Section 8.5

Objectives

- **Describe** how electronegativity is used to determine bond type.
- **Compare and contrast** polar and nonpolar covalent bonds and polar and nonpolar molecules.
- **Generalize** about the characteristics of covalently bonded compounds.

Review Vocabulary

electronegativity: the relative ability of an atom to attract electrons in a chemical bond

New Vocabulary

polar covalent bond

Electronegativity and Polarity

MAIN Idea A chemical bond's character is related to each atom's attraction for the electrons in the bond.

Real-World Reading Link The stronger you are, the more easily you can do pull-ups. Just as people have different abilities for doing pull-ups, atoms in chemical bonds have different abilities to attract (pull) electrons.

Electron Affinity, Electronegativity, and Bond Character

The type of bond formed during a reaction is related to each atom's attraction for electrons. Electron affinity is a measure of the tendency of an atom to accept an electron. Excluding noble gases, electron affinity increases with increasing atomic number within a period and decreases with increasing atomic number within a group. The scale of electronegativities—shown in **Figure 8.20**—allows chemists to evaluate the electron affinity of specific atoms in a compound. Recall from Chapter 6 that electronegativity indicates the relative ability of an atom to attract electrons in a chemical bond. Note that electronegativity values were assigned, whereas electron affinity values were measured.

Electronegativity The version of the periodic table of the elements shown in **Figure 8.20** lists electronegativity values**.** Note that fluorine has the greatest electronegativity value (3.98), while francium has the least (0.7). Because noble gases do not generally form compounds, individual electronegativity values for helium, neon, and argon are not listed. However, larger noble gases, such as xenon, sometimes bond with highly electronegative atoms, such as fluorine.

Figure 8.20 Electronegativity values are derived by comparing an atom's attraction for shared electrons to that of a fluorine's atom attraction for shared electrons. Note that the electronegativity values for the lanthanide and actinide series, which are not shown, range from 1.12 to 1.7.

Electronegativity Values for Selected Elements

Metal
Metalloid
Nonmetal

1 H 2.20																
3 Li 0.98	4 Be 1.57											5 B 2.04	6 C 2.55	7 N 3.04	8 O 3.44	9 F 3.98
11 Na 0.93	12 Mg 1.31											13 Al 1.61	14 Si 1.90	15 P 2.19	16 S 2.58	17 Cl 3.16
19 K 0.82	20 Ca 1.00	21 Sc 1.36	22 Ti 1.54	23 V 1.63	24 Cr 1.66	25 Mn 1.55	26 Fe 1.83	27 Co 1.88	28 Ni 1.91	29 Cu 1.90	30 Zn 1.65	31 Ga 1.81	32 Ge 2.01	33 As 2.18	34 Se 2.55	35 Br 2.96
37 Rb 0.82	38 Sr 0.95	39 Y 1.22	40 Zr 1.33	41 Nb 1.6	42 Mo 2.16	43 Tc 2.10	44 Ru 2.2	45 Rh 2.28	46 Pd 2.20	47 Ag 1.93	48 Cd 1.69	49 In 1.78	50 Sn 1.96	51 Sb 2.05	52 Te 2.1	53 I 2.66
55 Cs 0.79	56 Ba 0.89	57 La 1.10	72 Hf 1.3	73 Ta 1.5	74 W 1.7	75 Re 1.9	76 Os 2.2	77 Ir 2.2	78 Pt 2.2	79 Au 2.4	80 Hg 1.9	81 Tl 1.8	82 Pb 1.8	83 Bi 1.9	84 Po 2.0	85 At 2.2
87 Fr 0.7	88 Ra 0.9	89 Ac 1.1														

