most nonmetals can even bond with another atom of the same element, as is the case with fluorine in Figure 22. When you count the electrons on each atom, count the shared pair each time. By sharing electrons, each atom has a stable set of eight. **The force that holds atoms together in a covalent bond is the attraction of each atom's nucleus for the shared pair of electrons.** The two bonded fluorine atoms form a molecule. A **molecule** is a neutral group of atoms joined by covalent bonds.

How Many Bonds? Look at the electron dot diagrams in Figure 23. Count the valence electrons around each atom. The number of covalent bonds these atoms can form equals the number of electrons needed to make a total of eight (or in the case of hydrogen, two).

For example, oxygen has six valence electrons, so it can form two covalent bonds. In a water molecule, oxygen forms one covalent bond with each of two hydrogen atoms. As a result, the oxygen atom has a stable set of eight valence electrons. Each hydrogen atom can form one bond because it needs only a total of two electrons to be stable. Do you see why water's formula is H_2O, instead of H_3O, H_4O, or just HO?

FIGURE 22
Sharing Electrons
By sharing electrons in a covalent bond, each fluorine atom has a stable set of eight valence electrons.

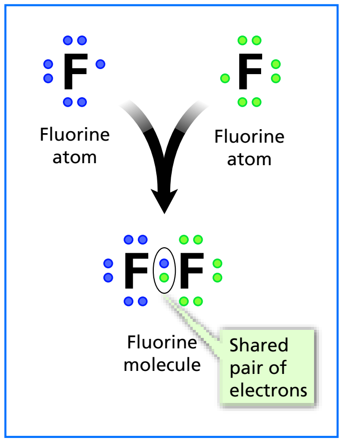
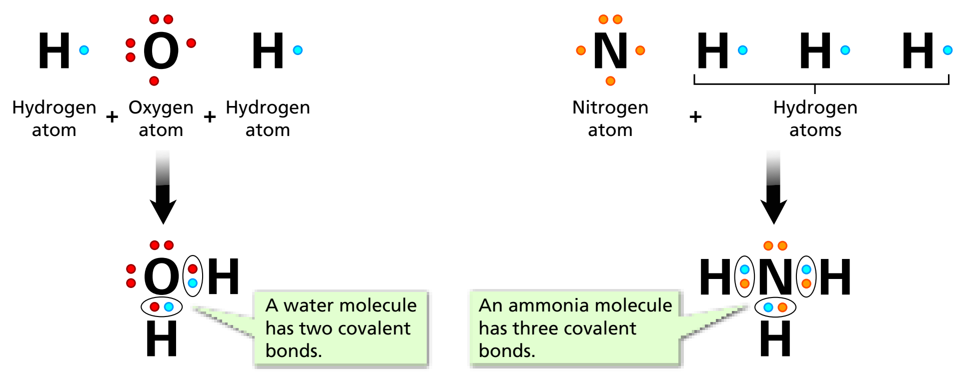


FIGURE 23
Covalent Bonds
The oxygen atom in water and the nitrogen atom in ammonia are each surrounded by eight electrons as a result of sharing electrons with hydrogen atoms.
Interpreting Diagrams *How many electrons does each hydrogen atom have as a result of sharing?*



Instruct

How Covalent Bonds Form

Teach Key Concepts L2

Comparing and Contrasting Covalent and Ionic Bonds

Focus Introduce covalent bonds by comparing and contrasting them with ionic bonds.

Teach Remind students that ionic bonds form between oppositely charged ions that have gained or lost electrons. Then, tell them that covalent bonds form between uncharged atoms that share electrons.

Apply Ask: **In a fluorine molecule, how many valence electrons does each fluorine atom have?** *(Eight)* **learning modality: verbal**

Use Visuals: Figure 23 L2

Number of Covalent Bonds

Focus Say that the number of covalent bonds atoms form equals the number of electrons needed for eight (two for hydrogen) valence electrons.

