

13 Properties of Solutions

Visualizing Concepts

- 13.1 (a) < (b) < (c). In Section 13.1, *entropy* is qualitatively defined as randomness or dispersal in space. In container (a) the two kinds of particles are not mixed and the particles are close together, so (a) has the least entropy. In container (b), the particles occupy approximately the same volume as container (a) but the two kinds of particles are homogeneously mixed, so the degree of dispersal and randomness is greater than in (a). In container (c) the two kinds of particles are homogeneously mixed and they occupy a larger volume than in (b), so (c) has the greatest entropy.
- 13.2 The energy of ion-solvent interaction is greater for Li^+ than Na^+ . The smaller size of the Li^+ ion means that ion-dipole interactions with polar water molecules are stronger.
- 13.3 Lattice energy is the main component of ΔH_{solute} , the enthalpy required to separate solute particles. The greater the lattice energy of the ionic solid, the more endothermic the contribution from $\Delta H_{\text{solute}} + \Delta H_{\text{solvent}}$ and the more endothermic the overall dissolving process. If ΔH_{soln} is prohibitively endothermic, the substance is not very soluble. The greater the lattice energy of an ionic solid, the less soluble it is in water.
- 13.4 The blue solid is hydrated $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$. The waters of hydration are either associated with Cu^{2+} , SO_4^{2-} , or sit in specific sites in the crystal lattice. When heated in an oven, the water molecules incorporated into the crystal lattice gradually gain kinetic energy and vaporize. The white solid is anhydrous CuSO_4 , absent the waters of hydration and with a different solid-state structure than the blue hydrate.
- 13.5 Diagram (b) is the best representation of a saturated solution. There is some undissolved solid with particles that are close together and ordered, in contact with a solution containing mobile, separated solute particles. As much solute has dissolved as can dissolve, leaving some undissolved solid in contact with the saturated solution.
- 13.6 Solubility increases in the order $\text{Ar}, 1.50 \times 10^{-3} \text{ M} < \text{Kr}, 2.79 \times 10^{-3} \text{ M} < \text{Xe}, 5 \times 10^{-3} \text{ M}$, the order of increasing polarizability. As the molar mass of the ideal gas increases, atomic size increases and the electron cloud is less tightly held by the nucleus, causing the cloud to be more polarizable. The greater the polarizability, the stronger the dispersion forces between the gas atoms and water, the more likely the gas atom is to stay dissolved rather than escape the solution, the greater the solubility of the gas.
- 13.7 Vitamin B_6 is likely to be largely water soluble. The three $-\text{OH}$ groups and the $-\ddot{\text{N}}-$ can enter into many hydrogen bonding interactions with water. The relatively small molecular size indicates that dispersion forces will not play a large role in intermolecular interactions and the hydrogen bonding will dominate. Vitamin E is

likely to be largely fat soluble. The long, rod-like hydrocarbon chain will lead to stronger dispersion forces among vitamin E and the mostly nonpolar fats. Although vitamin E has one $-OH$ and one $-\ddot{O}-$ group, the long hydrocarbon chain prevents water from surrounding and separating the vitamin E molecules, reducing its water-solubility.

- 13.8 According to Figure 13.19, the solubility of CO at 25°C and 1 atm pressure is approximately 0.96 mM. By Henry's Law, $S_g = k P_g$. At the same temperature and pressure, k will be the same, so $S_1/P_1 = S_2/P_2$.

$$\frac{0.96 \text{ mM}}{1 \text{ atm}} = \frac{2.5 \text{ mM}}{x \text{ atm}}; x = \frac{2.5 \text{ mM} \times 1 \text{ atm}}{0.96 \text{ atm}} = 2.6 \text{ atm}$$

- 13.9 (a) Yes, the *molarity* changes with a change in temperature. Molarity is defined as moles solute per unit volume of solution. If solution volume is different, molarity is different.
- (b) No, *molality* does not change with change in temperature. Molality is defined as moles solute per kilogram of solvent. Even though the volume of solution has changed due to increased kinetic energy, the mass of solute and solvent have not changed, and the molality stays the same.
- 13.10 (a) The blue line represents the solution. According to Raoult's law, the presence of a nonvolatile solute lowers the vapor pressure of a volatile solvent. At any given temperature, the blue line has a lower vapor pressure and represents the solution.
- (b) The boiling point of a liquid is the temperature at which the vapor pressure of the liquid is equal to atmospheric pressure. Assuming atmospheric pressure of 1.0 atm, the boiling point of the solvent (red line) is approximately 64°C. The boiling point of the solution is approximately 70°C.
- 13.11 Ideally, 0.50 L. If the volume outside the balloon is very large compared to 0.25 L, solvent will flow across the semipermeable membrane until the molarities of the inner and outer solutions are equal, 0.1 M. This requires an "inner" solution volume twice as large as the initial volume, or 0.50 L. (In reality, osmosis across the balloon membrane is not perfect. The solution concentration inside the balloon will be slightly greater than 0.1 M and the volume of the balloon will be slightly less than 0.50 L.)
- 13.12 A detergent for solubilizing large hydrophobic proteins (or any other large nonpolar solute, such as greasy dirt) needs a hydrophobic part to interact with the solute, and a hydrophilic part to interact with water. In *n*-octyl glycoside, the eight-carbon *n*-octyl chain has strong dispersion interactions with the hydrophobic (nonpolar) protein. The $-OH$ groups on the glycoside (sugar) ring form strong hydrogen bonds with water. This causes the glycoside to dissolve, dragging the hydrophobic protein along with it.

The Solution Process (section 13.1)

- 13.13 If the magnitude of the enthalpy released due to solute-solvent attractive forces ($-\Delta H_{\text{mix}}$) is at least as large as the magnitude of the enthalpy required to separate the solute particles ($+\Delta H_{\text{solute}}$), the overall enthalpy of solution (ΔH_{soln}) will be either

slightly endothermic (owing to $+\Delta H_{\text{solvent}}$) or exothermic. Even if ΔH_{soln} is slightly endothermic, the increase in disorder due to mixing will cause a significant amount of solute to dissolve. If the magnitude of ΔH_{mix} is small relative to the magnitude of ΔH_{solute} , ΔH_{soln} will be large and endothermic (energetically unfavorable) and not much solute will dissolve.

- 13.14 (a) For the same solute, NaCl, in different solvents, solute-solute interactions (ΔH_{solute}) are the same. Because water experiences hydrogen bonding while benzene has only dispersion forces, solvent-solvent interactions ($\Delta H_{\text{solvent}}$) are greater for water. On the other hand, solute-solvent interactions (ΔH_{mix}) are much weaker between ionic NaCl and nonpolar benzene than between ionic NaCl and polar water. It is the large difference in ΔH_{mix} that causes NaCl to be soluble in water but not in benzene.
- (b) Ion-dipole forces between cations and water molecules and relatively small lattice energies (ion-ion forces between cations and anions) lead to strongly hydrated cations.
- 13.15 *Analyze/Plan.* Decide whether the solute and solvent in question are ionic, polar covalent, or nonpolar covalent. Draw Lewis structures as needed. Then state the appropriate type of solute-solvent interaction. *Solve.*
- (a) CCl_4 , nonpolar; benzene, nonpolar; dispersion forces
- (b) methanol, polar with hydrogen bonding; water, polar with hydrogen bonding; hydrogen bonding
- (c) KBr, ionic; water, polar; ion-dipole forces
- (d) HCl, polar; CH_3CN , polar; dipole-dipole forces
- 13.16 From weakest to strongest solvent-solute interactions:
(b), dispersion forces < (c), hydrogen bonding < (a), ion-dipole
- 13.17 Very soluble. In order for ΔH_{soln} to be negative (exothermic), ΔH_{mix} must have a greater magnitude than ($\Delta H_{\text{solute}} + \Delta H_{\text{solvent}}$). The collective attractive interactions formed upon mixing must be greater than the interactions being disrupted in the pure solvent and solute. The entropy of mixing always encourages solubility. In this case, the enthalpy of the system decreases and the entropy increases, so the ionic compound dissolves.
- 13.18 (a) This solution process is endothermic. The enthalpy of the solution is greater than the enthalpy of unmixed solute plus solvent.
- (b) The solution forms because the favorable entropy of mixing outweighs the increase in enthalpy by the solution.
- 13.19 (a) Lattice energy is the amount of energy required to completely separate a mole of solid ionic compound into its gaseous ions (Section 8.2). For ionic solutes, this corresponds to ΔH_{solute} (solute-solute interactions) in Equation [13.1].
- (b) In Equation [13.1], ΔH_{mix} is always exothermic. Formation of attractive interactions, no matter how weak, always lowers the energy of the system, relative to the energy of the isolated particles.