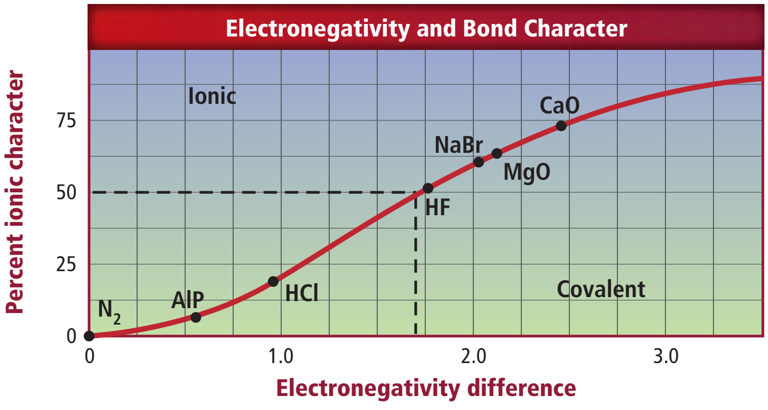
Table 8.7 EN Difference and Bond Character

Electronegativity Difference	Bond Character
> 1.7	mostly ionic
0.4 – 1.7	polar covalent
< 0.4	mostly covalent
0	nonpolar covalent

Bond character A chemical bond between atoms of different elements is never completely ionic or covalent. The character of a bond depends on how strongly each of the bonded atoms attracts electrons. As shown in **Table 8.7,** the character and type of a chemical bond can be predicted using the electronegativity difference of the elements that bond. Electrons in bonds between identical atoms have an electronegativity difference of zero—meaning that the electrons are equally shared between the two atoms. This type of bond is considered nonpolar covalent, or a pure covalent bond. On the other hand, because different elements have different electronegativities, the electron pairs in a covalent bond between different atoms are not shared equally. Unequal sharing results in a **polar covalent bond.** When there is a large difference in the electronegativity between bonded atoms, an electron is transferred from one atom to the other, which results in bonding that is primarily ionic.

Bonding is not often clearly ionic or covalent. An electronegativity difference of 1.70 is considered 50 percent covalent and 50 percent ionic. As the difference in electronegativity increases, the bond becomes more ionic in character. Generally, ionic bonds form when the electronegativity difference is greater than 1.70. However, this cutoff is sometimes inconsistent with experimental observations of two nonmetals bonding together. **Figure 8.21** summarizes the range of chemical bonding between two atoms. What percent ionic character is a bond between two atoms that have an electronegativity difference of 2.00? Where would LiBr be plotted on the graph?

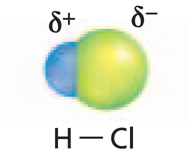
Reading Check **Analyze** What is the percent ionic character of a pure covalent bond?



■ **Figure 8.21** This graph shows that the difference in electronegativity between bonding atoms determines the percent ionic character of the bond. Above 50% ionic character, bonds are mostly ionic.

Graph Check
Determine the percent ionic charcter of calcium oxide.

Electronegativity	Cl	= 3.16
Electronegativity	H	= 2.20
Difference		= 0.96



■ **Figure 8.22** Chlorine's electronegativity is higher than that of hydrogen. Therefore, in a molecule containing hydrogen and chlorine, the shared pair of electrons is with the chlorine atom more often than it is with the hydrogen atom. Symbols are used to indicate the partial charge at each end of the molecule from this unequal sharing of electrons.

Concepts In Motion

Interactive Figure To see an animation of bond types, visit glencoe.com.

Polar Covalent Bonds

As you just learned, polar covalent bonds form because not all atoms that share electrons attract them equally. A polar covalent bond is similar to a tug-of-war in which the two teams are not of equal strength. Although both sides share the rope, the stronger team pulls more of the rope toward its side. When a polar bond forms, the shared electron pair or pairs are pulled toward one of the atoms. Thus, the electrons spend more time around that atom than the other atom. This results in partial charges at the ends of the bond.