Teach Have students study the figure and read the caption. Ask: **How many valence electrons does oxygen have before and after bonding with hydrogen?** *(Six before; eight after)* **How many valence electrons does nitrogen have before and after bonding with hydrogen?** *(Five before; eight after)*

Apply Ask: **How many hydrogen atoms would you expect to bind to an atom with four valence electrons?** *(Four)* **learning modality: visual**

All in One Teaching Resources
- Transparency L10

Independent Practice L2

All in One Teaching Resources
- *Guided Reading and Study Worksheet: Covalent Bonds*

Student Edition on Audio CD

Monitor Progress L2

Drawing Have students draw electron dot diagrams to show how two chlorine atoms bond together to form a chlorine molecule.

Answer
Figure 23 Two electrons

Differentiated Instruction

Less Proficient Readers L1

Interpreting Diagrams Guide students in a closer comparison of covalent bonds with the now-familiar ionic bonds. Have students look for differences between Figures 17 and 22. Ask them to describe what happens to the valence electrons in each type of bond. **learning modality: visual**

Gifted and Talented L3

Explaining Differences in Bonding Challenge students to use their knowledge of valence electrons to explain why covalent bonds usually form between atoms of nonmetals, whereas ionic bonds usually form between atoms of metals and nonmetals. **learning modality: logical/mathematical**

Use Visuals: Figure 24 L2

Formation of Double and Triple Bonds

Focus Help students understand why some molecules contain double or triple bonds.

Teach Have students look at the figure and read the caption and labels. Ask: **If two oxygen molecules were to share just two electrons instead of four, how many valence electrons would each oxygen atom have?** *(Six)* **Why must two oxygen atoms share four electrons?** *(So that each atom has eight)*

Apply Have students answer the caption question. **learning modality: visual**

All in One **Teaching Resources**

- Transparency L11

Molecular Compounds

Teach Key Concepts L2

Summarizing Molecular Compounds

Focus Use a graphic organizer to summarize the important points about molecular compounds and their properties.

Teach On the board, make a concept map to show that molecular compounds consist of covalently bonded atoms, have low melting and boiling points, and do not conduct electricity well. Have students copy the concept map in their science notebooks and use it for review.

Apply Challenge students to explain the properties of molecular compounds. For example, Ask: **Why do you think molecular compounds do not conduct electricity well?** *(Sample answer: Molecular compounds consist of electrically neutral atoms, not ions, so they do not have charged particles to carry a current.)* **learning modality: visual**

Go Online SCI LINKS NSTA

For: Links on molecular compounds
Visit: www.SciLinks.org
Web Code: scn-1214

Download a worksheet that will guide students' review of Internet sources on molecular compounds.

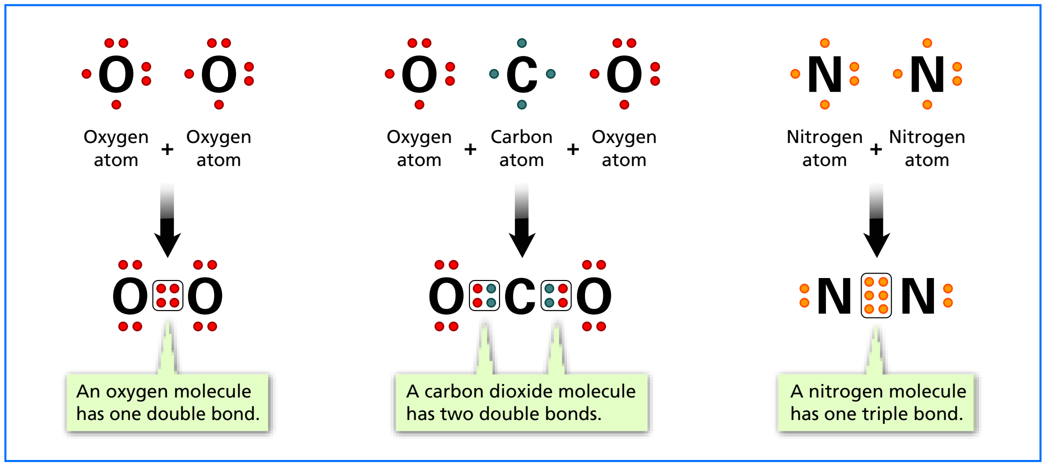


FIGURE 24
Double and Triple Bonds
An oxygen molecule contains one double bond, while a carbon dioxide molecule has two double bonds. A nitrogen molecule contains one triple bond.
Interpreting Diagrams *In a nitrogen molecule, how many electrons does each nitrogen atom share with the other?*