- 13.20 ΔH_{mix} is much more negative (exothermic) than $\Delta H_{\text{solvent}}$ or ΔH_{solute} . Both $\Delta H_{\text{solvent}}$ and ΔH_{solute} will be endothermic, because separating solvent molecules or solute ions requires energy. The magnitude of ΔH_{solute} will be larger, because ionic bonds among Li^+ and Cl^- are much stronger than hydrogen bonds among water molecules. Since ΔH_{soln} is exothermic, ΔH_{mix} must be exothermic, and not just more negative than the other two, but more negative than the sum of the other two. This is not surprising, since ΔH_{mix} involves formation of many ion-dipole interactions, strong interparticle forces.
- 13.21 (a) ΔH_{soln} is determined by the relative magnitudes of the "old" solute-solute (ΔH_{solute}) and solvent-solvent ($\Delta H_{\text{solvent}}$) interactions and the new solute-solvent interactions (ΔH_{mix}); $\Delta H_{\text{soln}} = \Delta H_{\text{solute}} + \Delta H_{\text{solvent}} + \Delta H_{\text{mix}}$. Since the solute and solvent in this case experience very similar London dispersion forces, the energy required to separate them individually and the energy released when they are mixed are approximately equal. $\Delta H_{\text{solute}} + \Delta H_{\text{solvent}} \approx -\Delta H_{\text{mix}}$. Thus, ΔH_{soln} is nearly zero.
- (b) Mixing hexane and heptane produces a homogeneous solution from two pure substances, and the randomness of the system increases. Since no strong intermolecular forces prevent the molecules from mixing, they do so spontaneously due to the increase in disorder.
- 13.22 KBr is quite soluble in water because of the sizeable increase in disorder of the system (ordered KBr lattice \rightarrow freely moving hydrated ions) associated with the dissolving process. An increase in disorder or randomness in a process tends to make that process spontaneous.

Saturated Solutions; Factors Affecting Solubility (sections 13.1 and 13.2)

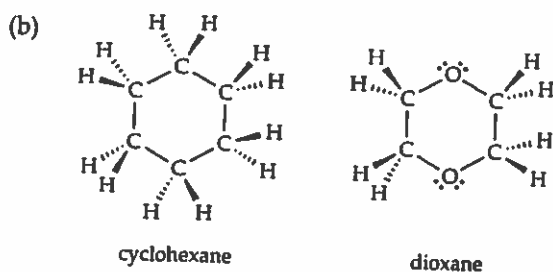
- 13.23 (a) Supersaturated
- (b) Add a seed crystal. Supersaturated solutions exist because not enough solute molecules are properly aligned for crystallization to occur. A seed crystal provides a nucleus of already aligned molecules, so that ordering of the dissolved particles is more facile.
- 13.24 (a)
$$\frac{1.22 \text{ mol MnSO}_4 \cdot \text{H}_2\text{O}}{1 \text{ L soln}} \times \frac{169.0 \text{ g MnSO}_4 \cdot \text{H}_2\text{O}}{1 \text{ mol}} \times 0.100 \text{ L}$$

$$= 20.6 \text{ g MnSO}_4 \cdot \text{H}_2\text{O}/100 \text{ mL}$$

The 1.22 M solution is unsaturated.

(b) Add a known mass, say 5.0 g, of $\text{MnSO}_4 \cdot \text{H}_2\text{O}$, to the unknown solution. If the solid dissolves, the solution is unsaturated. If there is undissolved $\text{MnSO}_4 \cdot \text{H}_2\text{O}$, filter the solution and weigh the solid. If there is less than 5.0 g of solid, some of the added $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ dissolved and the unknown solution is unsaturated. If there is exactly 5.0 g, no additional solid dissolved and the unknown is saturated. If there is more than 5.0 g, excess solute has precipitated and the solution is supersaturated.

- 13.25 *Analyze/Plan.* On Figure 13.18, find the solubility curve for the appropriate solute. Find the intersection of 40°C and 40 g solute on the graph. If this point is below the solubility curve, more solute can dissolve and the solution is unsaturated. If the intersection is on or above the curve, the solution is saturated. *Solve.*
- (a) unsaturated (b) saturated (c) saturated (d) unsaturated
- 13.26 (a) at 30°C, $\frac{10 \text{ g KClO}_3}{100 \text{ g H}_2\text{O}} \times 250 \text{ g H}_2\text{O} = 25 \text{ g KClO}_3$
- (b) $\frac{66 \text{ g Pb(NO}_3)_2}{100 \text{ g H}_2\text{O}} \times 250 \text{ g H}_2\text{O} = 165 = 1.7 \times 10^2 \text{ g Pb(NO}_3)_2$
- (c) $\frac{3 \text{ g Ce}_2(\text{SO}_4)_3}{100 \text{ g H}_2\text{O}} \times 250 \text{ g H}_2\text{O} = 7.5 = 8 \text{ g Ce}_2(\text{SO}_4)_3$
- 13.27 The liquids water and glycerol form homogenous mixtures (solutions), regardless of the relative amounts of the two components. Glycerol has an -OH group on each C atom in the molecule. This structure facilitates strong hydrogen bonding similar to that in water. Like dissolves like and the two liquids are miscible in all proportions.
- 13.28 Immiscible means that oil and water do not mix homogeneously; they do not dissolve. Many substances are called "oil," but they are typically nonpolar carbon-based molecules with fairly high molecular weights. As such, there are fairly strong dispersion forces among oil molecules. The properties of water are dominated by its strong hydrogen bonding. The dispersion-dipole interactions between water and oil are likely to be weak. Thus, ΔH_{solute} and $\Delta H_{\text{solvent}}$ are large and positive, while ΔH_{mix} is small and negative. The net ΔH_{soln} is large and positive, and mixing does not occur.
- 13.29 *Analyze/Plan.* Evaluate molecules in the four common laboratory solvents for strength of intermolecular interactions with nonpolar solutes. *Solve.* Toluene, $\text{C}_6\text{H}_5\text{CH}_3$, is the best solvent for nonpolar solutes. Without polar groups or nonbonding electron pairs, it forms only dispersion interactions with itself and other molecules. The enthalpy of solution, ΔH_{soln} , is essentially zero (as in Solution 13.21) and solution occurs because of the favorable entropy of mixing.
- 13.30 We expect alanine to be more soluble in water than hexane. Alanine has a -COOH and a -NH₂ group available to form hydrogen bonds with water molecules. While there are some potential dispersion forces between the terminal -CH₃ group of alanine and hexane molecules, we expect the hydrogen bonding between alanine and water to be stronger. Stronger intermolecular attractive forces between alanine and water lead to a more negative ΔH_{mix} and more negative (smaller positive) ΔH_{soln} for water than for hexane.
- 13.31 (a) Dispersion interactions among nonpolar $\text{CH}_3(\text{CH}_2)_{16}$ -chains dominate the properties of stearic acid. It is more soluble in nonpolar CCl_4 than polar (hydrogen bonding) water, despite the presence of the -COOH group.



Dioxane can act as a hydrogen bond acceptor, so it will be more soluble than cyclohexane in water.

- 13.32 Ibuprofen has a phenyl ring and several $-\text{CH}_3$ groups that form a large nonpolar area covering most of the molecule. This area of the molecule has strong dispersion interactions with like molecules, and does not form strong interactions with polar water. The one isolated carboxyl group of ibuprofen enhances its water solubility.
- 13.33 *Analyze/Plan.* Hexane is a nonpolar hydrocarbon that experiences dispersion forces with other nonpolar molecules. Solute that primarily experience dispersion forces will be more soluble in hexane. *Solve.*
- (a) CCl_4 is more soluble because dispersion forces among nonpolar CCl_4 molecules are similar to dispersion forces in hexane. Ionic bonds in CaCl_2 are unlikely to be broken by weak solute-solvent interactions. For CaCl_2 , ΔH_{solute} is large, relative to ΔH_{mix} .
- (b) Benzene, C_6H_6 , is also a nonpolar hydrocarbon and will be more soluble in hexane. Glycerol experiences hydrogen bonding with itself; these solute-solute interactions are less likely to be overcome by weak solute-solvent interactions.
- (c) Octanoic acid, $\text{CH}_3(\text{CH}_2)_6\text{COOH}$, will be more soluble than acetic acid CH_3COOH . Both solutes experience hydrogen bonding by $-\text{COOH}$ groups, but octanoic acid has a long, rod-like hydrocarbon chain with dispersion forces similar to those in hexane, facilitating solubility in hexane.
- 13.34 *Analyze/Plan.* Water, H_2O , is a polar solvent that forms hydrogen bonds with other H_2O molecules. The more soluble solute in each case will have intermolecular interactions that are most similar to the hydrogen bonding in H_2O . *Solve.*
- (a) Glucose, $\text{C}_6\text{H}_{12}\text{O}_6$, is more soluble because it is capable of hydrogen bonding (Figure 13.12). Nonpolar C_6H_{12} is capable only of dispersion interactions and does not have strong intermolecular interactions with polar (hydrogen bonding) H_2O .
- (b) Ionic sodium propionate, $\text{CH}_3\text{CH}_2\text{COONa}$, is more soluble. Sodium propionate is a crystalline solid, while propionic acid is a liquid. The increase in disorder or entropy when an ionic solid dissolves leads to significant water solubility, despite the strong ion-ion forces (large ΔH_{solute}) present in the solute (see Solution 13.22).
- (c) HCl is more soluble because it is a strong electrolyte and completely ionized in water. Ionization leads to ion-dipole solute-solvent interactions, and an increase in disorder. $\text{CH}_3\text{CH}_2\text{Cl}$ is a molecular solute capable of relatively weak dipole-dipole solute-solvent interactions and is much less soluble in water.

