6.2 Covalent Bonding

Reading Focus

Key Concepts

- How are atoms held together in a covalent bond?
- What happens when atoms don't share electrons equally?
- What factors determine whether a molecule is polar?
- How do attractions between polar molecules compare to attractions between nonpolar molecules?

Vocabulary

- covalent bond
- molecule
- polar covalent bond

Reading Strategy

Relating Text and Visuals Copy the table. As you read, look closely at Figure 9. Complete the table by describing each type of model shown.

Model	Description
Electron dot	a. ___?___
Structural formula	b. ___?___
Space-filling	c. ___?___
Electron cloud	d. ___?___

Plants absorb water through their roots from soil or from a solution containing nutrients, as in Figure 8. Carbon dioxide from the air enters the plants through small openings in their leaves. The plants use the energy from sunlight to convert water and carbon dioxide into a sugar. Energy is stored in the chemical bonds of the sugar.

The elements in sugar are carbon, oxygen, and hydrogen. All three are nonmetals, which have relatively high ionization energies. A transfer of electrons does not tend to occur between nonmetal atoms. So, how are two nonmetals able to form bonds?

Covalent Bonds

You and a friend are participating in a treasure hunt. The rules state that the first person to find all eight items on a list will win a 21-speed bicycle. After about an hour, you have found six of the items on the list and your friend has found the other two. You and your friend have incomplete sets of items. But if you are willing to share your items with your friend, together you will have a complete set of items and qualify for the prize. Of course, you will have to be willing to share the bicycle, too. When nonmetals join together, they display a similar sharing strategy.

Figure 8 When plants are grown in water instead of soil, you can see their roots. Plants absorb water through their roots and carbon dioxide through small openings in their leaves.

Section Resources

Print
- ***Laboratory Manual,*** Investigation 6B
- ***Reading and Study Workbook With Math Support,*** Section 6.2
- ***Transparencies,*** Section 6.2

Technology
- ***Interactive Textbook,*** Section 6.2
- ***Presentation Pro CD-ROM,*** Section 6.2
- ***Go Online,*** NSTA SciLinks, Covalent bonding

Section 6.2

1 FOCUS

Objectives

6.2.1 **Describe** how covalent bonds form and the attractions that keep atoms together in molecules.

6.2.2 **Compare** polar and nonpolar bonds, and **demonstrate** how polar bonds affect the polarity of a molecule.

6.2.3 **Compare** the attractions between polar and nonpolar molecules.

Reading Focus

Build Vocabulary L2

Concept Map Have students construct a concept map using the terms *atoms, molecules, ions, covalent bonds, ionic bonds, polar, nonpolar,* and *electrons.* Instruct students to place the terms in ovals and connect the ovals with lines on which linking words are placed. Students should place the main concept (Chemical Bonding) at the top or the center. As the distance from the main concept increases, the content should become more specific.

Reading Strategy L2

a. Dots represent valence electrons. **b.** A line represents a pair of shared valence electrons. **c.** Three-dimensional spheres represent atoms. **d.** Electron clouds represent atoms.

2 INSTRUCT

Covalent Bonds

Address Misconceptions L2

Many students do not differentiate among atoms, ions, and molecules in their sketches of particle models. Challenge this misconception by asking students to make drawings to represent an atom, a molecule, and an ion. Students should draw a single sphere for an atom, at least two spheres joined in some way for a molecule, and one sphere with either a plus or a minus charge for an ion.
Visual

Section 6.2 (continued)

Use Visuals L1

Figure 10 Have students examine Figure 10. Ask, **Why are the atoms in the models of diatomic molecules not complete spheres?** *(The space-filling models show that orbitals of atoms overlap when they form covalent bonds.)* Have students compare the space-filling models in Figure 10 to the data on atomic radii in the Data Analysis on p. 160. Ask, **Why are the spheres in the models of fluorine, chlorine, and bromine different sizes?** *(The different sizes of spheres model the different atomic radii of the atoms.)* **Logical**

Build Reading Literacy L1

Visualize Refer to page **354D** in **Chapter 12**, which provides the guidelines for visualizing.

After students have read about ionic and covalent bonds and the difference between polar and nonpolar bonds, encourage students to draw diagrams that demonstrate the differences between three types of bonding: nonpolar covalent, polar covalent, and ionic. **Visual, Portfolio**

FYI

Not all nonmetal elements exist as molecules. Of those that do, not all form diatomic molecules. Molecules of crystalline sulfur contain eight sulfur atoms, S_8. Molecules of white phosphorus contain four phosphorus atoms, P_4.