Go Online SCI LINKS NSTA

For: Links on molecular compounds
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Web Code: scn-1214

Double Bonds and Triple Bonds Look at the diagram of the oxygen molecule (O_2) in Figure 24. What do you see that's different? This time the two atoms share two pairs of electrons, forming a **double bond.** In a carbon dioxide molecule (CO_2), carbon forms a double bond with each of two oxygen atoms. Elements such as nitrogen and carbon can form **triple bonds** in which their atoms share three pairs of electrons.

Reading Checkpoint **What is the difference between a double bond and a triple bond?**

Molecular Compounds

A **molecular compound** is a compound that is composed of molecules. The molecules of a molecular compound contain atoms that are covalently bonded. Molecular compounds have very different properties than ionic compounds. **Compared to ionic compounds, molecular compounds generally have lower melting points and boiling points, and they do not conduct electricity when dissolved in water.**

Low Melting Points and Boiling Points Study the table in the Analyzing Data box on the next page. It lists the melting points and boiling points for a few molecular compounds and ionic compounds. In molecular solids, forces hold the molecules close to one another. But, the forces between molecules are much weaker than the forces between ions in an ionic solid. Compared with ionic solids, less heat must be added to molecular solids to separate the molecules and change the solid to a liquid. That is why most familiar compounds that are liquids or gases at room temperature are molecular compounds.

Math Analyzing Data

Comparing Molecular and Ionic Compounds

The table compares the melting points and boiling points of a few molecular compounds and ionic compounds. Use the table to answer the following questions.

1. **Graphing** Create a bar graph of just the melting points of these compounds. Put the molecular compounds on the left and the ionic compounds on the right. Arrange the bars in order of increasing melting point. The *y*-axis should start at –200°C and go to 900°C.
2. **Interpreting Data** Describe what your graph reveals about the melting points of molecular compounds compared to those of ionic compounds.
3. **Inferring** How can you account for the differences in melting points between molecular compounds and ionic compounds?
4. **Interpreting Data** How do the boiling points of the molecular and ionic compounds compare?

Melting Points and Boiling Points of Molecular and Ionic Compounds

Substance	Formula	Melting Point (°C)	Boiling Point (°C)
Methane	CH_4	–182.4	–161.5
Rubbing alcohol	C_3H_8O	–89.5	82.4
Water	H_2O	0	100
Zinc chloride	$ZnCl_2$	290	732
Magnesium chloride	$MgCl_2$	714	1,412
Sodium chloride	NaCl	800.7	1,465

Molecular compound   Ionic compound

5. **Predicting** Ammonia's melting point is –78°C and its boiling point is –34°C. Is ammonia a molecular compound or an ionic compound? Explain.

Poor Conductivity Most molecular compounds do not conduct electricity. No charged particles are available to move, so electricity cannot flow. Materials such as plastic and rubber are used to insulate wires because these materials are composed of molecular substances. Even as liquids, molecular compounds are poor conductors. Pure water, for example, does not conduct electricity. Neither does table sugar or alcohol when they are dissolved in pure water.

Unequal Sharing of Electrons

Have you ever played tug of war? If you have, you know that if both teams pull with equal force, the contest is a tie. But what if the teams pull on the rope with unequal force? Then the rope moves toward the side of the stronger team. The same is true of electrons in a covalent bond. **Atoms of some elements pull more strongly on shared electrons than do atoms of other elements. As a result, the electrons are pulled more toward one atom, causing the bonded atoms to have slight electrical charges.** These charges are not as strong as the charges on ions.