- 13.35 (a) Carbonated beverages are stored with a partial pressure of $\text{CO}_2(\text{g})$ greater than 1 atm above the liquid. A sealed container is required to maintain this CO_2 pressure.
- (b) Since the solubility of gases increases with decreasing temperature, more $\text{CO}_2(\text{g})$ will remain dissolved in the beverage if it is kept cool.

13.36 Pressure has an effect on O_2 solubility in water because, at constant temperature and volume, pressure is directly related to the amount of O_2 available to dissolve. The greater the partial pressure of O_2 above water, the more O_2 molecules are available for dissolution, and the more molecules that strike the surface of the liquid.

Pressure does not affect the amount or physical properties of NaCl , or ionic solids in general, so it has little influence on the dissolving of NaCl in water.

13.37 *Analyze/Plan.* Follow the logic in Sample Exercise 13.3. *Solve.*

$$S_{\text{H}_2} = 3.7 \times 10^{-4} \text{ M/atm} \times 1.5 \text{ atm} = 5.6 \times 10^{-4} \text{ M}$$

$$S_{\text{N}_2} = 6.0 \times 10^{-4} \text{ M/atm} \times 1.5 \text{ atm} = 9.0 \times 10^{-4} \text{ M}$$

13.38 $650 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 0.855 \text{ atm}$; $P_{\text{O}_2} = \chi_{\text{O}_2}(P_1) = 0.21(0.855 \text{ atm}) = 0.1796 = 0.18 \text{ atm}$

$$S_{\text{O}_2} = kP_{\text{O}_2} = \frac{1.38 \times 10^{-3} \text{ mol}}{\text{L} \cdot \text{atm}} \times 0.1796 \text{ atm} = 2.5 \times 10^{-4} \text{ M}$$

Concentrations of Solutions (section 13.4)

13.39 *Analyze/Plan.* Follow the logic in Sample Exercise 13.3. *Solve.*

(a) $\text{mass \%} = \frac{\text{mass solute}}{\text{total mass solution}} \times 100 = \frac{10.6 \text{ g Na}_2\text{SO}_4}{10.6 \text{ g Na}_2\text{SO}_4 + 483 \text{ g H}_2\text{O}} \times 100 = 2.15\%$

(b) $\text{ppm} = \frac{\text{mass solute}}{\text{total mass solution}} \times 10^6$; $\frac{2.86 \text{ g Ag}}{1 \text{ ton ore}} \times \frac{1 \text{ ton}}{2000 \text{ lb}} \times \frac{1 \text{ lb}}{453.6 \text{ g}} \times 10^6 = 3.15 \text{ ppm}$

13.40 (a) $\text{mass \%} = \frac{\text{mass solute}}{\text{total mass solution}} \times 100$

$$\text{mass solute} = 0.035 \text{ mol I}_2 \times \frac{253.8 \text{ g I}_2}{1 \text{ mol I}_2} = 8.883 = 8.9 \text{ g I}_2$$

$$\text{mass \% I}_2 = \frac{8.883 \text{ g I}_2}{8.883 \text{ g I}_2 + 125 \text{ g CCl}_4} \times 100 = 6.635 = 6.6\% \text{ I}_2$$

(b) $\text{ppm} = \frac{\text{mass solute}}{\text{total mass solution}} \times 10^6 = \frac{0.0079 \text{ g Sr}^{2+}}{1 \times 10^3 \text{ g H}_2\text{O}} \times 10^6 = 7.9 \text{ ppm Sr}^{2+}$

13.41 *Analyze/Plan.* Given masses of CH_3OH and H_2O , calculate moles of each component.

(a) Mole fraction $\text{CH}_3\text{OH} = (\text{mol CH}_3\text{OH})/(\text{total mol})$

(b) mass % $\text{CH}_3\text{OH} = [(\text{g CH}_3\text{OH})/(\text{total mass})] \times 100$

(c) molality $\text{CH}_3\text{OH} = (\text{mol CH}_3\text{OH})/(\text{kg H}_2\text{O})$. *Solve.*

- (a) $14.6 \text{ g CH}_3\text{OH} \times \frac{1 \text{ mol CH}_3\text{OH}}{32.04 \text{ g CH}_3\text{OH}} = 0.4557 = 0.456 \text{ mol CH}_3\text{OH}$
- $184 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.02 \text{ g H}_2\text{O}} = 10.211 = 10.2 \text{ mol H}_2\text{O}$
- $\chi_{\text{CH}_3\text{OH}} = \frac{0.4557}{0.4557 + 10.211} = 0.04272 = 0.0427$
- (b) $\text{mass \% CH}_3\text{OH} = \frac{14.6 \text{ g CH}_3\text{OH}}{14.6 \text{ g CH}_3\text{OH} + 184 \text{ g H}_2\text{O}} \times 100 = 7.35\% \text{ CH}_3\text{OH}$
- (c) $m = \frac{0.4557 \text{ mol CH}_3\text{OH}}{0.184 \text{ kg H}_2\text{O}} = 2.477 = 2.48 \text{ m CH}_3\text{OH}$
- 13.42 (a) $\frac{20.8 \text{ g C}_6\text{H}_5\text{OH}}{94.11 \text{ g/mol}} = 0.2210 = 0.221 \text{ mol C}_6\text{H}_5\text{OH}$
- $\frac{425 \text{ g CH}_3\text{CH}_2\text{OH}}{46.07 \text{ g/mol}} = 9.2251 = 9.23 \text{ mol CH}_3\text{CH}_2\text{OH}$
- $\chi_{\text{C}_6\text{H}_5\text{OH}} = \frac{0.2210}{0.2210 + 9.2251} = 0.02340 = 0.0234$
- (b) $\text{mass \%} = \frac{20.8 \text{ g C}_6\text{H}_5\text{OH}}{20.8 \text{ g C}_6\text{H}_5\text{OH} + 425 \text{ g CH}_3\text{CH}_2\text{OH}} \times 100 = 4.67\% \text{ C}_6\text{H}_5\text{OH}$
- (c) $m = \frac{0.2210 \text{ mol C}_6\text{H}_5\text{OH}}{0.425 \text{ kg CH}_3\text{CH}_2\text{OH}} = 0.5200 = 0.520 \text{ m C}_6\text{H}_5\text{OH}$
- 13.43 *Analyze/Plan.* Given mass solute and volume solution, calculate mol solute, then molarity = mol solute/L solution. Or, for dilution, $M_c \times L_c = M_d \times L_d$. *Solve.*
- (a) $M = \frac{\text{mol solute}}{\text{L soln}}; \frac{0.540 \text{ g Mg(NO}_3)_2}{0.2500 \text{ L soln}} \times \frac{1 \text{ mol Mg(NO}_3)_2}{148.3 \text{ g Mg(NO}_3)_2} = 1.46 \times 10^{-2} \text{ M Mg(NO}_3)_2$
- (b) $\frac{22.4 \text{ g LiClO}_4 \cdot 3\text{H}_2\text{O}}{0.125 \text{ L soln}} \times \frac{1 \text{ mol LiClO}_4 \cdot 3\text{H}_2\text{O}}{160.4 \text{ g LiClO}_4 \cdot 3\text{H}_2\text{O}} = 1.12 \text{ M LiClO}_4 \cdot 3\text{H}_2\text{O}$
- (c) $M_c \times L_c = M_d \times L_d; 3.50 \text{ M HNO}_3 \times 0.0250 \text{ L} = ? \text{ M HNO}_3 \times 0.250 \text{ L}$
250 mL of 0.350 M HNO₃
- 13.44 (a) $M = \frac{\text{mol solute}}{\text{L soln}}; \frac{15.0 \text{ g Al}_2(\text{SO}_4)_3}{0.250 \text{ L soln}} \times \frac{1 \text{ mol Al}_2(\text{SO}_4)_3}{342.2 \text{ g Al}_2(\text{SO}_4)_3} = 0.175 \text{ M Al}_2(\text{SO}_4)_3$
- (b) $\frac{5.25 \text{ g Mn(NO}_3)_2 \cdot 2\text{H}_2\text{O}}{0.175 \text{ L soln}} \times \frac{1 \text{ mol Mn(NO}_3)_2 \cdot 2\text{H}_2\text{O}}{215.0 \text{ g Mn(NO}_3)_2 \cdot 2\text{H}_2\text{O}} = 0.140 \text{ M Mn(NO}_3)_2$
- (c) $M_c \times L_c = M_d \times L_d; 9.00 \text{ M H}_2\text{SO}_4 \times 0.0350 \text{ L} = ? \text{ M H}_2\text{SO}_4 \times 0.500 \text{ L}$
500 mL of 0.630 M H₂SO₄
- 13.45 *Analyze/Plan.* Follow the logic in Sample Exercise 13.4. *Solve.*
- (a) $m = \frac{\text{mol solute}}{\text{kg solvent}}; \frac{8.66 \text{ g C}_6\text{H}_6}{23.6 \text{ g CCl}_4} \times \frac{1 \text{ mol C}_6\text{H}_6}{78.11 \text{ g C}_6\text{H}_6} \times \frac{1000 \text{ g CCl}_4}{1 \text{ kg CCl}_4} = 4.70 \text{ m C}_6\text{H}_6$