Based on the octet rule, a molecule of ozone, O_3, should contain one double bond and one single coordinate covalent bond (a bond in which one of the atoms donates an unshared pair of electrons). However, the measured bond lengths for the two bonds in an ozone molecule are identical. The bonds are hybrids—not strictly single bonds or double bonds.

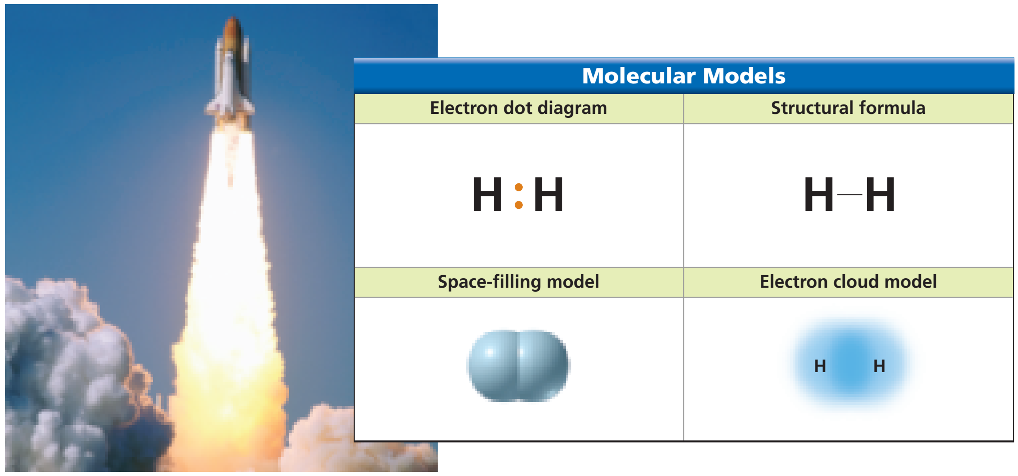


Figure 9 As a space shuttle lifts off, it leaves a water vapor trail. A reaction of hydrogen and oxygen produces the water. **Using Models** ***How is the bond between hydrogen atoms represented in each model of a hydrogen molecule?***

Sharing Electrons A hydrogen atom has one electron. If it had two electrons, it would have the same electron configuration as a helium atom. Two hydrogen atoms can achieve a stable electron configuration by sharing their electrons and forming a covalent bond. A **covalent bond** is a chemical bond in which two atoms share a pair of valence electrons. When two atoms share one pair of electrons, the bond is called a single bond.

Figure 9 shows four different ways to represent a covalent bond. In the electron dot model, the bond is shown by a pair of dots in the space between the symbols for the hydrogen atoms. In the structural formula, the pair of dots is replaced by a line. The electron cloud model and the space-filling model show that orbitals of atoms overlap when a covalent bond forms.

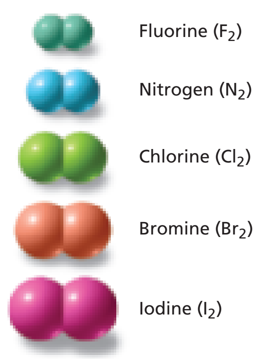


Figure 10 These space-filling models represent diatomic molecules of five elements. **Using Models** ***How many atoms are in a diatomic molecule?***

Molecules of Elements Two hydrogen atoms bonded together form a unit called a molecule. A **molecule** is a neutral group of atoms that are joined together by one or more covalent bonds. The hydrogen molecule is neutral because it contains two protons (one from each atom) and two electrons (one from each atom). What keeps the hydrogen atoms together in the molecule? **The attractions between the shared electrons and the protons in each nucleus hold the atoms together in a covalent bond.**

A chemical formula can be used to describe the molecules of an element as well as a compound. The element hydrogen has the chemical formula H_2. The subscript 2 indicates that there are two atoms in a molecule of hydrogen.

Many nonmetal elements exist as diatomic molecules. *Diatomic* means "two atoms." Four of the models in Figure 10 are of halogens. A halogen atom has seven valence electrons. If two halogen atoms share a valence electron from each atom, both atoms have eight valence electrons.

Customize for English Language Learners

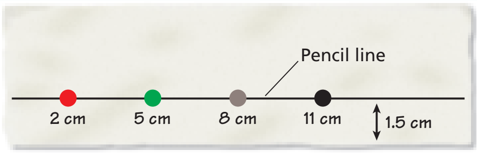
Think-Pair-Share
Have students work in pairs to think of situations that serve as analogies for ionic and covalent bonding. For example, if a jeweler lends an expensive piece of jewelry to a presenter at an awards show, a guard will accompany the presenter and stay as close as possible. This is similar to an ionic bond, in which a cation stays close to an anion to which it donates an electron. By contrast, students reading from one copy of the same book are like two atoms sharing a pair of electrons in a covalent bond. Strengthen discussion skills by having students share analogies with the class.