Math Analyzing Data

Math Skill Making and interpreting graphs

Focus Direct students in analyzing melting and boiling points of compounds.

Teach Remind students that compounds need energy to break bonds when they change state (in this case, melt or boil).

Answers

1. Check that graphs are correctly set up and labeled before students plot the data.

2. Melting points of molecular compounds are lower than those of ionic compounds.

3. Molecular compounds have lower melting points; they have relatively weak covalent bonds that require less energy to break.

4. Boiling points of molecular compounds are lower than those of ionic compounds.

5. Students may predict that ammonia is a molecular compound because it has relatively low melting and boiling points.

Unequal Sharing of Electrons

Teach Key Concepts L2

Unequal Electron Sharing

Focus Use the familiar example of water to explain why some molecules are polar.

Teach Draw an electron dot diagram of a water molecule. Explain that oxygen's more massive nucleus exerts a greater pull on the shared electrons. Add arrows to indicate this pull. Ask: **What happens to the charge of oxygen if it pulls electrons more strongly?** *(It becomes negative.)* **What happens to the charge of hydrogen if it pulls electrons less strongly?** *(It becomes positive.)* Add plus and minus signs to indicate polarity.

Apply Ask: **Which do you think has a stronger positive charge, hydrogen atoms in water or sodium ions in sodium chloride?** *(Sodium ions; the hydrogen atoms do not actually gain or lose electrons as ions do.)* **learning modality: visual**

Differentiated Instruction

Special Needs L1

Organizing Information Help students make a table comparing and contrasting molecular and ionic compounds. Tell them to use the table for review and as a reference guide when they are doing activities and labs for this chapter. **learning modality: visual**

Gifted and Talented L3

Using Analogies Call students' attention to the position of water in the table in the Analyzing Data feature. Challenge students to use an analogy to explain why water's melting point and boiling point fall in between those of ionic compounds and those of the other molecular compounds in the table. **learning modality: verbal**

Monitor Progress L2

Writing Have students describe how molecular compounds form.

Answers

Figure 24 Six electrons

Reading Checkpoint In a double bond, four electrons are shared. In a triple bond, six electrons are shared.

Use Visuals: Figure 26 L2

Nonpolar and Polar Molecules

Focus Guide students in identifying why water is polar whereas carbon dioxide is not.

Teach Ask: **How do the shapes of the two molecules modeled in Figure 26 differ?** *(Carbon dioxide has a straight-line shape. Water has a bent shape.)* **How do the differences in shape affect the charges of the molecules?** *(Sample answer: In carbon dioxide, oxygen atoms pull on the electrons more strongly than carbon does, but they pull in opposite directions and cancel each other out. In water, the oxygen end of the molecule has a slight negative charge and the hydrogen end has a slight positive charge because oxygen pulls the electrons more strongly.)*

Apply Ask: **How do you think the slight positive and negative charges affect the properties of molecules like water?** *(Students might predict that the molecules would resemble ionic compounds. For example, they might have higher melting and boiling points than other covalent molecules or be better conductors of electricity.)* **learning modality: visual**

All in One Teaching Resources

- Transparency L12

Lab zone Teacher Demo L2

Attraction Between Polar Molecules

Materials glass, water, clear plastic drinking straw

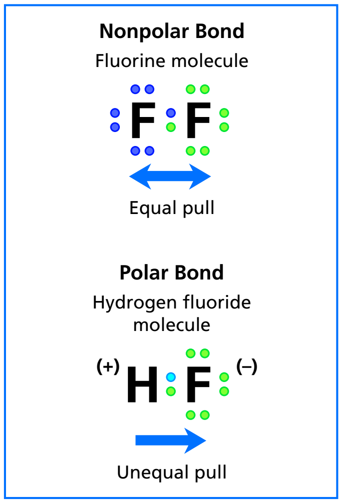
Time 5 minutes

Focus Demonstrate how polar molecules attract each other.