The Greek letter delta (δ) is used to represent a partial charge. In a polar covalent bond, δ^- represent a partial negative charge and δ^+ represents a partial positive charge. As shown in **Figure 8.22,** δ^- and δ^+ can be added to a molecular model to indicate the polarity of the covalent bond. The more-electronegative atom is at the partially negative end, while the less-electronegative atom is at the partially positive end. The resulting polar bond often is referred to as a dipole (two poles).

Molecular polarity Covalently bonded molecules are either polar or nonpolar; which type depends on the location and nature of the covalent bonds in the molecule. A distinguishing feature of nonpolar molecules is that they are not attracted by an electric field. Polar molecules, however, are attracted by an electric field. Because polar molecules are dipoles with partially charged ends, they have an uneven electron density. This results in the tendency of polar molecules to align with an electric field.

Polarity and molecular shape You can learn why some molecules are polar and some are not by comparing water (H_2O) and carbon tetrachloride (CCl_4) molecules. Both molecules have polar covalent bonds. According to the data in **Figure 8.20,** the electronegativity difference between a hydrogen atom and a oxygen atom is 1.24. The electronegativity difference between a chlorine atom and a carbon atom is 0.61. Although these electronegativity differences vary, a H—O bond and a C—Cl bond are considered to be polar covalent.

$$\overset{\delta^+\ \ \delta^-}{\text{H—O}} \qquad \overset{\delta^+\ \ \delta^-}{\text{C—Cl}}$$

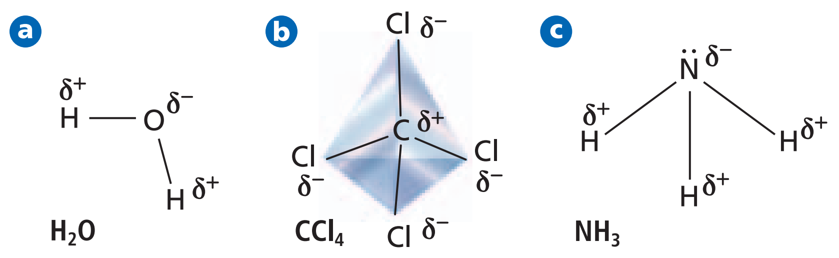
According to their molecular formulas, both molecules have more than one polar covalent bond. However, only the water molecule is polar.

Reading Check **Apply** Why does a statically charged balloon cause a slow stream of water from a faucet to bend when placed next to it?

CAREERS IN CHEMISTRY

Flavor Chemist A flavor chemist, or flavorist, must know how chemicals react and change in different conditions. A degree in chemistry is an asset, but is not required. Most flavorists work for companies that supply flavors to the food and beverage industries. A certified flavorist trains for five years in a flavor laboratory, passes an oral examination, and then works under supervision for another two years. For more information on chemistry careers, visit glencoe.com.

■ **Figure 8.23** A molecule's shape determines its polarity.



The bent shape of a water molecule makes it polar.

The symmetry of a CCl_4 molecule results in an equal distribution of charge, and the molecule is nonpolar.

The asymmetric shape of an ammonia molecule results in an unequal charge distribution and the molecule is polar.

The shape of a H_2O molecule, as determined by VSEPR, is bent because the central oxygen atom has lone pairs of electrons, as shown in **Figure 8.23a.** Because the polar H—O bonds are asymmetric in a water molecule, the molecule has a definite positive end and a definite negative end. Thus, it is polar.

A CCl_4 molecule is tetrahedral, and therefore, symmetrical, as shown in **Figure 8.23b.** The electric charge measured at any distance from its center is identical to the charge measured at the same distance to the opposite side. The average center of the negative charge is located on the chlorine atom. The positive center is also located on the carbon atom. Because the partial charges are balanced, CCl_4 is a nonpolar molecule. Note that symmetric molecules are usually nonpolar, and molecules that are asymmetric are polar as long as the bond type is polar.

