Types of covalent bonds. One shared pair of electrons constitutes a single covalent bond. Two or three pairs of electrons may be shared between atoms to give double and triple covalent bonds. Most often, both atoms of the bond contribute an equal number of electrons to the bond. In a few cases, however, both electrons of a shared pair come from the same atom; this is a coordinate covalent bond (Sections 5.3 and 5.5).

Number of covalent bonds formed. There is a strong tendency for nonmetals to form a particular number of covalent bonds. The number of valence electrons the nonmetal has and the number of covalent bonds it forms give a sum of eight (Section 5.4).

Molecular geometry. Molecular geometry describes the way atoms in a molecule are arranged in space relative to one another. VSEPR theory is a set of procedures used to predict molecular geometry from a compound's Lewis structure. VSEPR theory is based on the concept that valence shell electron groups about an atom (bonding or nonbonding) orient themselves as far away from one another as possible (to minimize repulsions) (Section 5.8).

Electronegativity. Electronegativity is a measure of the relative attraction that an atom has for the shared electrons in a bond. Electronegativity values are useful in predicting the type of bond that forms (ionic or covalent) (Section 5.9).

Bond polarity. When atoms of like electronegativity participate in a bond, the bonding electrons are equally shared and the bond is nonpolar. When atoms of differing electronegativity participate in a bond, the bonding electrons are unequally shared and the bond is polar. In a polar bond, the more electronegative atom dominates the sharing process. The greater the electronegativity difference between two bonded atoms, the greater the polarity of the bond (Section 5.10).

Molecular polarity. Molecules as a whole can have polarity. If individual bond polarities do not cancel because of the symmetrical nature of a molecule, then the molecule as a whole is polar (Section 5.11).

Binary molecular compound nomenclature. Names for binary molecular compounds usually contain numerical prefixes that give the number of each type of atom present per molecule in addition to the names of the elements (Section 5.12).

KEY REACTIONS AND EQUATIONS

1. Molecular geometry and central atom VSEPR electron group count (Section 5.8)

Four VSEPR electron groups none of which is nonbonding	= tetrahedral geometry
Four VSEPR electron groups one of which is nonbonding	= trigonal pyramidal geometry
Four VSEPR electron groups two of which are nonbonding	= angular geometry
Three VSEPR electron groups none of which is nonbonding	= trigonal planar geometry
Three VSEPR electron groups one of which is nonbonding	= angular geometry
Two VSEPR electron groups none of which is nonbonding	= linear geometry

2. Bond characterization and electronegativity difference (Section 5.10)

Electronegativity difference of 0 to 0.4	= nonpolar covalent bond
Electronegativity difference greater than 0.4 but less than 1.5	= polar covalent bond
Electronegativity difference from 1.5 to 2.0	= ionic bond or polar covalent bond depending on the atoms involved in the bond
Electronegativity difference greater than 2.0	= ionic bond

EXERCISES *and* PROBLEMS

The members of each pair of problems in this section test similar material.

The Covalent Bond Model (Section 5.1)

5.1 Contrast the types of atoms involved in ionic and covalent bonds.

5.2 Contrast the mechanisms by which ionic and covalent bonds form.

5.3 Contrast the basic structural unit in ionic and molecular compounds.

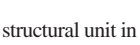
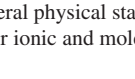
5.4 Contrast the general physical state at room temperature and room pressure for ionic and molecular compounds.

Lewis Structures for Molecular Compounds (Section 5.2)

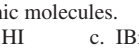
5.5 Draw Lewis structures to illustrate the covalent bonding in the following diatomic molecules.
a. Br_2 b. HI c. IBr d. BrF

5.6 Draw Lewis structures to illustrate the covalent bonding in the following diatomic molecules.
a. I_2 b. HF c. IF d. F_2

5.7 How many nonbonding electron pairs are present in each of the following Lewis structures?

a. 
b. 
c. 
d. 

5.8 How many nonbonding electron pairs are present in each of the following Lewis structures?

a. 
b.
c.
d.

