

# SELECTED ANSWERS

## Chapter 1 Exercises

- 1.1. (a) 1 megagram =  $10^6$  gram (b) 1 milliliter =  $10^{-3}$  liter  
1.2. (a) 71 mL to 73 mL (b) 8.22 m to 8.24 m  
(c)  $4.54 \times 10^{-5}$  g to  $4.56 \times 10^{-5}$  g  
1.3. 2.30 g because the reported values differ by about  $\pm 0.01$ .

## Chapter 1 Key Ideas

1. observation, data, hypothesis, research (or experimentation), research, published, applications, hypothesizing and testing 3. meter, m  
5. second, time. 7. base units, derive 9. mass, distance  
11. Celsius, Kelvin 13. certain, estimated

## Chapter 1 Problems

15. megagram, mass, Mg; milliliter, volume, mL; nanometer, length, nm; Kelvin, temperature, K  
17. (a)  $10^3$  (b)  $10^9$  (c)  $10^{-3}$  (d)  $10^{-9}$   
19. (a) 10,000,000 (b) 1,000,000,000,000 (c) 0.0000001 (d) 0.000000000001  
21. (a)  $10^3$  m = 1 km (b)  $10^{-3}$  L = 1 mL (c)  $10^6$  g = 1 Mg (d)  $1$  cm<sup>3</sup> = 1 mL (e)  $10^3$  kg = 1 t (t = metric ton)  
23. (a) meter (b) centimeter (c) millimeter (d) kilometer  
25. inch is larger 27. (a) milliliter (b) cubic meter (c) liter  
29. fluid ounce is larger  
31. Mass is usually defined as a measure of the amount of matter in an object. The weight of an object, on Earth, is a measure of the force of gravitational attraction between the object and Earth. The more mass an object has, the greater the gravitational attraction between it and another object. The farther an object gets from Earth, the less that attraction is, and the lower its weight. Unlike the weight of an object, the mass of an object is independent of location. Mass is described with mass units, such as grams and kilograms. Weight can be described with force units, such as newtons.  
32. ounce is larger 36. degree Celsius is larger 38.  $10^{\circ}\text{F}$   
41. (a) 30.5 m means  $30.5 \pm 0.1$  m or 30.4 m to 30.6 m.  
(b) 612 g means  $612 \pm 1$  g or 611 g to 613 g.  
(c) 1.98 m means  $1.98 \pm 0.01$  m or 1.97 m to 1.99 m.  
(d)  $9.1096 \times 10^{-28}$  g means  $(9.1096 \pm 0.0001) \times 10^{-28}$  g or  $9.1095 \times 10^{-28}$  g to  $9.1097 \times 10^{-28}$  g.  
(e)  $1.5 \times 10^{18}$  m<sup>3</sup> means  $(1.5 \pm 0.1) \times 10^{18}$  m<sup>3</sup> or  $1.4 \times 10^{18}$  m<sup>3</sup> to  $1.6 \times 10^{18}$  m<sup>3</sup>.  
43. (a) It's difficult to estimate the hundredth position accurately. For the object on the left, we might report 7.67 cm, 7.68 cm, or 7.69. The end of the right object seems to be right on the 9 cm mark, so we report 9.00 cm.  
(b) 7.7 cm and 9.0 cm  
45. Our uncertainty is in the tenth position, so we report 10.4 s.  
47. (a) 101.4315 g (b) Our convention calls for only reporting one uncertain digit in our value. Because we are uncertain about the thousandth position, we might report 101.432 g (or perhaps even 101.43 g).

## Chapter 2 Exercises

2.1 aluminum, Al, 13, 3A or IIIA, metal, representative (or main-group) element, 3, solid; silicon, Si, 14, 4A or IVA, metalloid, representative (or main-group) element, 3, solid; nickel, Ni, 10, 8B or VIII B, metal, transition metal, 4, solid; sulfur, S, 16, 6A or VIA, nonmetal, representative (or main-group) element, 3, solid; fluorine, F, 17, 7A or VIIA, nonmetal, representative (or main-group) element, 2, gas; potassium, K, 1, 1A or IA, metal, representative (or main-group) element, 4, solid;

mercury, Hg, 12, 2B or IIB, metal, transition metal, 6, liquid; uranium, U, (No group number), metal, inner transition metal, 7, solid; manganese, Mn, 7, 7B or VIIB, metal, transition metal, 4, solid; calcium, Ca, 2, 2A or IIA, metal, representative (or main-group) element, 4, solid; bromine, Br, 17, nonmetal, representative (or main-group) element, 4, liquid; silver, Ag, 1B, metal, transition metal, 5, solid; carbon, C, 14, nonmetal, representative (or main-group) element, 2, solid  
2.2 (a) noble gases (b) halogens (c) alkaline earth metals (d) alkali metals  
2.3 (a) +2 cation (b) -1 anion.

## Chapter 2 Review Questions

1. Matter is anything that occupies space and has mass.  
2. The distance between the floor and a typical doorknob is about one meter. A penny weighs about three grams.

## Chapter 2 Key Ideas

3. simplified but useful 5. motion 7. attract 9. empty space, expands  
11. escape 13. straight-line path 15. simpler 17. vertical column  
19. solid, liquid, gas 21. sun 23.  $10^{-15}$  25. cloud 27. gains 29. chemical  
31. single atom

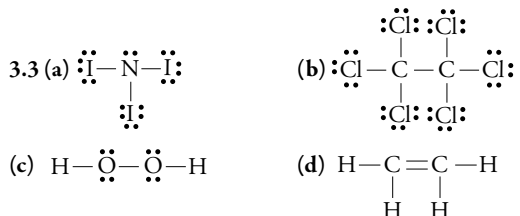
## Chapter 2 Problems

- 33(a) Strong attractions between the particles keep each particle at the same average distance from other particles and in the same general position with respect to its neighbors. (b) The velocity of the particles increases, causing more violent collisions between them. This causes them to move apart, so the solid expands. See Figure 2.1. (c) The particles break out of their positions in the solid and move more freely throughout the liquid, constantly breaking old attractions and making new ones. Although the particles are still close together in the liquid, they are more disorganized, and there is more empty space between them.  
35 (a) The attractions between liquid particles are not strong enough to keep the particles in position like the solid. The movement of particles allows the liquid to take the shape of its container. The attractions are strong enough to keep the particles at the same average distance, leading to constant volume. (b) The velocity of the particles increases, so they will move throughout the liquid more rapidly. The particles will collide with more force. This causes them to move apart, so the liquid expands slightly. (c) Particles that are at the surface of the liquid and that are moving away from the surface fast enough to break the attractions that pull them back will escape to the gaseous form. The gas particles will disperse throughout the neighborhood as they mix with the particles in the air. See Figures 2.3 and 2.4.  
37. The air particles are moving faster.  
39. There is plenty of empty space between particles in a gas.  
40 (a) Cl (b) Zn (c) P (d) U  
43. (a) carbon (b) copper (c) neon (d) potassium  
46. sodium, Na, 1 or 1A or IA, metal, representative (or main-group) element, 3; tin, Sn, 14 or 4A or IVA, metal, representative element, 5; helium, He, 18 or 8A or VIIIA, nonmetal, representative (or main-group) element, 1; nickel, Ni, 10 or 8B or VIII B, metal, transition metal, 4; silver, Ag, 11 or 1B or IB, metal, transition metal, 5; aluminum, Al, 13 or 3A or IIIA, metal, representative (or main-group) element, 3; silicon, Si, 14 or 4A or IVA, metalloid, representative (or main-group) element, 3; sulfur, S, 16, nonmetal, representative (or main-group) element, 3; mercury, Hg, 2B, metal, transition metal, 6  
48. (a) halogens (b) noble gases (c) alkali metals (d) alkaline earth metals

50. (a) gas (b) liquid (c) solid (d) gas (e) solid (f) solid  
 52. lithium and potassium  
 54. (a) chlorine, Cl (b) potassium, K (c) silicon, Si  
 56. Because manganese is a metal, we expect it to be malleable.  
 58. Protons and neutrons are in a tiny core of the atom called the nucleus, which has a diameter of about 1/100,000 the diameter of the atom. The position and motion of the electrons are uncertain, but they generate a negative charge that is felt in the space that surrounds the nucleus.  
 60. (a) +1 cation (b) -2 anion  
 63. (a) 8 (b) 12 (c) 92 (d) 3 (e) 82 (f) 25  
 66. (a) cobalt, Co (b) tin, Sn (c) calcium, Ca (d) fluorine, F  
 68. See Figure 2.13. The cloud around the two hydrogen nuclei represents the negative charge cloud generated by the two electrons in the covalent bond that holds the atoms together in the H<sub>2</sub> molecule.  
 70. (a) Neon is composed of separate neon atoms. Its structure is very similar to the structure of He shown in Figure 2.12.  
 (b) Bromine is composed of Br<sub>2</sub> molecules. See Figure 2.16. (c) Nitrogen is composed of N<sub>2</sub> molecules. Its structure is very similar to the structure of H<sub>2</sub> shown in Figure 2.15.  
 72. Each atom in a metallic solid has released one or more electrons, allowing the electrons to move freely throughout the solid. When the atoms lose these electrons, they become cations, which form the organized structure we associate with solids. The released electrons flow between the stationary cations like water flows between islands in the ocean. See Figure 2.18.

### Chapter 3 Exercises

- 3.1 (a) element (b) compound (c) mixture 3.2 (a) molecular (b) ionic



- 3.4 (a) diphosphorus pentoxide (b) phosphorus trichloride (c) carbon monoxide (d) dihydrogen monosulfide or hydrogen sulfide (e) ammonia  
 3.5 (a) S<sub>2</sub>F<sub>10</sub> (b) NF<sub>3</sub> (c) C<sub>3</sub>H<sub>8</sub> (d) HCl  
 3.6 (a) magnesium ion (b) fluoride ion (c) tin(II) ion  
 3.7 (a) Br<sup>-</sup> (b) Al<sup>3+</sup> (c) Au<sup>+</sup>  
 3.8 (a) lithium chloride (b) chromium(III) sulfate  
 (c) ammonium hydrogen carbonate  
 3.9 (a) Al<sub>2</sub>O<sub>3</sub> (b) CoF<sub>3</sub> (c) FeSO<sub>4</sub> (d) (NH<sub>4</sub>)<sub>2</sub>HPO<sub>4</sub> (e) KHCO<sub>3</sub>

### Chapter 3 Review Questions

1. ion 2. cation 3. anion 4. covalent 5. molecule 6. diatomic  
 7. See Figures 2.1, 2.2, and 2.4.  
 8. Protons and neutrons are in a tiny core of the atom called the nucleus, which has a diameter about 1/100,000 the diameter of the atom. The position and motion of the electrons are uncertain, but they generate a negative charge that is felt in the space that surrounds the nucleus.  
 9. The hydrogen atoms are held together by a covalent bond formed due to the sharing of two electrons. See Figure 2.13.  
 10. lithium, Li, 1 or 1A, metal; carbon, C, 14 or 4A, nonmetal; chlorine, Cl, 17 or 7A, nonmetal; oxygen, O, 16 or 6A, nonmetal; copper, Cu, 11 or 1B, metal; calcium, Ca, 2 or 2A, metal; scandium, Sc, 3 or 3B, metal  
 11. (a) halogens (b) noble gases (c) alkali metals (d) alkaline earth metals

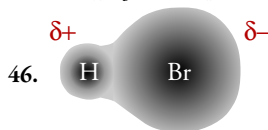
### Chapter 3 Key Ideas

12. whole-number ratio 14. symbols, subscripts 16. variable  
 18. cations, anions 20. negative, positive, partial negative, partial positive  
 22. usually ionic 24. octet 26. four 28. arranged in space

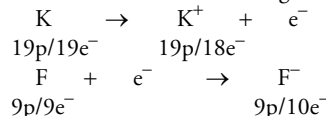
30. electron-charge clouds 32. same average distance apart, constantly breaking, forming new attractions 34. nonmetallic 36. noble gas  
 38. larger, smaller 40. H<sup>+</sup>

### Chapter 3 Problems

42. (a) mixture - variable composition (b) element and pure substance - The symbol K is on the periodic table of the elements. All elements are pure substances. (c) The formula shows the constant composition, so ascorbic acid is a pure substance. The three element symbols in the formula indicate a compound.  
 44. (a) N<sub>2</sub>O<sub>3</sub> (b) SF<sub>4</sub> (c) AlCl<sub>3</sub> (d) Li<sub>2</sub>CO<sub>3</sub>



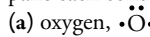
48. The metallic potassium atoms lose one electron and form +1 cations, and the nonmetallic fluorine atoms gain one electron and form -1 anions.



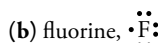
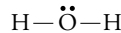
The ionic bonds are the attractions between K<sup>+</sup> cations and F<sup>-</sup> anions.

50. See Figure 3.6.  
 52. (a) covalent...nonmetal-nonmetal (b) ionic...metal-nonmetal  
 54. (a) all nonmetallic atoms - molecular (b) metal-nonmetal - ionic  
 56. (a) 7 (b) 4

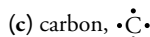
58. Each of the following answers is based on the assumption that non-metallic atoms tend to form covalent bonds in order to get an octet (8) of electrons around each atom, like the very stable noble gases (other than helium). Covalent bonds (represented by lines in Lewis structures) and lone pairs each contribute two electrons to the octet.



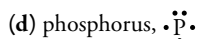
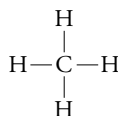
If oxygen atoms form two covalent bonds, they will have an octet of electrons around them. Water is an example:



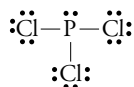
If fluorine atoms form one covalent bond, they will have an octet of electrons around them. Hydrogen fluoride, HF, is an example:



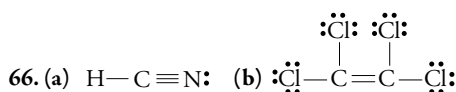
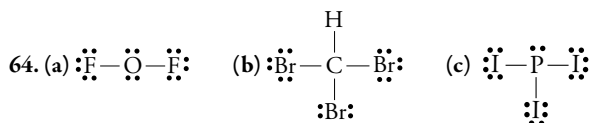
If carbon atoms form four covalent bonds, they will have an octet of electrons around them. Methane, CH<sub>4</sub>, is an example:



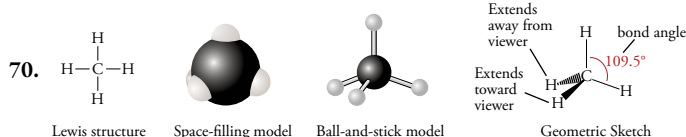
If phosphorus atoms form three covalent bonds, they will have an octet of electrons around them. Phosphorus trichloride, PCl<sub>3</sub>, is an example:



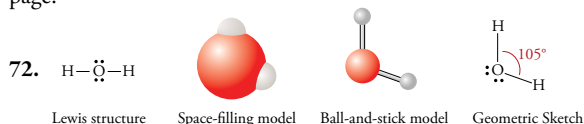
60. The molecule contains a carbon atom, two chlorine atoms, and two fluorine atoms. There are two covalent C-Cl bonds and two covalent C-F bonds. The Cl and F atoms have three lone pairs each.  
 62. (a) H - one bond, no lone pairs (b) iodine - one bond, three lone pairs (c) sulfur - two bonds, two lone pairs (d) N - three bonds, one lone pair



68. (a) methanol and methyl alcohol (b) ethanol and ethyl alcohol  
(c) 2-propanol and isopropyl alcohol



The Lewis structure shows the four covalent bonds between the carbon atoms and the hydrogen atoms. The space-filling model provides the most accurate representation of the electron charge clouds for the atoms in  $\text{CH}_4$ . The ball-and-stick model emphasizes the molecule's correct molecular shape and shows the covalent bonds more clearly. Each ball represents an atom, and each stick represents a covalent bond between two atoms. The geometric sketch shows the three-dimensional tetrahedral structures with a two-dimensional drawing. Picture the hydrogen atoms connected to the central carbon atom with solid lines as being in the same plane as the carbon atom. The hydrogen atom connected to the central carbon with a solid wedge comes out of the plane toward you. The hydrogen atom connected to the carbon atom by a dashed wedge is located back behind the plane of the page.



The Lewis structure shows the two O-H covalent bonds and the two lone pairs on the oxygen atom. The space-filling model provides the most accurate representation of the electron charge clouds for the atoms and the bonding electrons. The ball-and-stick model emphasizes the molecule's correct molecular shape and shows the covalent bonds more clearly. The geometric sketch shows the structure with a two-dimensional drawing.

74. Water is composed of  $\text{H}_2\text{O}$  molecules. Pairs of these molecules are attracted to each other by the attraction between the partially positive hydrogen atom of one molecule and the partially negative oxygen atom of the other molecule. See Figure 3.13. Each water molecule is moving constantly, breaking the attractions to some molecules, and making new attractions to other molecules. Figure 3.14 shows the model we will use to visualize liquid water.

76.  $\text{BrF}_5$  – bromine pentafluoride

78.  $\text{SCl}_2$  – sulfur dichloride

80. (a) diiodine pentoxide (b) bromine trifluoride (c) iodine monobromide (d) methane (e) hydrogen bromide or hydrogen monobromide

82. (a)  $\text{C}_3\text{H}_8$  (b)  $\text{ClF}$  (c)  $\text{P}_4\text{S}_7$  (d)  $\text{CBr}_4$  (e)  $\text{HF}$

84. Because metallic atoms hold some of their electrons relatively loosely, they tend to lose electrons and form cations. Because nonmetallic atoms attract electrons more strongly than metallic atoms, they tend to gain electrons and form anions. Thus, when a metallic atom and a nonmetallic atom combine, the nonmetallic atom often pulls one or more electrons far enough away from the metallic atom to form ions and an ionic bond.

85. (a) 4 protons and 2 electrons (b) 16 protons and 18 electrons

87. (a) calcium ion (b) lithium ion (c) chromium(II) ion

(d) fluoride ion (e) silver ion or silver(I) ion (f) scandium ion

(g) phosphine ion (h) lead(II) ion

89. (a)  $\text{Mg}^{2+}$  (b)  $\text{Na}^+$  (c)  $\text{S}^{2-}$  (d)  $\text{Fe}^{3+}$  (e)  $\text{Sc}^{3+}$  (f)  $\text{N}^{3-}$  (g)  $\text{Mn}^{3+}$  (h)  $\text{Zn}^{2+}$

91. The metallic silver atoms form cations, and the nonmetallic bromine

atoms form anions. The anions and cations alternate in the ionic solid with each cation surrounded by six anions and each anion surrounded by six cations. See Figure 3.18, picturing  $\text{Ag}^+$  ions in the place of the  $\text{Na}^+$  ions and  $\text{Br}^-$  in the place of the  $\text{Cl}^-$  ions.

93. (a) ammonium (b) acetate (c) hydrogen sulfate

95. (a)  $\text{NH}_4^+$  (b)  $\text{HCO}_3^-$  (c)  $\text{HSO}_4^-$

96. (a) sodium oxide (b) nickel(III) oxide (c) lead(II) nitrate

(d) barium hydroxide (e) potassium hydrogen carbonate

98. (a)  $\text{K}_2\text{S}$  (b)  $\text{Zn}_3\text{P}_2$  (c)  $\text{NiCl}_2$  (d)  $\text{Mg}(\text{H}_2\text{PO}_4)_2$  (e)  $\text{LiHCO}_3$

100. copper(II) fluoride, ammonium chloride, cadmium oxide, and mercury(II) sulfate

102.  $\text{CuCl}_2$ ,  $\text{LiNO}_3$ , and  $\text{CdS}$

### Chapter 4 Exercises

4.1. (a)  $\text{P}_4(\text{s}) + 6\text{Cl}_2(\text{g}) \rightarrow 4\text{PCl}_3(\text{l})$

(b)  $3\text{PbO}(\text{s}) + 2\text{NH}_3(\text{g}) \rightarrow 3\text{Pb}(\text{s}) + \text{N}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l})$

(c)  $\text{P}_4\text{O}_{10}(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}_3\text{PO}_4(\text{aq})$

(d)  $3\text{Mn}(\text{s}) + 2\text{CrCl}_3(\text{aq}) \rightarrow 3\text{MnCl}_2(\text{aq}) + 2\text{Cr}(\text{s})$

(e)  $\text{C}_2\text{H}_2(\text{g}) + \frac{5}{2}\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$

or  $2\text{C}_2\text{H}_2(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$

(f)  $3\text{Co}(\text{NO}_3)_2(\text{aq}) + 2\text{Na}_3\text{PO}_4(\text{aq}) \rightarrow \text{Co}_3(\text{PO}_4)_2(\text{s}) + 6\text{NaNO}_3(\text{aq})$

(g)  $2\text{CH}_3\text{NH}_2(\text{g}) + \frac{9}{2}\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 5\text{H}_2\text{O}(\text{l}) + \text{N}_2(\text{g})$

or  $4\text{CH}_3\text{NH}_2(\text{g}) + 9\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l}) + 2\text{N}_2(\text{g})$

(h)  $2\text{FeS}(\text{s}) + \frac{9}{2}\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{Fe}_2\text{O}_3(\text{s}) + 2\text{H}_2\text{SO}_4(\text{aq})$

or  $4\text{FeS}(\text{s}) + 9\text{O}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{Fe}_2\text{O}_3(\text{s}) + 4\text{H}_2\text{SO}_4(\text{aq})$

4.2. (a) soluble (b) insoluble (c) soluble (d) insoluble (e) insoluble

4.3. (a)  $3\text{CaCl}_2(\text{aq}) + 2\text{Na}_3\text{PO}_4(\text{aq}) \rightarrow \text{Ca}_3(\text{PO}_4)_2(\text{s}) + 6\text{NaCl}(\text{aq})$

(b)  $3\text{KOH}(\text{aq}) + \text{Fe}(\text{NO}_3)_3(\text{aq}) \rightarrow 3\text{KNO}_3(\text{aq}) + \text{Fe}(\text{OH})_3(\text{s})$

(c)  $\text{NaC}_2\text{H}_3\text{O}_2(\text{aq}) + \text{CaSO}_4(\text{aq})$  No Reaction

(d)  $\text{K}_2\text{SO}_4(\text{aq}) + \text{Pb}(\text{NO}_3)_2(\text{aq}) \rightarrow 2\text{KNO}_3(\text{aq}) + \text{PbSO}_4(\text{s})$

### Chapter 4 Review Questions

1.  $\text{H}_2$ ,  $\text{N}_2$ ,  $\text{O}_2$ ,  $\text{F}_2$ ,  $\text{Cl}_2$ ,  $\text{Br}_2$ ,  $\text{I}_2$

2. (a) ionic (b) covalent (c) ionic (d) covalent

3. Water is composed of  $\text{H}_2\text{O}$  molecules that are attracted to each other due to the attraction between partially positive hydrogen atoms and the partially negative oxygen atoms of other molecules. See Figure 3.13. Each water molecule is moving constantly, breaking the attractions to some molecules, and making new attractions to other molecules. See Figure 3.14.

4. (a)  $\text{NH}_3$  (b)  $\text{CH}_4$  (c)  $\text{C}_3\text{H}_8$  (d)  $\text{H}_2\text{O}$

5. (a)  $\text{NO}_2$  (b)  $\text{CBr}_4$  (c)  $\text{Br}_2\text{O}$  (d)  $\text{NO}$

6. (a)  $\text{LiF}$  (b)  $\text{Pb}(\text{OH})_2$  (c)  $\text{K}_2\text{O}$  (d)  $\text{Na}_2\text{CO}_3$  (e)  $\text{CrCl}_3$  (f)  $\text{Na}_2\text{HPO}_4$

### Chapter 4 Key Ideas

7. converted into 9. shorthand description 11. continuous, delta,  $\Delta$

13. subscripts 15. same proportions 17. solute, solvent 19. minor, major

21. organized, repeating 23. left out

### Chapter 4 Problems

25. For each two particles of solid copper(I) hydrogen carbonate that are heated strongly, one particle of solid copper(I) carbonate, one molecule of liquid water, and one molecule of gaseous carbon dioxide are formed.

27. (a)  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$

(b)  $4\text{Cl}_2(\text{g}) + 2\text{CH}_4(\text{g}) + \text{O}_2(\text{g}) \rightarrow 8\text{HCl}(\text{g}) + 2\text{CO}(\text{g})$

(c)  $\text{B}_2\text{O}_3(\text{s}) + 6\text{NaOH}(\text{aq}) \rightarrow 2\text{Na}_3\text{BO}_3(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$

(d)  $2\text{Al}(\text{s}) + 2\text{H}_3\text{PO}_4(\text{aq}) \rightarrow 2\text{AlPO}_4(\text{s}) + 3\text{H}_2(\text{g})$

(e)  $\text{CO}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$  or  $2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g})$

(f)  $\text{C}_6\text{H}_{14}(\text{l}) + \frac{19}{2}\text{O}_2(\text{g}) \rightarrow 6\text{CO}_2(\text{g}) + 7\text{H}_2\text{O}(\text{l})$

or  $2\text{C}_6\text{H}_{14}(\text{l}) + 19\text{O}_2(\text{g}) \rightarrow 12\text{CO}_2(\text{g}) + 14\text{H}_2\text{O}(\text{l})$

(g)  $\text{Sb}_2\text{S}_3(\text{s}) + \frac{9}{2}\text{O}_2(\text{g}) \rightarrow \text{Sb}_2\text{O}_3(\text{s}) + 3\text{SO}_2(\text{g})$

or  $2\text{Sb}_2\text{S}_3(\text{s}) + 9\text{O}_2(\text{g}) \rightarrow 2\text{Sb}_2\text{O}_3(\text{s}) + 6\text{SO}_2(\text{g})$

(h)  $2\text{Al}(\text{s}) + 3\text{CuSO}_4(\text{aq}) \rightarrow \text{Al}_2(\text{SO}_4)_3(\text{aq}) + 3\text{Cu}(\text{s})$

(i)  $3\text{P}_2\text{H}_4(\text{l}) \rightarrow 4\text{PH}_3(\text{g}) + \frac{1}{2}\text{P}_4(\text{s})$  or  $6\text{P}_2\text{H}_4(\text{l}) \rightarrow 8\text{PH}_3(\text{g}) + \text{P}_4(\text{s})$

29.  $\text{CS}_2 + 3\text{Cl}_2 \rightarrow \text{S}_2\text{Cl}_2 + \text{CCl}_4$   
 $4\text{CS}_2 + 8\text{S}_2\text{Cl}_2 \rightarrow 3\text{S}_8 + 4\text{CCl}_4$   
 $\text{S}_8 + 4\text{C} \rightarrow 4\text{CS}_2$
31.  $2\text{HF} + \text{CHCl}_3 \rightarrow \text{CHClF}_2 + 2\text{HCl}$
33. When solid lithium iodide is added to water, all of the ions at the surface of the solid can be viewed as vibrating back and forth between moving out into the water and returning to the solid surface. Sometimes when an ion vibrates out into the water, a water molecule collides with it, helping to break the ionic bond, and pushing it out into the solution. Water molecules move into the gap between the ion in solution and the solid and shield the ion from the attraction to the solid. The ions are kept stable and held in solution by attractions between them and the polar water molecules. The negatively charged oxygen ends of water molecules surround the lithium ions, and the positively charged hydrogen ends of water molecules surround the iodide ions. (See Figures 4.4 and 4.5 with  $\text{Li}^+$  in the place of  $\text{Na}^+$  and  $\text{I}^-$  in the place of  $\text{Cl}^-$ .)
35. Same answer as problem 33 but with sodium ions,  $\text{Na}^+$ , instead of lithium ions,  $\text{Li}^+$ , and sulfate ions,  $\text{SO}_4^{2-}$ , in the place of iodide ions,  $\text{I}^-$ . The final solution will have two times as many sodium ions as sulfate ions.
37. In a solution of a solid in a liquid, the solid is generally considered the solute, and the liquid is the solvent. Therefore, camphor is the solute in this solution, and ethanol is the solvent.
40. At the instant that the solution of silver nitrate is added to the aqueous sodium bromide, there are four different ions in solution surrounded by water molecules,  $\text{Ag}^+$ ,  $\text{NO}_3^-$ ,  $\text{Na}^+$ , and  $\text{Br}^-$ . The oxygen ends of the water molecules surround the silver and sodium cations, and the hydrogen ends of water molecules surround the nitrate and bromide anions. When silver ions and bromide ions collide, they stay together long enough for other silver ions and bromide ions to collide with them, forming clusters of ions that precipitate from the solution. The sodium and nitrate ions are unchanged in the reaction. They were separate and surrounded by water molecules at the beginning of the reaction, and they are still separate and surrounded by water molecules at the end of the reaction. See Figures 4,7 to 4,9 with silver ions in the place of calcium ions and bromide ions in the place of carbonate ions.
42. (a) soluble (b) soluble (c) insoluble (d) insoluble
44. (a) insoluble (b) soluble (c) soluble (d) insoluble
46. (a)  $\text{Co}(\text{NO}_3)_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{CoCO}_3(\text{s}) + 2\text{NaNO}_3(\text{aq})$   
 (b)  $2\text{KI}(\text{aq}) + \text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2(\text{aq}) \rightarrow 2\text{KC}_2\text{H}_3\text{O}_2(\text{aq}) + \text{PbI}_2(\text{s})$   
 (c)  $\text{CuSO}_4(\text{aq}) + \text{LiNO}_3(\text{aq})$  No reaction  
 (d)  $3\text{Ni}(\text{NO}_3)_2(\text{aq}) + 2\text{Na}_3\text{PO}_4(\text{aq}) \rightarrow \text{Ni}_3(\text{PO}_4)_2(\text{s}) + 6\text{NaNO}_3(\text{aq})$   
 (e)  $\text{K}_2\text{SO}_4(\text{aq}) + \text{Ba}(\text{NO}_3)_2(\text{aq}) \rightarrow 2\text{KNO}_3(\text{aq}) + \text{BaSO}_4(\text{s})$
48.  $\text{Al}^{3+}(\text{aq}) + \text{PO}_4^{3-}(\text{aq}) \rightarrow \text{AlPO}_4(\text{s})$
50.  $\text{Cd}(\text{C}_2\text{H}_3\text{O}_2)_2(\text{aq}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{Cd}(\text{OH})_2(\text{s}) + 2\text{NaC}_2\text{H}_3\text{O}_2(\text{aq})$
52. (a)  $\text{SiCl}_4 + 2\text{H}_2\text{O} \rightarrow \text{SiO}_2 + 4\text{HCl}$   
 (b)  $2\text{H}_3\text{BO}_3 \rightarrow \text{B}_2\text{O}_3 + 3\text{H}_2\text{O}$   
 (c)  $\text{I}_2 + 3\text{Cl}_2 \rightarrow 2\text{ICl}_3$   
 (d)  $2\text{Al}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Al} + 3\text{CO}_2$
54. (a)  $4\text{NH}_3 + \text{Cl}_2 \rightarrow \text{N}_2\text{H}_4 + 2\text{NH}_4\text{Cl}$   
 (b)  $\text{Cu} + 2\text{AgNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + 2\text{Ag}$   
 (c)  $\text{Sb}_2\text{S}_3 + 6\text{HNO}_3 \rightarrow 2\text{Sb}(\text{NO}_3)_3 + 3\text{H}_2\text{S}$   
 (d)  $\text{Al}_2\text{O}_3 + 3\text{Cl}_2 + 3\text{C} \rightarrow 2\text{AlCl}_3 + 3\text{CO}$
56.  $2\text{Ca}_3(\text{PO}_4)_2 + 6\text{SiO}_2 + 10\text{C} \rightarrow \text{P}_4 + 10\text{CO} + 6\text{CaSiO}_3$   
 $\text{P}_4 + 5\text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4\text{H}_3\text{PO}_4$
58. (a) soluble (b) soluble (c) insoluble (d) insoluble
60. (a)  $\text{NaCl}(\text{aq}) + \text{Al}(\text{NO}_3)_3(\text{aq})$  No reaction  
 (b)  $\text{Ni}(\text{NO}_3)_2(\text{aq}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{Ni}(\text{OH})_2(\text{s}) + 2\text{NaNO}_3(\text{aq})$   
 (c)  $3\text{MnCl}_2(\text{aq}) + 2\text{Na}_3\text{PO}_4(\text{aq}) \rightarrow \text{Mn}_3(\text{PO}_4)_2(\text{s}) + 6\text{NaCl}(\text{aq})$   
 (d)  $\text{Zn}(\text{C}_2\text{H}_3\text{O}_2)_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{ZnCO}_3(\text{s}) + 2\text{NaC}_2\text{H}_3\text{O}_2(\text{aq})$
62.  $\text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl}$
64.  $\text{Al}_2\text{O}_3 + 3\text{H}_2\text{SO}_4 \rightarrow \text{Al}_2(\text{SO}_4)_3 + 3\text{H}_2\text{O}$
66.  $\text{CaF}_2 + \text{H}_2\text{SO}_4 \rightarrow 2\text{HF} + \text{CaSO}_4$
68.  $\text{Na}_2\text{CO}_3 + \text{Ca}(\text{OH})_2 \rightarrow 2\text{NaOH} + \text{CaCO}_3$

