5. Dr. Ronald Gillespie, the co-creator of VSEPR theory, is currently Professor Emeritus at McMaster University. He holds B.Sc. and Ph.D. degrees in science, and a D.Sc. from London University. He has won many significant awards, including the Chemical Institute of Canada Medal, the Henry Marshall Tory Medal of the Royal Society of Canada, and the Izaak Walter Killam Memorial Prize of the Canada Council for Pure Science, to name just a few. He is a visiting professor at nine international universities in Europe, Australia, and Asia, and has been awarded four honorary doctorates. His major topic of research, in cooperation with Dr. Richard Bader, is using calculated electron probability distributions to better understand the VSEPR model.

6. The sense of taste seems to be essentially built around the ability of taste receptors to form hydrogen bonds at specific locations with certain molecules. Thus, artificial sweeteners like saccharin and cyclamate and acesulfame-K are non-nutritive molecules with structural similarities to natural sugars. The molecular structure for sweetness involves part of the molecule being a small pentagon or hexagon of atom with the ability to hydrogen bond at a specific spot on the ring. Similarly, artificial compounds like Bitrex®—added as a safety precaution to many medications to make the taste extremely bitter—are structured to a shape that triggers human taste receptors for bitterness to react strongly.

4.4 POLAR MOLECULES

PRACTICE

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Understanding Concepts

1. (a)
$$\overset{\delta^+}{H} \overset{\delta^-}{—} Cl \qquad \text{polar covalent}$$
2.1 3.0

   (b)
$$\overset{\delta^-}{C} \overset{\delta^+}{—} H \qquad \text{polar covalent}$$
2.5 2.1

   (c)
$$\overset{\delta^+}{N} \overset{\delta^-}{—} O \qquad \text{polar covalent}$$
3.0 3.5

   (d)
$$\overset{\delta^+}{I} \overset{\delta^-}{—} Br \qquad \text{polar covalent}$$
2.5 2.8

   (e)
$$\overset{+}{Mg} \overset{-}{—} S \qquad \text{ionic}$$
1.2 2.5

   (f)
$$P — H \qquad \text{nonpolar covalent}$$
2.1 2.1

2. (a) polar covalent
   (b) ionic
   (c) nonpolar covalent

3. The list of the bonds in order of increasing bond polarity is assumed to be the same as the order of increasing difference in electronegativity of the bonded atoms. Thus, the orders are as follows:
   (a) H—H, C—H, Be—H, N—H, Li—H, O—H, F—H
   (b) I—I, I—Cl, P—Cl, (Li—I, Al—Cl), Rb—F   (Note: Li—I and Al—Cl have equal dipoles.)
   (c) C—H, C—O, O—H
   (d) C—H, C—Cl, C—F

Applying Inquiry Skills

4. Empirical (measured, observed) values change as new and better methods of determining values are found. As well, the electronegativity of an atom is not an exact concept. It also varies somewhat, depending on the bonded atoms. The new values could be described as more accurate values, but the word "true" cannot properly be applied to relative numerical values of this sort.
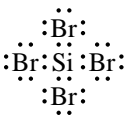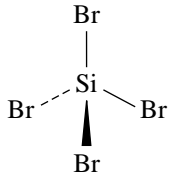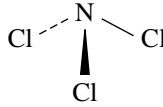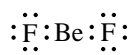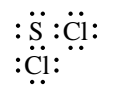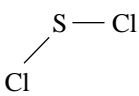
Extension

5. Pauling's electronegativity scale is derived from measurements of bond energies; the Mulliken-Jaffé scale is derived from the electron affinity and ionization potentials; and the Allred-Rochow scale is derived from the covalent radius and the effective charge on the electron (allowing for nuclear shielding). The relative values for electronegativity of the elements, and predictions made from these values, naturally vary slightly depending on which scale is used.
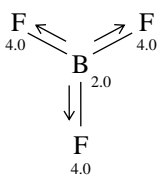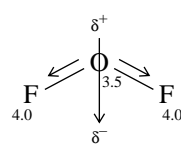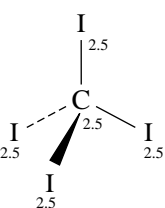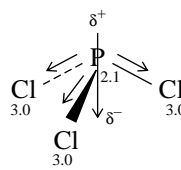
PRACTICE