(b) The density of $\text{H}_2\text{O} = 0.997 \text{ g/mL} = 0.997 \text{ kg/L}$.

$$\frac{4.80 \text{ g NaCl}}{0.350 \text{ L H}_2\text{O}} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} \times \frac{1 \text{ L H}_2\text{O}}{0.997 \text{ kg H}_2\text{O}} = 0.235 \text{ m NaCl}$$

13.46 (a) $16.0 \text{ mol H}_2\text{O} \times \frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} = 288.3 \text{ g H}_2\text{O} = 0.288 \text{ kg H}_2\text{O}$

$$m = \frac{1.12 \text{ mol KCl}}{0.2883 \text{ kg H}_2\text{O}} = 3.8846 = 3.88 \text{ m KCl}$$

(b) $m = \frac{\text{mol solute}}{\text{kg solute}}$; $\text{mol S}_8 = m \times \text{kg C}_{10}\text{H}_8 = 0.12 \text{ m} \times 0.1000 \text{ kg C}_{10}\text{H}_8 = 0.012 \text{ mol}$

$$0.012 \text{ mol S}_8 \times \frac{256.5 \text{ g S}_8}{1 \text{ mol S}_8} = 3.078 = 3.1 \text{ g S}_8$$

13.47

Analyze/Plan. Assume 1 L of solution. Density gives the total mass of 1 L of solution. The g $\text{H}_2\text{SO}_4/\text{L}$ are also given in the problem. Mass % = (mass solute/total mass solution) \times 100. Calculate mass solvent from mass solution and mass solute. Calculate moles solute and solvent and use the appropriate definitions to calculate mole fraction, molality, and molarity. *Solve.*

(a) $\frac{571.6 \text{ g H}_2\text{SO}_4}{1 \text{ L soln}} \times \frac{1 \text{ L soln}}{1329 \text{ g soln}} = 0.430098 \text{ g H}_2\text{SO}_4/\text{g soln}$

mass percent is thus $0.4301 \times 100 = 43.01\% \text{ H}_2\text{SO}_4$

(b) In a liter of solution there are $1329 - 571.6 = 757.4 = 757 \text{ g H}_2\text{O}$.

$$\frac{571.6 \text{ g H}_2\text{SO}_4}{98.09 \text{ g/mol}} = 5.827 \text{ mol H}_2\text{SO}_4; \frac{757.4 \text{ g H}_2\text{O}}{18.02 \text{ g/mol}} = 42.03 = 42.0 \text{ mol H}_2\text{O}$$

$$x_{\text{H}_2\text{SO}_4} = \frac{5.827}{42.03 + 5.827} = 0.122$$

(The result has 3 sig figs because (g H_2O) resulting from subtraction is limited to 3 sig figs.)

(c) $\text{molality} = \frac{5.827 \text{ mol H}_2\text{SO}_4}{0.7574 \text{ kg H}_2\text{O}} = 7.693 = 7.69 \text{ m H}_2\text{SO}_4$

(d) $\text{molarity} = \frac{5.827 \text{ mol H}_2\text{SO}_4}{1 \text{ L soln}} = 5.827 \text{ M H}_2\text{SO}_4$

13.48 (a) $\text{mass \%} = \frac{\text{mass C}_6\text{H}_8\text{O}_6}{\text{total mass solution}} \times 100;$

$$\frac{80.5 \text{ g C}_6\text{H}_8\text{O}_6}{80.5 \text{ g C}_6\text{H}_8\text{O}_6 + 210 \text{ g H}_2\text{O}} \times 100 = 27.71 = 27.7\% \text{ C}_6\text{H}_8\text{O}_6$$

(b) $\text{mol C}_6\text{H}_8\text{O}_6 = \frac{80.5 \text{ g C}_6\text{H}_8\text{O}_6}{176.1 \text{ g/mol}} = 0.4571 = 0.457 \text{ mol C}_6\text{H}_8\text{O}_6$

$$\text{mol H}_2\text{O} = \frac{210 \text{ g H}_2\text{O}}{18.02 \text{ g/mol}} = 11.654 = 11.7 \text{ mol H}_2\text{O}$$

$$\chi_{\text{C}_6\text{H}_8\text{O}_6} = \frac{0.4571 \text{ mol C}_6\text{H}_8\text{O}_6}{0.4571 \text{ mol C}_6\text{H}_8\text{O}_6 + 11.654 \text{ mol H}_2\text{O}} = 0.0377$$

$$(c) \quad m = \frac{0.4571 \text{ mol C}_6\text{H}_8\text{O}_6}{0.210 \text{ kg H}_2\text{O}} = 2.18 \text{ m C}_6\text{H}_8\text{O}_6$$

$$(d) \quad M = \frac{\text{mol C}_6\text{H}_8\text{O}_6}{\text{L solution}}; 290.5 \text{ g soln} \times \frac{1 \text{ mL}}{1.22 \text{ g}} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.2381 = 0.238 \text{ L}$$

$$M = \frac{0.4571 \text{ mol C}_6\text{H}_8\text{O}_6}{0.2381 \text{ L soln}} = 1.92 \text{ M C}_6\text{H}_8\text{O}_6$$

- 13.49 *Analyze/Plan.* Given: 98.7 mL of $\text{CH}_3\text{CN}(\text{l})$, 0.786 g/mL; 22.5 mL CH_3OH , 0.791 g/mL. Use the density and volume of each component to calculate mass and then moles of each component. Use the definitions to calculate mole fraction, molality, and molarity. *Solve.*

$$(a) \quad \text{mol CH}_3\text{CN} = \frac{0.786 \text{ g}}{1 \text{ mL}} \times 98.7 \text{ mL} \times \frac{1 \text{ mol CH}_3\text{CN}}{41.05 \text{ g CH}_3\text{CN}} = 1.8898 = 1.89 \text{ mol}$$

$$\text{mol CH}_3\text{OH} = \frac{0.791 \text{ g}}{1 \text{ mL}} \times 22.5 \text{ mL} \times \frac{1 \text{ mol CH}_3\text{OH}}{32.04 \text{ g CH}_3\text{OH}} = 0.5555 = 0.556 \text{ mol}$$

$$\chi_{\text{CH}_3\text{OH}} = \frac{0.5555 \text{ mol CH}_3\text{OH}}{1.8898 \text{ mol CH}_3\text{CN} + 0.5555 \text{ mol CH}_3\text{OH}} = 0.227$$

- (b) Assuming CH_3OH is the solute and CH_3CN is the solvent,

$$98.7 \text{ mL CH}_3\text{CN} \times \frac{0.786 \text{ g}}{1 \text{ mL}} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 0.07758 = 0.0776 \text{ kg CH}_3\text{CN}$$

$$m_{\text{CH}_3\text{OH}} = \frac{0.5555 \text{ mol CH}_3\text{OH}}{0.07758 \text{ kg CH}_3\text{CN}} = 7.1604 = 7.16 \text{ m CH}_3\text{OH}$$