71.  $\text{CaCO}_3 + 2\text{NaCl} \rightarrow \text{Na}_2\text{CO}_3 + \text{CaCl}_2$
73.  $\text{NH}_3 + 2\text{O}_2 \rightarrow \text{HNO}_3 + \text{H}_2\text{O}$
75.  $\text{C}_3\text{H}_8(\text{g}) + 6\text{H}_2\text{O}(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 10\text{H}_2(\text{g})$
77. (a)  $\text{C} + \frac{1}{2}\text{O}_2 \rightarrow \text{CO}$  or  $2\text{C} + \text{O}_2 \rightarrow 2\text{CO}$   
 (b)  $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$   
 (c)  $2\text{CO} \rightarrow \text{C} + \text{CO}_2$
79. Add a water solution of an ionic compound that forms an insoluble substance with aluminum ions and a soluble substance with sodium ions. For example, a potassium carbonate solution would precipitate the aluminum ions as  $\text{Al}_2(\text{CO}_3)_3$ .
81.  $\text{FeCl}_3(\text{aq}) + 3\text{AgNO}_3(\text{aq}) \rightarrow \text{Fe}(\text{NO}_3)_3(\text{aq}) + 3\text{AgCl}(\text{s})$
83.  $2\text{C}_5\text{H}_{11}\text{NSO}_2(\text{s}) + 3\frac{1}{2}\text{O}_2(\text{g})$   
 $\rightarrow 10\text{CO}_2(\text{g}) + 11\text{H}_2\text{O}(\text{l}) + 2\text{SO}_2(\text{g}) + \text{N}_2(\text{g})$   
 or  $4\text{C}_5\text{H}_{11}\text{NSO}_2(\text{s}) + 31\text{O}_2(\text{g})$   
 $\rightarrow 20\text{CO}_2(\text{g}) + 22\text{H}_2\text{O}(\text{l}) + 4\text{SO}_2(\text{g}) + 2\text{N}_2(\text{g})$

## Chapter 5 Exercises

- 5.1. (a)  $\text{HF}(\text{aq})$  (b)  $\text{H}_3\text{PO}_4$
- 5.2 (a) hydriodic acid. (The "o" in hydro- is usually left off.) (b) acetic acid
- 5.3 (a) aluminum fluoride (b) phosphorus trifluoride (c) phosphoric acid  
 (d) calcium sulfate (e) calcium hydrogen sulfate (f) copper(II) chloride  
 (g) ammonium fluoride (h) hydrochloric acid (i) ammonium phosphate
- 5.4. (a)  $\text{NH}_4\text{NO}_3$  (b)  $\text{HC}_2\text{H}_3\text{O}_2$  (c)  $\text{NaHSO}_4$  (d)  $\text{KBr}$  (e)  $\text{MgHPO}_4$   
 (f)  $\text{HF}(\text{aq})$  (g)  $\text{P}_2\text{O}_4$  (h)  $\text{Al}_2(\text{CO}_3)_3$  (i)  $\text{H}_2\text{SO}_4$
- 5.5. (a) strong acid (b) strong base (c) weak base (d) weak acid
- 5.6. (a)  $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{NaCl}(\text{aq})$   
 (b)  $\text{HF}(\text{aq}) + \text{LiOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{LiF}(\text{aq})$   
 (c)  $\text{H}_3\text{PO}_4(\text{aq}) + 3\text{LiOH}(\text{aq}) \rightarrow 3\text{H}_2\text{O}(\text{l}) + \text{Li}_3\text{PO}_4(\text{aq})$   
 (d)  $\text{Fe}(\text{OH})_3(\text{s}) + 3\text{HNO}_3(\text{aq}) \rightarrow \text{Fe}(\text{NO}_3)_3(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$
- 5.7.  $\text{Na}_2\text{CO}_3(\text{aq}) + 2\text{HBr}(\text{aq}) \rightarrow 2\text{NaBr}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
- 5.8. (a)  $\text{HNO}_2$  (b)  $\text{H}_2\text{CO}_3$  (c)  $\text{H}_3\text{O}^+$  (d)  $\text{HPO}_4^{2-}$
- 5.9. (a)  $\text{HC}_2\text{O}_4^-$  (b)  $\text{BrO}_4^-$  (c)  $\text{NH}_2^-$  (d)  $\text{HPO}_4^{2-}$
- 5.10. (a)  $\text{HNO}_2$ (B/L acid),  $\text{NaBrO}$ (B/L base) (b)  $\text{HNO}_2$ (B/L acid),  $\text{H}_2\text{AsO}_4^-$ (B/L base) (c)  $\text{H}_2\text{AsO}_4^-$ (B/L acid),  $2\text{OH}^-$ (B/L base)

## Chapter 5 Review Questions

1. (a) Aqueous solutions are water solutions. (b) Spectator ions are ions that are important for delivering other ions into solution to react, but do not actively participate in the reaction themselves.  
 (c) A double displacement reaction is a chemical reaction that has the following form.  
 $\text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB}$   
 (d) A net ionic equation is a chemical equation for which the spectator ions have been eliminated leaving only the substances actively involved in the reaction.
2. (a) carbonate (b) hydrogen carbonate 3. (a)  $\text{H}_2\text{PO}_4^-$  (b)  $\text{C}_2\text{H}_3\text{O}_2^-$
4. (a) ionic (b) not ionic (c) ionic (d) ionic (e) not ionic
5. (a) potassium bromide (b) copper(II) nitrate (c) ammonium hydrogen phosphate 6. (a)  $\text{Ni}(\text{OH})_2$  (b)  $\text{NH}_4\text{Cl}$  (c)  $\text{Ca}(\text{HCO}_3)_2$
7. (a) insoluble (b) insoluble (c) soluble (d) soluble
8. When solid sodium hydroxide,  $\text{NaOH}$ , is added to water, all of the sodium ions,  $\text{Na}^+$ , and hydroxide ions,  $\text{OH}^-$ , at the surface of the solid can be viewed as shifting back and forth between moving out into the water and returning to the solid surface. Sometimes when an ion moves out into the water, a water molecule collides with it, helping to break the ionic bond, and pushing it out into the solution. Water molecules move into the gap between the ion in solution and the solid and shield the ion from the attraction to the solid. The ions are kept stable and held in solution by attractions between them and the polar water molecules. The negatively charged oxygen ends of water molecules surround the sodium ions, and the positively charged hydrogen ends of water molecules surround the hydroxide ions. (See Figures 4.4 and 4.5 with  $\text{OH}^-$  in the place of  $\text{Cl}^-$ .)
9.  $3\text{ZnCl}_2(\text{aq}) + 2\text{Na}_3\text{PO}_4(\text{aq}) \rightarrow \text{Zn}_3(\text{PO}_4)_2(\text{s}) + 6\text{NaCl}(\text{aq})$

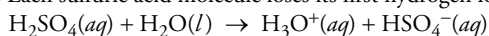
## Chapter 5 Key Ideas

10. sour 12. acidic 14.  $H_aX_bO_c$  16. nearly one, significantly less than one  
 18. weak 20. hydro, -ic, acid 22. hydroxide ions,  $OH^-$  24. hydroxides  
 26. fewer 28. greater than 7, higher 30. neutralize  
 32. double-displacement 34. donor, acceptor, transfer 36. removed  
 38. Brønsted-Lowry, Arrhenius

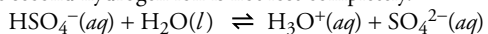
## Chapter 5 Problems

39. When  $HNO_3$  molecules dissolve in water, each  $HNO_3$  molecule donates a proton,  $H^+$ , to water forming hydronium ion,  $H_3O^+$ , and nitrate ion,  $NO_3^-$ . This reaction goes to completion, and the solution of the  $HNO_3$  contains essentially no uncharged acid molecules. Once the nitrate ion and the hydronium ion are formed, the negatively charged oxygen atoms of the water molecules surround the hydronium ion and the positively charged hydrogen atoms of the water molecules surround the nitrate ion. Figure 5.12 shows you how you can picture this solution.

41. Each sulfuric acid molecule loses its first hydrogen ion completely.



The second hydrogen ion is not lost completely.



In a typical solution of sulfuric acid, for each 100 sulfuric acid molecules added to water, the solution contains about 101 hydronium ions,  $H_3O^+$ , 99 hydrogen sulfate ions,  $HSO_4^-$ , and 1 sulfate ion,  $SO_4^{2-}$ .

43. A weak acid is a substance that is incompletely ionized in water due to a reversible reaction with water that forms hydronium ion,  $H_3O^+$ . A strong acid is a substance that is completely ionized in water due to a completion reaction with water that forms hydronium ions,  $H_3O^+$ .

45. (a) weak (b) strong (c) weak

47. (a) weak (b) weak (c) weak

49. (a)  $HNO_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_2^-(aq)$

(b)  $HBr(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Br^-(aq)$

51. (a)  $HNO_3$ , nitric acid (b)  $H_2CO_3$ , carbonic acid

(c)  $H_3PO_4$ , phosphoric acid

53. (a) oxyacid,  $H_3PO_4$  (b) ionic compound with polyatomic ion,  $NH_4Br$  (c) binary covalent compound,  $P_2I_4$  (d) ionic compound with polyatomic ion,  $LiHSO_4$  (e) binary acid,  $HCl(aq)$  (f) binary ionic compound,  $Mg_3N_2$  (g) oxyacid,  $HC_2H_3O_2$  (h) ionic compound with polyatomic ion,  $PbHPO_4$

55. (a) binary acid, hydrobromic acid (b) binary covalent compound, chlorine trifluoride (c) binary ionic compound, calcium bromide (d) ionic compound with polyatomic ion, iron(III) sulfate (e) oxyacid, carbonic acid (f) ionic compound with polyatomic ion, ammonium sulfate (g) ionic compound with polyatomic ion, potassium hydrogen sulfate

58. (a) weak acid (b) strong base (c) weak acid (d) weak base

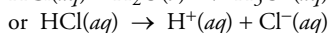
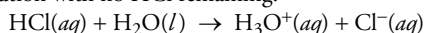
(e) weak base (f) weak acid (g) strong acid (h) weak acid

60. (a) acidic (b) basic (c) essentially neutral (or more specifically, very slightly acidic)

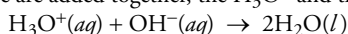
62. Carbonated water is more acidic than milk.

64. (a) acid (b) acid (c) base

66. Because hydrochloric acid,  $HCl(aq)$ , is an acid, it reacts with water to form hydronium ions,  $H_3O^+$ , and chloride ions,  $Cl^-$ . Because it is a strong acid, the reaction is a completion reaction, leaving only  $H_3O^+$  and  $Cl^-$  in solution with no  $HCl$  remaining.

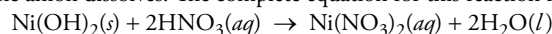


Because  $NaOH$  is a water-soluble ionic compound, it separates into sodium ions,  $Na^+$ , and hydroxide ions,  $OH^-$ , when it dissolves in water. Thus, at the instant that the two solutions are mixed, the solution contains water molecules, hydronium ions,  $H_3O^+$ , chloride ions,  $Cl^-$ , sodium ions,  $Na^+$ , and hydroxide ions,  $OH^-$ . When the hydronium ions collide with the hydroxide ions, they react to form water. If an equivalent amount of acid and base are added together, the  $H_3O^+$  and the  $OH^-$  will be completely reacted.

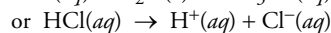
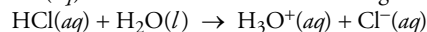


The sodium ions and chloride ions remain in solution with the water molecules.

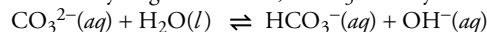
68. A solution with an insoluble ionic compound, such as  $Ni(OH)_2$ , at the bottom has a constant escape of ions from the solid into the solution balanced by the constant return of ions to the solid due to collisions of ions with the surface of the solid. Thus, even though  $Ni(OH)_2$  has very low solubility in water, there are always a few  $Ni^{2+}$  and  $OH^-$  ions in solution. If a nitric acid solution is added to water with solid  $Ni(OH)_2$  at the bottom, a neutralization reaction takes place. Because the nitric acid is a strong acid, it is ionized in solution, so the nitric acid solution contains hydronium ions,  $H_3O^+$ , and nitrate ions,  $NO_3^-$ . The hydronium ions will react with the basic hydroxide ions in solution to form water molecules. Because the hydronium ions remove the hydroxide anions from solution, the return of ions to the solid is stopped. The nickel(II) cations cannot return to the solid unless they are accompanied by anions to balance their charge. The escape of ions from the surface of the solid continues. When hydroxide ions escape, they react with the hydronium ions and do not return to the solid. Thus there is a steady movement of ions into solution, and the solid that contains the basic anion dissolves. The complete equation for this reaction is below.



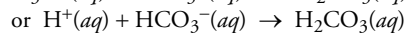
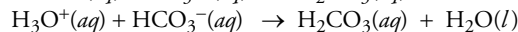
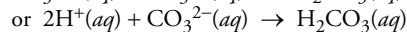
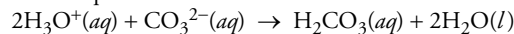
70. Because hydrochloric acid,  $HCl(aq)$ , is an acid, it reacts with water to form hydronium ions,  $H_3O^+$ , and chloride ions,  $Cl^-$ . Because it is a strong acid, the reaction is a completion reaction, leaving only  $H_3O^+$  and  $Cl^-$  in an  $HCl(aq)$  solution with no  $HCl$  remaining.



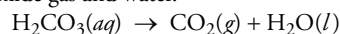
Because  $K_2CO_3$  is a water-soluble ionic compound, it separates into potassium ions,  $K^+$ , and carbonate ions,  $CO_3^{2-}$ , when it dissolves in water. The carbonate ions are weakly basic, so they react with water in a reversible reaction to form hydrogen carbonate,  $HCO_3^-$  and hydroxide,  $OH^-$ .



Thus, at the instant that the two solutions are mixed, the solution contains water molecules, hydronium ions,  $H_3O^+$ , chloride ions,  $Cl^-$ , potassium ions,  $K^+$ , carbonate ions,  $CO_3^{2-}$ , hydrogen carbonate ions,  $HCO_3^-$ , and hydroxide ions,  $OH^-$ . The hydronium ions react with hydroxide ions, carbonate ions, and hydrogen carbonate ions. When the hydronium ions collide with the hydroxide ions, they react to form water. When the hydronium ions collide with the carbonate ions or hydrogen carbonate ions, they react to form carbonic acid,  $H_2CO_3$ . The carbonate with its minus two charge requires two  $H^+$  ions to yield a neutral compound, and the hydrogen carbonate requires one  $H^+$  to neutralize its minus one charge.



The carbonic acid is unstable in water and decomposes to form carbon dioxide gas and water.



If an equivalent amount of acid and base are added together, the  $H_3O^+$ ,  $OH^-$ ,  $CO_3^{2-}$ , and  $HCO_3^-$ , will be completely reacted. The potassium ions and chloride ions remain in solution with the water molecules.

72. (a)  $HCl(aq) + LiOH(aq) \rightarrow H_2O(l) + LiCl(aq)$

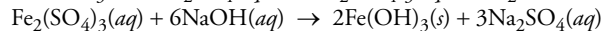
(b)  $H_2SO_4(aq) + 2NaOH(aq) \rightarrow 2H_2O(l) + Na_2SO_4(aq)$

(c)  $KOH(aq) + HF(aq) \rightarrow KF(aq) + H_2O(l)$

(d)  $Cd(OH)_2(s) + 2HCl(aq) \rightarrow CdCl_2(aq) + 2H_2O(l)$

74.  $2HI(aq) + CaCO_3(s) \rightarrow H_2O(l) + CO_2(g) + CaI_2(aq)$

76.  $2Fe(OH)_3(s) + 3H_2SO_4(aq) \rightarrow Fe_2(SO_4)_3(aq) + 6H_2O(l)$

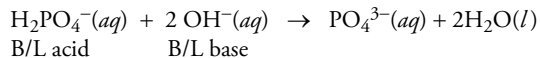
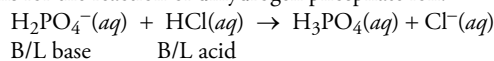
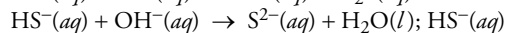


78. (a)  $HCl(aq) + NaOH(aq) \rightarrow H_2O(l) + NaCl(aq)$

(b)  $H_2SO_4(aq) + 2LiOH(aq) \rightarrow 2H_2O(l) + Li_2SO_4(aq)$

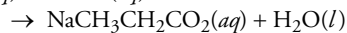
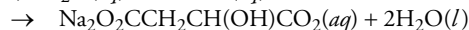
(c)  $2HCl(aq) + K_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g) + 2KCl(aq)$

81. (a)  $HIO_3$  (b)  $H_2SO_3$  (c)  $HPO_3^{2-}$  (d)  $H_2$

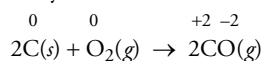
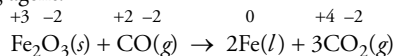
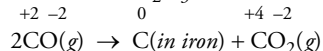
83. (a)  $\text{ClO}_4^-$  (b)  $\text{SO}_3^{2-}$  (c)  $\text{H}_2\text{O}$  (d)  $\text{H}_2\text{PO}_2^-$ 85. The same substance can donate an  $\text{H}^+$  in one reaction (and act as a Brønsted-Lowry acid) and accept an  $\text{H}^+$  in another reaction (and act as a Brønsted-Lowry base). For example, consider the following net ionic equations for the reaction of dihydrogen phosphate ion.87. (a) NaCN (B/L base),  $\text{HC}_2\text{H}_3\text{O}_2$  (B/L acid)(b)  $\text{H}_2\text{PO}_3^-$  (B/L base), HF (B/L acid)(c)  $\text{H}_2\text{PO}_3^-$  (B/L acid),  $2\text{OH}^-$  (B/L base)(d) 3NaOH (B/L base),  $\text{H}_3\text{PO}_3$  (B/L acid)89. Conjugate base -  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2^-$  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$  (B/L acid),  $\text{H}_2\text{O}$  (B/L base)91.  $\text{HCl}(aq) + \text{HS}^-(aq) \rightarrow \text{Cl}^-(aq) + \text{H}_2\text{S}(aq)$ 93. (a)  $\text{HBr}(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(l) + \text{NaBr}(aq)$ (b)  $\text{H}_2\text{SO}_3(aq) + 2\text{LiOH}(aq) \rightarrow 2\text{H}_2\text{O}(l) + \text{Li}_2\text{SO}_3(aq)$ (c)  $\text{KHCO}_3(aq) + \text{HF}(aq) \rightarrow \text{KF}(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)$ (d)  $\text{Al}(\text{OH})_3(s) + 3\text{HNO}_3(aq) \rightarrow \text{Al}(\text{NO}_3)_3(aq) + 3\text{H}_2\text{O}(l)$ 

95. (a) acidic (b) basic (c) very slightly basic (essentially neutral)

97. acidic

99.  $\text{CaCO}_3(s) + 2\text{H}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)$ 100.  $\text{H}_2\text{SO}_4(aq) + \text{Mg}(\text{OH})_2(s) \rightarrow 2\text{H}_2\text{O}(l) + \text{MgSO}_4(aq)$ 102.  $\text{CH}_3\text{CH}_2\text{CO}_2\text{H}(aq) + \text{NaOH}(aq)$ 104.  $\text{HO}_2\text{CCH}_2\text{CH}(\text{OH})\text{CO}_2\text{H}(aq) + 2\text{NaOH}(aq)$ 106. NaHS (B/L base),  $\text{NaHSO}_4$  (B/L acid)Conjugate acid base pairs:  $\text{HS}^-/\text{H}_2\text{S}$  and  $\text{HSO}_4^-/\text{SO}_4^{2-}$ or  $\text{NaHS}/\text{H}_2\text{S}$  and  $\text{NaHSO}_4^-/\text{Na}_2\text{SO}_4$ **Chapter 6 Exercises**

6.1. They are all redox reactions.

C(s) is oxidized and is the reducing agent.  $\text{O}_2$  is reduced and is the oxidizing agent.Each carbon atom in  $\text{CO}(g)$  is oxidized, and  $\text{CO}(g)$  is the reducing agent.Each Fe atom in  $\text{Fe}_2\text{O}_3$  is reduced, and  $\text{Fe}_2\text{O}_3$  is the oxidizing agent.Some of the carbon atoms in  $\text{CO}(g)$  are oxidized from +2 to +4, and some of them are reduced from +2 to 0. Thus carbon atoms in CO are both oxidized and reduced, and CO is both the oxidizing agent and the reducing agent.6.2. (a)  $2\text{C}_4\text{H}_{10}(g) + 13\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(l)$ (b)  $2\text{C}_3\text{H}_7\text{OH}(l) + 9\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 8\text{H}_2\text{O}(l)$ (c)  $2\text{C}_4\text{H}_9\text{SH}(l) + 15\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(l) + 2\text{SO}_2(g)$ 

6.3. (a) decomposition (b) combustion (c) single displacement

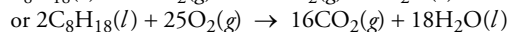
(d) combination

**Chapter 6 Review Questions**1. (a)  $\text{Fe}^{3+}$  and  $\text{Br}^-$  (b)  $\text{Co}^{2+}$  and  $\text{PO}_4^{3-}$  (c)  $\text{Ag}^+$  and  $\text{Cl}^-$ (d)  $\text{NH}_4^+$  and  $\text{SO}_4^{2-}$ 

2. (a) molecular (b) ionic with polyatomic ion (c) binary ionic

(d) molecular (e) molecular (f) molecular (g) ionic with polyatomic ion

(h) molecular

3. (a)  $\text{C}_8\text{H}_{18}(l) + 25/2\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 9\text{H}_2\text{O}(l)$ (b)  $4\text{P}_4(s) + 5\text{S}_8(s) \rightarrow 8\text{P}_2\text{S}_5(s)$ **Chapter 6 Key Ideas**

4. loses 6. rarely, oxidized, reduced, oxidation, reduction 8. half-reactions

10. oxidizing agent 12. flow of electrons 14. two or more 16. heat, light

18. water 20. pure element 21. voltaic cells, chemical energy, electrical

energy 23. electrical conductors 25. reduction, positive electrode

27. force, electrolysis

**Chapter 6 Problems**

30. (a) complete – ionic bonds formed (b) incomplete – polar covalent bonds formed

32. (a) incomplete – polar covalent bonds formed (b) incomplete – polar covalent bonds formed

34.  $2\text{Al} \rightarrow 2\text{Al}^{3+} + 6e^-$  oxidation – loss of electrons $3\text{Br}_2 + 6e^- \rightarrow 6\text{Br}^-$  reduction – gain of electrons

36. (a) S is zero. (b) S is –2. (c) Na is +1, and the S is –2. (d) The Fe is +2, and the S is –2.

38. (a) Each Sc is +3, and each O is –2. (b) The Rb is +1, and the H is –1.

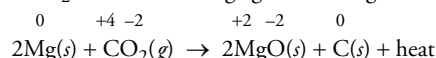
(c) N is zero. (d) H is +1. N is –3.

40. (a) Cl is +3. F is –1. (b) H is +1. O is –1.

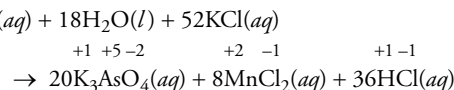
(c) H is +1. O is –2. S is +6.

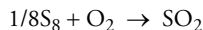
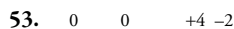
42. (a) H is +1. O is –2. P is +5. (b) The Ni is +2. O is –2. S is +6.

(c) O is –2. N is +3. (d) Mn is +2. O is –2. P is +5.

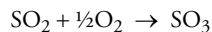
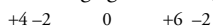
45.  $\begin{array}{ccc} 0 & 0 & +1 \quad -1 \\ \text{Cl}_2(g) + \text{H}_2(g) & \rightarrow & 2\text{HCl}(g) \end{array}$ Yes, it's redox. H atoms in  $\text{H}_2$  are oxidized, Cl atoms in  $\text{Cl}_2$  are reduced,  $\text{Cl}_2$  is the oxidizing agent, and  $\text{H}_2$  is the reducing agent.47.  $\begin{array}{cccc} 0 & +1 & -2 & +2 & -2 & +1 & 0 \\ \text{Mg}(s) + 2\text{H}_2\text{O}(l) & \rightarrow & \text{Mg}(\text{OH})_2(aq) + \text{H}_2(g) + \text{heat} \end{array}$ Yes, it's redox. Mg atoms in  $\text{Mg}(s)$  are oxidized, H atoms in  $\text{H}_2\text{O}$  are reduced,  $\text{H}_2\text{O}$  is the oxidizing agent, and Mg is the reducing agent.Yes, it's redox. Mg atoms in  $\text{Mg}(s)$  are oxidized, C atoms in  $\text{CO}_2$  are reduced,  $\text{CO}_2$  is the oxidizing agent, and Mg is the reducing agent.49.  $\begin{array}{cccc} -2 & +1 & -2 & +1 & 0 & 0 & +1 & -2 & +1 & -2 \\ 2\text{CH}_3\text{OH} + \text{O}_2 & \rightarrow & 2\text{CH}_2\text{O} + 2\text{H}_2\text{O} \end{array}$ Yes, it's redox. C atoms in  $\text{CH}_3\text{OH}$  are oxidized, O atoms in  $\text{O}_2$  are reduced,  $\text{O}_2$  is the oxidizing agent, and  $\text{CH}_3\text{OH}$  is the reducing agent.51.  $\begin{array}{cccc} 0 & +1 & +5 & -2 & +2 & +5 & -2 & 0 \\ \text{Co}(s) + 2\text{AgNO}_3(aq) & \rightarrow & \text{Co}(\text{NO}_3)_2(aq) + 2\text{Ag}(s) \end{array}$ Co in  $\text{Co}(s)$  is oxidized, and  $\text{Co}(s)$  is the reducing agent. Ag in  $\text{AgNO}_3$  is reduced, and  $\text{AgNO}_3$  is the oxidizing agent.(b)  $\begin{array}{cccc} +5 & -2 & 0 & 0 & +2 & -2 \\ \text{V}_2\text{O}_5(s) + 5\text{Ca}(l) & \rightarrow & 2\text{V}(l) + 5\text{CaO}(s) \end{array}$ V in  $\text{V}_2\text{O}_5$  is reduced, and  $\text{V}_2\text{O}_5$  is the oxidizing agent. Ca in  $\text{Ca}(l)$  is oxidized, and  $\text{Ca}(l)$  is the reducing agent.(c)  $\begin{array}{cccc} +2 & +4 & -2 & +4 & -2 & +2 & +4 & -2 & +4 & -2 \\ \text{CaCO}_3(aq) + \text{SiO}_2(s) & \rightarrow & \text{CaSiO}_3(s) + \text{CO}_2(g) \end{array}$ 

Not redox

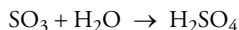
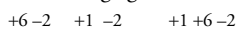
(d)  $\begin{array}{ccc} +1 & -1 & 0 & 0 \\ 2\text{NaH}(s) & \rightarrow & 2\text{Na}(s) + \text{H}_2(g) \end{array}$ Na in NaH is reduced, and NaH (or  $\text{Na}^+$  in NaH) is the oxidizing agent. H in NaH is oxidized, and NaH (or  $\text{H}^-$  in NaH) is also the reducing agent.(e)  $\begin{array}{cccc} +3 & -2 & +1 & +7 & -2 & +1 & -2 & +1 & -1 \\ 5\text{As}_4\text{O}_6(s) + 8\text{KMnO}_4(aq) + 18\text{H}_2\text{O}(l) + 52\text{KCl}(aq) \end{array}$ As in  $\text{As}_4\text{O}_6$  is oxidized, and  $\text{As}_4\text{O}_6$  is the reducing agent. Mn in  $\text{KMnO}_4$  is reduced, and  $\text{KMnO}_4$  is the oxidizing agent.