Teach Place a clear drinking straw in a glass of water. Have students observe how the water appears to "climb up" the side of the straw. (The same effect occurs at the sides of the glass, but may be less apparent there.) Explain that water molecules behave this way because they are attracted to the sides of the straw and even more so to each other.

Apply Ask: **Would a nonpolar liquid behave this way? Why or why not?** *(No, because molecules of a nonpolar substance are not charged and therefore are not attracted to each other)* **learning modality: visual**

FIGURE 25
Nonpolar and Polar Bonds
Fluorine forms a nonpolar bond with another fluorine atom. In hydrogen fluoride, fluorine attracts electrons more strongly than hydrogen does, so the bond formed is polar.



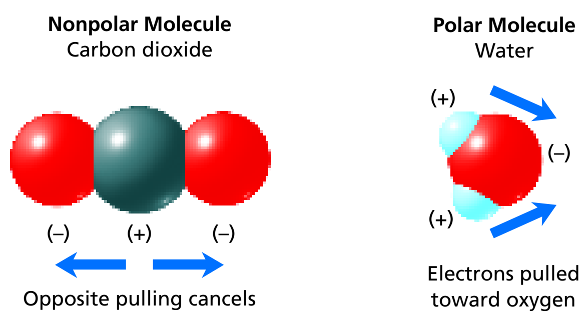
Polar Bonds and Nonpolar Bonds The unequal sharing of electrons is enough to make the atom with the stronger pull slightly negative and the atom with the weaker pull slightly positive. A covalent bond in which electrons are shared unequally is called a **polar bond.** Of course, if two atoms pull equally on the electrons, neither atom becomes charged. A covalent bond in which electrons are shared equally is a **nonpolar bond.** Compare the bond in fluorine (F_2) with the bond in hydrogen fluoride (HF) in Figure 25.

Polar Bonds in Molecules It makes sense that a molecule with nonpolar bonds will itself be nonpolar. But a molecule may contain polar bonds and still be nonpolar overall. In carbon dioxide, the oxygen atoms attract electrons much more strongly than carbon does. So, the bonds between the oxygen and carbon atoms are polar. But, as you can see in Figure 26, a carbon dioxide molecule has a shape like a straight line. So, the two oxygen atoms pull with equal strength in opposite directions. In a sense, the attractions cancel out, and the molecule is nonpolar.

In contrast, other molecules that have polar covalent bonds are themselves polar. In a water molecule, the two hydrogen atoms are at one end of the molecule, while the oxygen atom is at the other end. The oxygen atom attracts electrons more strongly than do the hydrogen atoms. As a result, the oxygen end has a slight negative charge and the hydrogen end has a slight positive charge.

Attractions Between Molecules If you could shrink small enough to move among a bunch of water molecules, what would you find? The negatively charged oxygen ends of the polar water molecules attract the positively charged hydrogen ends of nearby water molecules. These attractions pull water molecules toward each other. In contrast, there is little attraction between nonpolar molecules, such as carbon dioxide molecules.

FIGURE 26
Nonpolar and Polar Molecules
A carbon dioxide molecule is a nonpolar molecule because of its straight-line shape. In contrast, a water molecule is a polar molecule because of its bent shape.
Interpreting Diagrams *What do the arrows in the diagram show?*



The properties of polar and nonpolar compounds differ because of differences in attractions between their molecules. For example, water and vegetable oil don't mix. The molecules in vegetable oil are nonpolar, and nonpolar molecules have little attraction for polar water molecules. On the other hand, the water molecules are attracted more strongly to one another than to the molecules of oil. Thus, water stays with water, and oil stays with oil.

If you did the Discover activity, you found that adding detergent helped oil and water to mix. This is because one end of a detergent molecule has nonpolar covalent bonds. The other end includes an ionic bond. The detergent's nonpolar end mixes easily with the oil. Meanwhile, the charged ionic end is attracted to polar water molecules, so the detergent dissolves in water.