- (c) The total volume of the solution is 121.2 mL, assuming volumes are additive.

$$M = \frac{0.5555 \text{ mol CH}_3\text{OH}}{0.1212 \text{ L solution}} = 4.58 \text{ M CH}_3\text{OH}$$

- 13.50 Given: 8.10 g $\text{C}_4\text{H}_4\text{S}$, 1.065 g/mL; 250.0 mL C_7H_8 , 0.867 g/mL

$$(a) \quad \text{mol C}_4\text{H}_4\text{S} = 8.10 \text{ g C}_4\text{H}_4\text{S} \times \frac{1 \text{ mol C}_4\text{H}_4\text{S}}{84.15 \text{ g C}_4\text{H}_4\text{S}} = 0.09626 = 0.0963 \text{ mol C}_4\text{H}_4\text{S}$$

$$\text{mol C}_7\text{H}_8 = \frac{0.867 \text{ g}}{1 \text{ mL}} \times 250.0 \text{ mL} \times \frac{1 \text{ mol C}_7\text{H}_8}{92.14 \text{ g C}_7\text{H}_8} = 2.352 = 2.35 \text{ mol}$$

$$\chi_{\text{C}_4\text{H}_4\text{S}} = \frac{0.09626 \text{ mol C}_4\text{H}_4\text{S}}{0.09626 \text{ mol C}_4\text{H}_4\text{S} + 2.352 \text{ mol C}_7\text{H}_8} = 0.03932 = 0.0393$$

$$(b) \quad m_{\text{C}_4\text{H}_4\text{S}} = \frac{\text{mol C}_4\text{H}_4\text{S}}{\text{kg C}_7\text{H}_8}; 250.0 \text{ mL} \times \frac{0.867 \text{ g}}{1 \text{ mL}} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 0.2168 = 0.217 \text{ kg C}_7\text{H}_8$$

$$m_{\text{C}_4\text{H}_4\text{S}} = \frac{0.09626 \text{ mol C}_4\text{H}_4\text{S}}{0.2168 \text{ kg C}_7\text{H}_8} = 0.444 \text{ m C}_4\text{H}_4\text{S}$$

$$(c) \quad 8.10 \text{ g C}_4\text{H}_4\text{S} \times \frac{1 \text{ mL}}{1.065 \text{ g}} = 7.606 = 7.61 \text{ mL C}_4\text{H}_4\text{S};$$

$$V_{\text{soln}} = 7.61 \text{ mL C}_4\text{H}_4\text{S} + 250.0 \text{ mL C}_7\text{H}_8 = 257.6 \text{ mL}$$

$$M_{\text{C}_4\text{H}_4\text{S}} = \frac{0.09626 \text{ mol C}_4\text{H}_4\text{S}}{0.2576 \text{ L soln}} = 0.374 \text{ M C}_4\text{H}_4\text{S}$$

13.51 *Analyze/Plan.* Given concentration and volume of solution use definitions of the appropriate concentration units to calculate amount of solute; change amount to moles if needed. *Solve.*

$$(a) \quad \text{mol} = M \times L; \frac{0.250 \text{ mol SrBr}_2}{1 \text{ L soln}} \times 0.600 \text{ L} = 0.150 \text{ mol SrBr}_2$$

(b) Assume that for dilute aqueous solutions, the mass of the solvent is the mass of solution. Use proportions to get mol KCl.

$$\frac{0.180 \text{ mol KCl}}{1 \text{ kg H}_2\text{O}} = \frac{x \text{ mol KCl}}{0.0864 \text{ kg H}_2\text{O}}; x = 1.56 \times 10^{-2} \text{ mol KCl}$$

(c) Use proportions to get mass of glucose, then change to mol glucose.

$$\frac{6.45 \text{ g C}_6\text{H}_{12}\text{O}_6}{100 \text{ g soln}} = \frac{x \text{ g C}_6\text{H}_{12}\text{O}_6}{124.0 \text{ g soln}}; x = 8.00 \text{ g C}_6\text{H}_{12}\text{O}_6$$

$$8.00 \text{ g C}_6\text{H}_{12}\text{O}_6 \times \frac{1 \text{ mol C}_6\text{H}_{12}\text{O}_6}{180.2 \text{ g C}_6\text{H}_{12}\text{O}_6} = 4.44 \times 10^{-2} \text{ mol C}_6\text{H}_{12}\text{O}_6$$

$$13.52 \quad (a) \quad \frac{1.50 \text{ mol HNO}_3}{1 \text{ L soln}} \times 0.255 \text{ L} = 0.3825 = 0.383 \text{ mol HNO}_3$$

(b) Assume that for dilute aqueous solutions, the mass of the solvent is the mass of solution.

$$\frac{1.50 \text{ mol NaCl}}{1 \text{ kg H}_2\text{O}} = \frac{x \text{ mol}}{50.0 \times 10^{-6} \text{ kg}}; x = 7.50 \times 10^{-5} \text{ mol NaCl}$$

$$(c) \quad \frac{1.50 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}}{100 \text{ g soln}} = \frac{x \text{ g C}_{12}\text{H}_{22}\text{O}_{11}}{75.0 \text{ g soln}}; x = 1.125 = 1.13 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}$$

$$1.125 \text{ g C}_{12}\text{H}_{22}\text{O}_{11} \times \frac{1 \text{ mol C}_{12}\text{H}_{22}\text{O}_{11}}{342.3 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}} = 3.287 \times 10^{-3} = 3.29 \times 10^{-3} \text{ mol C}_{12}\text{H}_{22}\text{O}_{11}$$

13.53 *Analyze/Plan.* When preparing solution, we must know amount of solute and solvent. Use the appropriate concentration definition to calculate amount of solute. If this amount is in moles, use molar mass to get grams; use mass in grams directly. Amount of solvent can be expressed as total volume or mass of solution. Combine mass solute and solvent to produce the required amount (mass or volume) of solution. *Solve.*

$$(a) \quad \text{mol} = M \times L; \frac{1.50 \times 10^{-2} \text{ mol KBr}}{1 \text{ L soln}} \times 0.75 \text{ L} \times \frac{119.0 \text{ g KBr}}{1 \text{ mol KBr}} = 1.3 \text{ g KBr}$$

Weigh out 1.3 g KBr, dissolve in water, dilute with stirring to 0.75 L (750 mL).

- (b) Mass of solution is required, but density is not specified. Use molality to calculate mass fraction, and then the masses of solute and solvent needed for 125 g of solution.

$$\frac{0.180 \text{ mol KBr}}{1000 \text{ g H}_2\text{O}} \times \frac{119.0 \text{ g KBr}}{1 \text{ mol KBr}} = 21.42 = 21.4 \text{ g KBr/kg H}_2\text{O} \text{ Thus,}$$

$$\text{mass fraction} = \frac{21.42 \text{ g KBr}}{1000 + 21.42} = 0.02097 = 0.0210$$

In 125 g of the 0.180 *m* solution, there are

$$(125 \text{ g soln}) \times \frac{0.02097 \text{ g KBr}}{1 \text{ g soln}} = 2.621 = 2.62 \text{ g KBr}$$

Weigh out 2.62 g KBr, dissolve it in $125 - 2.62 = 122.38 = 122 \text{ g H}_2\text{O}$ to make exactly 125 g of 0.180 *m* solution.

- (c) Using solution density, calculate the total mass of 1.85 L of solution, and from the mass % of KBr, the mass of KBr required.

$$1.85 \text{ L soln} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1.10 \text{ g soln}}{1 \text{ mL}} = 2035 = 2.04 \times 10^3 \text{ g soln}$$

$$0.120 (2035 \text{ g soln}) = 244.2 = 244 \text{ g KBr}$$

Dissolve 244 g KBr in water, dilute with stirring to 1.85 L.

- (d) Calculate moles KBr needed to precipitate 16.0 g AgBr. AgNO₃ is present in excess.

$$16.0 \text{ g AgBr} \times \frac{1 \text{ mol AgBr}}{187.8 \text{ g AgBr}} \times \frac{1 \text{ mol KBr}}{1 \text{ mol AgBr}} = 0.08520 = 0.0852 \text{ mol KBr}$$

$$0.0852 \text{ mol KBr} \times \frac{1 \text{ L soln}}{0.150 \text{ mol KBr}} = 0.568 \text{ L soln}$$

Weigh out 0.0852 mol KBr (10.1 g KBr), dissolve it in a small amount of water, and dilute to 0.568 L.