5.9 What would be the predicted chemical formula for the simplest molecular compound formed between the following pairs of elements?

a. Nitrogen and fluorine
b. Chlorine and oxygen
c. Hydrogen and sulfur
d. Carbon and hydrogen

5.10 What would be the predicted chemical formula for the simplest molecular compound formed between the following pairs of elements?

a. Nitrogen and hydrogen
b. Oxygen and fluorine
c. Sulfur and bromine
d. Carbon and chlorine

Single, Double, and Triple Covalent Bonds (Section 5.3)

5.11 Specify the number of single, double, and triple covalent bonds present in molecules represented by the following Lewis structures.

a. $:N:::N:$

b. $H:\ddot{O}:\ddot{O}:H$

c. $H:\underset{\underset{:\ddot{O}:}{\vdots}}{\ddot{C}}:H$

d. $H:\underset{H}{\overset{\cdot\cdot}{C}}::\underset{H}{\overset{\cdot\cdot}{C}}:H$

5.12 Specify the number of single, double, and triple covalent bonds present in molecules represented by the following Lewis structures.

a. $:C:::O:$

b. $H:\underset{H}{\overset{\cdot\cdot}{N}}:\underset{H}{\overset{\cdot\cdot}{N}}:H$

c. $:\ddot{O}:\underset{\underset{:\ddot{O}:}{\vdots}}{\ddot{S}}:\ddot{O}:$

d. $H:C:::C:H$

5.13 Convert each of the Lewis structures in Problem 5.11 into the form in which lines are used to denote shared electron pairs. Include nonbonding electron pairs in the rewritten structures.

5.14 Convert each of the Lewis structures in Problem 5.12 into the form in which lines are used to denote shared electron pairs. Include nonbonding electron pairs in the rewritten structures.

Valence Electrons and Number of Covalent Bonds Formed (Section 5.4)

5.15 Indicate whether each of the following is or is not a normally expected bonding pattern for the element shown.

a. $-\ddot{O}-$ b. $:N\equiv$ c. $:\ddot{C}=$ d. $:\ddot{O}=$

5.16 Indicate whether each of the following is or is not a normally expected bonding pattern for the element shown.

a. $-\ddot{N}=$ b. $:O\equiv$ c. $-C\equiv$ d. $=C=$

5.17 Identify the Period 2 nonmetal that would normally be expected to exhibit each of the following bonding capabilities.

a. Forms three single bonds
b. Forms two double bonds
c. Forms one single bond and one double bond
d. Forms two single bonds and one double bond

5.18 Identify the Period 3 nonmetal that would normally be expected to exhibit each of the following bonding capabilities.

a. Forms one triple bond
b. Forms one single bond and one triple bond
c. Forms four single bonds
d. Forms one double bond

Coordinate Covalent Bonds (Section 5.5)

5.19 What aspect of the following Lewis structure gives you a "hint" that the concept of coordinate covalency is needed to explain the bonding in the molecule?

$$:C:::O:$$

5.20 What aspect of the following Lewis structure gives you a "hint" that the concept of coordinate covalency is needed to explain the bonding in the molecule?

$$:N:::N:\ddot{O}:$$

5.21 Identify the coordinate covalent bond(s) present, if any, in each of the following molecules by listing the two atoms involved in the bond. Name the atom on the left or the bottom in the bond first.

a. $:N\equiv N-\ddot{O}:$

b. $H-\ddot{O}-\ddot{F}:$

c. $:\ddot{O}-\ddot{Cl}-\ddot{O}-H$

d. $:\ddot{O}-\underset{\underset{:\ddot{O}:}{|}}{Br}-\ddot{O}-H$

5.22 Identify the coordinate covalent bond(s) present, if any, in each of the following molecules by listing the two atoms involved in the bond. Name the atom on the left or the bottom in the bond first.

a. $:\ddot{S}=\ddot{S}-\ddot{O}:$

b. $H-\ddot{O}-\ddot{Br}:$

c. $:\ddot{O}-\ddot{I}-\ddot{O}-H$

d. $:\ddot{O}-\underset{\underset{:\ddot{O}:}{|}}{Cl}-\ddot{O}-H$

Drawing Lewis Structures (Section 5.6)

5.23 Without actually drawing the Lewis structure, determine the total number of "dots" present in the Lewis structure of each of the following molecules. That is, determine the total number of valence electrons available for bonding in each of the molecules.

a. Cl_2O b. H_2S c. NH_3 d. SO_3

5.24 Without actually drawing the Lewis structure, determine the total number of "dots" present in the Lewis structure of each of the following molecules. That is, determine the total number of valence electrons available for bonding in each of the molecules.