Is the molecule of ammonia (NH_3), shown in **Figure 8.23c,** polar? It has a central nitrogen atom and three terminal hydrogen atoms. Its shape is a trigonal pyramidal because of the lone pair of electrons present on the nitrogen atom. Using **Figure 8.20,** you can find that the electronegativity difference of hydrogen and nitrogen is 0.84 making each N—H bond polar covalent. The charge distribution is unequal because the molecule is asymmetric. Thus, the molecule is polar.

Solubility of polar molecules The physical property known as solubility is the ability of a substance to dissolve in another substance. The bond type and the shape of the molecules present determine solubility. Polar molecules and ionic compounds are usually soluble in polar substances, but nonpolar molecules dissolve only in nonpolar substances, as shown in **Figure 8.24.** Solubility is discussed in detail in Chapter 14.

■ **Figure 8.24** Symmetric covalent molecules, such as oil and most petroleum products, are nonpolar. Asymmetric molecules, such as water, are usually polar. As shown in this photo, polar and nonpolar substances usually do not mix.

Infer ***Will water alone clean oil from a fabric?***

Properties of Covalent Compounds

Table salt, an ionic solid, and table sugar, a covalent solid, are similar in appearance. However, these compounds behave differently when heated. Salt does not melt, but sugar melts at a relatively low temperature. Does the type of bonding in a compound affect its properties?

Intermolecular forces Differences in properties are a result of differences in attractive forces. In a covalent compound, the covalent bonds between atoms in molecules are strong, but the attraction forces between molecules are relatively weak. These weak attraction forces are known as intermolecular forces, or van der Waals forces, which are discussed in Chapter 12. Intermolecular forces vary in strength but are weaker than the bonds that join atoms in a molecule or ions in an ionic compound.

There are different types of intermolecular forces. Between nonpolar molecules, the force is weak and is called a dispersion force, or induced dipole. The force between oppositely charged ends of two polar molecules is called a dipole-dipole force. The more polar the molecule, the stronger the dipole-dipole force. The third force, a hydrogen bond, is especially strong. It forms between the hydrogen end of one dipole and a fluorine, oxygen, or nitrogen atom on another dipole.

DATA ANALYSIS LAB

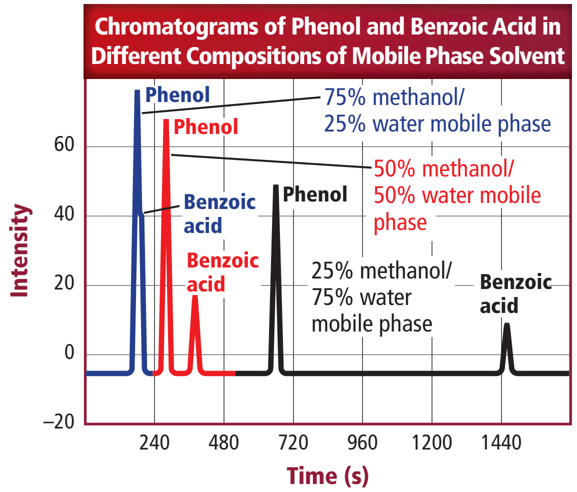
Based on Real Data*

Interpret Data

How does the polarity of the mobile phase affect chromatograms? Chromatography is a technique in which a moving phase transports and separates the components of a mixture. A chromatograph is created by recording the intensity of each component carried in the moving phase versus time. The peak intensities on the chromatograph indicate the amount of each component present in the mixture.

High-performance liquid chromatography, or HPLC, is used by analytical chemists to separate mixtures of solutes. During HPLC, components that are strongly attracted to the extracting solvent are retained longer by the moving phase and tend to appear early on a chromatograph. Several scientists performed HPLC using a methanol-water mixture as the extracting solvent to separate a phenol-benzoic acid mixture. Their results are shown in the graph to the right.