13.54 (a)
$$\frac{0.110 \text{ mol (NH}_4)_2\text{SO}_4}{1 \text{ L soln}} \times 1.50 \text{ L} \times \frac{132.2 \text{ g (NH}_4)_2\text{SO}_4}{1 \text{ mol (NH}_4)_2\text{SO}_4} = 21.81 = 21.8 \text{ g (NH}_4)_2\text{SO}_4$$

Weigh 21.8 g (NH₄)₂SO₄, dissolve in a small amount of water, continue adding water with thorough mixing up to a total solution volume of 1.50 L.

- (b) Determine the mass fraction of Na₂CO₃ in the solution:

$$\frac{0.65 \text{ mol Na}_2\text{CO}_3}{1000 \text{ g H}_2\text{O}} \times \frac{106.0 \text{ g Na}_2\text{CO}_3}{1 \text{ mol Na}_2\text{CO}_3} = 68.9 \text{ g} = \frac{69 \text{ g Na}_2\text{CO}_3}{1000 \text{ g H}_2\text{O}}$$

$$\text{mass fraction} = \frac{68.9 \text{ g Na}_2\text{CO}_3}{1000 \text{ g H}_2\text{O} + 68.9 \text{ g Na}_2\text{CO}_3} = 0.06446 = 0.064$$

In 225 g of solution, there are $0.06446(225) = 14.503 = 15 \text{ g Na}_2\text{CO}_3$.

Weigh out 15 g Na₂CO₃ and dissolve it in $225 - 15 = 210 \text{ g H}_2\text{O}$ to make exactly 225 g of solution. ($210 \text{ g H}_2\text{O} / 0.997 \text{ g H}_2\text{O/mL} @ 25^\circ = 211 \text{ mL H}_2\text{O}$)

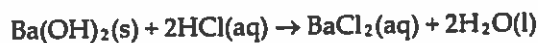
[Carrying 3 sig figs, weigh 14.5 g Na₂CO₃ and dissolve it in $225 - 14.5 = 210.5 \text{ g H}_2\text{O}$. This produces a solution that is much closer to 0.65 *m*.]

$$(c) \quad 1.20 \text{ L} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1.16 \text{ g}}{1 \text{ mL}} = 1392 \text{ g solution}; \quad 0.150(1392 \text{ g soln}) = 209 \text{ g Pb(NO}_3)_2$$

Weigh 209 g $\text{Pb(NO}_3)_2$ and add $(1392 - 209) = 1183 \text{ g H}_2\text{O}$ to make exactly $(1392 = 1.39 \times 10^3) \text{ g}$ or 1.20 L of solution.

$$(1183 \text{ g H}_2\text{O} / 0.997 \text{ g/mL @ } 25^\circ\text{C} = 1187 \text{ mL H}_2\text{O})$$

(d) Calculate the mol HCl necessary to neutralize 5.5 g Ba(OH)_2 .



$$5.5 \text{ g Ba(OH)}_2 + \frac{1 \text{ mol Ba(OH)}_2}{171 \text{ g Ba(OH)}_2} \times \frac{2 \text{ mol HCl}}{1 \text{ mol Ba(OH)}_2} = 0.0643 = 0.064 \text{ mol HCl}$$

$$M = \frac{\text{mol}}{\text{L}}; \quad \text{L} = \frac{\text{mol}}{M} = \frac{0.0643 \text{ mol HCl}}{0.50 \text{ M HCl}} = 0.1287 = 0.13 \text{ L} = 130 \text{ mL}$$

130 mL of 0.50 M HCl are needed.

$$M_c \times L_c = M_d \times L_d; \quad 6.0 \text{ M} \times L_c = 0.50 \text{ M} \times 0.1287 \text{ L}; \quad L_c = 0.01072 \text{ L} = 11 \text{ mL}$$

Using a pipette, measure exactly 11 mL of 6.0 M HCl and dilute with water to a total volume of 130 mL.

13.55 *Analyze/Plan.* Assume a solution volume of 1.00 L. Calculate the mass of 1.00 L of solution and the mass of HNO_3 in 1.00 L of solution. $\text{Mass \%} = (\text{mass solute}/\text{mass solution}) \times 100$. *Solve.*

$$1.00 \text{ L} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1.42 \text{ g soln}}{1 \text{ mL soln}} = 1.42 \times 10^3 \text{ g soln}$$

$$16 \text{ M} = \frac{16 \text{ mol HNO}_3}{1 \text{ L soln}} \times \frac{63.02 \text{ g HNO}_3}{1 \text{ mol HNO}_3} = 1008 = 1.0 \times 10^3 \text{ g HNO}_3$$

$$\text{mass \%} = \frac{1008 \text{ g HNO}_3}{1.42 \times 10^3 \text{ g soln}} \times 100 = 71\% \text{ HNO}_3$$

13.56 *Analyze/Plan.* Assume 1.00 L of solution. Calculate mass of 1 L of solution using density. Calculate mass of NH_3 using mass %, then mol NH_3 in 1.00 L. *Solve.*

$$1.00 \text{ L soln} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{0.90 \text{ g soln}}{1 \text{ mL soln}} = 9.0 \times 10^2 \text{ g soln/L}$$

$$\frac{900 \text{ g soln}}{1.00 \text{ L soln}} \times \frac{28 \text{ g NH}_3}{100 \text{ g soln}} \times \frac{1 \text{ mol NH}_3}{17.03 \text{ g NH}_3} = 14.80 = 15 \text{ mol NH}_3/\text{L soln} = 15 \text{ M NH}_3$$

13.57 *Analyze.* Given: 80.0% Cu, 20.0% Zn by mass; density = 8750 kg/m^3 . Find: (a) m of Zn (b) M of Zn

(a) *Plan.* In the brass alloy, Zn is the solute (lesser component) and Cu is the solvent (greater component). $m = \text{mol Zn/kg Cu}$. 1 m^3 brass alloy weighs 8750 kg. 80.0% is Cu, 20.0% is Zn. Change g Zn \rightarrow mol Zn and solve for m . *Solve.*

$$8750 \text{ kg brass} \times \frac{80 \text{ g Cu}}{100 \text{ g brass}} = 7.00 \times 10^3 \text{ kg Cu}$$

$$8750 \text{ kg brass} - 7000 \text{ kg Cu} = 1750 \text{ kg Zn}$$

$$1750 \text{ kg Zn} \times \frac{1000 \text{ g}}{\text{kg}} \times \frac{1 \text{ mol Zn}}{65.39 \text{ g Zn}} = 26,762.5 = 2.68 \times 10^4 \text{ mol Zn}$$

$$m = \frac{2.676 \times 10^4 \text{ mol Zn}}{7000 \text{ kg Cu}} = 3.82 \text{ m Zn}$$

- (b) *Plan.* $M = \text{mol Zn/L brass}$. Use mol Zn from part (a). Change $1 \text{ m}^3 \rightarrow \text{L brass}$ and calculate M . *Solve.*

$$1 \text{ m}^3 \times \frac{(10)^3 \text{ dm}^3}{\text{m}^3} \times \frac{1 \text{ L}}{1 \text{ dm}^3} = 1000 \text{ L}$$

$$M = \frac{2.676 \times 10^4 \text{ mol Zn}}{1000 \text{ L brass}} = 26.76 = 26.8 \text{ M Zn}$$

13.58 (a) $\frac{0.0500 \text{ mol C}_8\text{H}_{10}\text{N}_4\text{O}_2}{1 \text{ kg CHCl}_3} \times \frac{194.2 \text{ g C}_8\text{H}_{10}\text{N}_4\text{O}_2}{1 \text{ mol C}_8\text{H}_{10}\text{N}_4\text{O}_2} = 9.7100$

$$= 9.71 \text{ g C}_8\text{H}_{10}\text{N}_4\text{O}_2/\text{kg CHCl}_3$$

$$\frac{9.710 \text{ g C}_8\text{H}_{10}\text{N}_4\text{O}_2}{9.710 \text{ g C}_8\text{H}_{10}\text{N}_4\text{O}_2 + 1000.00 \text{ g CHCl}_3} \times 100 = 0.9617 = 0.962\% \text{ C}_8\text{H}_{10}\text{N}_4\text{O}_2 \text{ by mass}$$

(b) $1000 \text{ g CHCl}_3 \times \frac{1 \text{ mol CHCl}_3}{119.4 \text{ g CHCl}_3} = 8.375 = 8.38 \text{ mol CHCl}_3$

$$\chi_{\text{C}_8\text{H}_{10}\text{N}_4\text{O}_2} = \frac{0.0500}{0.0500 + 8.375} = 0.00593$$

- 13.59 *Analyze.* Given: 4.6% CO_2 by volume (in air), 1 atm total pressure. Find: partial pressure and molarity of CO_2 in air.