Yes, it's redox. S atoms in  $S_8$  are oxidized, O atoms in  $O_2$  are reduced,  $O_2$  is the oxidizing agent, and  $S_8$  is the reducing agent.



Yes, it's redox. S atoms in  $SO_2$  are oxidized, O atoms in  $O_2$  are reduced,  $O_2$  is the oxidizing agent, and  $SO_2$  is the reducing agent.



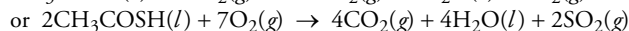
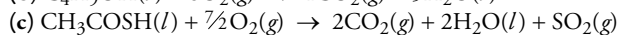
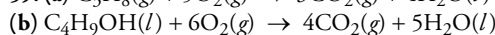
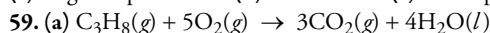
Because none of the atoms change their oxidation number, this is not redox.

55. (a) decomposition (b) single-displacement (c) combustion

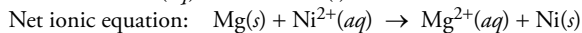
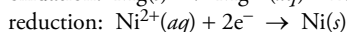
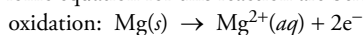
(d) single-displacement (e) combination and combustion

57. (a) combination and combustion (b) combustion

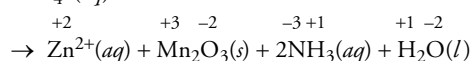
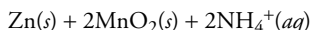
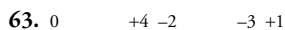
(c) single-displacement (d) combustion (e) decomposition



61. (a) Because nickel(II) nitrate is a water soluble ionic compound, the  $Ni(NO_3)_2$  solution contains  $Ni^{2+}$  ions surrounded by the negatively charged oxygen ends of water molecules and separate  $NO_3^-$  ions surrounded by the positively charged hydrogen ends of water molecules. These ions move throughout the solution colliding with each other, with water molecules, and with the walls of their container. When solid magnesium is added to the solution, nickel ions begin to collide with the surface of the magnesium. When each  $Ni^{2+}$  ion collides with an uncharged magnesium atom, two electrons are transferred from the magnesium atom to the nickel(II) ion. Magnesium ions go into solution, and uncharged nickel solid forms on the surface of the magnesium. (See Figure 6.4. Picture  $Ni^{2+}$  in the place of  $Cu^{2+}$  and magnesium metal in the place of zinc metal.) Because the magnesium atoms lose electrons and change their oxidation number from 0 to +2, they are oxidized and act as the reducing agent. The  $Ni^{2+}$  ions gain electrons and decrease their oxidation number from +2 to 0, so they are reduced and act as the oxidizing agent. The half-reaction equations and the net ionic equation for this reaction are below.



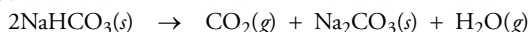
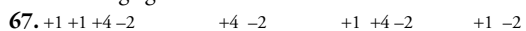
62. See Figure 6.5, substituting Mn for Zn and Pb for Cu. The voltaic cell that utilizes the redox reaction between manganese metal and lead(II) ions is composed of two half-cells. The first half-cell consists of a strip of manganese metal in a solution of manganese(II) nitrate. The second half-cell consists of a strip of lead metal in a solution of lead(II) nitrate. In the Mn/Mn<sup>2+</sup> half-cell, manganese atoms lose two electrons and are converted to manganese ions. The electrons pass through the wire to the Pb/Pb<sup>2+</sup> half cell where Pb<sup>2+</sup> ions gain the two electrons to form uncharged lead atoms. Mn is oxidized to Mn<sup>2+</sup> at the manganese electrode, so this electrode is the anode. Pb<sup>2+</sup> ions are reduced to uncharged lead atoms at the lead strip, so metallic lead is the cathode.



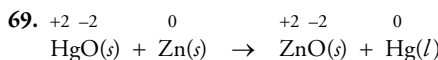
Zn is oxidized and is the reducing agent. Mn in  $MnO_2$  is reduced, so  $MnO_2$  is the oxidizing agent.



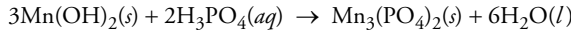
Pb is oxidized and is the reducing agent. Pb in  $PbO_2$  is reduced, so  $PbO_2$  is the oxidizing agent.



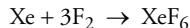
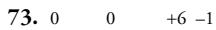
Because none of the atoms change their oxidation number, this is not redox.



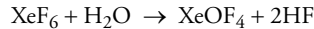
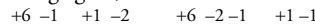
Yes, it's redox. Zn atoms in  $Zn(s)$  are oxidized, Hg atoms in  $HgO$  are reduced,  $HgO$  is the oxidizing agent, and Zn is the reducing agent.



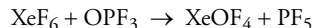
No, none of the atoms change their oxidation number, so it's not redox.



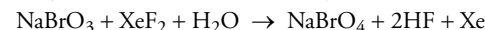
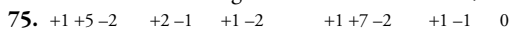
Yes, it's redox. Xe atoms are oxidized, F atoms in  $F_2$  are reduced,  $F_2$  is the oxidizing agent, and Xe is the reducing agent.



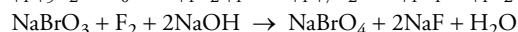
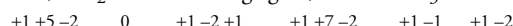
None of the atoms change their oxidation number, so it's not redox.



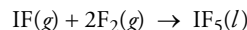
None of the atoms change their oxidation number, so it's not redox.



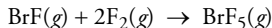
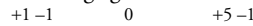
Yes, it's redox. Br atoms in  $NaBrO_3$  are oxidized, Xe atoms in  $XeF_2$  are reduced,  $XeF_2$  is the oxidizing agent, and  $NaBrO_3$  is the reducing agent.



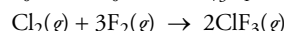
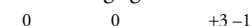
Yes, it's redox. Br atoms in  $NaBrO_3$  are oxidized, F atoms in  $F_2$  are reduced,  $F_2$  is the oxidizing agent, and  $NaBrO_3$  is the reducing agent.



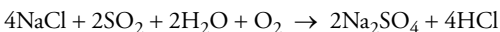
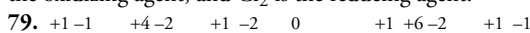
Yes, it's redox. I atoms in  $IF$  are oxidized, F atoms in  $F_2$  are reduced,  $F_2$  is the oxidizing agent, and  $IF$  is the reducing agent.



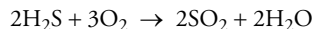
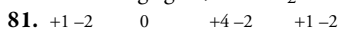
Yes, it's redox. Br atoms in  $BrF$  are oxidized, F atoms in  $F_2$  are reduced,  $F_2$  is the oxidizing agent, and  $BrF$  is the reducing agent.



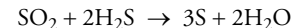
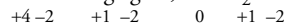
Yes, it's redox. Cl atoms in  $Cl_2$  are oxidized, F atoms in  $F_2$  are reduced,  $F_2$  is the oxidizing agent, and  $Cl_2$  is the reducing agent.



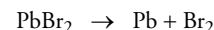
Yes, it's redox. S atoms in  $SO_2$  are oxidized, O atoms in  $O_2$  are reduced,  $O_2$  is the oxidizing agent, and  $SO_2$  is the reducing agent.



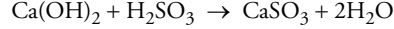
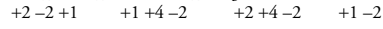
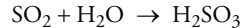
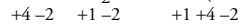
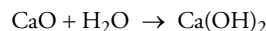
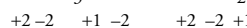
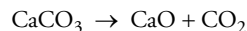
Yes, it's redox. S atoms in  $H_2S$  are oxidized, O atoms in  $O_2$  are reduced,  $O_2$  is the oxidizing agent, and  $H_2S$  is the reducing agent.



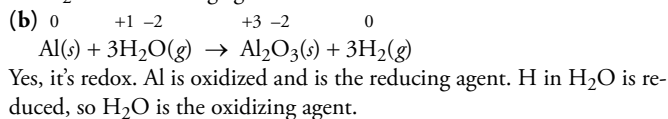
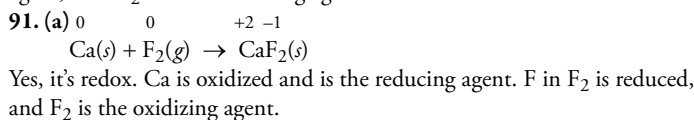
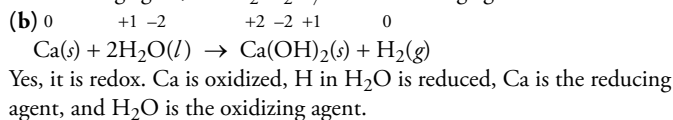
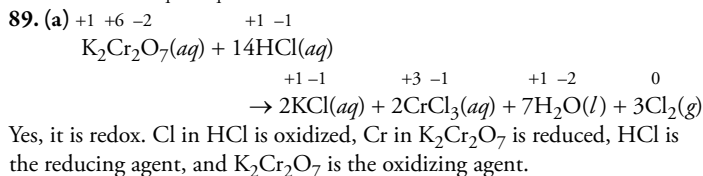
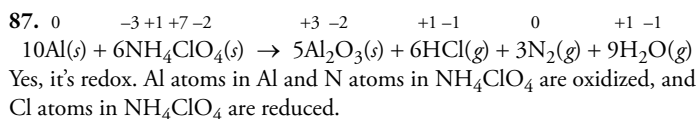
Yes, it's redox. S atoms in  $H_2S$  are oxidized, S atoms in  $SO_2$  are reduced,  $SO_2$  is the oxidizing agent, and  $H_2S$  is the reducing agent.



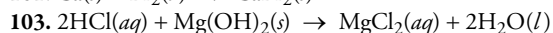
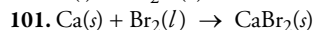
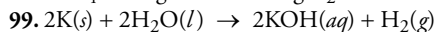
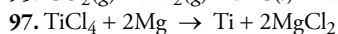
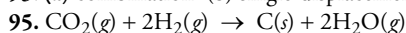
Yes, it's redox. Br atoms in  $PbBr_2$  are oxidized, and Pb atoms in  $PbBr_2$  are reduced.



Because none of the atoms change their oxidation number, none of these reactions are redox reactions.



93. (a) combination (b) single-displacement (c) decomposition



### Chapter 7 Exercises

7.1 (a) HO and  $\text{NO}_2$  have higher potential energy than  $\text{HNO}_3$ . Separated atoms are less stable and have higher potential energy than atoms in a chemical bond, so energy is required to break a chemical bond. Thus energy is required to separate the nitrogen and oxygen atoms being held together by mutual attraction in a chemical bond. The energy supplied goes to an increased potential energy of the separated HO and  $\text{NO}_2$  molecules compared to  $\text{HNO}_3$ . If the bond is reformed, the potential energy is converted into a form of energy that could be used to do work.

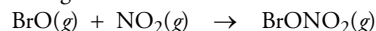
(b) A nitrogen dioxide molecule with a velocity of 439 m/s has greater kinetic energy than the same molecule with a velocity of 399 m/s. Any object in motion can collide with another object and move it, so any object in motion has the capacity to do work. This capacity to do work resulting from the motion of an object is called kinetic energy, KE. The particle with the higher velocity will move another object (such as another molecule) farther, so it can do more work. It must therefore have more energy.

(c) The more massive nitrogen dioxide molecule has greater kinetic energy than the less massive nitrogen monoxide molecule with the same velocity. The moving particle with the higher mass can move another object (like another molecule) farther, so it can do more work. It must therefore have more energy.

(d) Gaseous nitrogen has higher potential energy than liquid nitrogen. When nitrogen goes from liquid to gas, the attractions that link the  $\text{N}_2$  molecules together are broken. The energy that the nitrogen liquid must absorb to break these attractions goes to an increased potential energy of the nitrogen gas. If the nitrogen returns to the liquid form, attractions are reformed, and potential energy is converted into a form of energy that could be used to do work.

(e) Separate BrO and  $\text{NO}_2$  molecules have a higher potential energy than the  $\text{BrONO}_2$  molecule that they form. Atoms in a chemical bond are more stable and have lower potential energy than separated atoms, so energy is released when chemical bonds form. When BrO and  $\text{NO}_2$  are converted into  $\text{BrONO}_2$ , a new bond is formed, and some of the potential energy of the BrO and  $\text{NO}_2$  is released. The energy could be used to do some work. For

example, if some of the potential energy is converted into increased kinetic energy of a molecule like  $\text{N}_2$ , the faster moving molecule could bump into something and move it and therefore do work.



(f) An alpha particle and 2 separate electrons have higher potential energy than an uncharged helium atom. The attraction between the alpha particle and the electrons will pull them together, and as they move together, they could bump into something, move it, and do work.

### Chapter 7 Review Questions

1. (a) The particles in the liquid are close together with the particles occupying about 70% of the total volume. Because the particles in a liquid are moving faster than in a solid, they break the attractions to the particles around them and constantly move into new positions to form new attractions. This leads to a less organized arrangement of particles compared to that of the solid. See Figure 2.2.

(b) The particles of a gas are much farther apart than in the solid or liquid. For a typical gas, the average distance between particles is about 10 times the diameter of each particle. This leads to the gas particles themselves taking up only about 0.1% of the total volume. The other 99.9% of the total volume is empty space. According to our model, each particle in a gas moves freely in a straight-line path until it collides with another gas particle or with a liquid or solid. The particles are usually moving fast enough to break any attraction that might form between them, so after two particles collide, they bounce off each other and continue on their way alone. See Figure 2.4.

(c) Particles that are at the surface of the liquid and that are moving away from the surface fast enough to break the attractions that pull them back will escape to the gaseous form. See Figure 2.3.

(d) Increased temperature leads to an increase in the average velocity of the particles in the liquid. This makes it easier for the particles to break the attractions between them and move from one position to another, including away from the surface into the gaseous form.

2. (a) According to our model, the particles of a solid can be pictured as spheres that are packed as closely together as possible. The spheres for NaCl are alternating  $\text{Na}^+$  cations and  $\text{Cl}^-$  anions. Strong attractions hold these particles in the same general position, but the particles are still constantly moving (Figure 2.1). Each particle is constantly changing its direction and speeding up and slowing down. Despite the constant changes in direction and velocity, at a constant temperature, the strong attractions between particles keep them the same average distance apart and in the same general orientation to each other.

(b) When a solid is heated, the average velocity of the particles increases. The more violent collisions between the faster moving particles usually cause each particle to push its neighbors farther away. Therefore, increased temperature usually leads to an expansion of solids (Figure 2.1).

(c) As the heating of a solid continues, the movement of each particle eventually becomes powerful enough to enable it to push the other particles around it completely out of position. Because there is very little empty space between the particles, each one that moves out of position has to push its neighbors out of their positions too. Therefore, for one particle to move out of its general position, all of the particles must be able to move. The organized structure collapses, and the solid becomes a liquid.

### Chapter 7 Key Ideas

3. energy, resistance 5. mass 7. created, destroyed, transferred, changed 9. change 11. increases 13. decrease 15. 4.184 17. thermal 19. collisions 21. massless 23. peaks, cycle 25. released 27. absorbed 29. oxygen,  $\text{O}_2$ , ozone,  $\text{O}_3$  31. cars, sun 33. shorter, longer 35. 10, 50 37. UV-B, sunburn, premature aging, skin cancer 39. 242 nm, 240 nm to 320 nm 41. stable 39. 242 nm, 240 nm to 320 nm 41. stable



## Chapter 7 Problems

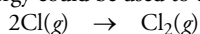
**43. (a)** An ozone molecule,  $O_3$ , with a velocity of 410 m/s has greater kinetic energy than the same molecule with a velocity of 393 m/s. Any object in motion can collide with another object and move it, so any object in motion has the capacity to do work. This capacity to do work resulting from the motion of an object is called kinetic energy, KE. The particle with the higher velocity will move another object (like another molecule) farther, so it can do more work. It must therefore have more energy.

**(b)** An ozone molecule,  $O_3$ , has greater kinetic energy than an  $O_2$  molecule with the same velocity. The moving particle with the higher mass can move another object (such as another molecule) farther, so it can do more work. It must therefore have more energy.

**(c)** The attraction between the separated electron and a proton will pull them together, and as they move together, they could bump into something, move it, and do work. Therefore, a proton and an electron farther apart have higher potential energy than a proton and an electron close together.

**(d)** Separated atoms are less stable than atoms in a chemical bond, so the potential energy of OH and Cl is higher than HOCl. Energy is required to separate the oxygen atom and the chlorine atom being held together by mutual attraction in a chemical bond. The energy supplied goes to an increased potential energy of the separate OH and Cl compared to HOCl. If the bond is re formed, the potential energy is converted into a form of energy that could be used to do work.

**(e)** Separated atoms are less stable than atoms in a chemical bond, so the potential energy of two separate Cl atoms is greater than one  $Cl_2$  molecule. When two Cl atoms are converted into a  $Cl_2$  molecule, a new bond is formed, and some of the potential energy of the Cl atoms is released. The energy could be used to do some work.



**(f)** Gaseous water has higher potential energy than liquid water. When water evaporates, the hydrogen bonds that link the water molecules together are broken. The energy that the water must absorb to break these attractions goes to an increased potential energy of the water vapor. If the water returns to the liquid form, hydrogen bonds are reformed, and the potential energy is converted into a form of energy that could be used to do work.

**46. (a)** If you nudge the brick off the top of the building, its potential energy will be converted into kinetic energy as it falls. If it hits the roof of a parked car, it will move the metal of the roof down, making a dent. When an object, such as the metal roof, is moved, work is done.

**(b)** You can shoot the rubber band across the room at a paper airplane. When you release the rubber band, its potential energy is converted into kinetic energy, which is used to do the work of moving the airplane.

**(c)** It is possible to run a car on pure alcohol. When the alcohol is burned, its potential energy is converted into energy that does the work of moving the car.

**48. (a)** Some of the kinetic energy of the moving hand is transferred to the string to set it moving and to the tips of the bow as it bends. Some of this kinetic energy is converted into potential energy of the stretched string and bow.

**(b)** Some of the potential energy of the stretched string and bow are converted into kinetic energy of the moving arrow.

**51. (a)** Because a chemical bond is broken in this reaction, energy would need to be absorbed to supply the energy necessary to move to the higher potential energy products. In the stratosphere, this energy comes from the radiant energy of a photon.

**(b)** Because a chemical bond is made in this reaction, energy would be released as the system moves to the lower potential energy product. This potential energy could be converted into kinetic energy.

**53.** A speeding bullet has a certain kinetic energy that is related to its overall mass and its velocity. This is its external kinetic energy. The bullet is also composed of silver atoms that, like all particles, are moving in a random way. The particles within the bullet are constantly moving, colliding with

their neighbors, changing their direction of motion, and changing their velocities. The kinetic energy associated with this internal motion is the internal kinetic energy. The internal motion is independent of the overall motion of the bullet.

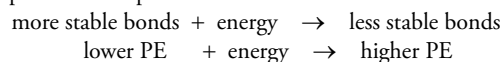
**55.** A typical thermometer used in the chemical laboratory consists of a long cylindrical glass container with a bulb at the bottom that contains a reservoir of mercury and a thin tube running up the inside of the thermometer that the mercury can rise into as it expands. When the thermometer is first placed in the hot water, the particles in the water have a greater average kinetic energy than the particles of the glass and mercury in the thermometer. When the more energetic water molecules collide with the particles in the glass, the particles of water slow down, and the particles in the glass speed up. The average kinetic energy of the water molecules decreases and the average kinetic energy of the particles of the glass increases. Thermal energy has been transferred from the water to the glass. The glass particles then collide with the less energetic mercury atoms, speeding them up and slowing down themselves. The average kinetic energy of the mercury increases, as thermal energy is transferred from the glass to the mercury. Thus some of the kinetic energy of the water is transferred to the glass, which then transfers some of this energy to the mercury. This will continue until the particles of water, glass, and mercury all have the same average kinetic energy. Try to picture the atoms of mercury in the liquid mercury. Now that they are moving faster, they collide with the particles around them with greater force. This pushes the particles farther apart and causes the liquid mercury to expand. Because the mercury has a larger volume, it moves farther up the thin column in the center of the thermometer.

**56.** In the particle view, radiant energy is a stream of tiny, massless packets of energy called photons. Different forms of radiant energy differ with respect to the energy of each of their photons. The energies of the photons of visible light are lower than for ultraviolet radiation. In the wave view, as radiant energy moves away from the source, it has an effect on the space around it that can be described as a wave consisting of an oscillating electric field perpendicular to an oscillating magnetic field (Figure 7.11). Different forms of radiant energy differ with respect to the wavelengths and frequencies of these oscillating waves. The waves associated with visible light have longer wavelengths than the waves associated with ultraviolet radiation.

**58. (a)** radio waves < microwaves < infrared radiation < visible light < ultraviolet radiation < X rays < gamma rays

**(b)** gamma rays < X rays < ultraviolet radiation < visible light < infrared radiation < microwaves < radio waves

**60.** The bonds in the products must be less stable and therefore higher potential energy than the bonds in the reactants. Energy is absorbed in the reaction to supply the energy necessary to increase the potential energy of the products compared to reactants.



**62. (a)** The bonds in the products must be more stable and therefore lower potential energy than the bonds in the reactants. The potential energy difference between reactants and products is released.

**(b)** Some of the potential energy of the reactants is converted into kinetic energy of the products, making the average kinetic energy of the products higher than the average kinetic energy of the reactants.

**(c)** The particles of the higher-temperature products collide with the particles of the lower-temperature container with greater average force than the particles of the container. Therefore, collisions between the particles of the products and the container speed up the particles of the container, increasing its internal kinetic energy or thermal energy, while slowing the particles of the products, decreasing their thermal energy. In this way, thermal energy is transferred from the products to the container. Likewise, the container, which is now at a higher temperature, transfers thermal energy to the lower-temperature surroundings. Heat has been transferred from the products to the container to the surroundings.

**65. (a)** exothermic **(b)** endothermic **(c)** exothermic

67. See Figure 7.15.

68. Ozone is a very powerful oxidizing agent. This can be useful. For example, ozone mixed with oxygen can be used to sanitize hot tubs, and it is used in industry to bleach waxes, oils, and textiles. Conversely, when the levels in the air get too high, the highly reactive nature of ozone becomes a problem. For example,  $O_3$  is a very strong respiratory irritant that can lead to shortness of breath, chest pain when inhaling, wheezing, and coughing. It also damages rubber and plastics, leading to premature deterioration of products made with these materials.

70. Shorter wavelengths of radiant energy are associated with higher energy photons. Radiant energy of wavelengths less than 400 nm has enough energy to break N–O bonds in  $NO_2$  molecules, but radiant energy with wavelengths longer than 400 nm does not supply enough energy to separate the atoms.

72. The shorter wavelength UV-B radiation (from about 290 nm to 320 nm) has higher energy than UV-A radiation. Radiation in this portion of the spectrum has high enough energy so that excessive exposure can cause sunburn, premature skin aging, and skin cancer.

74.  $O_2$  molecules absorb UV radiation with wavelengths less than 242 nm, and  $O_3$  molecules absorb radiant energy with wavelengths from 240 nm to 320 nm. See Figure 7.18.

76. Gases are removed from the lower atmosphere in two general ways. They either dissolve in the clouds and are rained out, or they react chemically to be converted into other substances. Neither of these mechanisms are important for CFCs. Chlorofluorocarbons are insoluble in water, and they are so stable that they can exist in the lower atmosphere for years. During this time, the CFC molecules wander around in the atmosphere, moving wherever the air currents take them. They can eventually make their way up into the stratosphere.

79. (a) When the natural gas burns, some of its potential energy is used to do the work of moving the bus.

(b) If you put an object, such as a small ball of paper, on one end of the compressed spring and then release the spring, the potential energy stored in the compressed spring will be converted into kinetic energy of the moving spring as it stretches out. The kinetic energy of the moving spring will do the work of moving the object.

(c) When a squirrel chews off the pinecone, allowing it to fall to the ground, the potential energy that it has because it is higher than the ground will be converted into kinetic energy as it falls. The falling pinecone can collide with another pinecone and do the work of knocking the second pinecone off its branch.

81. (a) The kinetic energy of the mover's hands is transferred to the kinetic energy of the moving ropes, which is transferred to the kinetic energy of the moving piano. Some of this kinetic energy is converted into potential energy as the piano rises.

(b) Some of the potential energy of the piano is converted into kinetic energy as it falls.

83. (a) Some of the potential energy of the gasoline molecules is converted into the kinetic energy of moving product particles. This is reflected in an increase in the temperature of the gaseous products.

(b) Some of the kinetic energy of the moving gaseous product particles is transferred into the kinetic energy of the moving piston.

(c) Some of the kinetic energy of the moving piston is transferred into the kinetic energy of the moving crankshaft and ultimately into the kinetic energy of the moving wheels.

85. (a) exothermic (b) endothermic

### Chapter 8 Exercises

8.1. (a)  $\frac{10^3 \text{ J}}{1 \text{ kJ}}$  and  $\frac{1 \text{ kJ}}{10^3 \text{ J}}$  (b)  $\frac{10^2 \text{ cm}}{1 \text{ m}}$  and  $\frac{1 \text{ m}}{10^2 \text{ cm}}$

(c)  $\frac{10^9 \text{ L}}{1 \text{ GL}}$  and  $\frac{1 \text{ GL}}{10^9 \text{ L}}$  (d)  $\frac{10^6 \mu\text{g}}{1 \text{ g}}$  and  $\frac{1 \text{ g}}{10^6 \mu\text{g}}$

(e)  $\frac{10^6 \text{ g}}{1 \text{ Mg}}$  and  $\frac{1 \text{ Mg}}{10^6 \text{ g}}$

8.2.  $? \text{ Mg} = 4.352 \mu\text{g} \left( \frac{1 \text{ g}}{10^6 \mu\text{g}} \right) \left( \frac{1 \text{ Mg}}{10^6 \text{ g}} \right) = 4.352 \times 10^{-12} \text{ Mg}$

8.3.  $? \text{ gal} = 1.5 \times 10^{18} \text{ kL} \left( \frac{10^3 \text{ L}}{1 \text{ kL}} \right) \left( \frac{1 \text{ gal}}{3.785 \text{ L}} \right) = 4.0 \times 10^{20} \text{ gal}$

8.4. The 10.5 comes from a measurement and has three significant figures. The 453.6 is calculated and rounded off. It has four significant figures. The 16 comes from a definition and is exact. We report three significant figures in our answer.

8.5. The 25.0 comes from a measurement and has three significant figures. The 11.0 comes from a blend of measurement and calculations. It also has three significant figures. All of the other numbers come from definitions and are therefore exact. We report three significant figures in our answer.