a. PCl_3 b. H_2O_2 c. SF_2 d. HCl

5.25 Draw Lewis structures to illustrate the covalent bonding in the following polyatomic molecules. The first atom in each formula is the central atom to which all other atoms are bonded.

a. PH_3 b. PCl_3 c. $SiBr_4$ d. OF_2

5.26 Draw Lewis structures to illustrate the covalent bonding in the following polyatomic molecules. The first atom in each formula is the central atom to which all other atoms are bonded.

a. AsH_3 b. $AsCl_3$ c. CBr_4 d. SCl_2

5.27 Draw Lewis structures for the simplest molecular compound likely to form between these pairs of elements.

a. Sulfur and fluorine
b. Carbon and iodine
c. Nitrogen and bromine
d. Selenium and hydrogen

5.28 Draw Lewis structures for the simplest molecular compound likely to form between these pairs of elements.

a. Nitrogen and chlorine
b. Bromine and hydrogen
c. Phosphorus and fluorine
d. Selenium and bromine

5.29 Draw Lewis structures to illustrate the bonding in the following molecules. In each case, there will be at least one multiple bond present in a molecule.

a. C_3H_4: A central carbon atom has two other carbon atoms bonded to it. Each of the noncentral carbon atoms also has two hydrogen atoms bonded to it.

b. N_2F_2: The two nitrogen atoms are bonded to one another, and each nitrogen atom also has a fluorine atom bonded to it.
c. C_2H_3N: The two carbon atoms are bonded to each other. One of the carbon atoms has a nitrogen atom bonded to it, and the other carbon atom has three hydrogen atoms bonded to it.
d. C_3H_4: A central carbon atom has two other carbon atoms bonded to it. One of the noncentral carbon atoms also has one hydrogen atom bonded to it, and the other one has three hydrogen atoms bonded to it.

5.30 Draw Lewis structures to illustrate the bonding in the following molecules. In each case, there will be at least one multiple bond present in a molecule.
a. $COCl_2$: Both chlorine atoms and the oxygen atom are bonded to the carbon atom.
b. $C_2H_2Br_2$: The two carbon atoms are bonded to one another. Each carbon atom also has a bromine atom and a hydrogen atom bonded to it.
c. C_2N_2: The two carbon atoms are bonded to one another, and each carbon atom also has a nitrogen bonded to it.
d. CH_2N_2: A central carbon atom has both nitrogen atoms bonded to it. Both hydrogen atoms are bonded to one of the two nitrogen atoms.

Lewis Structures for Polyatomic Ions (Section 5.7)

5.31 Draw Lewis structures for the following polyatomic ions.
a. OH^- b. BeH_4^{2-} c. $AlCl_4^-$ d. NO_3^-

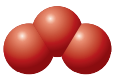
5.32 Draw Lewis structures for the following polyatomic ions.
a. CN^- b. PF_4^+ c. BH_4^- d. ClO_3^-

5.33 Draw Lewis structures for the following compounds that contain polyatomic ions.
a. NaCN b. K_3PO_4

5.34 Draw Lewis structures for the following compounds that contain polyatomic ions.
a. KOH b. NH_4Br

Molecular Geometry (VSEPR Theory) (Section 5.8)

5.35 Specify the molecular geometry of each of the following molecules using the terms *linear, angular, trigonal pyramidal,* and *tetrahedral.*

a.  b.  c.  d. 

5.36 Specify the molecular geometry of each of the following molecules using the terms *linear, angular, trigonal pyramidal,* and *tetrahedral.*

a.  b. 

c.  d. 