Quick Lab

Analyzing Inks

Materials

test paper, metric ruler, felt-tip markers, stapler, beaker, alcohol-water mixture, Petri dish



Procedure

1. Place the test paper on a clean surface. Use the ruler to draw the pencil line shown in the drawing. Use your markers to place color dots at the locations shown in the drawing.
2. With the ink marks on the outside, staple the two ends of the paper together to form a tube.
3. Pour the alcohol-water mixture into the beaker to a depth of 0.5 cm. Stand the paper in the beaker so that the dots are at the bottom. The paper should not touch the sides of the beaker. Invert the Petri dish over the beaker.
4. When the mixture reaches the top of the paper, remove the paper from the beaker. Unstaple the paper and lay it flat. Make a drawing of the results with each colored area labeled.

Analyze and Conclude

1. **Observing** Which markers contained inks that were mixtures of colored substances?
2. **Formulating Hypotheses** How did some molecules in the ink move up the paper?
3. **Predicting** Assume that molecules in the test paper are more polar than molecules in the alcohol-water mixture. Would you expect the most polar molecules in ink to stick tightly to the paper or to move with the liquid? Explain.
4. **Designing Experiments** How could the procedure from this lab be used to identify a black ink whose composition is unknown?

Multiple Covalent Bonds Nitrogen has five valence electrons. If two nitrogen atoms shared a pair of electrons, each one would have only six valence electrons. If they shared two pairs of electrons, each atom would have only seven valence electrons. When the atoms in a nitrogen molecule (N_2) share three pairs of electrons, each atom has eight valence electrons. Each pair of shared electrons is represented by a long dash in the structural formula N≡N. When two atoms share three pairs of electrons, the bond is called a triple bond. When two atoms share two pairs of electrons, the bond is called a double bond.

Reading Checkpoint ***What does the subscript 2 in the formula for a hydrogen molecule indicate?***

Unequal Sharing of Electrons

In general, elements on the right of the periodic table have a greater attraction for electrons than elements on the left have (except for noble gases). In general, elements at the top of a group have a greater attraction for electrons than elements at the bottom of a group have. Fluorine is on the far right and is at the top of its group. It has the strongest attraction for electrons and is the most reactive nonmetal.

Go Online NSTA SCILINKS

For: Links on covalent bonding
Visit: www.SciLinks.org
Web Code: ccn-1062

Analyze and Conclude

1. In general, darker inks (such as brown or black) contain two or more red, blue, and yellow pigments.
2. Molecules that dissolved easily in the alcohol-water mixture moved up the paper with the mixture.
3. The most polar molecules would be found near the bottom of the paper because they are more strongly attracted to the paper than to the alcohol-water mixture.
4. If an unknown black ink produces a color pattern similar to one of the known inks, they are likely to be identical.

Visual, Logical

Unequal Sharing of Electrons

Quick Lab

Analyzing Inks L2

Objective
After completing this activity, students will be able to
- explain how differences in polarity can be used to separate the components of a solution.

Skills Focus **Observing, Inferring**

Prep Time 10 minutes

Advance Prep Provide each group with an 8-cm × 16-cm piece of test (chromatography) paper. The alcohol-water mixture is 70% isopropyl alcohol in water.

Class Time 20 minutes

Safety Provide only markers containing water-based inks or inks that are low in volatile organic compounds (VOCs). Make sure that there are no flames in the laboratory when alcohol is in use.

Teaching Tips
- Have students do this lab after they study polar molecules and attractions between molecules.
- Tell students not to touch the test paper with their bare hands because oil naturally present on their fingers will interfere with the results. They should wear plastic gloves.

Expected Outcome Most inks will contain more than one pigment.

Go Online NSTA SCILINKS

Download a worksheet on covalent bonding for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 9 *A pair of dots, a line, overlapping spheres, and overlapping electron clouds*

Figure 10 *Two*

Reading Checkpoint *The subscript 2 shows that there are two atoms in a hydrogen molecule.*

Section 6.2 (continued)

Teacher Demo

Modeling Overall Polarity **L2**

Purpose Students examine a model for molecular polarity.