8.6. (a)  $684 - 595.325 = 89$  (b)  $92.771 + 9.3 = 102.1$

8.7. (a)  $? \text{ kg} = 15.6 \text{ gal} \left( \frac{3.785 \text{ L}}{1 \text{ gal}} \right) \left( \frac{10^3 \text{ mL}}{1 \text{ L}} \right) \left( \frac{0.70 \text{ g gas.}}{1 \text{ mL gas.}} \right) \left( \frac{1 \text{ kg}}{10^3 \text{ g}} \right)$

or  $? \text{ kg} = 15.6 \text{ gal} \left( \frac{3.785 \text{ L}}{1 \text{ gal}} \right) \left( \frac{0.70 \text{ kg gas.}}{1 \text{ L gas.}} \right) = 41 \text{ kg gasoline}$

(b)  $? \text{ L} = 242.6 \text{ t} \left( \frac{10^3 \text{ kg}}{1 \text{ t}} \right) \left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left( \frac{1 \text{ mL Fe}}{7.86 \text{ g Fe}} \right) \left( \frac{1 \text{ L}}{10^3 \text{ mL}} \right)$

or  $? \text{ L} = 242.6 \text{ t} \left( \frac{10^3 \text{ kg}}{1 \text{ t}} \right) \left( \frac{1 \text{ L Fe}}{7.86 \text{ kg Fe}} \right) = 3.09 \times 10^4 \text{ L Fe}$

8.8. (a)  $\frac{? \text{ g}}{\text{mL}} = \frac{(57.452 - 48.737) \text{ g}}{13.2 \text{ mL}} = 0.660 \text{ g/mL}$

(b)  $\frac{? \text{ g}}{1 \text{ mL}} = \frac{1.2 \times 10^4 \text{ kg}}{2.4 \times 10^4 \text{ L}} \left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left( \frac{1 \text{ L}}{10^3 \text{ mL}} \right) = 0.50 \text{ g/mL}$

8.9. (a)

$$? \text{ lb HCO}_3^- = 1.8 \times 10^{21} \text{ kg ocean} \left( \frac{0.014 \text{ kg HCO}_3^-}{100 \text{ kg ocean}} \right) \left( \frac{2.205 \text{ lb}}{1 \text{ kg}} \right)$$

$$= 5.6 \times 10^{17} \text{ lb HCO}_3^-$$

(b)  $? \text{ L blood to muscles} = 5.2 \text{ L blood total} \left( \frac{78 \text{ L blood to muscles}}{100 \text{ L blood total}} \right)$

$$= 4.1 \text{ L blood to muscles}$$

8.10. (a)  $? \text{ nm} = 2 \times 10^{-15} \text{ m} \left( \frac{10^9 \text{ nm}}{1 \text{ m}} \right) = 2 \times 10^{-6} \text{ nm}$

(b)  $? \text{ ng} = 9.1093897 \times 10^{-31} \text{ kg} \left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left( \frac{10^9 \text{ ng}}{1 \text{ g}} \right)$

$$= 9.1093897 \times 10^{-19} \text{ ng}$$

(c)  $? \text{ kg} = 4.070 \times 10^6 \text{ lb} \left( \frac{453.6 \text{ g}}{1 \text{ lb}} \right) \left( \frac{1 \text{ kg}}{10^3 \text{ g}} \right) = 1.846 \times 10^6 \text{ kg}$

$$(d) \frac{? \text{ g}}{\text{mL}} = \frac{88.978 \text{ g}}{2.9659 \text{ L}} \left( \frac{1 \text{ L}}{10^3 \text{ mL}} \right) = \mathbf{0.030000 \text{ g/mL}}$$

$$(e) ? \text{ kg} = 2.5 \text{ L} \left( \frac{10^3 \text{ mL}}{1 \text{ L}} \right) \left( \frac{1.03 \text{ g}}{1 \text{ mL}} \right) \left( \frac{1 \text{ kg}}{10^3 \text{ g}} \right)$$

$$\text{or } ? \text{ kg} = 2.5 \text{ L} \left( \frac{1.03 \text{ kg}}{1 \text{ L}} \right) = \mathbf{2.6 \text{ kg}}$$

$$(f) ? \text{ s} = 6.0 \text{ ft} \left( \frac{12 \text{ in.}}{1 \text{ ft}} \right) \left( \frac{2.54 \text{ cm}}{1 \text{ in.}} \right) \left( \frac{1 \text{ m}}{10^2 \text{ cm}} \right) \left( \frac{1 \text{ s}}{18 \text{ m}} \right) = \mathbf{0.10 \text{ s}}$$

$$(g) \frac{? \text{ km}}{\text{hr}} = \frac{22 \text{ in.}}{6.2 \times 10^{-9} \text{ s}} \left( \frac{2.54 \text{ cm}}{1 \text{ in.}} \right) \left( \frac{1 \text{ m}}{10^2 \text{ cm}} \right) \left( \frac{1 \text{ km}}{10^3 \text{ m}} \right) \left( \frac{60 \text{ s}}{1 \text{ min}} \right) \left( \frac{60 \text{ min}}{1 \text{ hr}} \right)$$

$$= \mathbf{3.2 \times 10^8 \text{ km/hr}}$$

$$(h) ? \text{ ton Ca}^{2+} = 1.8 \times 10^{21} \text{ kg ocean} \left( \frac{0.041 \text{ kg Ca}^{2+}}{100 \text{ kg ocean}} \right) \left( \frac{2.205 \text{ lb}}{1 \text{ kg}} \right) \left( \frac{1 \text{ ton}}{2000 \text{ lb}} \right)$$

$$= \mathbf{8.1 \times 10^{14} \text{ ton Ca}^{2+}}$$

$$(i) ? \text{ L to brain} = 1.0 \text{ hr} \left( \frac{60 \text{ min}}{1 \text{ hr}} \right) \left( \frac{5.0 \text{ L total}}{1 \text{ min}} \right) \left( \frac{15 \text{ L to brain}}{100 \text{ L total}} \right) = \mathbf{45 \text{ L}}$$

$$8.11. (a) ^\circ\text{F} = 2.5 ^\circ\text{C} \left( \frac{1.8 ^\circ\text{F}}{1 ^\circ\text{C}} \right) + 32 ^\circ\text{F} = \mathbf{36.5 ^\circ\text{F}}$$

$$\text{K} = 2.5 ^\circ\text{C} + 273.15 = \mathbf{275.7 \text{ K}}$$

$$(b) ^\circ\text{C} = (5.4 ^\circ\text{F} - 32 ^\circ\text{F}) \frac{1 ^\circ\text{C}}{1.8 ^\circ\text{F}} = \mathbf{-14.8 ^\circ\text{C}}$$

$$\text{K} = -14.8 ^\circ\text{C} + 273.15 = \mathbf{258.4 \text{ K}}$$

$$(c) ^\circ\text{C} = 2.15 \times 10^3 \text{ K} - 273.15 = \mathbf{1.88 \times 10^3 ^\circ\text{C}}$$

$$^\circ\text{F} = 1.88 \times 10^3 ^\circ\text{C} \left( \frac{1.8 ^\circ\text{F}}{1 ^\circ\text{C}} \right) + 32 ^\circ\text{F} = \mathbf{3.42 \times 10^3 ^\circ\text{F}}$$

(or  $3.41 \times 10^3 ^\circ\text{F}$  if the unrounded answer to the first calculation is used in the second calculation.)

### Chapter 8 Review Questions

1. length, meter (m); mass, gram (g); volume, liter (L)

2. milliliter, volume, mL; microgram, mass,  $\mu\text{g}$ ; kilometer, length, km; kelvin, temperature, K

3. (a)  $10^{-6} \text{ m} = 1 \mu\text{m}$  (b)  $10^6 \text{ g} = 1 \text{ Mg}$  (c)  $10^{-3} \text{ L} = 1 \text{ mL}$

(d)  $10^{-9} \text{ m} = 1 \text{ nm}$  (e)  $1 \text{ cm}^3 = 1 \text{ mL}$  (f)  $10^3 \text{ L} = \text{m}^3$

(g)  $10^3 \text{ kg} = 1 \text{ t}$  (t = metric ton) (h)  $1 \text{ Mg} = 1 \text{ t}$

4. We assume that each reported number is  $\pm 1$  in the last decimal position reported. Therefore, we assume the mass of the graduated cylinder between 1124.1 g and 1124.3 g, the volume of the methanol is between 1.19 L and 1.21 L, and the total mass is between 2073.8 g and 2074.0 g.

### Chapter 8 Key Ideas

5. unit conversion, correct 7. unwanted, desired units 9. cancel 11. one 13. inexact, fewest 15. counting 17. decimal places, fewest decimal places 19. grams per milliliter, grams per cubic centimeter 21. identity, known 23. part, whole 25. definitions

### Chapter 8 Problems

26. (a)  $6.7294 \times 10^4$  (b)  $4.38763102 \times 10^8$  (c)  $7.3 \times 10^{-5}$   
(d)  $4.35 \times 10^{-8}$

28. (a) 4,097 (b) 15,541.2 (c) 0.0000234 (d) 0.000000012

30. (a) 2,877 (b) 316 (c) 5.5 (d) 2.827

32. (a)  $10^{12}$  (b)  $10^9$  (c)  $10^7$  (d)  $10^5$  (e)  $10^{29}$  (f)  $10^3$

34. (a)  $7.6 \times 10^{15}$  (b)  $1.02 \times 10^{16}$  (c)  $3.3 \times 10^5$

(d)  $1.87 \times 10^{-3}$  or 0.00187 (e)  $8.203 \times 10^{13}$  (f)  $2.111 \times 10^4$

36. (a)  $\left( \frac{10^3 \text{ m}}{1 \text{ km}} \right)$  (b)  $\left( \frac{10^2 \text{ cm}}{1 \text{ m}} \right)$  (c)  $\left( \frac{10^3 \text{ mm}}{1 \text{ m}} \right)$  (d)  $\left( \frac{1 \text{ cm}^3}{1 \text{ mL}} \right)$

(e)  $\left( \frac{2.54 \text{ cm}}{1 \text{ in.}} \right)$  (f)  $\left( \frac{453.6 \text{ g}}{1 \text{ lb}} \right)$

38. (a)  $\left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right)$  (b)  $\left( \frac{10^3 \text{ mg}}{1 \text{ g}} \right)$  (c)  $\left( \frac{1.094 \text{ yd}}{1 \text{ m}} \right)$  (d)  $\left( \frac{2.205 \text{ lb}}{1 \text{ kg}} \right)$

40.  $9.1093897 \times 10^{-28} \text{ g}$  42.  $3.2 \mu\text{m}$

44. 0.04951 lb (or 0.049507 if you use more significant figures in the gram-to-pound conversion factor)

46.  $5.908 \times 10^{-26} \text{ oz}$  (or  $5.908138 \times 10^{-26} \text{ oz}$  if you use more significant figures in the gram-to-pound conversion factor)

48.  $2.2 \mu\text{m}$

50. (a) not exact—2 significant figures (b) exact

(c) not exact—2 significant figures (d) exact (e) exact (f) exact

(g) not exact—4 significant figures (h) not exact—6 significant figures

(i) not exact—4 significant figures (j) not exact—4 significant figures

52. (a) 5 (b) 3 (c) 3 (d) 5 (e) 4 54. (a) 3 (b) 4 (c) 4

56. (a) 34.6 (b) 193 (c) 24.0 (d) 0.00388 (e) 0.0230 (f)  $2.85 \times 10^3$

(g)  $7.84 \times 10^4$

58. (a) 103 (b) 6.2 (c)  $5.71 \times 10^{11}$  60. (a) 100.14 (b) 1

62.  $0.1200 \text{ g/mL}$  64.  $0.1850 \text{ kg}$  66.  $0.8799 \text{ qt}$  68.  $1.9 \times 10^{19} \text{ kg Na}^+$

70.  $94.3 \text{ L to brain}$  72.  $0.18 \text{ mg to energy}$  74.  $33 \text{ km/hr}$  76.  $0.275 \text{ s}$

78.  $3.5 \text{ hr}$  80.  $3.326 \times 10^5 \text{ kJ}$  82.  $0.444 \text{ kg C}$  84.  $2.7 \text{ lb beans/day}$

86.  $1.6 \times 10^8 \text{ kg HCl}$  88. 52 days 90. 9812 L air 92. 44.0 minutes

94. 28 qt 96.  $7.6 \times 10^5 \text{ beats}$  98.  $3.6 \times 10^9 \text{ molecules}$  100. 6.9 days

102. 95 ft 103.  $88 ^\circ\text{F}$ ,  $304 \text{ K}$  105.  $108 ^\circ\text{C}$ ,  $381 \text{ K}$

107.  $2.750 \times 10^3 ^\circ\text{C}$ ,  $4982 ^\circ\text{F}$  109.  $5.5 \times 10^3 ^\circ\text{C}$ ,  $5.8 \times 10^3 \text{ K}$

### Chapter 9 Exercises

9.1 (a) 196.9665 (from periodic table)

(b) 196.9665 g (There are  $6.022 \times 10^{23}$  atoms per mole of atoms, and one mole of an element has a mass in grams equal to its atomic mass.)

$$(c) \left( \frac{196.9665 \text{ g Au}}{1 \text{ mol Au}} \right)$$

$$(d) ? \text{ g Au} = 0.20443 \text{ mol Au} \left( \frac{196.9665 \text{ g Au}}{1 \text{ mol Au}} \right) = \mathbf{40.266 \text{ g Au}}$$

$$(e) ? \text{ mg Au} = 7.046 \times 10^{-3} \text{ mol Au} \left( \frac{196.9665 \text{ g Au}}{1 \text{ mol Au}} \right) \left( \frac{10^3 \text{ mg}}{1 \text{ g}} \right)$$

$$= \mathbf{1388 \text{ mg Au}}$$

$$(f) ? \text{ mol Au} = 1.00 \text{ troy oz Au} \left( \frac{31.10 \text{ g}}{1 \text{ troy oz}} \right) \left( \frac{1 \text{ mol Au}}{196.9665 \text{ g Au}} \right)$$

$$= \mathbf{0.158 \text{ mol Au}}$$

9.2 (a)  $2(12.011) + 6(1.00794) + 1(15.9994) = 46.069$

(b) 46.069 g (One mole of a molecular compound has a mass in grams equal to its molecular mass.)

$$(c) \left( \frac{46.069 \text{ g C}_2\text{H}_5\text{OH}}{1 \text{ mol C}_2\text{H}_5\text{OH}} \right)$$

$$(d) ? \text{ mol C}_2\text{H}_5\text{OH} = 16 \text{ g C}_2\text{H}_5\text{OH} \left( \frac{1 \text{ mol C}_2\text{H}_5\text{OH}}{46.069 \text{ g C}_2\text{H}_5\text{OH}} \right)$$

$$= \mathbf{0.35 \text{ mole C}_2\text{H}_5\text{OH}}$$

(e)

$$? \text{ mL C}_2\text{H}_5\text{OH} = 1.0 \text{ mol C}_2\text{H}_5\text{OH} \left( \frac{46.069 \text{ g C}_2\text{H}_5\text{OH}}{1 \text{ mol C}_2\text{H}_5\text{OH}} \right) \left( \frac{1 \text{ mL C}_2\text{H}_5\text{OH}}{0.7893 \text{ g C}_2\text{H}_5\text{OH}} \right)$$

$$= \mathbf{58 \text{ mL C}_2\text{H}_5\text{OH}}$$

9.3 (a) Formula Mass = 1(22.9898) + 1(1.00794) + 1(12.011) + 3(15.9994) = **84.007**

(b) 84.007 g (One mole of an ionic compound has a mass in grams equal to its formula mass.)

(c)  $\left( \frac{84.007 \text{ g NaHCO}_3}{1 \text{ mol NaHCO}_3} \right)$

(d)  $? \text{ mol NaHCO}_3 = 0.4 \text{ g NaHCO}_3 \left( \frac{1 \text{ mol NaHCO}_3}{84.007 \text{ g NaHCO}_3} \right)$

$$= \mathbf{5 \times 10^{-3} \text{ mol NaHCO}_3}$$

9.4 (a)  $\left( \frac{6 \text{ mol H}}{1 \text{ mol C}_2\text{H}_5\text{OH}} \right)$  (b)  $\left( \frac{3 \text{ mol O}}{1 \text{ mol NaHCO}_3} \right)$

(c) There is 1 mole of  $\text{HCO}_3^-$  per 1 mole of  $\text{NaHCO}_3$ .

9.5  $? \text{ g S}_2\text{Cl}_2 = 123.8 \text{ g S} \left( \frac{1 \text{ mol S}}{32.066 \text{ g S}} \right) \left( \frac{1 \text{ mol S}_2\text{Cl}_2}{2 \text{ mol S}} \right) \left( \frac{135.037 \text{ g S}_2\text{Cl}_2}{1 \text{ mol S}_2\text{Cl}_2} \right)$

$$= \mathbf{260.7 \text{ g S}_2\text{Cl}_2}$$

9.6  $? \text{ kg V} = 2.3 \text{ kg V}_2\text{O}_5 \left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left( \frac{1 \text{ mol V}_2\text{O}_5}{181.880 \text{ g V}_2\text{O}_5} \right) \left( \frac{2 \text{ mol V}}{1 \text{ mol V}_2\text{O}_5} \right)$

$$\left( \frac{50.9415 \text{ g V}}{1 \text{ mol V}} \right) \left( \frac{1 \text{ kg}}{10^3 \text{ g}} \right) = \mathbf{1.3 \text{ kg V}}$$

9.7  $? \text{ mol Bi} = 32.516 \text{ g Bi} \left( \frac{1 \text{ mol Bi}}{208.9804 \text{ g Bi}} \right) = 0.15559 \text{ mol Bi} \div 0.15559$

$$= 1 \text{ mol Bi} \times 2 = \mathbf{2 \text{ mol Bi}}$$

$$? \text{ mol S} = 7.484 \text{ g S} \left( \frac{1 \text{ mol S}}{32.066 \text{ g S}} \right) = 0.2334 \text{ mol S} \div 0.15559$$

$$\cong 1\frac{1}{2} \text{ mol S} \times 2 = \mathbf{3 \text{ mol S}}$$

Our empirical formula is **Bi<sub>2</sub>S<sub>3</sub>** or bismuth(III) sulfide.

9.8  $? \text{ mol K} = 35.172 \text{ g K} \left( \frac{1 \text{ mol K}}{39.0983 \text{ g K}} \right) = 0.89958 \text{ mol K} \div 0.89958$

$$= 1 \text{ mol K} \times 2 = \mathbf{2 \text{ mol K}}$$

$$? \text{ mol S} = 28.846 \text{ g S} \left( \frac{1 \text{ mol S}}{32.066 \text{ g S}} \right) = 0.89958 \text{ mol S} \div 0.89958$$

$$= 1 \text{ mol S} \times 2 = \mathbf{2 \text{ mol S}}$$

$$? \text{ mol O} = 35.982 \text{ g O} \left( \frac{1 \text{ mol O}}{15.9994 \text{ g O}} \right) = 2.2490 \text{ mol O} \div 0.89958$$

$$\cong 2\frac{1}{2} \text{ mol O} \times 2 = \mathbf{5 \text{ mol O}}$$

Empirical Formula **K<sub>2</sub>S<sub>2</sub>O<sub>5</sub>**

9.9  $? \text{ mol C} = 39.94 \text{ g C} \left( \frac{1 \text{ mol C}}{12.011 \text{ g C}} \right) = 3.325 \text{ mol C} \div 1.11$

$$= 3 \text{ mol C} \times 2 = \mathbf{6 \text{ mol C}}$$

$$? \text{ mol H} = 1.12 \text{ g H} \left( \frac{1 \text{ mol H}}{1.00794 \text{ g H}} \right) = 1.11 \text{ mol H} \div 1.11$$

$$= 1 \text{ mol H} \times 2 = \mathbf{2 \text{ mol C}}$$

$$? \text{ mol Cl} = 58.94 \text{ g Cl} \left( \frac{1 \text{ mol Cl}}{35.4527 \text{ g Cl}} \right) = 1.662 \text{ mol Cl} \div 1.11$$

$$\cong 1\frac{1}{2} \text{ mol Cl} \times 2 = \mathbf{3 \text{ mol C}}$$

Empirical Formula **C<sub>6</sub>H<sub>2</sub>Cl<sub>3</sub>**

$$n = \left( \frac{\text{molecular mass}}{\text{empirical formula mass}} \right) = \left( \frac{360.88}{180.440} \right) \cong 2$$

Molecular Formula = (C<sub>6</sub>H<sub>2</sub>Cl<sub>3</sub>)<sub>2</sub> or **C<sub>12</sub>H<sub>4</sub>Cl<sub>6</sub>**

### Chapter 9 Review Questions

1. (a)  $\left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right)$  (b)  $\left( \frac{10^3 \text{ mg}}{1 \text{ g}} \right)$  (c)  $\left( \frac{10^3 \text{ kg}}{1 \text{ t}} \right)$  (d)  $\left( \frac{10^6 \text{ } \mu\text{g}}{1 \text{ g}} \right)$

2.  $3.45 \times 10^7 \text{ g}$  3. 0.184570 kg 4. 4.5000 Mg 5.  $8.71 \times 10^8 \text{ g}$

6. 695 kg Al<sub>2</sub>O<sub>3</sub>

### Chapter 9 Key Ideas

7. impossible 9. weighted, naturally 11. atomic mass 13. formula unit, kinds, numbers 15. formula units 17. simplest 19. whole-number

### Chapter 9 Problems

21. (a) 22.9898 u (b) 15.9994 u 23. (a) 32.066 g (b) 18.9984 g

25. (a) 65.39 g/mol (b) 26.9815 g/mol

27. (a)  $\left( \frac{55.845 \text{ g Fe}}{1 \text{ mol Fe}} \right)$  (b)  $\left( \frac{83.80 \text{ g Kr}}{1 \text{ mol Kr}} \right)$

29.  $6.3 \times 10^{-7} \text{ mol Se}$  31. 8.9 mg Fe

33. (a) 65.9964,  $\left( \frac{65.9964 \text{ g H}_3\text{PO}_2}{1 \text{ mol H}_3\text{PO}_2} \right)$

(b) 93.128,  $\left( \frac{93.128 \text{ g C}_6\text{H}_5\text{NH}_2}{1 \text{ mol C}_6\text{H}_5\text{NH}_2} \right)$

35. (a)  $7.398 \times 10^{-3} \text{ mol C}_8\text{H}_9\text{NO}$  (b)  $2.03 \times 10^3 \text{ g C}_8\text{H}_9\text{NO}$

38. (a) molecular compound – molecules

(b) ionic compound – formula units (c) ionic compound – formula units

(d) molecular compound - molecules

40. (a) 448.69,  $\left( \frac{448.69 \text{ g BiBr}_3}{1 \text{ mol BiBr}_3} \right)$  (b) 342.154,  $\left( \frac{342.154 \text{ g Al}_2(\text{SO}_4)_3}{1 \text{ mol Al}_2(\text{SO}_4)_3} \right)$

42. (a)  $5.00 \times 10^{-3} \text{ mol CaCO}_3$  (b) 10.01 kg CaCO<sub>3</sub>

44.  $1.5 \times 10^{-3} \text{ mol Al}_2\text{O}_3$

46.  $\left( \frac{2 \text{ mol N}}{1 \text{ mol N}_2\text{O}_5} \right)$  48.  $\left( \frac{2 \text{ mol Cr}}{1 \text{ mol Cr}_2\text{O}_3} \right)$

50. There are 2 moles of ammonium ions in one mole of (NH<sub>4</sub>)<sub>2</sub>C<sub>2</sub>O<sub>4</sub>.

52. (a)  $\left( \frac{1 \text{ mol Ca}}{1 \text{ mol CaCO}_3} \right)$  (b) 0.162 g Ca (c) 16.2% of daily value Ca

54. 24 μg NaVO<sub>3</sub> 56. 101 kg Ti 59. Ag<sub>3</sub>N, silver nitride

61. Ca<sub>2</sub>P<sub>2</sub>O<sub>7</sub> 63. Ni<sub>3</sub>As<sub>2</sub>O<sub>8</sub> 65. CaI<sub>2</sub>O<sub>6</sub> or Ca(IO<sub>3</sub>)<sub>2</sub>, calcium iodate

67. C<sub>2</sub>N<sub>2</sub>H<sub>8</sub> 69. C<sub>6</sub>H<sub>6</sub>Cl<sub>6</sub> 71. C<sub>3</sub>H<sub>6</sub>N<sub>6</sub>

73. 2.88 g,  $1.1 \times 10^4$  screws, 74 gross screws 75. 4.515 mol Al<sub>2</sub>O<sub>3</sub>

77.  $1.1 \times 10^2 \text{ mol Be}$  79. 12 carats

81. (a)  $5.3 \times 10^{-5} \text{ mol C}_6\text{H}_5\text{OH}$  (b) 0.08720 kg C<sub>6</sub>H<sub>5</sub>OH

83. 50.60 kg Be 85. MoSi<sub>2</sub> 87. KHC<sub>2</sub>O<sub>4</sub> 89. Na<sub>2</sub>S<sub>2</sub>O<sub>5</sub>

91. MnH<sub>4</sub>P<sub>2</sub>O<sub>8</sub> or Mn(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub> manganese(II) dihydrogen phosphate

93. C<sub>13</sub>H<sub>10</sub>O<sub>4</sub>N<sub>2</sub> 95.  $7.30 \times 10^3 \text{ kg Zn}$  97. 47 kg As

99. (a)  $1.3 \times 10^2 \text{ t Mg}$  (b)  $2.9 \times 10^2 \text{ t ore}$

101. 6.8 t ore 103.  $2.3 \times 10^2 \text{ g}$  baking powder 105. 11 t zircon sand

## Chapter 10 Exercises

$$10.1 \text{ (a)} \left( \frac{8 \text{ mol C}_2\text{H}_4\text{Cl}_2}{6 \text{ mol Cl}_2} \right) \text{ or } \left( \frac{8 \text{ mol C}_2\text{H}_4\text{Cl}_2}{7 \text{ mol O}_2} \right) \text{ or } \left( \frac{8 \text{ mol C}_2\text{H}_4\text{Cl}_2}{4 \text{ mol C}_2\text{HCl}_3} \right)$$

$$\text{or } \left( \frac{8 \text{ mol C}_2\text{H}_4\text{Cl}_2}{4 \text{ mol C}_2\text{Cl}_4} \right) \text{ or } \left( \frac{8 \text{ mol C}_2\text{H}_4\text{Cl}_2}{14 \text{ mol H}_2\text{O}} \right) \text{ or } \left( \frac{6 \text{ mol Cl}_2}{7 \text{ mol O}_2} \right)$$

$$\text{or } \left( \frac{6 \text{ mol Cl}_2}{4 \text{ mol C}_2\text{HCl}_3} \right) \text{ or } \left( \frac{6 \text{ mol Cl}_2}{4 \text{ mol C}_2\text{Cl}_4} \right) \text{ or } \left( \frac{6 \text{ mol Cl}_2}{14 \text{ mol H}_2\text{O}} \right)$$

$$\text{or } \left( \frac{7 \text{ mol O}_2}{4 \text{ mol C}_2\text{HCl}_3} \right) \text{ or } \left( \frac{7 \text{ mol O}_2}{4 \text{ mol C}_2\text{Cl}_4} \right) \text{ or } \left( \frac{7 \text{ mol O}_2}{14 \text{ mol H}_2\text{O}} \right)$$

$$\text{or } \left( \frac{4 \text{ mol C}_2\text{HCl}_3}{4 \text{ mol C}_2\text{Cl}_4} \right) \text{ or } \left( \frac{4 \text{ mol C}_2\text{HCl}_3}{14 \text{ mol H}_2\text{O}} \right) \text{ or } \left( \frac{4 \text{ mol C}_2\text{Cl}_4}{14 \text{ mol H}_2\text{O}} \right)$$

$$\text{(b)} ? \text{ g H}_2\text{O} = 362.47 \text{ g C}_2\text{Cl}_4 \left( \frac{1 \text{ mol C}_2\text{Cl}_4}{165.833 \text{ g C}_2\text{Cl}_4} \right) \left( \frac{14 \text{ mol H}_2\text{O}}{4 \text{ mol C}_2\text{Cl}_4} \right) \left( \frac{18.0153 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \right)$$

$$\text{or } 362.47 \text{ g C}_2\text{Cl}_4 \left( \frac{14 \times 18.0153 \text{ g H}_2\text{O}}{4 \times 165.833 \text{ g C}_2\text{Cl}_4} \right) = \mathbf{137.82 \text{ H}_2\text{O}}$$

$$\text{(c)} ? \text{ kg C}_2\text{Cl}_4 = 23.75 \text{ kg C}_2\text{H}_4\text{Cl}_2 \left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left( \frac{1 \text{ mol C}_2\text{H}_4\text{Cl}_2}{98.959 \text{ g C}_2\text{H}_4\text{Cl}_2} \right)$$

$$\left( \frac{4 \text{ mol C}_2\text{Cl}_4}{8 \text{ mol C}_2\text{H}_4\text{Cl}_2} \right) \left( \frac{165.833 \text{ g C}_2\text{Cl}_4}{1 \text{ mol C}_2\text{Cl}_4} \right) \left( \frac{1 \text{ kg}}{10^3 \text{ g}} \right)$$

$$\text{or } 23.75 \text{ kg C}_2\text{H}_4\text{Cl}_2 \left( \frac{4 \times 165.833 \text{ kg C}_2\text{Cl}_4}{8 \times 98.959 \text{ kg C}_2\text{H}_4\text{Cl}_2} \right) = \mathbf{19.90 \text{ kg C}_2}$$

$$10.2 \text{ (a)} ? \text{ Mg UO}_2\text{F}_2 = 24.543 \text{ Mg UF}_6 \left( \frac{10^6 \text{ g}}{1 \text{ Mg}} \right) \left( \frac{1 \text{ mol UF}_6}{352.019 \text{ g UF}_6} \right)$$

$$\left( \frac{1 \text{ mol UO}_2\text{F}_2}{1 \text{ mol UF}_6} \right) \left( \frac{308.0245 \text{ g UO}_2\text{F}_2}{1 \text{ mol UO}_2\text{F}_2} \right) \left( \frac{1 \text{ Mg}}{10^6 \text{ g}} \right)$$

$$\text{or } ? \text{ Mg UO}_2\text{F}_2 = 24.543 \text{ Mg UF}_6 \left( \frac{1 \times 308.0245 \text{ Mg UO}_2\text{F}_2}{1 \times 352.019 \text{ Mg UF}_6} \right)$$

$$= \mathbf{21.476 \text{ Mg UO}_2\text{F}_2}$$

$$? \text{ Mg UO}_2\text{F}_2 = 8.0 \text{ Mg H}_2\text{O} \left( \frac{10^6 \text{ g}}{1 \text{ Mg}} \right) \left( \frac{1 \text{ mol H}_2\text{O}}{18.0153 \text{ g H}_2\text{O}} \right)$$

$$\left( \frac{1 \text{ mol UO}_2\text{F}_2}{2 \text{ mol H}_2\text{O}} \right) \left( \frac{308.0245 \text{ g UO}_2\text{F}_2}{1 \text{ mol UO}_2\text{F}_2} \right) \left( \frac{1 \text{ Mg}}{10^6 \text{ g}} \right)$$

$$\text{or } ? \text{ Mg UO}_2\text{F}_2 = 8.0 \text{ Mg H}_2\text{O} \left( \frac{1 \times 308.0245 \text{ Mg UO}_2\text{F}_2}{2 \times 18.0153 \text{ Mg H}_2\text{O}} \right)$$

$$= \mathbf{68 \text{ Mg UO}_2\text{F}_2}$$

(b) Water is much less toxic and less expensive than the radioactive and rare uranium compound. Water in the form of either liquid or steam is also very easy to separate from the solid product mixture.