5.37 Using VSEPR theory, predict whether each of the following triatomic molecules is linear or angular (bent).

a. H:S:H b. H:O:Cl:

c. :O::O:O: d. :N::N::O:

5.38 Using VSEPR theory, predict whether each of the following triatomic molecules is linear or angular (bent).

a. H:C:::N: b. :N::S:F:

c. :F:S:F: d. :Cl:O:Cl:

5.39 Using VSEPR theory, predict the molecular geometry of the following molecules.

a. :F:N:F: (:F:) b. :Cl:C:Cl: (:O:)

c. (:O:) :Cl:P:Cl: (:Cl:) d. H :Cl:C:Cl: (:Cl:)

5.40 Using VSEPR theory, predict the molecular geometry of the following molecules.

a. H:P:H (:Cl:) b. :Cl:C::O: (H)

c. H :Cl:C:Cl: (H) d. :F: H:Si:H (:Cl:)

5.41 Using VSEPR theory, predict the molecular geometry of the following molecules.
a. NCl_3 b. $SiCl_4$ c. H_2Se d. SBr_2

5.42 Using VSEPR theory, predict the molecular geometry of the following molecules.
a. HOBr b. H_2Te c. NBr_3 d. SiF_4

5.43 Using VSEPR theory, predict the molecular geometry of the following molecules.

a. H:C::C:H (H H) b. H H:C:O:H (H)

5.44 Using VSEPR theory, predict the molecular geometry of the following molecules.

a. (:O:) :O::N:O:H b. H :O: H:C:C:H (H)

Electronegativity (Section 5.9)

5.45 Using a periodic table, but not a table of electronegativity values, arrange each of the following sets of atoms in order of increasing electronegativity.
a. Na, Al, P, Mg b. Cl, Br, I, F
c. S, P, O, Al d. Ca, Mg, O, C

5.46 Using a periodic table, but not a table of electronegativity values, arrange each of the following sets of atoms in order of increasing electronegativity.
a. Be, N, O, B b. Li, C, B, K
c. S, Te, Cl, Se d. S, Mg, K, Ca

5.47 Use the information in Figure 5.11 as a basis for answering the following questions.
a. Which elements have electronegativity values that exceed that of the element carbon?
b. Which elements have electronegativity values of less than 1.0?
c. What are the four most electronegative elements listed in Figure 5.11?
d. By what constant amount do the electronegativity values for sequential Period 2 elements differ?

5.48 Use the information in Figure 5.11 as a basis for answering the following questions.
a. Which elements have electronegativity values that exceed that of the element sulfur?
b. What are the three least electronegative elements listed in Figure 5.11?
c. Which three elements in Figure 5.11 have an electronegativity of 2.5?
d. How does the electronegativity of the element hydrogen compare to that of the Period 2 elements?

Bond Polarity (Section 5.10)

5.49 Place δ^+ above the atom that is relatively positive and δ^- above the atom that is relatively negative in each of the following bonds. Try to answer this question without referring to Figure 5.11.
a. B—N b. Cl—F c. N—C d. F—O

5.50 Place δ^+ above the atom that is relatively positive and δ^- above the atom that is relatively negative in each of the following bonds. Try to answer this question without referring to Figure 5.11.
a. Cl—Br b. Al—S c. Br—S d. O—N

5.51 Rank the following bonds in order of increasing polarity.
a. H—Cl, H—O, H—Br b. O—F, P—O, Al—O
c. H—Cl, Br—Br, B—N d. P—N, S—O, Br—F

5.52 Rank the following bonds in order of increasing polarity.
a. H—Br, H—Cl, H—S b. N—O, Be—N, N—F
c. N—P, P—P, P—S d. B—Si, Br—I, C—H

5.53 Classify each of the following bonds as nonpolar covalent, polar covalent, or ionic on the basis of electronegativity differences.
a. C—O b. Na—Cl c. C—I d. Ca—S

5.54 Classify each of the following bonds as nonpolar covalent, polar covalent, or ionic on the basis of electronegativity differences.
a. Cl—F b. P—H c. C—H d. Ca—O

Molecular Polarity (Section 5.11)

5.55 Indicate whether each of the following hypothetical triatomic molecules is polar or nonpolar. Assume that A, X, and Y have different electronegativities.
a. A linear X—A—X molecule
b. A linear X—X—A molecule
c. An angular A—X—Y molecule
d. An angular X—A—Y molecule

5.56 Indicate whether each of the following hypothetical triatomic molecules is polar or nonpolar. Assume that A, X, and Y have different electronegativities.
a. A linear X—A—Y molecule
b. A linear A—Y—A molecule
c. An angular X—A—X molecule
d. An angular X—X—X molecule

5.57 Indicate whether each of the following triatomic molecules is polar or nonpolar. The molecular geometry is given in parentheses.
a. CS_2 (linear with C in the center position)
b. H_2Se (angular with Se in the center position)
c. FNO (angular with N in the center position)
d. N_2O (linear with N in the center position)