Plan. 4.6% CO_2 by volume means 4.6 mL of CO_2 could be isolated from 100 mL of air, at the same temperature and pressure. According to Avogadro's Law, equal volumes of gases at the same temperature and pressure contain equal numbers of moles. By inference, the volume ratio of CO_2 to air, 4.6/100 or 0.046, is also the mole ratio.

Solve. $P_{\text{CO}_2} = \chi_{\text{CO}_2} \times P_t = 0.046(1 \text{ atm}) = 0.046 \text{ atm}$

$$M = \text{mol CO}_2/\text{L air} = n/V. \quad PV = nRT, \quad M = n/V = P/RT$$

$$M_{\text{CO}_2} = \frac{P_{\text{CO}_2}}{RT} = \frac{0.046 \text{ atm}}{310 \text{ K}} \times \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} = 1.8 \times 10^{-3} \text{ M}$$

- 13.60 (a) For gases at the same temperature and pressure, volume % = mol %. The volume and mol % of CO_2 in this breathing air is 4.0%.

(b) $P_{\text{CO}_2} = \chi_{\text{CO}_2} \times P_t = 0.040(1 \text{ atm}) = 0.040 \text{ atm}$

$$M_{\text{CO}_2} = \frac{P_{\text{CO}_2}}{RT} = \frac{0.040 \text{ atm}}{310 \text{ K}} \times \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} = 1.6 \times 10^{-3} \text{ M}$$

Colligative Properties (section 13.5)

- 13.61 freezing point depression, $\Delta T_f = K_f(m)$; boiling point elevation, $\Delta T_b = K_b(m)$;
osmotic pressure, $\Pi = M RT$; vapor pressure lowering, $P_A = \chi_A P_A^\circ$

- 13.62 (a) decrease (b) decrease
(c) increase (d) increase

13.63 The vapor pressure over the sucrose solution is higher than the vapor pressure over the glucose solution. Since sucrose has a greater molar mass, 10 g of sucrose contains fewer particles than 10 g of glucose. The solution that contains fewer particles, the sucrose solution, will have the higher vapor pressure.

- 13.64 (a) An *ideal solution* is a solution that obeys Raoult's Law.
(b) *Analyze/Plan.* Calculate the vapor pressure predicted by Raoult's law and compare it to the experimental vapor pressure. Assume ethylene glycol (eg) is the solute. *Solve.*

$$\chi_{\text{H}_2\text{O}} = \chi_{\text{eg}} = 0.500; P_A = \chi_A P_A^\circ = 0.500(149) \text{ torr} = 74.5 \text{ torr}$$

The experimental vapor pressure (P_A), 67 torr, is less than the value predicted by Raoult's law for an ideal solution. The solution is not ideal.

Check. An ethylene glycol-water solution has extensive hydrogen bonding, which causes deviation from ideal behavior. We expect the experimental vapor pressure to be less than the ideal value and it is.

- 13.65 (a) *Analyze/Plan.* H_2O vapor pressure will be determined by the mole fraction of H_2O in the solution. The vapor pressure of pure H_2O at 338 K (65°C) = 187.5 torr. *Solve.*

$$\frac{22.5 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}}{342.3 \text{ g/mol}} = 0.06573 = 0.0657 \text{ mol}; \frac{200.0 \text{ g H}_2\text{O}}{18.02 \text{ g/mol}} = 11.09878 = 11.10 \text{ mol}$$

$$P_{\text{H}_2\text{O}} = \chi_{\text{H}_2\text{O}} P_{\text{H}_2\text{O}}^\circ = \frac{11.09878 \text{ mol H}_2\text{O}}{11.09878 + 0.06573} \times 187.5 \text{ torr} = 186.4 \text{ torr}$$

- (b) *Analyze/Plan.* For this problem, it will be convenient to express Raoult's law in terms of the lowering of the vapor pressure of the solvent, ΔP_A .

$$\Delta P_A = P_A^\circ - \chi_A P_A^\circ = P_A^\circ (1 - \chi_A). 1 - \chi_A = \chi_B, \text{ the mole fraction of the solute particles}$$

$\Delta P_A = \chi_B P_A^\circ$; the vapor pressure of the solvent (A) is lowered according to the mole fraction of solute (B) particles present. *Solve.*

$$P_{\text{H}_2\text{O}} \text{ at } 40^\circ\text{C} = 55.3 \text{ torr}; \frac{340 \text{ g H}_2\text{O}}{18.02 \text{ g/mol}} = 18.868 = 18.9 \text{ mol H}_2\text{O}$$

$$\chi_{\text{C}_3\text{H}_8\text{O}_2} = \frac{2.88 \text{ torr}}{55.3 \text{ torr}} = \frac{y \text{ mol C}_3\text{H}_8\text{O}_2}{y \text{ mol C}_3\text{H}_8\text{O}_2 + 18.868 \text{ mol H}_2\text{O}} = 0.05208 = 0.0521$$

$$0.05208 = \frac{y}{y + 18.868}; 0.05208 y + 0.98263 = y; 0.94792 y = 0.98263,$$

$$y = 1.0366 = 1.04 \text{ mol C}_3\text{H}_8\text{O}_2$$

This result has 3 sig figs because (0.340 kg water) has 3 sig figs.

$$1.0366 \text{ mol C}_3\text{H}_8\text{O}_2 \times \frac{76.09 \text{ g C}_3\text{H}_8\text{O}_2}{\text{mol C}_3\text{H}_8\text{O}_2} = 78.88 = 78.9 \text{ g C}_3\text{H}_8\text{O}_2$$

- 13.66 (a) H_2O vapor pressure will be determined by the mole fraction of H_2O in the solution. The vapor pressure of pure H_2O at 343 K (70°C) = 233.7 torr.

$$\frac{28.5 \text{ g C}_3\text{H}_8\text{O}_3}{92.10 \text{ g/mol}} = 0.3094 = 0.309 \text{ mol}; \quad \frac{125 \text{ g H}_2\text{O}}{18.02 \text{ g/mol}} = 6.937 = 6.94 \text{ mol}$$

$$P_{\text{H}_2\text{O}} = \frac{6.937 \text{ mol H}_2\text{O}}{6.937 + 0.309} \times 233.7 \text{ torr} = 223.7 = 224 \text{ torr}$$

- (b) Calculate χ_B by vapor pressure lowering; $\chi_B = \Delta P_A / P_A^\circ$ (see Solution 13.65(b)). Given moles solvent, calculate moles solute from the definition of mole fraction.

$$\chi_{\text{C}_2\text{H}_6\text{O}_2} = \frac{10.0 \text{ torr}}{100 \text{ torr}} = 0.100$$

$$\frac{1.00 \times 10^3 \text{ g C}_2\text{H}_5\text{OH}}{46.07 \text{ g/mol}} = 21.71 = 21.7 \text{ mol C}_2\text{H}_5\text{OH}; \text{ let } y = \text{mol C}_2\text{H}_6\text{O}_2$$

$$\chi_{\text{C}_2\text{H}_6\text{O}_2} = \frac{y \text{ mol C}_2\text{H}_6\text{O}_2}{y \text{ mol C}_2\text{H}_6\text{O}_2 + 21.71 \text{ mol C}_2\text{H}_5\text{OH}} = 0.100 = \frac{y}{y + 21.71}$$

$$0.100 y + 2.171 = y; \quad 0.900 y = 2.171; \quad y = 2.412 = 2.41 \text{ mol C}_2\text{H}_6\text{O}_2$$

$$2.412 \text{ mol C}_2\text{H}_6\text{O}_2 \times \frac{62.07 \text{ g}}{1 \text{ mol}} = 150 \text{ g C}_2\text{H}_6\text{O}_2$$

- 13.67 *Analyze/Plan.* At 63.5°C , $P_{\text{H}_2\text{O}}^\circ = 175 \text{ torr}$, $P_{\text{Eth}}^\circ = 400 \text{ torr}$. Let G = the mass of H_2O and/or $\text{C}_2\text{H}_5\text{OH}$. *Solve.*

$$(a) \quad \chi_{\text{Eth}} = \frac{\frac{G}{46.07 \text{ g C}_2\text{H}_5\text{OH}}}{\frac{G}{46.07 \text{ g C}_2\text{H}_5\text{OH}} + \frac{G}{18.02 \text{ g H}_2\text{O}}}$$