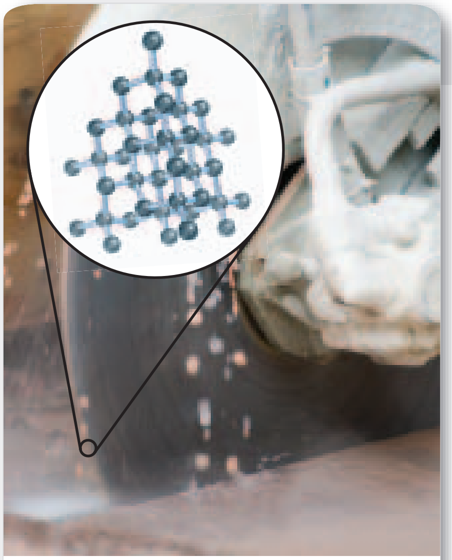
Data and Observations



*Data obtained from: Joseph, Seema M. and Palasota, John A. 2001. The combined effects of pH and percent methanol on the HPLC separation of benzoic acid and phenol. *Journal of Chemical Education* 78:1381.

Think Critically

1. **Explain** the different retention times shown on the chromatograms.
2. **Infer** from the graph the component, phenol or benzoic acid, that is in excess. Explain your answer.
3. **Infer** which component of the mixture has more polar molecules.
4. **Determine** the most effective composition of the mobile phase (of those tested) for separating phenol from benzoic acid. Explain.



■ **Figure 8.25** Network solids are often used in cutting tools because of their extreme hardness. Here, a diamond-tipped saw blade cuts through stone.

Forces and properties The properties of covalent molecular compounds are related to the relatively weak intermolecular forces holding the molecules together. These weak forces result in the relatively low melting and boiling points of molecular substances compared with those of ionic substances. That is why, when heated moderately, sugar melts but salt does not. Weak intermolecular forces also explain why many molecular substances exist as gases or vaporize readily at room temperature. Oxygen (O_2), carbon dioxide (CO_2), and hydrogen sulfide (H_2S) are examples of covalent gases. Because the hardness of a substance depends on the intermolecular forces between individual molecules, many covalent molecules are relatively soft solids. Paraffin, found in candles and other products, is a common example of a covalent solid.

In the solid phase, molecules align to form a crystal lattice. This molecular lattice is similar to that of an ionic solid, but with less attraction between particles. The structure of the lattice is affected by molecular shape and the type of intermolecular force. Most molecular information has been determined by studying molecular solids.

Covalent Network Solids

There are some solids, often called covalent network solids, that are composed only of atoms interconnected by a network of covalent bonds. Quartz and diamond are two common examples of network solids. In contrast to molecular solids, network solids are typically brittle, nonconductors of heat or electricity, and extremely hard. Analyzing the structure of a diamond explains some of its properties. In a diamond, each carbon atom is bonded to four other carbon atoms. This tetrahedral arrangement, which is shown in **Figure 8.25,** forms a strongly bonded crystal system that is extremely hard and has a very high melting point.

Section 8.5 Assessment

Section Summary

- The electronegativity difference determines the character of a bond between atoms.
- Polar bonds occur when electrons are not shared equally forming a dipole.
- The spatial arrangement of polar bonds in a molecule determines the overall polarity of a molecule.
- Molecules attract each other by weak intermolecular forces. In a covalent network solid, each atom is covalently bonded to many other atoms.

68. MAIN Idea **Summarize** how electronegativity difference is related to bond character.
69. **Describe** a polar covalent bond.
70. **Describe** a polar molecule.
71. **List** three properties of a covalent compound in the solid phase.
72. **Categorize** bond types using electronegativity difference.
73. **Generalize** Describe the general characteristics of covalent network solids.
74. **Predict** the type of bond that will form between the following pair of atoms:
    a. H and S
    b. C and H
    c. Na and S.
75. **Identify** each molecule as polar or nonpolar: SCl_2, CS_2, and CF_4.
76. **Determine** whether a compound made of hydrogen and sulfur atoms is polar or nonpolar.
77. **Draw** the Lewis structures for the molecules SF_4 and SF_6. Analyze each structure to determine whether the molecule is polar or nonpolar.

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