5.58 Indicate whether each of the following triatomic molecules is polar or nonpolar. The molecular geometry is given in parentheses.
a. SCl_2 (angular with S in the center position)
b. OF_2 (angular with O in the center position)
c. SO_2 (angular with S in the center position)
d. H_2S (angular with S in the center position)

5.59 Indicate whether each of the following molecules is polar or nonpolar. The molecular geometry is given in parentheses.
a. NF_3 (trigonal pyramid with N at the apex)
b. H_2Se (angular with Se in the center position)
c. CS_2 (linear with C in the center position)
d. $CHCl_3$ (tetrahedral with C in the center position)

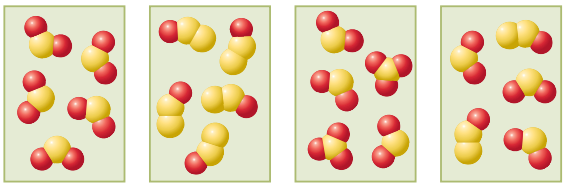
5.60 Indicate whether each of the following molecules is polar or nonpolar. The molecular geometry is given in parentheses.
a. PH_2Cl (trigonal pyramid with P at the apex)
b. SO_3 (trigonal planar with S in the center position)
c. CH_2Cl_2 (tetrahedral with C in the center position)
d. CCl_4 (tetrahedral with C in the center position)

Naming Binary Molecular Compounds (Section 5.12)

5.61 Name the following binary molecular compounds.
a. SF_4 b. P_4O_6 c. ClO_2 d. H_2S

5.62 Name the following binary molecular compounds.
a. Cl_2O b. CO c. PI_3 d. HI

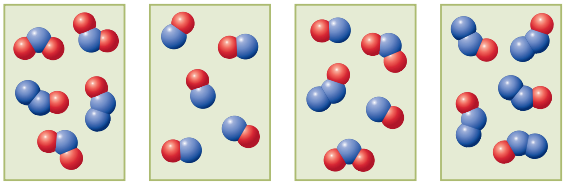
5.63 Each of the following diagrams depicts a collection of sulfur–oxygen molecules, where the yellow atoms are sulfur and the red atoms are oxygen.



I II III IV

Which diagram depicts the following?
a. Sulfur dioxide molecules
b. Disulfur monoxide molecules
c. A mixture of sulfur dioxide and disulfur monoxide molecules
d. A mixture of sulfur dioxide and sulfur trioxide molecules

5.64 Each of the following diagrams depicts a collection of nitrogen–oxygen molecules, where the blue atoms are nitrogen and the red atoms are oxygen.



I II III IV

Which diagram depicts the following?
a. Dinitrogen monoxide molecules
b. Nitrogen monoxide molecules
c. A mixture of nitrogen dioxide and dinitrogen monoxide molecules
d. A mixture of dinitrogen monoxide, nitrogen dioxide, and nitrogen monoxide molecules

5.65 Write chemical formulas for the following binary molecular compounds.
a. Iodine monochloride b. Dinitrogen monoxide
c. Nitrogen trichloride d. Hydrogen bromide

5.66 Write chemical formulas for the following binary molecular compounds.
a. Bromine monochloride b. Tetrasulfur dinitride
c. Sulfur trioxide d. Dioxygen difluoride

5.67 Write chemical formulas for the following binary molecular compounds.
a. Hydrogen peroxide b. Methane
c. Ammonia d. Phosphine

5.68 Write chemical formulas for the following binary molecular compounds.
a. Ethane b. Water
c. Hydrazine d. Arsine

ADDITIONAL PROBLEMS

5.69 How many electron dots should appear in the Lewis structure for each of the following molecules or polyatomic ions?
a. O_2F_2 b. $C_2H_2Br_2$ c. S_2^{2-} d. NH_4^+

5.70 In which of the following pairs of diatomic species do both members of the pair have bonds of the same multiplicity (single, double, triple)?
a. HCl and HF b. S_2 and Cl_2
c. CO and NO^+ d. OH^- and HS^-