## 10.3

$$? \text{ kg Na}_2\text{CrO}_4 = 1.0 \text{ kg FeCr}_2\text{O}_4 \left( \frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left( \frac{1 \text{ mol FeCr}_2\text{O}_4}{223.835 \text{ g FeCr}_2\text{O}_4} \right)$$

$$\left( \frac{8 \text{ mol Na}_2\text{CrO}_4}{4 \text{ mol FeCr}_2\text{O}_4} \right) \left( \frac{161.9733 \text{ g Na}_2\text{CrO}_4}{1 \text{ mol Na}_2\text{CrO}_4} \right) \left( \frac{1 \text{ kg}}{10^3 \text{ g}} \right)$$

$$\text{or } ? \text{ kg Na}_2\text{CrO}_4 = 1.0 \text{ kg FeCr}_2\text{O}_4 \left( \frac{8 \times 161.9733 \text{ kg Na}_2\text{CrO}_4}{4 \times 223.835 \text{ kg FeCr}_2\text{O}_4} \right)$$

$$= \mathbf{1.4 \text{ kg Na}_2\text{CrO}_4}$$

$$\text{Percent yield} = \left( \frac{\text{Actual yield}}{\text{Theoretical yield}} \right) \times 100 = \left( \frac{1.2 \text{ kg Na}_2\text{CrO}_4}{1.4 \text{ kg Na}_2\text{CrO}_4} \right) \times 100$$

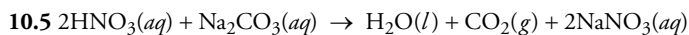
$$= \mathbf{86\% \text{ yield}}$$

## 10.4

$$\text{Molarity} = \frac{? \text{ mol AgClO}_4}{1 \text{ L AgClO}_4 \text{ soln}}$$

$$= \frac{29.993 \text{ g AgClO}_4}{50.0 \text{ mL AgClO}_4 \text{ soln}} \left( \frac{1 \text{ mol AgClO}_4}{207.3185 \text{ g AgClO}_4} \right) \left( \frac{10^3 \text{ mL}}{1 \text{ L}} \right)$$

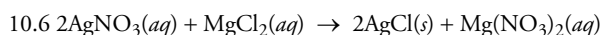
$$= \frac{2.893 \text{ mol AgClO}_4}{1 \text{ L AgClO}_4 \text{ soln}} = \mathbf{2.893 \text{ M AgClO}_4}$$



$$? \text{ mL HNO}_3 \text{ soln} = 75.0 \text{ mL Na}_2\text{CO}_3 \left( \frac{0.250 \text{ mol Na}_2\text{CO}_3}{10^3 \text{ mL Na}_2\text{CO}_3} \right)$$

$$\left( \frac{2 \text{ mol HNO}_3}{1 \text{ mol Na}_2\text{CO}_3} \right) \left( \frac{10^3 \text{ mL HNO}_3 \text{ soln}}{6.00 \text{ mol HNO}_3} \right)$$

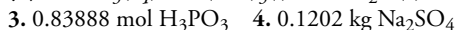
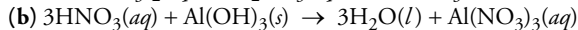
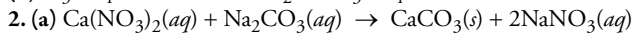
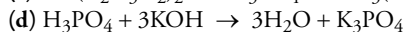
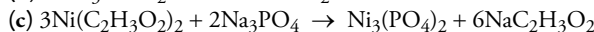
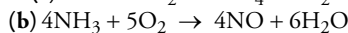
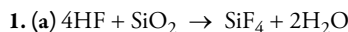
$$= \mathbf{6.25 \text{ mL HNO}_3 \text{ soln}}$$



$$? \text{ mL AgCl soln} = 25.00 \text{ mL MgCl}_2 \left( \frac{0.050 \text{ mol MgCl}_2}{10^3 \text{ mL MgCl}_2} \right)$$

$$\left( \frac{2 \text{ mol AgCl}}{1 \text{ mol MgCl}_2} \right) \left( \frac{143.3209 \text{ g AgCl}}{1 \text{ mol AgCl}} \right) = \mathbf{0.36 \text{ g AgCl}}$$

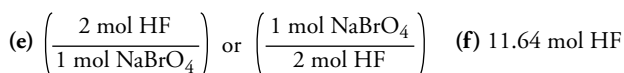
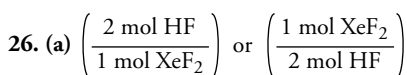
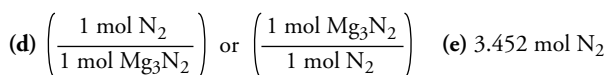
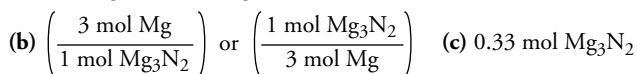
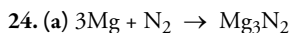
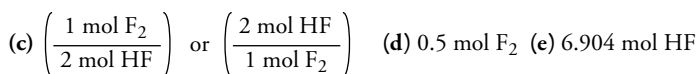
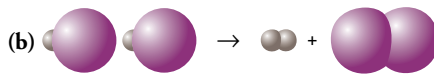
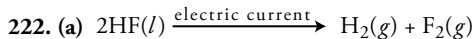
## Chapter 10 Review Questions

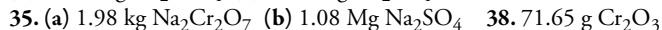
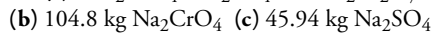
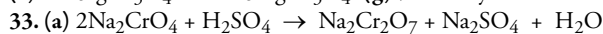
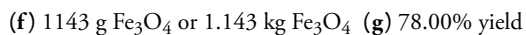
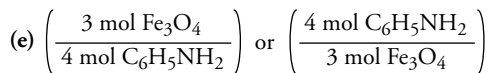
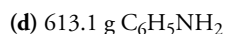
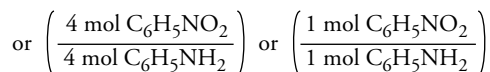
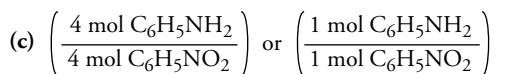
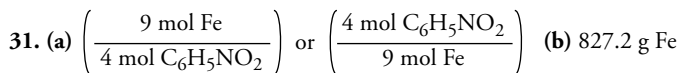
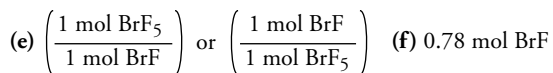
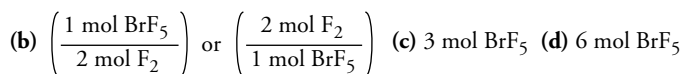
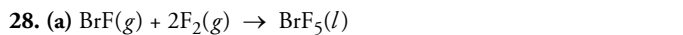


## Chapter 10 Key Ideas

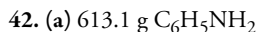
5. stoichiometry 7. stoichiometric 9. optimize 11. easy to separate 13. two or more amounts, amount of product 15. reversible 17. slow 19. volumes 21. molar mass, mass, volume of solution

## Chapter 10 Problems

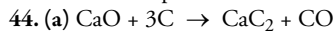




40. (a) 12.239 kg  $\text{B}_4\text{C}$  (b) There are two reasons why we are not surprised that the carbon is in excess. We would expect carbon to be less expensive than the less common boric acid, and the excess carbon can be separated easily from the solid  $\text{B}_4\text{C}$  by converting it to gaseous carbon dioxide or carbon monoxide.



(b) Both iron and water would be less expensive than nitrobenzene. They would also be expected to be less toxic than nitrobenzene.

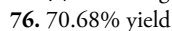
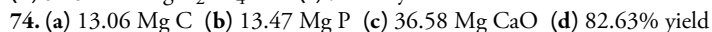
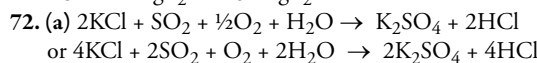
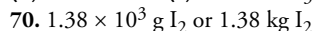
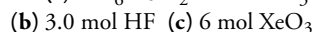
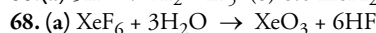
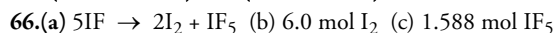
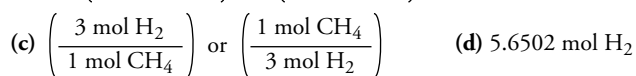
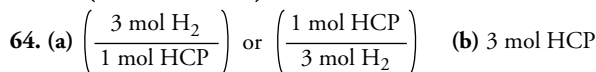
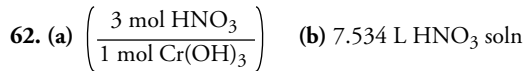
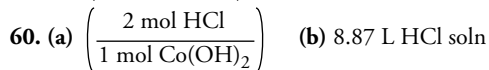
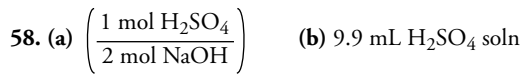
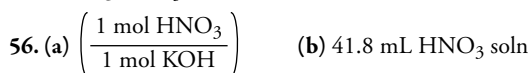
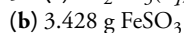
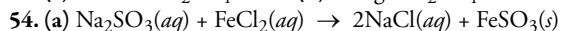
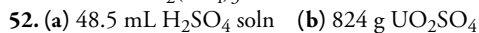
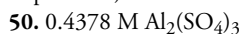


(b) The carbon is probably best to have in excess. We would expect carbon to be less expensive than the calcium oxide, and the excess carbon can be separated easily from the solid  $\text{CaC}_2$  by converting it to gaseous carbon dioxide or carbon monoxide. Thus the  $\text{CaO}$  would be limiting.

(c) We would add 752.8 g  $\text{CaO}$  and well over 483.7 g C.

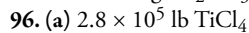
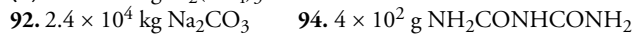
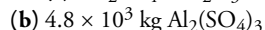
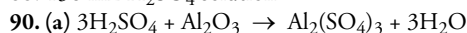
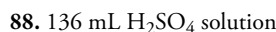
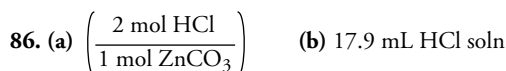
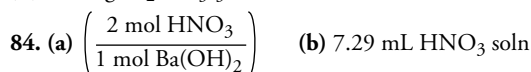
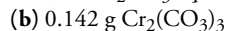
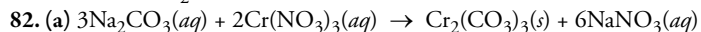
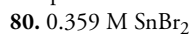
46. (1) Many chemical reactions are significantly reversible. Because there is a constant conversion of reactants to products and products to reactants, the reaction never proceeds completely to products. (2) It is common, especially in reactions involving organic compounds, to have side reactions. These reactions form products other than the desired product. (3) Sometimes a reaction is so slow that it has not reached the maximum yield by the time the product is isolated. (4) Even if 100% of the limiting reactant proceeds to products, the product still usually needs to be separated from the other components in the product mixture. (The other components include excess reactants, products of side reactions, and other impurities.) This separation generally involves some loss of product.

48. Although the maximum (or theoretical) yield of a reaction is determined by the limiting reactant rather than reactants in excess, reactants that are in excess can affect the actual yield of an experiment. Sometimes the actual yield is less than the theoretical yield because the reaction is reversible. Adding a large excess of one of the reactants ensures that the limiting reactant reacts as completely as possible (by speeding up the forward rate in the reversible reaction and driving the reaction toward a greater actual yield of products).

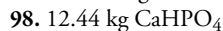


78. (a) Because the  $\text{Na}_2\text{CrO}_4$  forms the least product (70.860 g  $\text{Na}_2\text{Cr}_2\text{O}_7$ ), it is the limiting reactant.

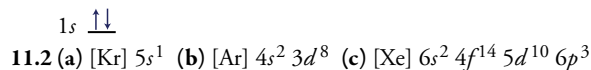
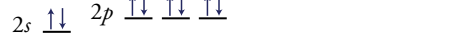
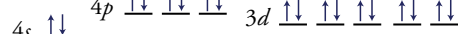
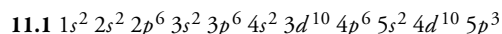
(b) Both water and carbon dioxide are very inexpensive and nontoxic. Because  $\text{CO}_2$  is a gas and because water can be easily converted to steam, they are also very easily separated from solid products. Adding an excess of these substances drives the reversible reaction toward products and yields a more complete conversion of  $\text{Na}_2\text{CrO}_4$  to  $\text{Na}_2\text{Cr}_2\text{O}_7$ .



(b) Carbon is inexpensive, nontoxic, and easy to convert to gaseous  $\text{CO}$  or  $\text{CO}_2$ , which are easy to separate from solid and liquid products. Although chlorine gas is a more dangerous substance, it is inexpensive and easy to separate from the product mixture. Because the ultimate goal is to convert the titanium in  $\text{TiO}_2$  into  $\text{TiCl}_4$ , the  $\text{TiO}_2$  is the more important reactant, so it is limiting.



### Chapter 11 Exercises



## Chapter 11 Review Questions

1. Protons and neutrons are in a tiny core of the atom called the nucleus, which has a diameter of about 1/100,000 the diameter of the atom. The position and motion of the electrons are uncertain, but they generate a negative charge that is felt in the space that surrounds the nucleus.  
 2. Increased stability of the components of a system leads to decreased potential energy, and decreased stability of the components of a system leads to increased potential energy.

## Chapter 11 Key Ideas

3. strange 5. impossible, exactly 7. probably, definitely 9. negative charge  
 11. intensity of movement, intensity of the negative charge 13. possible 15. other elements 17. high percentage, volume 19. cloud  
 21. strength, decreased 23. spontaneously returns 25. sublevel 27.  $n$   
 29. seventh 31. spinning 33. 2, spins 35.  $s$  orbitals 37.  $d$

## Chapter 11 Problems

39. The possible waveforms are limited by the fact that the string is tied down and cannot move at the ends. In theory, there are an infinite number of possible waveforms that allow the string to remain stationary at the ends.

41. The negative-charge distribution of an electron in a  $1s$  orbital of a hydrogen atom looks like the image in Figure 11.3 of the text. The cloud is pictured as surrounding the nucleus and represents the variation in the intensity of the negative charge at different positions outside the nucleus. The negative charge is most intense at the nucleus and diminishes with increasing distance from the nucleus. The variation in charge intensity for this waveform is the same in all directions, so the waveform is a sphere. Theoretically, the charge intensity decreases toward zero as the distance from the nucleus approaches infinity. The  $1s$  orbital can be described as a sphere that contains a high percentage (for example 90% or 99%) of the charge of the  $1s$  electron. According to the particle interpretation of the wave character of the electron, a  $1s$  orbital is a surface within which we have a high probability of finding the electron. In the particle view, the electron cloud can be compared to a multiple-exposure photograph of the electron. If we were able to take a series of sharply focused photos of an electron over a period of time without advancing the film, our final picture would look like the image in Figure 11.5. We would find a high density of dots near the nucleus (because most of the times when the shutter snaps, the electron would be near the nucleus) and a decrease in density with increasing distance from the nucleus (because some of the times the shutter snaps, the electron would be farther away from the nucleus). This arrangement of dots would bear out the wave equation's prediction of the probability of finding the electron at any given distance from the nucleus.

43. The  $2s$  orbital for an electron in a hydrogen atom is spherical like the  $1s$  orbital, but it is a larger sphere. For an electron in the  $2s$  orbital, the charge is most intense at the nucleus, it diminishes in intensity to a minimum with increasing distance from the nucleus, it increases again to a maximum, and finally it diminishes again. The section of the  $2s$  orbital where the charge intensity goes to zero is called a node. Figure 11.7 shows cutaway, quarter section views of the  $1s$  and  $2s$  orbitals.

45. The  $3p$  orbital is larger than the  $2p$  orbital. Because the average distance between the positively charged nucleus and the negative charge of an electron in a  $2p$  orbital would be less than for an electron in a  $3p$  orbital, the attraction between a  $2p$  electron and the nucleus would be stronger. This makes an electron in a  $2p$  orbital more stable and gives it lower potential energy than an electron in a  $3p$  orbital.

47. The three  $2p$  orbitals are identical in shape and size, but each is  $90^\circ$  from the other two. Because they can be viewed as being on the  $x$ ,  $y$  and  $z$  axes of a three-dimensional coordinate system, they are often called the  $2p_x$ ,  $2p_y$ , and  $2p_z$  orbitals. One electron with a  $2p$  waveform has its negative charge distributed in two lobes on opposite sides of the nucleus. We will call this a dumbbell shape. Figures 11.8 and 11.9 show two ways to visualize these orbitals, and Figure 11.10 shows the three  $2p$  orbitals together.

50. 3

52. There are 9 orbitals in the third principal energy level: 1 in the  $3s$  sublevel, 3 in the  $3p$  sublevel, and 5 in the  $3d$  sublevel.

54. (a) exists (b) exists (c) not exist (d) exists

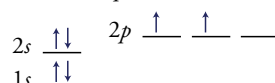
57. 2 The maximum number of electrons in *any* orbital is 2.

59. The maximum number of electrons in any  $p$  sublevel is 6. The maximum number of electrons in any  $d$  sublevel is 10.

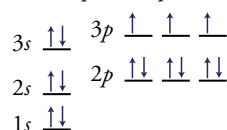
61. The third principal energy level can hold up to 18 electrons: 2 in the  $3s$ , 6 in the  $3p$ , and 10 in the  $3d$ .

63. (a)  $2s$  (b)  $3s$  (c)  $4s$  (d)  $6s$

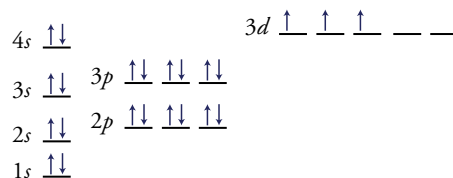
65. (a)  $1s^2 2s^2 2p^2$



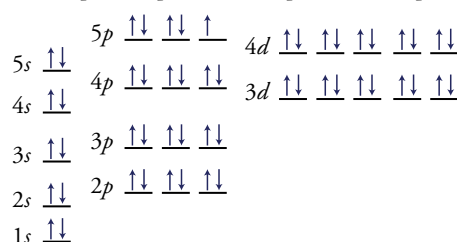
(b)  $1s^2 2s^2 2p^6 3s^2 3p^3$



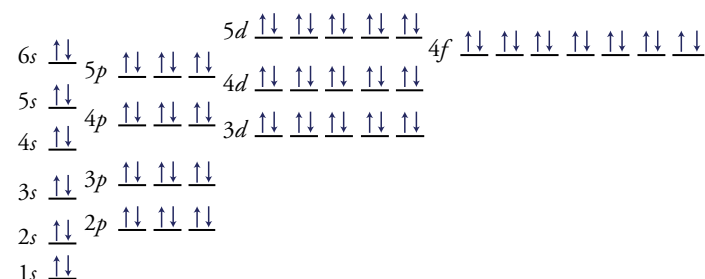
(c)  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$



(d)  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^5$



(e)  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10}$



67. (a) Be (b) Na (c) Br (d) Pb

69. (a) excited (b) ground (c) excited (d) ground

71. (a) [He]  $2s^2 2p^5$  (b) [Ne]  $3s^2 3p^2$  (c) [Ar]  $4s^2 3d^7$

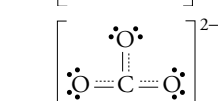
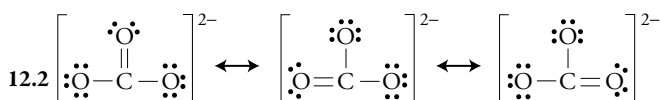
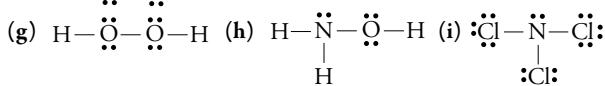
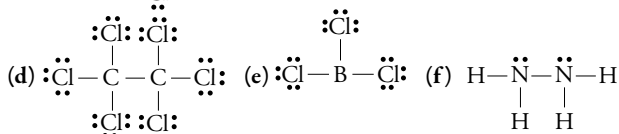
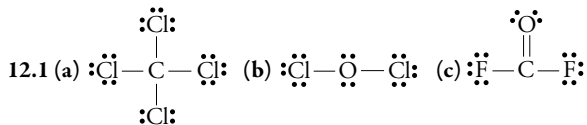
(d) [Kr]  $5s^2 4d^{10} 5p^1$  (e) [Xe]  $6s^2 4f^{14} 5d^{10} 6p^4$

73. (a)  $7s$  (b)  $3d$  (c)  $5f$  (d)  $6p$  75. (a) Al (b) Ca (c) Mn

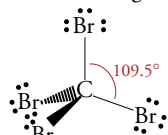
77. The pair "a" and "c" represent the alkaline earth metals magnesium and strontium.

79. (a) 30 (b) 2 (c) 128 82. [Uuo]  $8s^2 5g^1$  or [Uuo]  $5g^1 8s^2$

## Chapter 12 Exercises

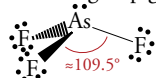


12.3 (a) Electron group geometry - **tetrahedral**



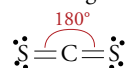
Molecular geometry - **tetrahedral**

(b) Electron group geometry - **tetrahedral**



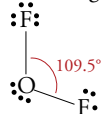
Molecular geometry - **trigonal pyramidal**

(c) Electron group geometry - **linear**



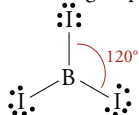
Molecular geometry - **linear**

(d) Electron group geometry - **tetrahedral**



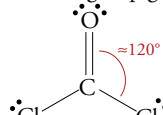
Molecular geometry - **bent**

(e) Electron group geometry - **trigonal planar**



Molecular geometry - **trigonal planar**

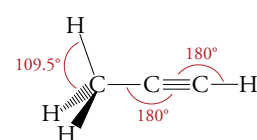
(f) Electron group geometry - **trigonal planar**



Molecular geometry - **trigonal planar**

(g) Electron group geometry for left carbon - **tetrahedral**

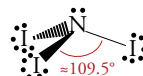
Electron group geometry for middle and right carbon - **linear**



Molecular geometry for left carbon - **tetrahedral**

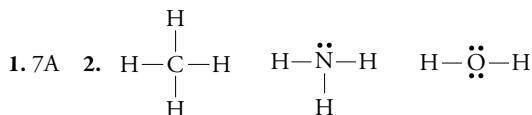
Molecular geometry for right carbon - **linear**

(h) Electron group geometry - **tetrahedral**



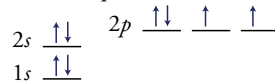
Molecular geometry - **trigonal pyramidal**

## Chapter 12 Review Questions

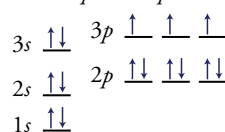


3. Orbital can be defined as the volume that contains a high percentage of the electron charge generated by an electron in an atom. It can also be defined as the volume within which an electron has a high probability of being found.

4. (a)  $1s^2 2s^2 2p^4$



(b)  $1s^2 2s^2 2p^6 3s^2 3p^3$



## Chapter 12 Key Ideas

5. true, useful 7. change 9. *s* and *p* 11. lone pairs 13. four 15. most common, polyatomic ions 17. cations 19. never 21. fewest 23. oxygen 25. two 27. structural 29. as far apart 31. electron group, molecular

## Chapter 12 Problems

32. Our models come with advantages and disadvantages. They help us to visualize, explain, and predict chemical changes, but we need to remind ourselves now and then that they are only models, and as models, they have their limitations. For example, because a model is a simplified version of what we think is true, the processes it depicts are sometimes described using the phrase *as if*. When you read, "It is as if an electron were promoted from one orbital to another," the phrase is a reminder that we do not necessarily think this is what really happens. We find it *useful* to talk about the process as if this is the way it happens. One characteristic of models is that they change with time. Because our models are a simplification of what we think is real, we are not surprised when they sometimes fail to explain experimental observation. When this happens, the model is altered to fit the new observations.

34. (a) 5 valence electrons— $2s^2 2p^3$  (b) 6 valence electrons— $3s^2 3p^4$

(c) 7 valence electrons— $5s^2 5p^5$  (d) 8 valence electrons— $3s^2 3p^6$

36. (a) 5  $\cdot\dot{\text{N}}\cdot$  (b) 6  $\cdot\dot{\text{S}}\cdot$  (c) 7  $\cdot\dot{\text{I}}\cdot$  (d) 8  $\cdot\dot{\text{R}}\cdot$

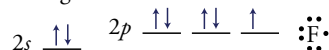
38. (a) Group 15 or 5A (b) Group 18 or 8A (c) Group 13 or 3A

40. (a)  $\text{—}\ddot{\text{N}}\text{—}$  or  $\text{—}\ddot{\text{N}}\text{—}$  (b)  $\text{—}\text{B}\text{—}$

(c)  $\text{—}\text{C}\text{—}$  or  $\text{—}\text{C}=\text{}$  or  $\text{—}\text{C}\equiv\text{}$  or  $\equiv\text{C}\text{:}$

42. The answers to each of these problems is based on the following assumptions of the valence bond model. (1) Only the highest energy electrons participate in bonding. (2) Covalent bonds usually form to pair unpaired electrons.

(a) Fluorine is in group 7A, so it has seven valence electrons per atom. The orbital diagram for the valence electrons of fluorine is below.



The one unpaired electron leads to one bond, and the three pairs of electrons give fluorine atoms three lone pairs.







## Chapter 13 Exercises

$$13.1 \text{ (a) } PV = nRT \quad n = \frac{PV}{RT} = \frac{117 \text{ kPa} (175 \text{ mL})}{\left(\frac{8.3145 \text{ L}\cdot\text{kPa}}{\text{K}\cdot\text{mol}}\right) 294.8 \text{ K}} \left(\frac{1 \text{ L}}{10^3 \text{ mL}}\right)$$

$$= 8.35 \times 10^{-3} \text{ mol Kr}$$

$$\text{(b) } V = ? \quad g = 1.196 \text{ g} \quad T = 97^\circ\text{C} + 273.15 = 370 \text{ K} \quad P = 1.70 \text{ atm}$$

$$PV = \frac{g}{M} RT$$

$$V = \frac{gRT}{PM} = \frac{1.196 \text{ g Kr} \left(\frac{0.082058 \text{ L}\cdot\text{atm}}{\text{K}\cdot\text{mol}}\right) 370 \text{ K}}{1.70 \text{ atm} (83.80 \text{ g/mol})} = 0.255 \text{ L Kr}$$

$$\text{(c) } \frac{g}{M} = ? \quad P = 762 \text{ mmHg} \quad T = 18.2^\circ\text{C} + 273.15 = 291.4 \text{ K}$$

$$PV = \frac{g}{M} RT$$

$$\frac{g}{M} = \frac{PM}{RT} = \frac{762 \text{ mmHg} (83.80 \text{ g/mol})}{\left(\frac{0.082058 \text{ L}\cdot\text{atm}}{\text{K}\cdot\text{mol}}\right) 291.4 \text{ K}} \left(\frac{1 \text{ atm}}{760 \text{ mmHg}}\right) = 3.51 \text{ g/L}$$

$$13.2 \text{ } P_1 = 102 \text{ kPa} \quad T_1 = 18^\circ\text{C} + 273.15 = 291 \text{ K} \quad V_1 = 1.6 \times 10^4 \text{ L}$$

$$P_2 = ? \quad T_2 = -8.6^\circ\text{C} + 273.15 = 264.6 \text{ K} \quad V_2 = 4.7 \times 10^4 \text{ L}$$

$$\frac{P_1 V_1}{n_1 T_1} = \frac{P_2 V_2}{n_2 T_2} \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$P_2 = P_1 \left(\frac{T_2}{T_1}\right) \left(\frac{V_1}{V_2}\right) = 1.02 \text{ kPa} \left(\frac{264.6 \text{ K}}{291 \text{ K}}\right) \left(\frac{1.6 \times 10^4 \text{ L}}{4.7 \times 10^4 \text{ L}}\right) = 32 \text{ kPa}$$

$$13.3 \text{ (a) } ? \text{ L O}_2 = 125 \text{ Mg C} \left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right) \left(\frac{1 \text{ mol C}}{12.011 \text{ g C}}\right) \left(\frac{1 \text{ mol O}_2}{2 \text{ mol C}}\right)$$

$$\left(\frac{22.414 \text{ L O}_2}{1 \text{ mol O}_2}\right)_{\text{STP}}$$

$$= 1.17 \times 10^8 \text{ L O}_2 \text{ or } 1.17 \times 10^5 \text{ m}^3 \text{ O}_2$$

$$\text{(b) } ? \text{ L CO} = 8.74 \times 10^5 \text{ L O}_2 \left(\frac{\text{K}\cdot\text{mol}}{0.082058 \text{ L}\cdot\text{atm}}\right) \left(\frac{0.994 \text{ atm}}{300 \text{ K}}\right)$$

$$\left(\frac{2 \text{ mol CO}}{1 \text{ mol O}_2}\right) \left(\frac{0.082058 \text{ L}\cdot\text{atm}}{\text{K}\cdot\text{mol}}\right) \left(\frac{308 \text{ K}}{1.05 \text{ atm}}\right)$$

$$= 1.70 \times 10^6 \text{ L CO}$$

$$13.4 \text{ } ? \text{ L Cl}_2 = 3525 \text{ L NaOH soln} \left(\frac{12.5 \text{ mol NaOH}}{1 \text{ L NaOH soln}}\right) \left(\frac{1 \text{ mol Cl}_2}{2 \text{ mol NaOH}}\right)$$

$$\left(\frac{8.3145 \text{ L}\cdot\text{kPa}}{\text{K}\cdot\text{mol}}\right) \left(\frac{291.0 \text{ K}}{101.4 \text{ kPa}}\right)$$

$$= 5.26 \times 10^5 \text{ L Cl}_2$$

$$13.5 \text{ (a) } P_{\text{total}} = P_{\text{Ne}} + P_{\text{Ar}} \quad P_{\text{Ar}} = P_{\text{total}} - P_{\text{Ne}} = 1.30 \text{ kPa} - 0.27 \text{ kPa}$$

$$= 1.03 \text{ kPa}$$

(b)

$$? \text{ mol Ar} = 6.3 \text{ mg Ar} \left(\frac{1 \text{ g}}{10^3 \text{ mg}}\right) \left(\frac{1 \text{ mol Ar}}{39.948 \text{ g Ar}}\right) = 1.6 \times 10^{-4} \text{ mol Ar}$$

$$? \text{ mol Ne} = 1.2 \text{ mg Ne} \left(\frac{1 \text{ g}}{10^3 \text{ mg}}\right) \left(\frac{1 \text{ mol Ne}}{20.1797 \text{ g Ne}}\right) = 5.9 \times 10^{-5} \text{ mol Ne}$$

$$\text{total moles} = 1.6 \times 10^{-4} \text{ mol Ar} + 5.9 \times 10^{-5} \text{ mol Ne} = 2.2 \times 10^{-4} \text{ mol}$$

$$P_{\text{total}} = (\Sigma n_{\text{each gas}}) \frac{RT}{V}$$

$$= \frac{2.2 \times 10^{-4} \text{ mol} \left(\frac{0.082058 \text{ L}\cdot\text{atm}}{\text{K}\cdot\text{mol}}\right) 291 \text{ K}}{375 \text{ mL}} \left(\frac{10^3 \text{ mL}}{1 \text{ L}}\right) \left(\frac{760 \text{ mmHg}}{1 \text{ atm}}\right)$$

$$= 11 \text{ mmHg}$$

## Chapter 13 Review Questions

1. The Kinetic Molecular Theory provides a simple model of the nature of matter. It has the following components:

- All matter is composed of tiny particles.
- These particles are in constant motion. The amount of motion is proportional to temperature. Increased temperature means increased motion.
- Solids, gases, and liquids differ in the degree of motion of their particles and the extent to which the particles interact.