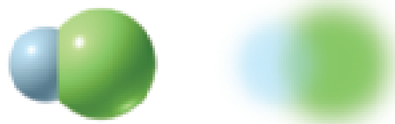
Materials molecular model kit, 4 12-inch pieces of string or yarn, tape, overhead projector

Procedure Show students ball-and-stick models of a carbon dioxide molecule and a water molecule. Have them compare the linear shape of CO_2 with the bent shape of H_2O. Tie or tape one piece of string onto each of the oxygen atoms of the CO_2 model and onto each of the hydrogen atoms of the H_2O model. Place the CO_2 model on the overhead and demonstrate the effect of pulling the strings gently in opposite directions. Explain that this represents the canceling effect of opposing polar bonds (dipoles). Place the H_2O model on the overhead and demonstrate the effect of pulling the strings gently away from the oxygen atom in the direction of the bond angles. Explain that this represents the additive effect of polar bonds that are at an angle.

Expected Outcome The CO_2 model will stay in one place. The H_2O model will move in the direction of the hydrogen atoms.
Visual

Build Science Skills **L2**

Using Models Show students a ball-and-stick molecular model of ammonia, NH_3. Ask students to predict whether the molecule is polar or nonpolar and to give a reason for their choice. *(Ammonia is a polar molecule because its three bonds are oriented to one side of the central nitrogen atom. The polar bonds do not cancel out.)* Now show students a molecular model of sulfur trioxide, SO_3. Ask students to predict whether this molecule is polar or nonpolar and to explain their reasoning. *(Sulfur trioxide is a nonpolar molecule because its three bonds are oriented symmetrically in a plane around the central sulfur atom. The polar bonds cancel each other out.)*
Logical, Visual



HCl

Figure 11 Shared electrons in a hydrogen chloride molecule spend less time near the hydrogen atom than near the chlorine atom. **Inferring** ***Which element has a greater attraction for electrons—hydrogen or chlorine?***

Polar Covalent Bonds In a molecule of an element, the atoms that form covalent bonds have the same ability to attract an electron. Shared electrons are attracted equally to the nuclei of both atoms. In a molecule of a compound, electrons may not be shared equally.

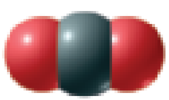
Figure 11 shows models of the molecule that forms when hydrogen reacts with chlorine. A chlorine atom has a greater attraction for electrons than a hydrogen atom does. In a hydrogen chloride molecule, the shared electrons spend more time near the chlorine atom than near the hydrogen atom. A covalent bond in which electrons are not shared equally is called a **polar covalent bond.** (One meaning of the term *polar* is "opposite in character, nature, or direction.")

When atoms form a polar covalent bond, the atom with the greater attraction for electrons has a partial negative charge. The other atom has a partial positive charge. The symbols $\delta-$ and $\delta+$ are used to show which atom has which charge. (δ is the lowercase version of the Greek letter delta.)

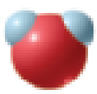
Polar and Nonpolar Molecules Can you assume that a molecule that contains a polar covalent bond is polar? If a molecule has only two atoms, it will be polar. But, when molecules have more than two atoms, the answer is not as obvious. **The type of atoms in a molecule and its shape are factors that determine whether a molecule is polar or nonpolar.**

Compare the models of carbon dioxide and water in Figure 12. In carbon dioxide, there are double bonds between each oxygen atom and the central carbon atom. Because oxygen has a greater attraction for electrons than carbon does, each double bond is polar. However, the molecule is linear: all three atoms are lined up in a row. The carbon-oxygen double bonds are directly opposite each other. There is an equal pull on the electrons from opposite directions. The pulls cancel out and the molecule as a whole is nonpolar.

There are two single bonds in a water molecule. The bonds are polar because oxygen has a greater attraction for electrons than hydrogen does. Because the water molecule has a bent shape rather than a linear shape, the polar bonds do not cancel out. The two hydrogen atoms are located on the same side of the molecule, opposite the oxygen atom. The oxygen side of the molecule has a partial negative charge. The hydrogen side of the molecule has a partial positive charge.



CO_2



H_2O

Figure 12 In a carbon dioxide (CO_2) molecule, the polar bonds between the carbon atom and the oxygen atoms cancel out because the molecule is linear. In a water (H_2O) molecule, the polar bonds between the oxygen atom and the hydrogen atoms do not cancel out because the molecule is bent.

Facts and Figures

Surface Tension Refer back to the discussion in Section 3.3 about the effect of intermolecular attractions on the evaporation of water. Hydrogen bonds explain other properties of water, including its high surface tension. Because molecules on the surface are drawn inward by attractions from molecules beneath the surface, surface area is reduced. Surface tension explains why water drops bead up on a clean, waxed surface.