5.71 Specify the reason why each of the following Lewis structures is incorrect using the following choices: (1) not enough electron dots, (2) too many electron dots, or (3) improper placement of a correct number of electron dots.
a. $:O\equiv O:$ b. $H:\ddot{\underset{\cdot\cdot}{O}}:Cl$
c. $H:\ddot{O}:::\ddot{O}:H$ d. $\left[:\ddot{N}::\ddot{O}:\right]^+$

5.72 Specify both the VSEPR electron group geometry about the central atom and the molecular geometry for each of the following species.
a. SiH_4 b. NH_4^+ c. ClNO d. NO_3^-

5.73 Classify each of the following molecules as polar or nonpolar, or indicate that no such classification is possible because of insufficient information.
a. A molecule in which all bonds are polar
b. A molecule in which all bonds are nonpolar
c. A molecule with two bonds, both of which are polar
d. A molecule with two bonds, one that is polar and one that is nonpolar

5.74 Indicate which molecule in each of the following pairs of molecules is *more* polar.
a. BrCl and BrI b. CO_2 and SO_2
c. SO_3 and NF_3 d. H_3CF and Cl_3CF

5.75 Four hypothetical elements, A, B, C, and D, have electronegativities A = 3.8, B = 3.3, C = 2.8, and D = 1.3. These elements form the compounds BA, DA, DB, and CA. Arrange these compounds in order of increasing *ionic* bond character.

5.76 Successive substitution of F atoms for H atoms in the molecule CH_4 produces the molecules CH_3F, CH_2F_2, CHF_3, and CF_4.
a. Draw Lewis structures for each of the five molecules.
b. Using VSEPR theory, predict the geometry of each of the five molecules.
c. Give the polarity (polar or nonpolar) of each of the five molecules.

5.77 The chemical formula for a compound containing two nitrogen atoms and one oxygen atom is written as N_2O and the compound's name is dinitrogen monoxide. The chemical formula is not written as ON_2 and the compound is not named oxygen dinitride. Explain.

5.78 The correct name for the compound $NaNO_3$ is not sodium nitrogen trioxide. Explain.

5.79 Name each of the following binary compounds. (*Caution:* At least one of the compounds is ionic.)
a. NaCl b. BrCl c. K_2S d. Cl_2O

Multiple-Choice Practice Test

5.80 In which of the following pairs of compounds are both members of the pair *molecular* compounds?
a. PCl_3 and LiBr b. CCl_4 and KOH
c. NaH and CaF_2 d. CO_2 and NH_3

5.81 Eighteen electrons are present in the Lewis structure of which of the following molecules?
a. CO_2 b. N_2O c. SO_2 d. HCN

5.82 Two nonbonding electrons are present in the Lewis structure of which of the following molecules?
a. CH_4 b. HCN c. SO_2 d. H_2O

5.83 An angular molecular geometry is associated with molecules in which the central atom has which of the following?
a. Three bonding groups and one nonbonding group
b. Two bonding groups and two nonbonding groups
c. Two bonding groups and zero nonbonding groups
d. Three bonding groups and zero nonbonding groups

5.84 In which of the following pairs of molecules do both members of the pair have the same molecular geometry?
a. SO_2 and CO_2 b. H_2S and HCN
c. NH_3 and SO_3 d. H_2O and OF_2

5.85 In which of the following pairs of bonds is the first listed bond *more* polar than the second listed bond?
a. N—N and N—F b. P—Cl and S—Cl
c. C—N and C—F d. N—Cl and C—H

5.86 If the electronegativity difference between two atoms is 1.0, the bond between the two atoms would be classified as which of the following?
a. Ionic b. Nonpolar covalent
c. Polar covalent d. Coordinate covalent

5.87 Which of the following statements concerning molecular polarity is *correct*?
a. All diatomic molecules are polar.
b. All diatomic molecules are nonpolar.
c. Some diatomic molecules are polar.
d. No diatomic molecules are nonpolar.

5.88 Which of the following is a molecular compound that contains five atoms per molecule?
a. Phosphorus trichloride b. Disulfur monoxide
c. Dinitrogen trioxide d. Carbon dioxide

5.89 Which of the following molecular compounds is paired with an incorrect name?
a. NH_3, ammonia
b. H_2S, hydrogen sulfide
c. N_2O_5, dinitrogen pentoxide
d. NO_2, mononitrogen dioxide