Because the particles of a gas are much farther apart than those of the solid or liquid, the particles do not have significant attractions between them.

The particles in a gas move freely in straight line paths until they collide with another particle or the walls of the container. If you were riding on a particle in the gas state, your ride would be generally boring with regular interruptions caused by violent collisions. Between these collisions, you would not even know there were other particles in the container. Because the particles are moving with different velocities and in different directions, the collisions lead to constant changes in the direction and velocity of the motion of each particle. The rapid, random movement of the gas particles allows gases to adjust to the shape and volume of their container.

2. 538.4 K, 292.6 °C 3. (a) 905 Mg (b) 905 Mg (c) 95.9% yield

(d)  $3.2 \times 10^6 \text{ L Na}_2\text{SO}_4$  solution

## Chapter 13 Key Ideas

4. ten 6. 0.1%, 99.9%, 70% 8. rapid, continuous 10. direction of motion, velocity 12. point masses 14. pressure, volume, number of particles, temperature 16. degrees Celsius, °C, Kelvin 18. pascal, Pa 20. moles of gas 22. Kelvin temperature 24. directly 26. temperature and volume 28. correct equation, algebra, necessary unit conversions 30. molar mass, molarity 32. alone

## Chapter 13 Problems

34. 0.1%

36. When we walk through air, we push the air particles out of the way as we move. Because the particles in a liquid occupy about 70% of the space that contains the liquid (as opposed to 0.1% of the space occupied by gas particles), there are a lot more particles to push out of the way as you move through water.

38. (1) The particles are assumed to be point masses, that is, particles that have a mass but occupy no volume. (2) There are no attractive or repulsive forces between the particles in an ideal gas.

40. The particles in the air ( $\text{N}_2$ ,  $\text{O}_2$ , Xe,  $\text{CO}_2$ , and others) are constantly moving and constantly colliding with everything surrounded by the air. Each of these collisions exerts a tiny force against the object with which they collide. The total force of these collisions per unit area is the atmospheric pressure.

42.  $4 \times 10^8 \text{ kPa}$ ,  $4 \times 10^6 \text{ atm}$ ,  $3 \times 10^9 \text{ mmHg}$ ,  $3 \times 10^9 \text{ torr}$

44. X and Y are inversely proportional if a decrease in X leads to a proportional increase in Y or an increase in X leads to a proportional decrease in Y. For example, volume of gas and its pressure are inversely proportional if the temperature and the number of gas particles are constant. If the volume is decreased to one half its original value, the pressure of the gas will double. If the volume is doubled, the pressure decreases to one half its original value. The following expression summarizes this inverse relationship:

$$P \propto \frac{1}{V} \text{ if } n \text{ and } T \text{ are constant}$$

47. In gases, there is plenty of empty space between the particles and essentially no attractions between them, so there is nothing to stop gases, such as ammonia and the gases in air, from mixing readily and thoroughly.

49. When the muscles of your diaphragm contract and your chest expands, the volume of your lungs increases. This leads to a decrease in the number of particles per unit volume inside the lungs, which leaves fewer particles near any given area of the inner surface of the lungs. There are then fewer collisions per second per unit area of lungs and a decrease in force per unit area or gas pressure. During quiet, normal breathing, this increase in volume decreases the pressure in the lungs to about 0.4 kilopascals lower than the atmospheric pressure. The larger volume causes air to move into the lungs faster than it moves out, bringing in fresh oxygen. When the muscles relax, the lungs return to their original volume, and the decrease in volume causes the pressure in the lungs to increase to about 0.4 kilopascals above atmospheric pressure. Air now goes out of the lungs faster than it comes in. See Figure 13.9.

51. (a) As the can cools, the water vapor in the can condenses to liquid, leaving fewer moles of gas. Decreased number of gas particles and decreased temperature both lead to decreased gas pressure in the can. Because the external pressure pushing on the outside of the can is then greater than the internal pressure pushing outward, the can collapses.

(b) The increased temperature causes the internal pressure of the ping-pong ball to increase. This leads to the pressure pushing out on the shell of the ball to be greater than the external pressure pushing in on the shell. If the difference in pressure is enough, the dents are pushed out.

53. 0.042 moles Ne

55. (a)  $8.8 \times 10^2$  K or  $6.1 \times 10^2$  °C (b) As the temperature is increased, the liquid would evaporate more rapidly, increasing the amount of gas in the container and increasing the pressure.

57.  $3.7 \times 10^{-6}$  atm 59.  $4.1 \times 10^5$  L 61. 0.0426 Pa 63.  $2.9 \times 10^3$  L

65. 0.115 mg 67. 411 K or 138 °C 69. 58.3 g/mol

71. Tank A – The following shows that density (g/V) is proportional to pressure when temperature is constant. Higher pressure means higher density at a constant temperature.

$$PV = \frac{g}{M}RT \quad \frac{g}{V} = P \frac{M}{RT}$$

73. 2.41 g/L 75. (a) 756 mmHg (b) 5.97 L

77. 13.5 L The diver had better exhale as he goes up.

78. Increased number of gas particles leads to increased pressure when temperature and volume are constant.

80. 0.45 mol 82. (a)  $3.77 \times 10^3$  m<sup>3</sup> (b) 71.8 kPa (c) 233 K

85. 1.4 Mg NaCl 87. 232 g NaN<sub>3</sub> 89.  $2.41 \times 10^3$  m<sup>3</sup> HCl

91. (a)  $4.2 \times 10^4$  L NH<sub>3</sub> (b)  $3.9 \times 10^4$  L CO<sub>2</sub>

93. 475 m<sup>3</sup> CH<sub>4</sub> 95. (a) 0.24 Mg CH<sub>2</sub>CH<sub>2</sub> (b) 18 cylinders

(c)  $8.3 \times 10^3$  L C<sub>2</sub>H<sub>4</sub>O (d) 27 kg C<sub>2</sub>H<sub>4</sub>O

97.  $9.1 \times 10^6$  m<sup>3</sup> Cl<sub>2</sub> 100. (a) 109.4 kPa (b) 156 kPa

102. 316 K or 43 °C 104. (a) 42 mol other (b) 83.7%

106. (a) Yes, the average kinetic energy is dependent on the temperature of the particles, so the average kinetic energy is the same when the temperature is the same. (b) Yes, if the composition of the air is the same, the average mass of the particles is the same. Because the average kinetic energy of the particles is the same for the same temperature, the average velocity must also be the same.

$$KE_{\text{average}} = \frac{1}{2} m\mu^2_{\text{average}}$$

(c) No, because there are fewer particles per unit volume at 50 km, the average distance between the particles is greater than that at sea level.

(d) No, because the average velocity of the particles is the same and the average distance between the particles at 50 km is longer, the average distance between the collisions at 50 km is greater than that at sea level. Thus the frequency of collisions is greater at sea level.

(e) No, because there are fewer particles per unit volume, the density of the air at 50 km is much less than at sea level. Thus the sea level air has the higher density.

(f) No, because the particles in the air in the two locations would have the same average mass and the same average velocity, they would collide with

the walls of a container with the same force per collision. Because there are more gas particles per unit volume at sea level than at 50 km, there would be more collisions with the walls of a container that holds a sample of the air along the California coastline. This would lead to a greater force pushing on the walls of the container and a greater gas pressure for the gas at sea level.

108. (a) The higher temperature at noon causes the pressure to increase.

(b) The interaction between the moving tires and the stationary road causes the particles in the tires to increase their velocity, so the temperature of the tires and ultimately of the gas in the tires goes up. The increase in the temperature of the gas in the tire increases the pressure of the gas.

110. Helium is less dense than air, so it is easier for our vocal cords to vibrate. Because of this, they vibrate faster, making our voices sound strange.

### Chapter 14 Exercises

14.1 (a) polar covalent; N is partial negative, and H is partial positive.

(b) nonpolar covalent (c) ionic; O is negative, and Ca is positive.

(d) polar covalent; F is partial negative, and P is partial positive.

14.2 P–F bond; greater difference in electronegativity

14.3 iron, Fe cations in a sea of electrons, metallic bonds

iodine, I<sub>2</sub> molecules, London forces

CH<sub>3</sub>OH, CH<sub>3</sub>OH molecules, hydrogen bonds

NH<sub>3</sub>, NH<sub>3</sub> molecules, hydrogen bonds

hydrogen chloride, HCl molecules, dipole-dipole attractions

KF, cations and anions, ionic bonds

C (diamond), atoms, covalent bonds

### Chapter 14 Review Questions

1. (a) ionic bonds (b) covalent bonds

2. (a) molecular (b) ionic (c) ionic (d) molecular

3(a) ionic, MgCl<sub>2</sub> (b) binary covalent, HCl

(c) ionic with polyatomic ion, NaNO<sub>3</sub>

(d) binary covalent (hydrocarbon), CH<sub>4</sub> (e) binary covalent, NH<sub>3</sub>

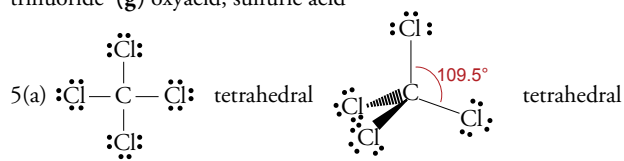
(f) binary acid, HCl(aq) (g) oxyacid, HNO<sub>3</sub> (h) alcohol, C<sub>2</sub>H<sub>5</sub>OH

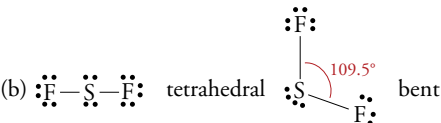
4(a) binary covalent, hydrogen fluoride (b) alcohol, methanol

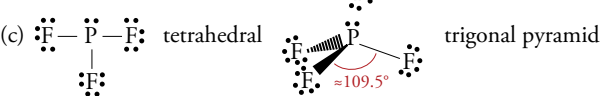
(c) ionic, lithium bromide (d) ionic with polyatomic ion, ammonium chloride

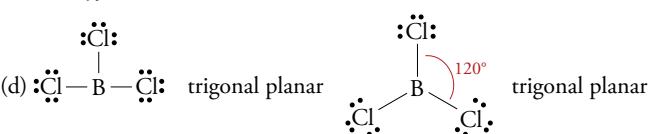
(e) binary covalent (hydrocarbon), ethane (f) binary covalent, boron trifluoride

(g) oxyacid, sulfuric acid



(b)  tetrahedral bent

(c)  tetrahedral trigonal pyramidal

(d)  trigonal planar trigonal planar

### Chapter 14 Key Ideas

6. significant, remain, large 8. more rapidly, lower 10. more

12. percentage 14. opposing, net 16. weaker 18. external pressure

20. internal vapor pressure 22. increased temperature

24. partial positive, partial negative 26. attract 28. polar

30. negative, positive 32. difference 34. nonpolar 36. Hydrogen

38. stronger, chance, less tightly

## Chapter 14 Problems

**40.** At the lower temperature during the night, the average velocity of the water molecules in the air is lower, making it more likely that they will stay together when they collide. They stay together long enough for other water molecules to collide with them forming clusters large enough for gravity to pull them down to the grass where they combine with other clusters to form the dew.

**42. (a)** In the closed test tube, the vapor particles that have escaped from the liquid are trapped in the space above the liquid. The concentration of acetone vapor rises quickly to the concentration that makes the rate of condensation equal to the rate of evaporation, so there is no net change in the amount of liquid or vapor in the test tube. In the open test tube, the acetone vapor escapes into the room. The concentration of vapor never gets high enough to balance the rate of evaporation, so all of the liquid finally disappears.

**(b)** No, the rate of evaporation is dependent on the strengths of attractions between particles in the liquid, the liquid's surface area, and temperature. All of these factors are the same for the two systems, so the initial rate of evaporation is the same for each.

**(c)** There will be some vapor above both liquids, so some vapor molecules will collide with the surface of the liquid and return to the liquid state. Thus there will be condensation in both test tubes. The concentration of acetone vapor above the liquid in the closed container will be higher, so the rate of collision between the vapor particles and the liquid surface will be higher. Thus the rate of condensation in the closed container will be higher.

**(d)** The liquid immediately begins to evaporate with a rate of evaporation that is dependent on the surface area of the liquid, the strengths of attractions between the liquid particles, and temperature. If these three factors remain constant, the rate of evaporation will be constant. If we assume that the container initially holds no vapor particles, there is no condensation of vapor when the liquid is first added. As the liquid evaporates, the number of vapor particles above the liquid increases, and the condensation process begins. As long as the rate of evaporation of the liquid is greater than the rate of condensation of the vapor, the concentration of vapor particles above the liquid will increase. As the concentration of vapor particles increases, the rate of collisions of vapor particles with the liquid increases, increasing the rate of condensation. If there is enough liquid in the container to avoid all of it evaporating, the rising rate of condensation eventually becomes equal to the rate of evaporation. At this point, for every particle that leaves the liquid, a particle somewhere else in the container returns to the liquid. Thus there is no net change in the amount of substance in the liquid form or the amount of substance in the vapor form.

**(e)** While the rate of evaporation is greater than the rate of condensation, there is a steady increase in the amount of vapor above the liquid. This increases the total pressure of gas above the liquid, so the balloon expands. When the rates of evaporation and condensation become equal, the amount of vapor and the total gas pressure remain constant, so the balloon maintains the same degree of inflation.

**(f)** The rate of evaporation is dependent on the temperature of the liquid. Increased temperature increases the average velocity and momentum of the particles in the liquid. This increases the percentage of particles that have the minimum velocity necessary to escape and increases the rate of evaporation. More particles escape per second, and the partial pressure due to the vapor above the liquid increases.

**43. (a)** The weaker attractions between diethyl ether molecules are easier to break, allowing a higher percentage of particles to escape from the surface of liquid diethyl ether than from liquid ethanol. If the surface area and temperature is the same for both liquids, more particles will escape per second from the diethyl ether than from the ethanol.

**(b)** Because the attractions between diethyl ether molecules are weaker than those between ethanol molecules, it is easier for a diethyl ether molecule to break them and move into the vapor phase. Therefore, the rate of evaporation from liquid diethyl ether is greater than for ethanol at the same

temperature. When the dynamic equilibrium between evaporation and condensation for the liquids is reached and the two rates become equal, the rate of condensation for the diethyl ether is higher than for ethanol. Because the rate of condensation is determined by the concentration of vapor above the liquid, the concentration of diethyl ether vapor at equilibrium is higher than for the ethanol. The higher concentration of diethyl ether particles leads to a higher equilibrium vapor pressure.

**45.** As the temperature of the liquid milk increases, its rate of evaporation increases. This will disrupt the equilibrium, making the rate of evaporation greater than the rate of condensation. This leads to an increase in the concentration of water molecules in the gas space above the liquid, which increases the rate of condensation until it increases enough to once again become equal to the rate of evaporation. At this new dynamic equilibrium, the rates of evaporation and condensation will both be higher.

**47. (a)** Ethanol molecules are moving constantly, sometimes at very high velocity. When they collide with other particles, they push them out of their positions, leaving small spaces in the liquid. Other particles move across the spaces and collide with other particles, and the spaces grow in volume. These spaces can be viewed as tiny bubbles. The surface of each of these tiny bubbles is composed of a spherical shell of liquid particles. Except for shape, this surface is the same as the surface at the top of the liquid. Particles can escape from the surface (evaporate) into the vapor phase in the bubble, and when particles in the vapor phase collide again with the surface of the bubble, they return to the liquid state (condense). A dynamic equilibrium between the rate of evaporation and the rate of condensation is set up in the bubble just like the liquid vapor equilibrium above the liquid in the closed container.

**(b)** Each time a particle moves across a bubble and collides with the surface of the bubble, it exerts a tiny force pushing the wall of the bubble out. All of the collisions with the shell of the bubble combine to yield a gas pressure inside the bubble. This pressure is the same as the equilibrium vapor pressure for the vapor above the liquid in a closed container. If the 1 atm of external pressure pushing on the bubble is greater than the vapor pressure of the bubble, the liquid particles are pushed closer together, and the bubble collapses. If the vapor pressure of the bubble is greater than the external pressure, the bubble will grow. If the two pressures are equal, the bubble maintains its volume. The vapor pressure of the bubbles in ethanol does not reach 1 atm until the temperature rises to 78.3 °C.

**(c)** If the external pressure acting on the bubbles in ethanol rises to 2 atm, the vapor pressure inside the bubbles must rise to 2 atm also to allow boiling. This requires an increase in the temperature, so the boiling point increases.

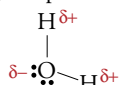
**49.** The pressure of the earth's atmosphere decreases with increasing distance from the center of the earth. Therefore, the average atmospheric pressure in Death Valley is greater than at sea level where it is 1 atmosphere. This greater external pressure acting on liquid water increases the vapor pressure necessary for the water to maintain bubbles and boil. This leads to a higher temperature necessary to reach the higher vapor pressure. Because the boiling point temperature of a liquid is the temperature at which the vapor pressure of the liquid reaches the external pressure acting on it, the boiling point temperature is higher in Death Valley.

**51.** Increased strength of attractions leads to decreased rate of evaporation, decreased rate of condensation at equilibrium, decreased concentration of vapor, and decreased vapor pressure at a given temperature. This leads to an increased temperature necessary to reach a vapor pressure of one atmosphere.

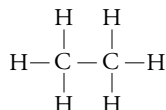
**54.** C–N, polar covalent, N; C–H, nonpolar covalent  
H–Br, polar covalent, Br; Li–F, ionic, F; C–Se, nonpolar covalent  
Se–S, nonpolar covalent; F–S, polar covalent, F;  
O–P, polar covalent, O; O–K, ionic, O; F–H, polar covalent, F

**56. (a)** C–O **(b)** H–Cl

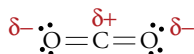
58. Water molecules have an asymmetrical distribution of polar bonds, so they are polar.



All of the bonds in ethane molecules are nonpolar, so the molecules are nonpolar.



Carbon dioxide molecules have a symmetrical distribution of polar bonds, so they are nonpolar.

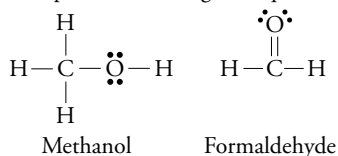


60. Ammonia is composed of  $\text{NH}_3$  molecules that are attracted by hydrogen bonds between the partially positive hydrogen atoms and the partially negative nitrogen atoms of other molecules. See Figure 14.25. The liquid would look much like the image for liquid water shown in Figure 3.14, except with  $\text{NH}_3$  molecules in the place of  $\text{H}_2\text{O}$  molecules.

62. The attractions are London forces. Because the Br-Br bond is nonpolar, the expected distribution of the electrons in the  $\text{Br}_2$  molecule is a symmetrical arrangement around the two bromine nuclei, but this arrangement is far from static. Even though the most probable distribution of charge in an isolated  $\text{Br}_2$  molecule is balanced, in a sample of bromine that contains many billions of molecules, there is a chance that a few of these molecules will have their electron clouds shifted more toward one bromine atom than the other. The resulting dipoles are often called *instantaneous dipoles* because they may be short-lived. Remember also that in all states of matter, there are constant collisions between molecules. When  $\text{Br}_2$  molecules collide, the repulsion between their electron clouds will distort the clouds and shift them from their nonpolar state. The dipoles that form are also called *instantaneous dipoles*. An instantaneous dipole can create a dipole in the molecule next to it. For example, the negative end of one instantaneous dipole will repel the negative electron cloud of a nonpolar molecule next to it, pushing the cloud to the far side of the neighboring molecule. The new dipole is called an *induced dipole*. The induced dipole can then induce a dipole in the molecule next to it. This continues until there are many polar molecules in the system. The resulting partial charges on these polar molecules lead to attractions between the opposite charges on the molecules. See Figure 14.25.

64. Both of these substances have nonpolar molecules held together by London forces. Because the  $\text{CS}_2$  molecules are larger, they have stronger London forces that raise carbon disulfide's boiling point to above room temperature.

66. Because of the O-H bond in methanol, the attractions between  $\text{CH}_3\text{OH}$  molecules are hydrogen bonds. The hydrogen atoms in  $\text{CH}_2\text{O}$  molecules are bonded to the carbon atom, not the oxygen atom, so there is no hydrogen bonding for formaldehyde. The C-O bond in each formaldehyde molecule is polar, and when there is only one polar bond in a molecule, the molecule is polar. Therefore,  $\text{CH}_2\text{O}$  molecules are held together by dipole-dipole attractions. For molecules of about the same size, hydrogen bonds are stronger than dipole-dipole attractions. The stronger hydrogen bonds between  $\text{CH}_3\text{OH}$  molecules raise its boiling point above room temperature, making it a liquid.



68. silver, Ag cations in a sea of electrons, metallic bonds

HCl, HCl molecules, dipole-dipole attractions

$\text{C}_2\text{H}_5\text{OH}$ ,  $\text{C}_2\text{H}_5\text{OH}$  molecules, hydrogen bonds

NaBr, cations and anions, ionic bonds

carbon (diamond), carbon atoms, covalent bonds

$\text{C}_5\text{H}_{12}$ ,  $\text{C}_5\text{H}_{12}$  molecules, London forces

water,  $\text{H}_2\text{O}$  molecules, hydrogen bonds

70. As a liquid spreads out on a surface, some of the attractions between liquid particles are broken. Because the metallic bonds between mercury atoms are much stronger than the hydrogen bonds between water molecules, they keep mercury from spreading out like water.

### Chapter 15 Exercises

15.1 (a) soluble (b) soluble (c) insoluble (d) soluble

15.2 (a) Ionic compound so insoluble (b) Nonpolar molecular compound so soluble

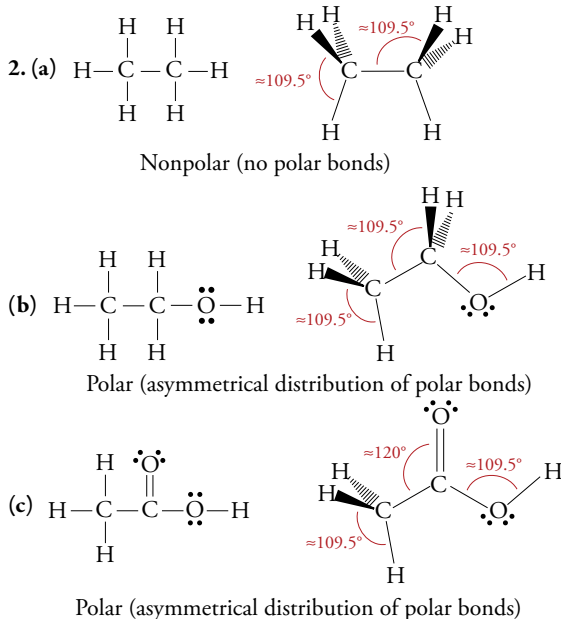
15.3 (a) Ionic compound so more soluble in water

(b) Nonpolar molecular compound so more soluble in hexane

15.4 The 2-methyl-2-propanol has a greater percentage of its structure that is polar, so we expect it to be more soluble in water.

### Chapter 15 Review Questions

1. When solid sodium bromide is added to water, all of the ions at the surface of the solid can be viewed as shifting back and forth between moving out into the water and returning to the solid surface. Sometimes when an ion moves out into the water, a water molecule collides with it, helping to break the ionic bond, and pushing it out into the solution. Water molecules move into the gap between the ion in solution and the solid and shield the ion from the attraction to the solid. The ions are kept stable and held in solution by attractions between them and the polar water molecules. The negatively charged oxygen ends of water molecules surround the sodium ions, and the positively charged hydrogen ends of water molecules surround the bromide ions. (See Figures 4.4 and 4.5 with  $\text{Br}^-$  in the place of  $\text{Cl}^-$ .) The sodium bromide is the solute, and the water is the solvent.



3. (a) nonpolar molecules / London forces

(b) polar molecules / hydrogen bonds

(c) cations and anions / ionic bonds (d) polar molecules / hydrogen bonds

(e) nonpolar molecules / London forces

(f) nonpolar molecules / London forces

4. As soon as the liquid propane is added to the tank, the liquid begins to evaporate. In the closed container, the vapor particles that have escaped from the liquid are trapped. The concentration of propane vapor rises quickly to the concentration that makes the rate of condensation equal to the rate of evaporation, so there is no net change in the amount of liquid or vapor in the tank. There are constant changes (from liquid to vapor and vapor to liquid), but because the rates of these two changes are equal (the rate of evaporation equals the rate of condensation), there is no net change in the system (the amount of liquid and vapor remains constant). Thus the system is a dynamic equilibrium.

### Chapter 15 Key Ideas

5. simplified 7. more complex 9. probability 11. insoluble 13. moderately 15. nonpolar solvents 17. Polar substances 19. attracted, nonpolar 21. fats, oils 23. cation, long chain 25. Hard, precipitate 27. surface area of the solute, degree of agitation or stirring, temperature 29. solubility

### Chapter 15 Problems

31. Changes tend to take place when they lead to an increase in the degree of dispersal of the system. Therefore, we expect that the system will shift from the less dispersed state to the more dispersed state where they fill the whole container. The reason for this shift is that there are more ways to arrange our system in the more dispersed form than in the more concentrated form. Because the particles can move freely in the container, they will shift to the more probable and more dispersed form. See Figure 15.2.

Gas in one chamber	$\longrightarrow$	Gas in both chambers
Particles closer together		Particles more dispersed
Fewer ways to arrange particles		More ways to arrange particles
Less probable		More probable

33. Picture a layer of acetic acid that is carefully added to water (See Figure 15.3. Picture acetic acid molecules in the place of the ethanol molecules.) Because the particles of a liquid are moving constantly, some of the acetic acid particles at the boundary between the two liquids will immediately move into the water, and some of the water molecules will move into the acetic acid. In this process, water-water and acetic acid-acetic acid attractions are broken and acetic acid-water attractions are formed. Both acetic acid and water are molecular substances with O–H bonds, so the attractions broken between water molecules and the attractions broken between acetic acid molecules are hydrogen bonds. The attractions that form between the acetic acid and water molecules are also hydrogen bonds. We expect the hydrogen bonds that form between water molecules and acetic acid molecules to be similar in strength to the hydrogen bonds that are broken. Because the attractions between the particles are so similar, the freedom of movement of the acetic acid molecules in the water solution is about the same as their freedom of movement in the pure acetic acid. The same can be said for the water. Because of this freedom of movement, both liquids will spread out to fill the total volume of the combined liquids. In this way, they will shift to the most probable, most dispersed state available, the state of being completely mixed. There are many more possible arrangements for this system when the acetic acid and water molecules are dispersed throughout a solution than when they are restricted to separate layers.

36. (a) soluble (b) insoluble (c) often soluble (d) often soluble (e) insoluble

38. (a) Acetic acid,  $\text{HC}_2\text{H}_3\text{O}_2$ , is like water because both are composed of small, polar molecules with hydrogen bonding between them.

(b) Ammonia,  $\text{NH}_3$ , is like water because both are composed of small, polar molecules with hydrogen bonding between them.