Attraction Between Molecules

In a molecular compound, there are forces of attraction between molecules. These attractions are not as strong as ionic or covalent bonds, but they are strong enough to hold molecules together in a liquid or solid. **Attractions between polar molecules are stronger than attractions between nonpolar molecules.**

Water molecules are similar in mass to methane (CH_4) molecules. Yet, methane boils at −161.5°C and water boils at 100°C because methane molecules are nonpolar and water molecules are polar. Each dashed line in Figure 13 represents an attraction between a partially positive hydrogen atom in one water molecule and a partially negative oxygen atom in another. Molecules on the surface of a water sample are attracted to molecules that lie below the surface and are pulled toward the center of the sample. These attractions increase the energy required for water molecules to evaporate. They raise the temperature at which vapor pressure equals atmospheric pressure—the boiling point.

Attractions among nonpolar molecules are weaker than attractions among polar molecules, but they do exist. After all, carbon dioxide can exist as solid dry ice. Attractions among nonpolar molecules explain why nitrogen can be stored as a liquid at low temperatures and high pressures. Because electrons are constantly in motion, there are times when one part of a nitrogen molecule has a small positive charge and one part has a small negative charge. At those times, one nitrogen molecule can be weakly attracted to another nitrogen molecule.

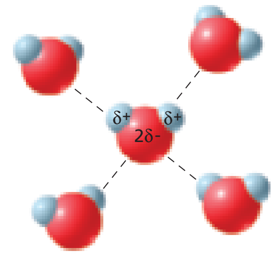


Figure 13 Each dashed line in the drawing represents an attraction between a hydrogen atom and an oxygen atom.
Interpreting Diagrams ***In a water molecule, which atom has a partial negative charge? Which has a partial positive charge?***

Section 6.2 Assessment

Reviewing Concepts

1. What attractions hold atoms together in a covalent bond?
2. What happens to the charge on atoms when they form a polar covalent bond?
3. Name the two factors that determine whether a molecule is polar.
4. Compare the strength of attractions between polar molecules to the strength of attractions between nonpolar molecules.
5. What is a molecule?

Critical Thinking

6. **Applying Concepts** Which of these elements does not bond to form molecules: oxygen, chlorine, neon, or sulfur?
7. **Inferring** Why is the boiling point of water higher than the boiling point of chlorine?
8. **Using Diagrams** Based on their electron dot diagrams, what is the formula for the covalently bonded compound of nitrogen and hydrogen?

Connecting Concepts

Viscosity Review the description of the physical property viscosity in Section 2.2. Then write a paragraph explaining how attractions between molecules might affect the viscosity of a liquid.

Section 6.2 Assessment

1. The attractions between the shared electrons and the protons in each nucleus hold the atoms together in a covalent bond.
2. When atoms form a polar covalent bond, the atom with the greater attraction for electrons has a partial negative charge. The other atom has a partial positive charge.
3. The type of atoms in a molecule and its shape are factors that determine whether a molecule is polar or nonpolar.
4. Attractions between polar molecules are stronger than attractions between nonpolar molecules.
5. A neutral group of atoms that are joined together by one or more covalent bonds
6. Neon
7. Attractions between polar water molecules are stronger than attractions between nonpolar chlorine molecules.
8. NH_3

Attraction Between Molecules

Teacher Demo

Surface Tension L2

Purpose Students observe how surface tension can support a needle.

Materials 200-mL beaker, water, sewing needle, tweezers, dropper pipet

Procedure Fill the beaker with water. Using tweezers, gently place the needle on the water's surface so that surface tension supports it. Remove the needle, and place it in the water vertically so that it sinks. Pour the water out and collect the needle.

Expected Outcome Surface tension supports the needle.
Logical, Visual

3 ASSESS

Evaluate Understanding L2

Have students make a chart that compares and contrasts polar covalent bonds and nonpolar covalent bonds. Be sure students discuss the bonding atoms' attractions for electrons, partial charges, and attractions between molecules.

Reteach L1

Use Figures 11, 12, and 13 as visual aids while reviewing polar covalent bonds, nonpolar and polar molecules, and attractions between molecules.

Connecting Concepts

A greater attraction between molecules is likely to produce an increase in viscosity because the attractions would act in opposition to the motion of the molecules and reduce their ability to flow.

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 6.2.

Answer to . . .

Figure 11 *Chlorine*

Figure 13 *The oxygen atom has a partial negative charge. The hydrogen atoms have partial positive charges.*