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Understanding Concepts

6. (a) tetrahedral

(b) pyramidal

(c) linear $F - Be - F$

(d) V–shape

7. (a) $C \equiv N$
   $\delta^+ \longrightarrow \delta^-$

(b) $N = O$
   $\delta^+ \longrightarrow \delta^-$

(c) $P - S$
   $\delta^+ \longrightarrow \delta^-$

(d) $C - C$
   no dipole

8. (a) zero resultant

(b) resultant dipole toward F side of molecule

(c) no bond dipoles

(d) resultant dipole toward Cl side of molecule

9. An octane, $C_8H_{18(l)}$, molecule should be nonpolar using the generalization that any molecule composed of carbons and only one other kind of atom is a nonpolar molecule.

10. For $N_2H_{4(l)}$, the molecular structure is symmetrical; thus, the molecule is nonpolar.

Applying Inquiry Skills

11. Hydrogen sulfide, $H_2S_{(g)}$, has a V-shaped molecule, with bond dipoles directed toward the sulfur. Thus, the molecular dipole should be slightly negative on the sulfur side, and slightly positive on the hydrogen side.

The hydrogen sulfide will be cooled to the liquid state, and a thin stream of the liquid allowed to flow downward past a strong electric charge. Molecular polarity should cause deflection of the liquid stream.

SECTION 4.4 QUESTIONS

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Understanding Concepts

1. (a) Beryllium bromide is nonpolar because it is symmetrical. Therefore, the bond dipoles add up to zero for the whole molecule.
   (b) Nitrogen trifluoride is polar because it has polar bonds and is not symmetrical. The sum of all of the bond dipoles produces a non-zero dipole for the whole molecule.
   (c) Methanol is polar because it has polar bonds and is not symmetrical. The sum of all of the bond dipoles produces a non-zero dipole for the whole molecule.
   (d) Hydrogen peroxide is nonpolar because it has polar bonds and is assumed to be symmetrical. The sum of all of the bond dipoles produces a zero dipole for the whole molecule. (Note that this answer ignores any rotation about the O-O bond and considers only the most stable arrangement.)
   (e) Ethylene glycol is nonpolar because it has polar bonds and is symmetrical. The bond dipoles have a zero resultant. (Again, this assumes the most stable arrangement.)

2. (a) polar nonsymmetric

   (b) nonpolar symmetric

   (c) polar nonsymmetric

   (d) polar nonsymmetric

   (e) polar nonsymmetric

   (f) nonpolar symmetric
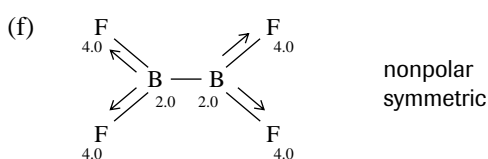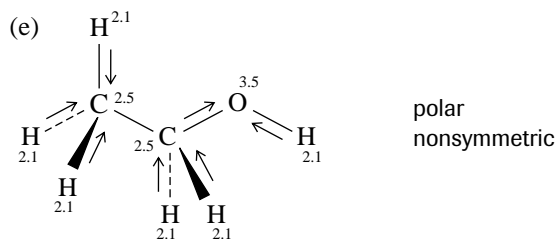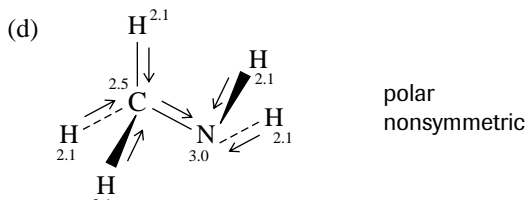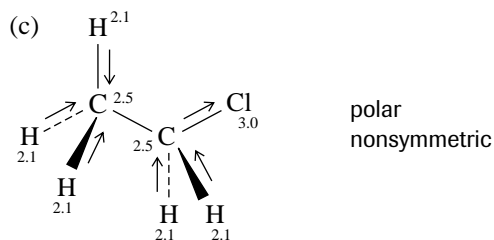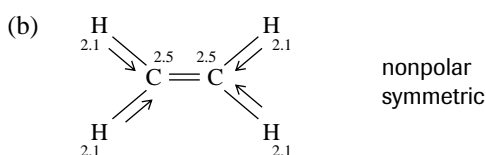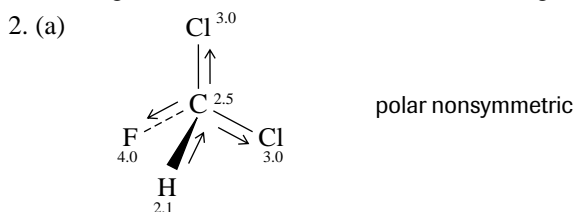
3. (a) Based upon polarity, water is a candidate for use in a capacitor, because it is a V-shaped (nonsymmetrical) molecule with high molecular polarity.
   (b) Other considerations for choosing a liquid inside a capacitor might be toxicity, corrosiveness, cost, ease of fabrication, and effectiveness as a storage material.