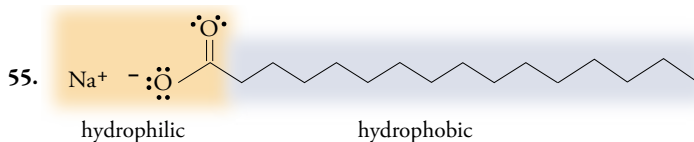
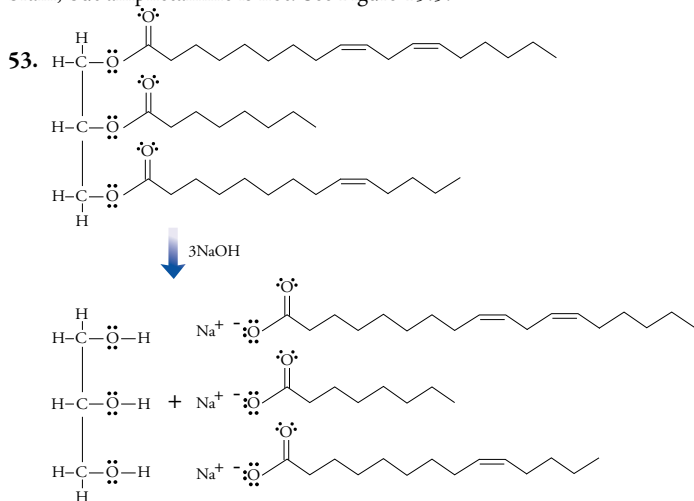
40. (a) soluble (b) insoluble (c) soluble (d) soluble

42. (a) soluble (b) insoluble 44. (a) hexane (b) water

47. acetone 49. ethane

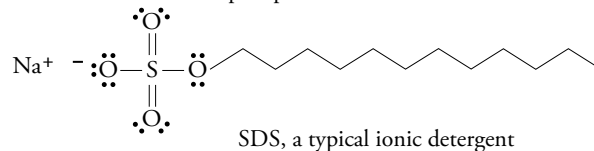
51. The three –OH groups and the N–H bond in the epinephrine structure give it a greater percentage of its structure that is polar, so we predict that

epinephrine would be more attracted to polar substances than amphetamine. The cell membranes that separate the blood stream from the inside of brain cells have a nonpolar interior and a polar exterior that tend to prevent polar substances in the blood from moving into the brain tissue. Epinephrine is too polar to move easily from the blood stream into the brain, but amphetamine is not. See Figure 15.5.



The very polar, ionic end of the soap molecule on the left is hydrophilic (attracted to water), and the nonpolar, hydrocarbon portion of the structure is hydrophobic.

57. For soap to work, its anions must stay in solution. Unfortunately, they tend to precipitate from solution when the water is “hard.” Hard water is water that contains dissolved calcium ions,  $\text{Ca}^{2+}$ , magnesium ions,  $\text{Mg}^{2+}$ , and often iron ions,  $\text{Fe}^{2+}$  or  $\text{Fe}^{3+}$ . These ions bind strongly to soap anions, causing the soap to precipitate from hard water solutions. Detergents have been developed to avoid this problem of soap in hard water. Their structures are similar to (although more varied than) soap but less likely to form insoluble compounds with hard water ions. Some detergents are ionic like soap, and some are molecular. For example, in sodium dodecyl sulfate (SDS), a typical ionic detergent, the  $-\text{CO}_2^-$  portion of the conventional soap structure is replaced by an  $-\text{OSO}_3^-$  group, which is less likely to link with hard water cations and precipitate from the solution:



59. (a) Picture the  $\text{MgSO}_4$  solid sitting on the bottom of the container. The magnesium and sulfate ions at the surface of the solid are constantly moving out into the water and being pulled back by the attractions to the other ions still on the surface of the solid. Sometimes when an ion moves out into the water, a water molecule collides with it and pushes it farther out into the solution. Other water molecules move into the gap between the ion in solution and the solid and shield the ion from the attraction to the solid. The ion is kept stable and held in solution by attractions between the polar water molecules and the charged ions. The negative oxygen atoms of the water molecules surround the cations, and the positive hydrogen ends of water molecules surround the anions. Once the ions are in solution, they move throughout the solution like any particle in a liquid. Eventually they collide with the surface of the solid. When this happens, they come back under the influence of the attractions that hold the particles in the solid, and they are likely to return to the solid form.

(b) The more particles of solute there are per liter of solution, the more collisions there will be between solute particles and the solid. More collisions lead to a greater rate of return of solute particles from the solution to the solid (See Figures 15.14 and 15.15.)

(c) As particles leave the solid and go into solution, localized high concentrations of dissolved solute form around the surface of the solid. Remember that the higher concentration of solute leads to a higher rate of return to the solid form. A higher rate of return leads to a lower overall net rate of solution. If you stir or in some way agitate the solution, the solute particles near the solid will be moved more quickly away from the solid, and the localized high concentrations of solute will be avoided. This will diminish the rate of return and increase the *net* rate of solution. This is why stirring the mixture of water and Epsom salts dissolves the magnesium sulfate more rapidly. (See Figures 15.17 and 15.18.)

(d) The solution becomes saturated when the rate of solution and the rate of return become equal. The solid continues to dissolve, but particles return to the solid from solution at the same rate. Even though the specific particles in solution are constantly changing, there is no *net* change in the total amount of solid or the amount of ions in solution.

61. (a) Higher temperature increases the rate at which particles escape from a solid, increasing the rate of solution. The higher temperature also helps the escaped particles to move away from the solid more quickly, minimizing the rate of return. Together these two factors make the net rate of solution in the hot water higher.

(b) Only particles at the surface of the solid sugar have a possibility of escaping into the solution. The particles in the center of each sugar crystal have to wait until the particles between them and the surface dissolve to have any chance of escaping. Powdered sugar has much smaller crystals, so a much higher percentage of the sugar particles are at the surface. This increases the rate of solution. (See Figure 15.16.)

63. A saturated solution has enough solute dissolved to reach the solubility limit. In a saturated solution of NaCl, Na<sup>+</sup> and Cl<sup>-</sup> ions are constantly escaping from the surface of the solid and moving into solution, but other Na<sup>+</sup> and Cl<sup>-</sup> ions in solution are colliding with the solid and returning to the solid at a rate equal to the rate of solution. Because the rate of solution and the rate of return to the solid are equal, there is no net shift to more or less salt dissolved.

65. Yes, a solution can be both concentrated and unsaturated. If the solubility of a substance is high, the concentration of the solute in solution can be high even in a solution where the rate of return to the undissolved solute is still below the rate of solution.

67. At the same temperature, the rate at which carbon dioxide molecules escape from the soft drink is the same whether the container is open or closed. When a soft drink is open to the air, the carbon dioxide molecules that escape can move farther from the surface of the liquid and are therefore less likely to collide with the surface of the liquid and return to the solution. This means a lower rate of return in the drink open to the air. Therefore, the difference between the rate of escape of the CO<sub>2</sub> from the soft drink and the rate of return will be greater in the bottle open to the air, so there is a greater net rate of escape of the gas from the soft drink.

### Chapter 16 Exercises

$$16.1 \quad K_C = \frac{[\text{SO}_2]^2 [\text{H}_2\text{O}]^2}{[\text{H}_2\text{S}]^2 [\text{O}_2]^3} \quad K_P = \frac{P_{\text{SO}_2}^2 P_{\text{H}_2\text{O}}^2}{P_{\text{H}_2\text{S}}^2 P_{\text{O}_2}^3}$$

$$16.2 \quad K_P = \frac{P_{\text{C}_2\text{H}_5\text{OH}}}{P_{\text{C}_2\text{H}_4} P_{\text{H}_2\text{O}}} = \frac{0.11 \text{ atm}}{0.35 \text{ atm} (0.75 \text{ atm})} = \mathbf{0.42 \text{ 1/atm or } 0.42}$$

16.3 (a) According to Table 16.1, the  $K_P$  for this reaction is  $2.2 \times 10^{12}$ , so it favors products. (b) According to Table 16.1, the  $K_P$  for this reaction is 6.7. Neither reactants nor products are favored.

$$16.4 \quad K_C = \frac{[\text{Cl}_2]^2}{[\text{O}_2]} \quad K_P = \frac{P_{\text{Cl}_2}^2}{P_{\text{O}_2}}$$

16.5 (a) Using Le Châtelier's Principle, we predict that the system will shift to more products to partially counteract the increase in H<sub>2</sub>O. The increase in the concentration of water vapor speeds the forward reaction without initially affecting the rate of the reverse reaction. The equilibrium is disrupted, and the system shifts to more products because the forward rate is greater than the reverse rate.

(b) Using Le Châtelier's Principle, we predict that the system will shift to more reactants to partially counteract the decrease in NO<sub>2</sub>. The decrease in the concentration of NO<sub>2</sub>(g) slows the forward reaction without initially affecting the rate of the reverse reaction. The equilibrium is disrupted, and the system shifts toward more reactants because the reverse rate is greater than the forward rate.

(c) Using Le Châtelier's Principle, we predict that the system will shift to more products to partially counteract the decrease in HNO<sub>3</sub>. The decrease in the concentration of HNO<sub>3</sub>(g) slows the reverse reaction without initially affecting the rate of the forward reaction. The equilibrium is disrupted, and the system shifts toward more products because the forward rate is greater than the reverse rate.

(d) Using Le Châtelier's Principle, we predict that the system shifts in the exothermic direction to partially counteract the decrease in temperature. As the system shifts toward more products, energy is released, and the temperature increases. The decreased temperature decreases the rates of both the forward and reverse reactions, but it has a greater effect on the endothermic reaction. Because the forward reaction is exothermic, the reverse reaction must be endothermic. Therefore, the reverse reaction is slowed more than the forward reaction. The system shifts toward more products because the forward rate becomes greater than the reverse rate.

(e) Le Châtelier's Principle does not apply here. The catalyst speeds both the forward and the reverse rates equally. Thus there is no shift in the equilibrium. The purpose of the catalyst is to bring the system to equilibrium faster.

### Chapter 16 Review Questions

1. The gas is composed of O<sub>2</sub> molecules that are moving constantly in the container. For a typical gas, the average distance between particles is about ten times the diameter of each particle. This leads to the gas particles themselves taking up only about 0.1% of the total volume. The other 99.9% of the total volume is empty space. According to our model, each O<sub>2</sub> molecule moves freely in a straight-line path until it collides with another O<sub>2</sub> molecule or one of the walls of the container. The particles are moving fast enough to break any attraction that might form between them, so after two particles collide, they bounce off each other and continue on alone. Due to collisions, each particle is constantly speeding up and slowing down, but its average velocity stays constant as long as the temperature stays constant.

2(a) energy (b) kinetic energy (c) endergonic (d) exergonic (e) thermal (f) heat (g) exothermic (h) endothermic (i) catalyst

3. Increased temperature means increased average kinetic energy.

4. Any time a change leads to decreased forces of attraction, it leads to increased potential energy. The Law of Conservation of Energy states that energy cannot be created or destroyed, so energy must be added to the system. It always takes energy to break attractions between particles.

5. Any time a change leads to increased forces of attraction, it leads to decreased potential energy. The Law of Conservation of Energy states that energy cannot be created or destroyed, so energy is released from the system. Energy is always released when new attractions between particles are formed.

6. If the bonds in the products are stronger and lower potential energy than in the reactants, energy will be released from the system. If the energy released is due to the conversion of potential energy to kinetic energy, the temperature of the products will be higher than the original reactants. The higher temperature products are able to transfer heat to the surroundings, and the temperature of the surroundings increases.

7. If the bonds in the products are weaker and higher potential energy than in the reactants, energy must be absorbed. If the energy absorbed is due to the conversion of kinetic energy to potential energy, the temperature of the products will be lower than the original reactants. The lower temperature products are able to absorb heat from the surroundings, and the temperature of the surroundings decreases.

8. The system must have two opposing changes, from state A to state B and from state B to state A. For a dynamic equilibrium to exist, the rates of the two opposing changes must be equal, so there are constant changes between state A and state B but no net change in the components of the system.

### Chapter 16 Key Ideas

9. balanced, transition state 11. minimum, equal to, greater than  
13. positive 15. new bonds, old bonds, close to each other 17. fraction  
19. alternative pathway, lower activation energy 21. heterogeneous  
23. equilibrium constant, moles per liter, coefficient 25. larger  
27. reactants 29. products 31. disrupts, change

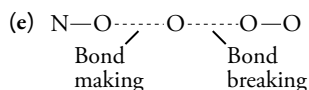
### Chapter 16 Problems

33. (a) NO and O<sub>3</sub> molecules are constantly moving in the container, sometimes with a high velocity and sometimes more slowly. The particles are constantly colliding, changing their direction of motion, and speeding up or slowing down. If the molecules collide in a way that puts the nitrogen atom in NO near one of the outer oxygen atoms in O<sub>3</sub>, one of the O–O bonds in the O<sub>3</sub> molecule begins to break, and a new bond between one of the oxygen atoms in the ozone molecule and the nitrogen atom in NO begins to form. If the collision yields enough energy to reach the activated complex, it proceeds on to products. If the molecules do not have the correct orientation, or if they do not have enough energy, they separate without a reaction taking place.

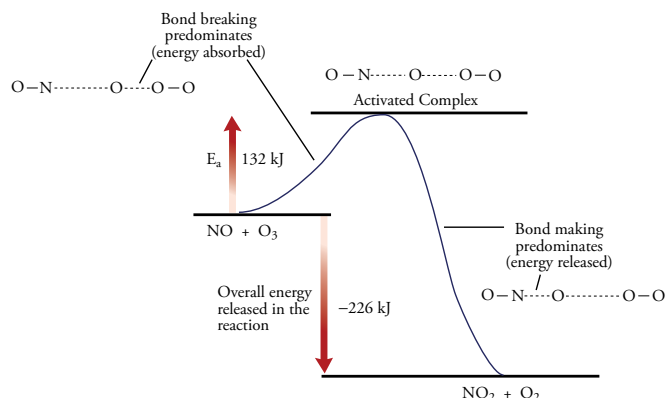
(b) NO and O<sub>3</sub> molecules must collide, they must collide with the correct orientation to form an N–O bond at the same time that an O–O bond is broken, and they must have the minimum energy necessary to reach the activated complex (the activation energy).

(c) The collision brings the atoms that will form the new bonds close, and the net kinetic energy in the collision provides the energy necessary to reach the activated complex and proceed to products.

(d) It takes a significant amount of energy to break O–O bonds, and collisions between particles are not likely to provide enough. As N–O bonds form, they release energy, so the formation of the new bonds can provide energy to supplement the energy provided by the collisions. The sum of the energy of collision and the energy released in bond formation is more likely to provide enough energy for the reaction.



(f) In the initial stage of the reaction, the energy released in bond making is less than the energy absorbed by bond breaking. Therefore, energy must be available from the colliding particles to allow the reaction to proceed. At some point in the change, the energy released in bond formation becomes equal to the energy absorbed in bond breaking. If the colliding particles have enough energy to reach this point (in other words, if they have the activation energy), the reaction proceeds to products.



(g)

(h) The negative sign for the heat of reaction shows that energy is released overall, so the reaction is exothermic.

(i) For a reaction to be likely, new bonds must be made at the same time as other bonds are broken. Therefore, the nitrogen atom in NO must collide with one of the outer oxygen atoms in O<sub>3</sub>.

35. (a) Increased concentration of reactant A leads to increased rate of collision between A and B and therefore leads to increased rate of reaction.

(b) Decreased temperature leads to decreased average kinetic energy of collisions between A and B. This leads to a decrease in the percentage of collisions with the minimum energy necessary for the reaction and therefore leads to decreased rate of reaction.

(c) With a lower activation energy, there is a greater percentage of collisions with the minimum energy necessary for the reaction and therefore an increased rate of reaction.

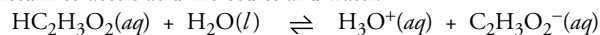
37. At a particular temperature, the lower the activation energy is, the higher the percentage of collisions with at least that energy or more will be. Thus the second reaction would have the higher fraction of collisions with the activation energy.

39. The approximate activation energy for reaction 1 is 30 kJ and for reaction 2 is 60 kJ. Reaction 1 is endothermic, and reaction 2 is exothermic.

41. In part, chlorine atoms are a threat to the ozone layer just because they provide another pathway for the conversion of O<sub>3</sub> and O to O<sub>2</sub>, but there is another reason. The reaction between O<sub>3</sub> and Cl that forms ClO and O<sub>2</sub> has an activation energy of 2.1 kJ/mole. At 25 °C, about three of every seven collisions (or 43%) have enough energy to reach the activated complex. The reaction between O and ClO to form Cl and O<sub>2</sub> has an activation energy of only 0.4 kJ/mole. At 25 °C, about 85% of the collisions have at least this energy. The uncatalyzed reaction has an activation energy of about 17 kJ/mole. At 25 °C (298 K), about one of every one thousand collisions (or 0.1%) between O<sub>3</sub> molecules and O atoms has a net kinetic energy large enough to form the activated complex and proceed to products. Thus a much higher fraction of the collisions have the minimum energy necessary to react for the catalyzed reaction than for the direct reaction between O<sub>3</sub> and O. Thus a much greater fraction of the collisions has the minimum energy necessary for the reaction to proceed for the catalyzed reaction than for the uncatalyzed reaction. Figures 16.14 and 16.15 illustrate this.

43. Step 1: The reactants (NO molecules) collide with the surface of the catalyst where they bind to the catalyst. This step is called adsorption. The bonds within the reactant molecules are weakened or even broken as the reactants are adsorbed. (N–O bonds are broken.) Step 2: The adsorbed particles (separate N and O atoms) move over the surface of the catalyst. Step 3: The adsorbed particles combine to form products (N<sub>2</sub> and O<sub>2</sub>). Step 4: The products (N<sub>2</sub> and O<sub>2</sub>) leave the catalyst. See Figure 16.16.

45. (a) Acetic acid molecules react with water to form hydronium ions and acetate ions, and at the same time, hydronium ions react with acetate ions to return to acetic acid molecules and water.



(b) Liquids evaporate to form vapor at a rate that is balanced by the return of vapor to liquid.



(c) Carbon dioxide escapes from the solution at a rate that is balanced by the return of  $\text{CO}_2$  to the solution.

47. (a) The forward reaction rate is at its peak when A and B are first mixed. Because A and B concentrations are diminishing as they form C and D, the rate of the forward reaction declines steadily until equilibrium is reached.

(b) The reverse reaction rate is at its peak when the reaction reaches equilibrium. Because C and D concentrations are increasing as they form from A and B, the rate of the reverse reaction increases steadily until equilibrium is reached.

49. (a) When  $\text{I}^-$  ions and  $\text{CH}_3\text{Br}$  molecules are added to a container, they begin to collide and react. As the reaction proceeds, the concentrations of  $\text{I}^-$  and  $\text{CH}_3\text{Br}$  diminish, so the rate of the forward reaction decreases. Initially, there are no  $\text{CH}_3\text{I}$  molecules or  $\text{Br}^-$  ions in the container, so the rate of the reverse reaction is initially zero. As the concentrations of  $\text{CH}_3\text{I}$  and  $\text{Br}^-$  increase, the rate of the reverse reaction increases. As long as the rate of the forward reaction is greater than the rate of the reverse reaction, the concentrations of the reactants ( $\text{I}^-$  and  $\text{CH}_3\text{Br}$ ) will steadily decrease, and the concentrations of products ( $\text{CH}_3\text{I}$  and  $\text{Br}^-$ ) will constantly increase. This leads to a decrease in the forward rate of the reaction and an increase in the rate of the reverse reaction. This continues until the two rates become equal. At this point, our system has reached a dynamic equilibrium.

(b) In a dynamic equilibrium for reversible chemical reactions, the forward and reverse reaction rates are equal, so although there are constant changes between reactants and products, there is no net change in the amounts of each.  $\text{I}^-$  and  $\text{CH}_3\text{Br}$  are constantly reacting to form  $\text{CH}_3\text{I}$  and  $\text{Br}^-$ , but  $\text{CH}_3\text{I}$  and  $\text{Br}^-$  are reacting to reform  $\text{CH}_3\text{Br}$  and  $\text{I}^-$  at the same rate. Thus there is no net change in the amounts of  $\text{I}^-$ ,  $\text{CH}_3\text{Br}$ ,  $\text{CH}_3\text{I}$ , or  $\text{Br}^-$ .

$$50. \text{(a)} \quad K_C = \frac{[\text{C}_2\text{H}_2][\text{H}_2]^3}{[\text{CH}_4]^2} \quad K_P = \frac{P_{\text{C}_2\text{H}_2} P_{\text{H}_2}^3}{P_{\text{CH}_4}^2}$$

$$\text{(b)} \quad K_C = \frac{[\text{NO}]^4}{[\text{N}_2\text{O}]^2 [\text{O}_2]} \quad K_P = \frac{P_{\text{NO}}^4}{P_{\text{N}_2\text{O}}^2 P_{\text{O}_2}}$$

$$\text{(c)} \quad K_C = \frac{[\text{H}_2\text{S}]^3}{[\text{H}_2]^3} \quad K_P = \frac{P_{\text{H}_2\text{S}}^3}{P_{\text{H}_2}^3}$$

52. (a) 2.2 (b) 4.7 (c) Changing temperature leads to a change in the value for an equilibrium constant. (Because  $K_P$  for this reaction decreases with increasing temperature, the reaction must be exothermic.)

54. (a)  $K_P < 10^{-2}$  so reactants favored (b)  $K_P > 10^2$  so products favored (c)  $10^{-2} < K_P < 10^2$  so neither favored

$$56. \quad K_C = \frac{1}{[\text{CO}][\text{H}_2]^2}$$

If the number of moles of  $\text{CH}_3\text{OH}(l)$  in the container is doubled, its volume doubles too, leaving the concentration (mol/L) of the methanol constant. Increasing or decreasing the total volume of the container will not change the volume occupied by the liquid methanol, so the concentration (mol/L) of the  $\text{CH}_3\text{OH}(l)$  also remains constant with changes in the volume of the container. The constant concentration of methanol can be incorporated into the equilibrium constant itself and left out of the equilibrium constant expression.

$$K' = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2} \quad \frac{K'}{[\text{CH}_3\text{OH}]} = \frac{1}{[\text{CO}][\text{H}_2]^2} = K_C$$

58. (a) Los Angeles has a much higher ozone concentration than in the Montana wilderness.

(b) Toward more products (Increased temperature favors the endothermic direction of reversible reactions.)

60. Increased temperature favors the endothermic direction of reversible reactions, so this reaction is endothermic in the reverse direction and exothermic in the forward direction.

62. Increased temperature will drive this endothermic reaction toward products, so warming the smelling salt container in your hands will increase the amount of ammonia released.

64. (a) Increased temperature increases the forward and the reverse reaction rate, but it increases the rate of the endergonic reaction more than it increases the rate of the exergonic reaction. Therefore, changing the temperature of a chemical system at equilibrium will disrupt the balance of the forward and reverse rates of reaction and shift the system in the direction of the endergonic reaction. Because this reaction is exothermic in the forward direction, it must be endothermic in the reverse direction. Increased temperature shifts the system toward more reactants, decreasing the ratio of products to reactants and, therefore, decreasing the equilibrium constant.

(b) To maximize the percentage yield at equilibrium, the reaction should be run at as low a temperature as possible, but at low temperature, the rates of the forward and reverse reactions are both very low, so it takes a long time for the system to come to equilibrium. In this case, it is best to run the reaction at high temperature to get to equilibrium quickly. (The unreacted methanol can be recycled back into the original reaction vessel after the formaldehyde has been removed from the product mixture.)

66. (a) Using Le Châtelier's Principle, we predict that the system will shift to more products to partially counteract the increase in  $\text{NH}_3$ . The increase in the concentration of ammonia speeds the forward reaction without initially affecting the rate of the reverse reaction. The equilibrium is disrupted, and the system shifts to more products because the forward rate is greater than the reverse rate.

(b) Using Le Châtelier's Principle, we predict that the system will shift to more products to partially counteract the decrease in  $\text{H}_2\text{O}$ . The decrease in the concentration of  $\text{H}_2\text{O}(g)$  slows the reverse reaction without initially affecting the rate of the forward reaction. The equilibrium is disrupted, and the system shifts toward more products because the forward rate is greater than the reverse rate.

(c) Using Le Châtelier's Principle, we predict that the system shifts in the endothermic direction to partially counteract the increase in temperature. Because the forward reaction is exothermic, the reverse reaction must be endothermic. As the system shifts toward more reactants, energy is absorbed, and the temperature decreases. The increased temperature increases the rates of both the forward and reverse reactions, but it has a greater effect on the endothermic reaction. Thus the system shifts toward more reactants because the reverse rate becomes greater than the forward rate.

68. The addition of either  $\text{H}_2$  or  $\text{I}_2$  (or both) would increase the concentrations of reactants, increasing the rate of collision between them, increasing the forward rate, and shifting the system toward more product. Lower temperature favors the exothermic direction of the reaction, so lower temperature would shift this reaction to a higher percentage of products at equilibrium.

70. (a) The system will shift toward products, which leads to increased  $\text{COCl}_2$ . (b) The system will shift toward products, which leads to decreased  $\text{Cl}_2$ . (c) Equilibrium constants are unaffected by reactant and product concentrations, so the equilibrium constant remains the same.

### Chapter 17 Exercises

17.1 (a) alkane (b) amine (c) ether (d) ester (e) ketone (f) carboxylic acid (g) amide (h) aldehyde (i) alcohol (j) alkene (k) amine (l) alkyne (m) arene

17.2 (a)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$  or  $\text{CH}_3(\text{CH}_2)_5\text{CH}_3$

(b)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$  or  $\text{CH}_3(\text{CH}_2)_7\text{NH}_2$

(c)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$

(d)  $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$   
or  $\text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$

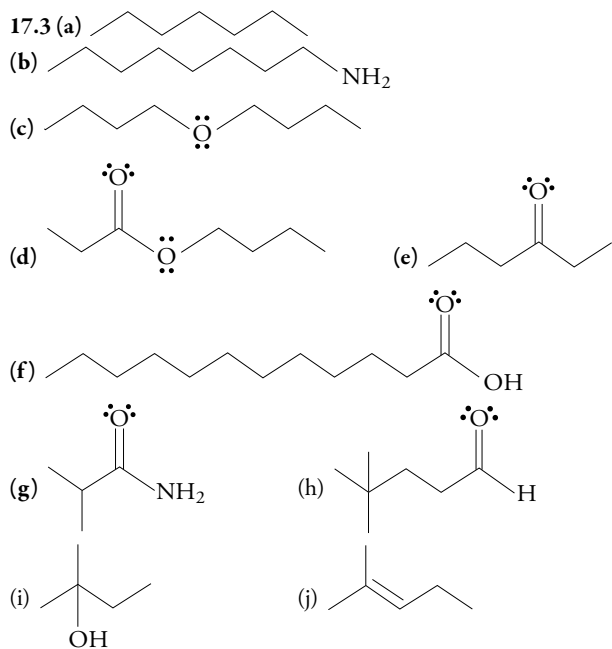
(e)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{COCH}_2\text{CH}_3$

(f)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$   
or  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH}$   
or  $\text{CH}_3(\text{CH}_2)_{10}\text{CO}_2\text{H}$  or  $\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$

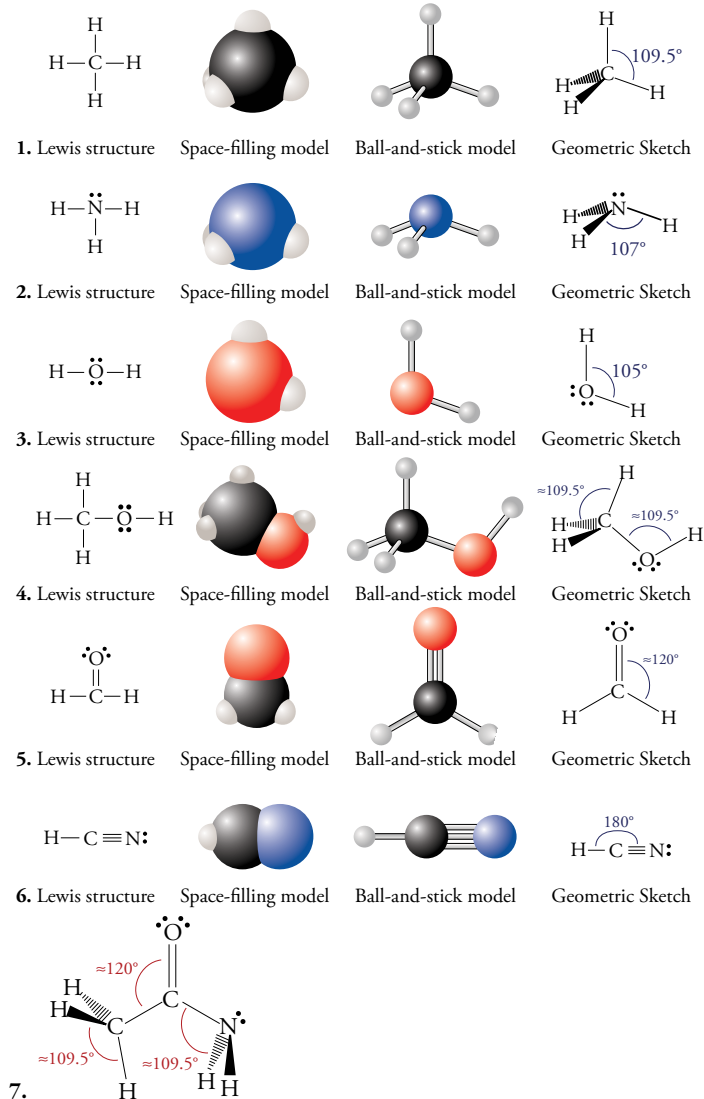
(g)  $(\text{CH}_3)_2\text{CHCONH}_2$  (h)  $(\text{CH}_3)_3\text{CCH}_2\text{CH}_2\text{CHO}$

(i)  $(\text{CH}_3)_2\text{C}(\text{OH})\text{CH}_2\text{CH}_3$  (j)  $(\text{CH}_3)_2\text{CCH}_2\text{CH}_2\text{CH}_3$