Reading Checkpoint **Why is water (H_2O) a polar molecule but a fluorine molecule (F_2) is not?**

FIGURE 27
Getting Out the Dirt
Most laundry dirt is oily or greasy. Detergents can mix with both oil and water, so when the wash water goes down the drain, the soap and dirt go with it.

Section 4 Assessment

Target Reading Skill **Asking Questions** Use the answers to the questions you wrote about the headings to help you answer the questions below.

Reviewing Key Concepts

1. a. **Identifying** What is the attraction that holds two covalently bonded atoms together?
   b. **Inferring** A carbon atom can form four covalent bonds. How many valence electrons does it have?
   c. **Interpreting Diagrams** What is a double bond? Use Figure 24 to explain how carbon dioxide achieves a stable set of eight electrons for each atom.
2. a. **Reviewing** How are the properties of molecular compounds different from those of ionic compounds?
   b. **Relating Cause and Effect** Why are most molecular compounds poor conductors of electricity?
3. a. **Reviewing** How do some atoms in covalent bonds become slightly negative or slightly positive? What type of covalent bonds do these atoms form?
   b. **Comparing and Contrasting** Both carbon dioxide molecules and water molecules have polar bonds. Why then is carbon dioxide a nonpolar molecule while water is a polar molecule?
   c. **Predicting** Predict whether carbon dioxide or water would have a higher boiling point. Explain your prediction in terms of the attractions between molecules.

Lab zone At-Home Activity

Laundry Chemistry Demonstrate the action of soaps and detergents to your family. Pour some vegetable oil on a clean cloth and show how a detergent solution can wash the oil away better than water alone can. Explain to your family the features of soap and detergent molecules in terms of their chemical bonds.

Lab zone At-Home Activity

Laundry Chemistry L2 Advise students to explain first why oil and water do not mix. Then they can explain how soap or detergent molecules form bonds on one end with a water molecule and on the other end with an oil molecule, causing the oil to break up and wash away.

Lab zone Chapter Project

Keep Students on Track
Students can use some of their model atoms to represent covalent molecules. Encourage them to create models of molecules with single, double, and triple bonds. Remind them that all of the atoms (except hydrogen) in their molecules should have eight valence electrons.

Monitor Progress L2

Answers
Figure 26 The directions in which shared electrons are pulled more strongly

Reading Checkpoint A water molecule is polar because shared electrons are pulled more strongly toward the oxygen atom, giving it a slight negative charge. A fluorine molecule is nonpolar because electrons are shared equally.

Assess

Reviewing Key Concepts

1. a. The attraction of each atom's nucleus for the shared electrons **b.** Four **c.** A double bond is a bond in which two atoms share two pairs of electrons. Figure 24 shows that carbon has a double bond with each of two oxygen atoms. This gives each atom a stable set of eight valence electrons.
2. a. The melting and boiling points of molecular compounds are lower than those of ionic compounds, and molecular compounds do not conduct electricity well.
b. Because they do not have charged particles to carry a current
3. a. Some atoms in covalent bonds become slightly negative or positive when they pull more or less strongly on shared electrons. These atoms form polar covalent bonds.
b. Carbon dioxide is nonpolar because its straight-line shape causes the two oxygen atoms to pull on the shared electrons in opposite directions and cancel each other out. Water is polar because its bent shape causes the oxygen end of the molecule to have a slight negative charge and the hydrogen end a slight positive charge.
c. Water would have a higher boiling point, because the attraction between its polar molecules requires more energy to overcome.

Reteach L1

Call on students to define or describe key terms. Call on other students to give examples of the terms.

Performance Assessment L2

Skills Check Have students make a Venn diagram comparing and contrasting polar and nonpolar covalent bonds.

All in One Teaching Resources
- Section Summary: *Covalent Bonds*
- Review and Reinforcement: *Covalent Bonds*
- Enrich: *Covalent Bonds*