Applying Inquiry Skills

4. Cis-1,2-dichloroethene is a nonsymmetrical molecule that should have a resultant molecular dipole; thus, the substance should be polar. The other stereoisomer, trans-1,2-dichloroethene, is symmetrical, and should not be a polar substance.
   Thin streams of each liquid are allowed to flow downward past a strong electric charge. Any stream deflection is noted. (The polar substance should deflect.)

Making Connections

5. The entire field of cleaning and stain removal is based on a knowledge of polar and nonpolar substances. Stains may be polar or nonpolar substances. Nonpolar substances pose particular problems because the common liquid for washing is water, which is very polar. Soaps and detergents are molecules selected or designed to have both polar and nonpolar regions so that they can dissolve oily or greasy dirt from a stain, and also dissolve in water to carry the material away.

4.5   INTERMOLECULAR FORCES

PRACTICE

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Understanding Concepts

1. (a) dipole–dipole forces and London forces
   (b) London forces
   (c) London forces
   (d) dipole–dipole forces and London forces
   (e) dipole–dipole forces and London forces
   (f) London forces
2. (a) hydrogen fluoride; the H-F bond is more polar (electronegativity difference is greater)
   (b) chloromethane; the C-Cl bond is more polar (electronegativity difference is greater)
   (c) nitrogen tribromide; the N-Br bonds are more polar (electronegativity difference is greater)
   (d) water; the O-H bonds are more polar (electronegativity difference is greater)
3. (a) ethane; because it has 8 more electrons (and protons) than methane
   (b) oxygen; because it has 2 more electrons (and protons) than nitrogen
   (c) sulfur dioxide; because it has 18 more electrons (and protons) than nitrogen dioxide
   (d) Methane and ammonia are isoelectronic, with 10 electrons each. They should have equal-strength London forces.
4. (a) oxygen difluoride; beryllium difluoride is nonpolar (no dipole–dipole forces) and also has fewer electrons (weaker London forces).
   (b) chloromethane; ethane is nonpolar (no dipole–dipole forces) and also has fewer electrons (weaker London forces).
5. Chlorine monoxide bonds are less polar than bonds in nitrogen trifluoride (possibly weaker dipole–dipole forces), and there are fewer bonds per molecule, but nitrogen trifluoride has fewer electrons than chlorine monoxide (weaker London forces). Therefore, no simple prediction is possible in this case.

Applying Inquiry Skills

6. Some patterns found in Table 4 include:
   - In the homologous series for the alkanes, alkenes, and alkynes, the boiling point increases proportionally to the number of electrons per molecule. Because these are all nonpolar molecules, the pattern can be explained as an increase in the strength of the London force.

   - In the comparison of alkanes with their corresponding alkenes (same number of carbons), we find the boiling point of the alkene is slightly lower. This is what we might expect because the molecules are nonpolar and the London force should decrease when the number of electrons is reduced by two.

   - Interestingly, the alkynes have higher boiling points than corresponding alkenes, even though they have fewer electrons. Since polarity is not a factor, there is obviously some other factor involved that has not yet been studied. (Note that the effect of molecular shape on the strength of intermolecular forces has not been considered.)

7. Look up in a reference, or determine experimentally, the melting points of the hydrocarbons listed in Table 4. Possible complications of this proposed experiment include the equipment needed if it is necessary to determine the melting points of substances that have freezing points well below 0°C. The interpretation of the results may also be complicated by the fact that the bonding changes between solid and liquid forms are not as clear as the change between liquid and gas states. With boiling points, we usually assume that no intermolecular bonding forces exist between molecules in a gas.