(k)  $\text{CH}_3\text{CH}_2\text{N}(\text{CH}_3)_2$  (l)  $\text{CH}_3\text{CCC}(\text{CH}_3)_3$



Chapter 17 Review Questions

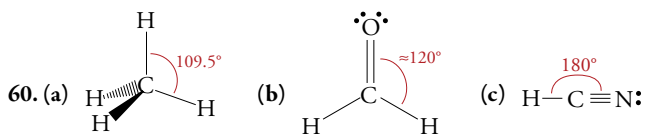
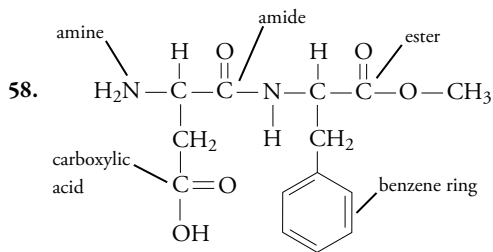
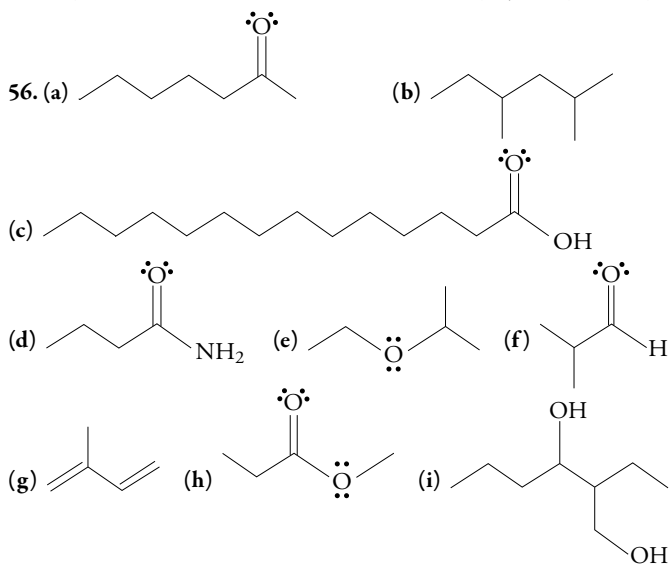


Chapter 17 Key Ideas

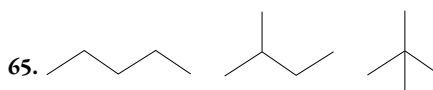
8. single 10. small section 12. benzene ring 14. hydrocarbon groups  
 16. disaccharides, polysaccharides 18. glucose 20. fructose  
 22. energy, amylase, amylopectin 24. repeating units  
 26. monomers, amino acids 28. water 30. close to each other  
 32. long-term 34. hydrogenation 36. double bonds 38. cholesterol  
 40. monosaccharides, protein, glycerol, fatty acids 42. acidic, denaturation  
 44. substrates, active site, shape 46. step-growth 48. diol

Chapter 17 Problems

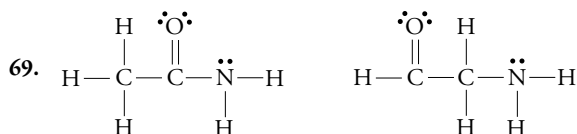
50. (a) inorganic (b) organic (c) organic (d) inorganic  
 52. (a) ketone (b) alkane (c) carboxylic acid (d) amide (e) ether  
 (f) aldehyde (g) alkene (h) ester (i) alcohol (j) alkyne (k) arene  
 54. (a)  $\text{CH}_3(\text{CH}_2)_4\text{COCH}_3$  or  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COCH}_3$   
 (b)  $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}(\text{CH}_3)_2$   
 or  $\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}(\text{CH}_3)\text{CH}_3$   
 (c)  $\text{CH}_3(\text{CH}_2)_{12}\text{COOH}$  or  $\text{CH}_3(\text{CH}_2)_{12}\text{CO}_2\text{H}$   
 (d)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CONH}_2$   
 (e)  $\text{CH}_3\text{CH}_2\text{OCH}(\text{CH}_3)_2$  or  $\text{CH}_3\text{CH}_2\text{OCH}(\text{CH}_3)\text{CH}_3$   
 (f)  $(\text{CH}_3)_2\text{CHCHO}$  or  $\text{CH}_3\text{CH}(\text{CH}_3)\text{CHO}$  (g)  $\text{CH}_2\text{C}(\text{CH}_3)\text{CHCH}_2$   
 (h)  $\text{CH}_3\text{CH}_2\text{COOCH}_3$  or  $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$   
 (i)  $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}(\text{OH})\text{CH}(\text{CH}_2\text{OH})\text{CH}_2\text{CH}_3$  (j)  $\text{CH}_3\text{CCCH}_3$



63. (a) isomers (b) same (c) isomers (d) same



67.  $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$   $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$   $\text{CH}_3\text{OCH}_2\text{CH}_3$



72. (a) amino acid (b) carbohydrate (c) triglyceride (d) steroid

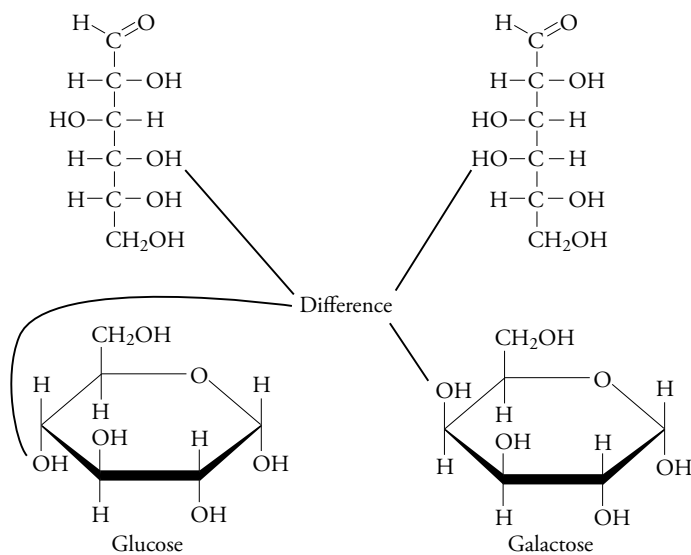
74. (a) polysaccharide (b) monosaccharide (c) disaccharide

(d) monosaccharide

76. (a) disaccharide (b) monosaccharide (c) polysaccharide

(d) polysaccharide

78. Glucose and galactose differ in the relative positions of an  $-H$  and an  $-OH$  on one of their carbon atoms. In the standard notation for the open chain form, glucose and galactose differ only in the relative position of the  $-H$  and  $-OH$  groups on the fourth carbon from the top. In the standard notation for the ring structures, the  $-OH$  group is down on the number 4 carbon of glucose and up on the number 4 carbon of galactose.



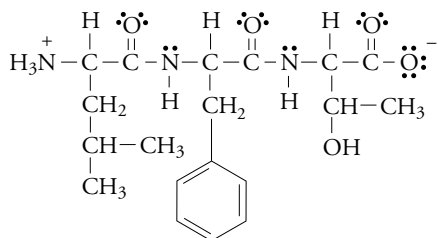
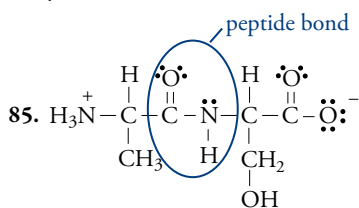
80. Maltose – two glucose units;

Sucrose – glucose and fructose

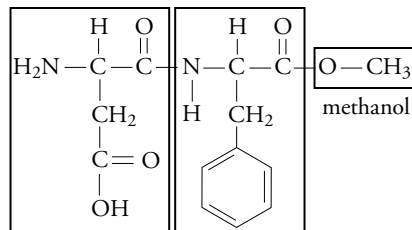
Lactose – glucose and galactose;

82. Starch and cellulose molecules are composed of many glucose molecules linked together, but cellulose has different linkages between the molecules than starch. See Figure 17.21.

84. One end of the amino acid has a carboxylic acid group that tends to lose an  $H^+$  ion, and the other end has a basic amine group that attracts  $H^+$  ions. Therefore, in the conditions found in our bodies, amino acids are likely to be in the second form.

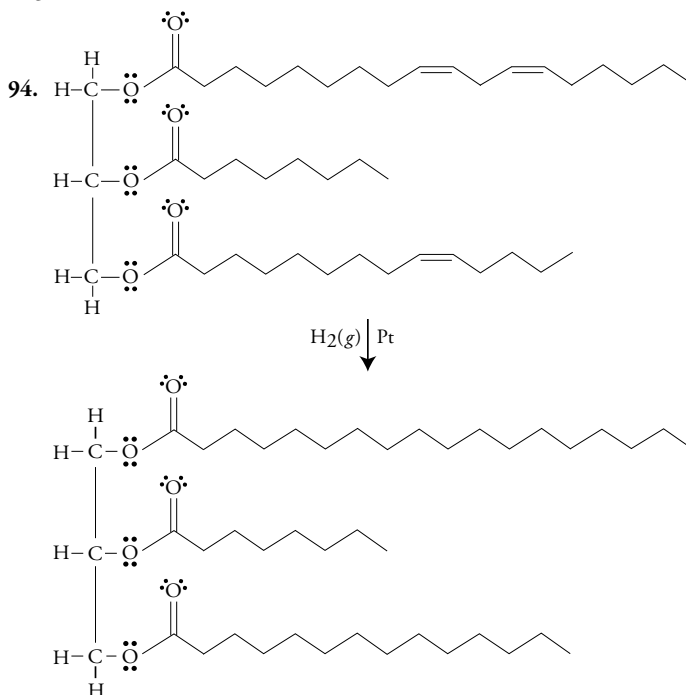


87.



89. aspartic acid phenylalanine

91. Each of these interactions draws specific amino acids in a protein chain close together, leading to a specific shape of the protein molecule. Disulfide bonds are covalent bonds between sulfur atoms from two cysteine amino acids (Figure 17.27). Hydrogen bonding forms between  $-OH$  groups in two amino acids, such as serine or threonine, in a protein chain (Figure 17.28). Salt bridges are attractions between negatively charged side chains and positively charged side chains. For example, the carboxylic acid group of an aspartic acid side chain can lose its  $H^+$ , leaving the side chain with a negative charge. The basic side chain of a lysine amino acid can gain an  $H^+$  and a positive charge. When these two charges form, the negatively charged aspartic acid is attracted to the positively charged lysine by a salt bridge (Figure 17.29).



96. Disaccharides – monosaccharides (glucose and galactose from lactose; fructose from other sources)

Polysaccharides – glucose

Protein – amino acids

fat – glycerol and fatty acids

98. Before an enzyme reaction takes place, the molecule or molecules that are going to react (called substrates) must fit into a specific section of the protein structure called the active site. Because the active site has a shape that fits specific substrates, because it has side chains that attract particular substrates, and because it has side chains in distinct positions that speed the reaction, each enzyme will only act on a specific molecule or a specific type of molecule.

100. One of the reasons for the exceptional strength of nylon is the hydrogen bonding between amide functional groups. A higher percentage of amide functional groups in nylon molecules' structures leads to stronger hydrogen bonds between them. Thus, changing the number of carbon atoms in the diamine and in the di-carboxylic acid changes the properties of nylon. Nylon 610, which has four more carbon atoms in the di-carboxylic acid molecules that form it than for Nylon 66, is somewhat weaker than Nylon 66 and has a lower melting point.

**102.** Polyethylene molecules can be made using different techniques. One process leads to branches that keep the molecules from fitting closely together. Other techniques have been developed to make polyethylene molecules with very few branches. These straight chain molecules fit together more efficiently, yielding a high density polyethylene, HDPE, that is more opaque, harder, and stronger than the low density polyethylene, LDPE.

**104.** Nonpolar molecules are attracted to each other by London forces, and increased size of molecules leads to stronger London forces. Polyethylene molecules are much larger than the ethylene molecules that are used to make polyethylene, so polyethylene molecules have much stronger attractions between them, making them solids at room temperature.

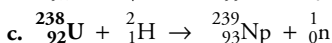
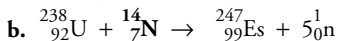
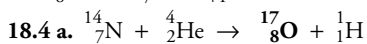
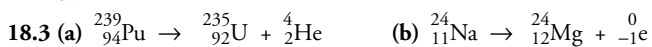
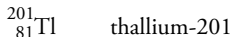
### Chapter 18 Exercises

**18.1** Because this nuclide has 39 protons, its atomic number,  $Z$ , is 39. This identifies the element as yttrium. This nuclide of yttrium has 90 total nucleons (39 protons + 51 neutrons), so its nucleon number,  $A$ , is 90.



**18.2** The periodic table shows us that the atomic number for thallium is 81, so each thallium atom has 81 protons. The superscript in the symbol  ${}^{201}\text{Tl}$  is this nuclide's mass number. The difference between the mass number (the sum of the numbers of protons and neutrons) and the atomic number (the number of protons) is equal to the number of neutrons, so this nuclide has 120 neutrons ( $201 - 81$ ).

Atomic number = 81 mass number = 201 81 protons 120 neutrons



**18.5** In each half-life of a radioactive nuclide, the amount diminishes by one-half. The fraction  $\frac{1}{8}$  is  $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$ , so it takes three half-lives to diminish to  $\frac{1}{8}$  remaining. Therefore, it will take 36.78 years for tritium to decrease to  $\frac{1}{8}$  of what was originally there.

**18.6** The length of time divided by the half-life yields the number of half-lives.

$$\frac{9.02 \times 10^9 \text{ years}}{4.51 \times 10^9 \text{ years}} = 2 \text{ half-lives}$$

Therefore, the fraction remaining would be  $\frac{1}{4}$  ( $\frac{1}{2} \times \frac{1}{2}$ ).

### Chapter 18 Review Questions

**1.** Protons and neutrons are in a tiny core of the atom called the nucleus, which has a diameter about 1/100,000 the diameter of the atom. The position and motion of the electrons are uncertain, but they generate a negative charge that is felt in the space that surrounds the nucleus.

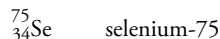
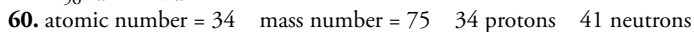
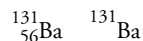
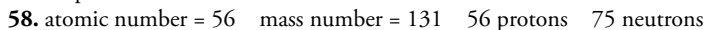
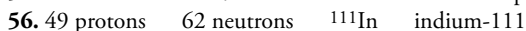
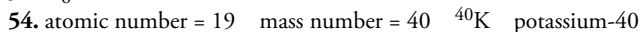
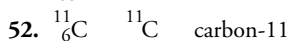
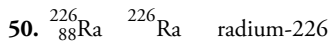
**2.** In the particle view, radiant energy is a stream of tiny, massless packets of energy called photons. Different forms of radiant energy differ with respect to the energy of each of their photons. The energies of the photons of radio waves are much lower than for gamma radiation. In the wave view, as radiant energy moves away from the source, it has an effect on the space around it that can be described as a wave consisting of an oscillating electric field perpendicular to an oscillating magnetic field. Different forms of radiant energy differ with respect to the wavelengths and frequencies of these oscillating waves. The waves associated with radio waves have much longer wavelength than the waves associated with gamma radiation.

**3.** isotopes **4.** atomic number **5.** mass number **6.** Energy  
**7.** Kinetic energy **8.** Law of Conservation of Energy **9.** Potential energy  
**10.** lower **11.** released **12.** ground state **13.** excited state

### Chapter 18 Key Ideas

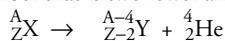
**14.** protons, neutrons **16.** electrostatic, strong **18.** ratio **20.** alpha  
**22.** too low **24.** releases, photons **26.** different **28.** energy **30.** one-half  
**32.** pull **34.** excite **36.** 100 **38.** rapidly reproducing **40.**  ${}^{14}\text{C}/{}^{12}\text{C}$  ratio  
**42.** 10,000 **44.** double magic numbers **46.** larger than **48.** furnace

### Chapter 18 Problems

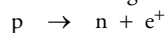


**62.** The first force among the particles in the nucleus is called the electrostatic force (or electromagnetic force). It is the force between electrically charged particles. Opposite charges attract each other, and like charges repel each other, so the positively charged protons in the nucleus of an atom have an electrostatic force pushing them apart. The second force, called the strong force, holds nucleons (protons and neutrons) together. You can think of neutrons as the nuclear glue that allows protons to stay together in the nucleus. Because neutrons are uncharged, there are no electrostatic repulsions among them and other particles, but each neutron in the nucleus of an atom is attracted to other neutrons and to protons by the strong force. Therefore, adding neutrons to a nucleus leads to more attractions holding the particles of the nucleus together without causing increased repulsion between those particles. Larger atoms with more protons in their nuclei require a greater ratio of neutrons to protons to balance the increased electrostatic repulsion between protons.

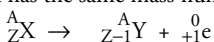
**64.** One of the ways that heavy nuclides change to move back into the band of stability is to release two protons and two neutrons in the form of a helium nuclei, called an alpha particle. In nuclear equations for alpha emission, the alpha particle is described as either  $\alpha$  or  ${}^4_2\text{He}$ . In alpha emission, the radioactive nuclide changes into a different element that has an atomic number that is two lower and a mass number that is four lower.



**66.** In positron emission ( $\beta^+$ ), a proton becomes a neutron and an anti-electron. The neutron stays in the nucleus, and the positron speeds out of the nucleus at high velocity.



In nuclear equations for positron emission, the electron is described as either  $\beta^+$ ,  ${}^0_{+1}\text{e}$ , or  ${}^0_1\text{e}$ . In positron emission, the radioactive nuclide changes into a different element that has an atomic number that is one lower but that has the same mass number.

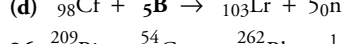
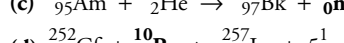
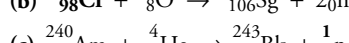
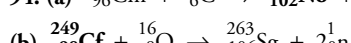
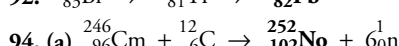
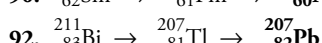
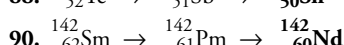
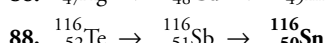
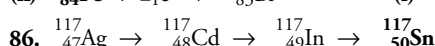
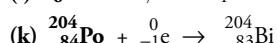
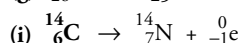
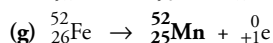
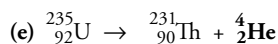
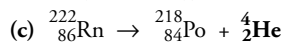
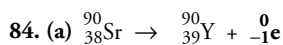
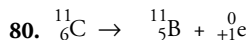
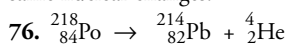


**68.** Bismuth-202, which has a lower neutron to proton ratio than the stable bismuth-209, undergoes electron capture, which increases the neutron to proton ratio. Bismuth-215, which has a higher neutron to proton ratio than the stable bismuth-209, undergoes beta emission, which decreases the neutron to proton ratio.

**71. (a)** beta emission **(b)** alpha emission **(c)** gamma emission **(d)** positron emission or electron capture **(e)** beta emission **(f)** alpha emission

**73.** Nuclear reactions involve changes in the nucleus, as opposed to chemical reactions that involve the loss, gain, and sharing of electrons. Different isotopes of the same element often undergo very different nuclear reactions, whereas they all share the same chemical characteristics. Unlike chemical reactions, the rates of nuclear reactions are unaffected by temperature, pressure, and the other atoms to which the radioactive atom is bonded. Nuclear reactions, in general, give off a lot more energy than chemical reactions.

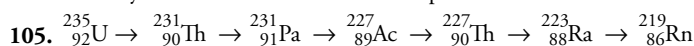
74. These two particles differ only in the number of their electrons. Because chemical reactions involve the loss, gain, and sharing of electrons, the number of electrons for an atom is very important for chemical changes. The attractions between charges are also very important for chemical changes, so the different charges of these particles change how they act chemically. Nuclear reactions are determined by the stability of nuclei, which is related to the number of protons and neutrons in the nuclei. They are unaffected by the number of electrons and unaffected by the overall charge of the particles. Therefore, these particles, which both have 17 protons and 21 neutrons in their nuclei, have the same nuclear stability and undergo the same nuclear changes.



98. It takes 2 half-lives for a radioactive nuclide to decay to  $\frac{1}{4}$  of its original amount ( $\frac{1}{2} \times \frac{1}{2}$ ). Therefore, it will take 60 years for cesium-133 to decrease to  $\frac{1}{4}$  of what was originally there.

100. The 42.9 days is 3 half-lives ( $42.9/14.3$ ), so the fraction remaining would be  $\frac{1}{8}$  ( $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$ ).

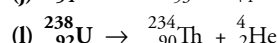
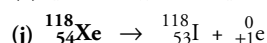
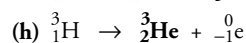
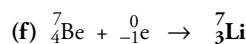
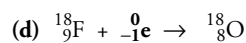
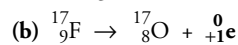
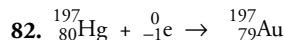
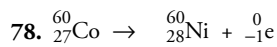
102. Although short-lived radioactive nuclides disappear relatively quickly once they form, they are constantly being replenished because they are products of other radioactive decays. There are three long-lived radioactive nuclides (uranium-235, uranium-238, and thorium-232) that are responsible for many of the natural radioactive isotopes.



107. alpha, beta, beta, alpha, alpha

109. As alpha particles, which move at up to 10% the speed of light, move through the tissues of our bodies, they drag electrons away from the tissue's atoms. Remember that alpha particles are helium nuclei, so they each have a +2 charge. Thus, as the alpha particle moves past an atom or molecule, it attracts the particle's electrons. One of the electrons might be pulled toward the passing alpha particle enough to escape, but it might not be able to catch up to the fast moving alpha particle. The electron lags behind the alpha particle and is quickly incorporated into another atom or molecule, forming an anion, and the particle that lost the electron becomes positively charged. The alpha particle continues on its way creating many ions before it is slowed enough for electrons to catch up to it and neutralize its charge.

111. Gamma photons can excite electrons enough to actually remove them from atoms.



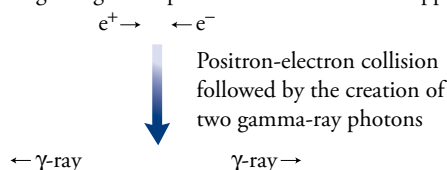
113. The greatest effect is on tissues with rapidly reproducing cells where there are more frequent chemical changes. This is why nuclear emissions have a greater effect on cancerous tumors with their rapidly reproducing cells and on children, who have more rapidly reproducing cells than adults.

115. Because both radium and calcium are alkaline earth metals in group 2 on the periodic table, they combine with other elements in similar ways. Therefore, if radioactive radium-226 is ingested, it concentrates in the bones in substances that would normally contain calcium.

117. Alpha and beta particles lose all of their energy over a very short distance, so they can do more damage to localized areas in the body than the same number of gamma photons would.

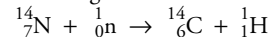
118. Cobalt-60 emits ionizing radiation in the form of beta particles and gamma photons. Gamma photons penetrate the body and do more damage to rapidly reproducing cells than others. Typically, a focused beam of gamma photons from cobalt-60 is directed at a cancerous tumor. The gamma photons enter the tumor and create ions and free radicals that damage the tumor cells to shrink the tumor.

120. To get a PET scan of a patient, a solution that contains a positron emitting substance is introduced into the body. The positrons that the radioactive atoms emit collide with electrons, and they annihilate each other, creating two gamma photons that move out in opposite directions.

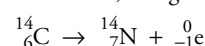


These photons can be detected, and the data can be computer analyzed to yield images that show where in the body the radioactive substances collected. Depending on the nuclide used and the substance into which it is incorporated, the radioactive substance will move to a specific part of the body.

122. Carbon-14 atoms are constantly being produced in our upper atmosphere through neutron bombardment of nitrogen atoms.



The carbon-14 formed is quickly oxidized to form carbon dioxide,  $\text{CO}_2$ , which is converted into many different substances in plants. When animals eat the plants, the carbon-14 becomes part of the animal too. For these reasons, carbon-14 is found in all living things. The carbon-14 is a beta emitter with a half life of 5730 years ( $\pm 40$  years), so as soon as it becomes part of a plant or animal, it begins to disappear.



As long as a plant or animal is alive, the intake of carbon-14 balances the decay so that the ratio of  ${}^{14}\text{C}$  to  ${}^{12}\text{C}$  remains constant at about 1 in 1,000,000,000,000. When the plant or animal dies, it stops taking in fresh carbon, but the carbon-14 it contains continues to decay. Thus the ratio of  ${}^{14}\text{C}$  to  ${}^{12}\text{C}$  drops steadily. Therefore, to date an artifact, a portion of it is analyzed to determine the  ${}^{14}\text{C}/{}^{12}\text{C}$  ratio, which can be used to calculate its age.

Initially, it was thought that determination of the age of something using this technique would be simple. For example, if the  ${}^{14}\text{C}/{}^{12}\text{C}$  ratio had dropped to one-half of the ratio found in the air today, it would be considered to be about 5730 years old. A  ${}^{14}\text{C}/{}^{12}\text{C}$  ratio of one-fourth of the ratio found in the air today would date it as 11,460 years old (two half-lives). This only works if we can assume that the  ${}^{14}\text{C}/{}^{12}\text{C}$  ratio in the air was the same when the object died as it is now, and scientists have discovered that this is not strictly true.

Study of very old trees, such as the bristlecone pines in California, have allowed researchers to develop calibration curves that adjust the results of radiocarbon dating experiments for the variation in the  ${}^{14}\text{C}/{}^{12}\text{C}$  ratio that go back about 10,000 years. These calibration curves are now used to get more precise dates for objects.

**124.** The radioactive iridium-192 is introduced to the pipe, and the connection is wrapped on the outside with film. If there is a crack in the connection, radiation leaks out and exposes the film.

**126.** Unstable nuclides have been used as radioactive tracers that help researchers discover a wide range of things. For example, incorporating carbon-14 into molecules helped scientists to study many of the aspects of photosynthesis. Because the radiation emitted from the carbon-14 atoms can be detected outside of the system into which the molecules are placed, the changes that involve carbon can be traced. Phosphorus-32 atoms can be used to trace phosphorus-containing chemicals as they move from the soil into plants under various conditions. Carbon-14, hydrogen-3, and sulfur-35 have been used to trace the biochemical changes that take place in our bodies.

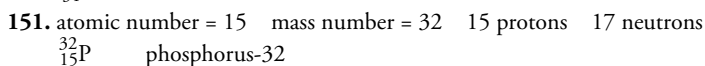
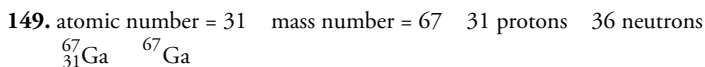
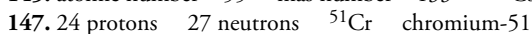
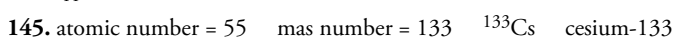
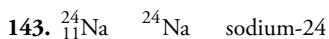
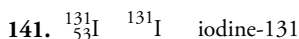
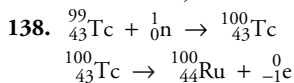
**128.** The greater the strengths of the attractions between nucleons, the more stable the nucleus and the greater the difference in potential energy between the separate nucleons and the nucleus. This is reflected in a greater binding energy per nucleon.

**130.** This can be explained by the fact that they have an even number of protons and an even number of the neutrons. Paired nucleons (like paired electrons) are more stable than unpaired ones.

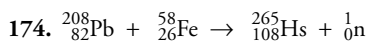
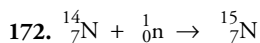
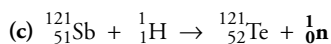
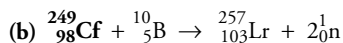
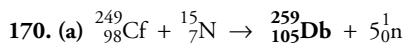
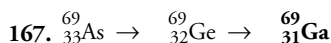
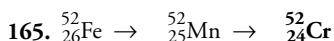
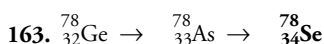
**132.** Paired nucleons are more stable than unpaired ones, and oxygen-16 with 8 protons and 8 neutrons would have its nucleons paired. Oxygen-15 with an odd number of neutrons (7) would be less stable. Oxygen-16 also has double magic numbers, making it especially stable. Finally, oxygen-15 has too few neutrons to be stable.

**134.** Heat is generated by the chain reaction of uranium-235, which is initiated by the bombardment of uranium fuel that is about 3% uranium-235. The products are significantly more stable than the initial reactants, so the system shifts from higher potential energy to lower potential energy, releasing energy as increased kinetic energy of the product particles. Higher kinetic energy means higher temperature.

**136.** Both uranium-235 and uranium-238 absorb fast neutrons, but if the neutrons are slowed down, they are much more likely to be absorbed by uranium-235 atoms than uranium-238 atoms. Therefore, in a nuclear reactor, the fuel rods are surrounded by a substance called a moderator, which slows the neutrons as they pass through it. Several substances have been used as moderators, but normal water is most common.



**153.** Neon-18, which has a lower neutron to proton ratio than the stable neon-20, undergoes positron emission, which increases the neutron to proton ratio. Neon-24, which has a higher neutron to proton ratio than the stable neon-20, undergoes beta emission, which decreases the neutron to proton ratio.



**176.** It takes 3 half-lives for a radioactive nuclide to decay to  $\frac{1}{8}$  of its original amount ( $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$ ). Therefore, it will take 103.5 hours (104 hours to three significant figures) for krypton-79 to decrease to  $\frac{1}{8}$  of what was originally there.

**178.** The 90 days is 2 half-lives (90/45), so the fraction remaining would be  $\frac{1}{4}$  ( $\frac{1}{2} \times \frac{1}{2}$ ).