Multiplying top and bottom of the right side of the equation by $1/G$ gives:

$$\chi_{\text{Eth}} = \frac{1/46.07}{1/46.07 + 1/18.02} = \frac{0.02171}{0.02171 + 0.05549} = 0.2812$$

$$(b) \quad P_t = P_{\text{Eth}} + P_{\text{H}_2\text{O}}; \quad P_{\text{Eth}} = \chi_{\text{Eth}} P_{\text{Eth}}^\circ; \quad P_{\text{H}_2\text{O}} = \chi_{\text{H}_2\text{O}} P_{\text{H}_2\text{O}}^\circ$$

$$\chi_{\text{Eth}} = 0.2812, \quad P_{\text{Eth}} = 0.2812 (400 \text{ torr}) = 112.48 = 112 \text{ torr}$$

$$\chi_{\text{H}_2\text{O}} = 1 - 0.2812 = 0.7188; \quad P_{\text{H}_2\text{O}} = 0.7188(175 \text{ torr}) = 125.8 = 126 \text{ torr}$$

$$P_t = 112.5 \text{ torr} + 125.8 \text{ torr} = 238.3 = 238 \text{ torr}$$

$$(c) \quad \chi_{\text{Eth in vapor}} = \frac{P_{\text{Eth}}}{P_{\text{total}}} = \frac{112.5 \text{ torr}}{238.3 \text{ torr}} = 0.4721 = 0.472$$

- 13.68 (a) Since C_6H_6 and C_7H_8 form an ideal solution, we can use Raoult's Law. Since both components are volatile, both contribute to the total vapor pressure of 35 torr.

$$P_t = P_{\text{C}_6\text{H}_6} + P_{\text{C}_7\text{H}_8}; \quad P_{\text{C}_6\text{H}_6} = \chi_{\text{C}_6\text{H}_6} P_{\text{C}_6\text{H}_6}^\circ; \quad P_{\text{C}_7\text{H}_8} = \chi_{\text{C}_7\text{H}_8} P_{\text{C}_7\text{H}_8}^\circ$$

$$\chi_{\text{C}_7\text{H}_8} = 1 - \chi_{\text{C}_6\text{H}_6}; \quad P_t = \chi_{\text{C}_6\text{H}_6} P_{\text{C}_6\text{H}_6}^\circ + (1 - \chi_{\text{C}_6\text{H}_6}) P_{\text{C}_7\text{H}_8}^\circ$$

$$35 \text{ torr} = \chi_{\text{C}_6\text{H}_6} (75 \text{ torr}) + (1 - \chi_{\text{C}_6\text{H}_6}) 22 \text{ torr}$$

$$13 \text{ torr} = 53 \text{ torr} (\chi_{\text{C}_6\text{H}_6}); \chi_{\text{C}_6\text{H}_6} = \frac{13 \text{ torr}}{53 \text{ torr}} = 0.2453 = 0.25; \chi_{\text{C}_7\text{H}_8} = 0.7547 = 0.75$$

$$(b) P_{\text{C}_6\text{H}_6} = 0.2453(75 \text{ torr}) = 18.4 \text{ torr}; P_{\text{C}_7\text{H}_8} = 0.7547(22 \text{ torr}) = 16.6 \text{ torr}$$

$$\text{In the vapor, } \chi_{\text{C}_6\text{H}_6} = \frac{P_{\text{C}_6\text{H}_6}}{P_t} = \frac{18.4 \text{ torr}}{18.4 \text{ torr} + 16.6 \text{ torr}} = 0.53; \chi_{\text{C}_7\text{H}_8} = 0.47$$

13.69

- (a) Because NaCl is a soluble ionic compound and a strong electrolyte, there are 2 mol dissolved particles for every 1 mol of NaCl solute. $\text{C}_6\text{H}_{12}\text{O}_6$ is a molecular solute, so there is 1 mol of dissolved particles per mol solute. Boiling point elevation is directly related to total moles of dissolved particles; 0.10 *m* NaCl has more dissolved particles so its boiling point is higher than 0.10 *m* $\text{C}_6\text{H}_{12}\text{O}_6$.

- (b) *Analyze/Plan.* $\Delta T = K_b m$; K_b for H_2O is 0.51 °C/*m* (Table 13.3) *Solve.*

$$0.10 \text{ m NaCl: } \Delta T = \frac{0.51^\circ\text{C}}{\text{m}} \times 0.20 \text{ m} = 0.102^\circ\text{C}; T_b = 100.0 + 0.102 = 100.1^\circ\text{C}$$

$$0.10 \text{ m C}_6\text{H}_{12}\text{O}_6: \Delta T = \frac{0.51^\circ\text{C}}{\text{m}} \times 0.10 \text{ m} = 0.051^\circ\text{C}; T_b = 100.0 + 0.051 = 100.1^\circ\text{C}$$

Check. Because K_b for H_2O is so small, there is little real difference in the boiling points of the two solutions.

- (c) In solutions of strong electrolytes like NaCl, electrostatic attractions between ions lead to ion pairing. Ion pairing reduces the effective number of particles in solution, decreasing the change in boiling point. The actual boiling point is then lower than the calculated boiling point for a 0.1 *M* solution.

13.70

Analyze/Plan. ΔT_b depends on mol dissolved particles. Assume 100 g of each solution, calculate mol solute and mol dissolved particles. Glucose and sucrose are molecular solutes, but NaNO_3 dissociates into 2 mol particles per mol solute. *Solve.*

10% by mass means 10 g solute in 100 g solution. If we have 10 g of each solute, the one with the smallest molar mass will have the largest mol solute. The molar masses are: glucose, 180.2 g/mol; sucrose, 342.3 g/mol; NaNO_3 , 85.0 g/mol. NaNO_3 has most mol solute, and twice as many dissolved particles, so it will have the highest boiling point. Sucrose has least mol solute and lowest boiling point. Glucose is intermediate.

In order of increasing boiling point: 10% sucrose < 10% glucose < 10% NaNO_3 .

13.71

Analyze/Plan. Follow the logic in Sample Exercise 13.9. *Solve.*

The more nonvolatile solute particles, the higher the boiling point of the solution. Since LiBr and $\text{Zn}(\text{NO}_3)_2$ are electrolytes, the particle concentrations in these solutions are 0.10 *m* and 0.15 *m*, respectively (although ion-ion attractive forces may decrease the effective concentrations some-what). Thus, the order of increasing boiling points is:

$$0.050 \text{ m LiBr} < 0.120 \text{ m glucose} < 0.050 \text{ m Zn}(\text{NO}_3)_2$$

13 Properties of Solutions

Solutions to Exercises

13.72 $0.030\text{ m phenol} > 0.040\text{ m glycerin} = 0.020\text{ m KBr}$. Phenol is very slightly ionized in water, but not enough to match the number of particles in a 0.040 m glycerin solution. The KBr solution is 0.040 m in particles, so it has the same freezing point as 0.040 m glycerin , which is a nonelectrolyte.

13.73 *Analyze/Plan.* $\Delta T = K(m)$; first, calculate the molality of each solution. *Solve.*

(a) 0.22 m

(b) $2.45\text{ mol CHCl}_3 \times \frac{119.4\text{ g CHCl}_3}{\text{mol CHCl}_3} = 292.53\text{ g} = 0.293\text{ kg}$;

$$\frac{0.240\text{ mol C}_{10}\text{H}_8}{0.29253\text{ kg CHCl}_3} = 0.8204 = 0.820\text{ m}$$

(c) $1.50\text{ g NaCl} \times \frac{1\text{ mol NaCl}}{58.44\text{ g NaCl}} \times \frac{2\text{ mol particles}}{1\text{ mol NaCl}} = 0.05133 = 0.0513\text{ mol particles}$

$$m = \frac{0.05133\text{ mol NaCl}}{0.250\text{ kg H}_2\text{O}} = 0.20534 = 0.205\text{ m}$$

(d) $2.04\text{ g KBr} \times \frac{1\text{ mol KBr}}{119.0\text{ g KBr}} \times \frac{2\text{ mol particles}}{1\text{ mol KBr}} = 0.03429 = 0.0343\text{ mol particles}$

$$4.82\text{ g C}_6\text{H}_{12}\text{O}_6 \times \frac{1\text{ mol C}_6\text{H}_{12}\text{O}_6}{180.2\text{ g C}_6\text{H}_{12}\text{O}_6} = 0.02675 = 0.0268\text{ mol particles}$$

$$m = \frac{(0.03429 + 0.02675)\text{ mol particles}}{0.188\text{ kg H}_2\text{O}} = 0.32465 = 0.325\text{ m}$$

Solve. Then, $f.p. = T_f - K_f(m)$; $b.p. = T_b + K_b(m)$; T in $^{\circ}\text{C}$

	m	T_f	$-K_f(m)$	$f.p.$	T_b	$+K_b(m)$	$b.p.$
(a)	0.22	-114.6	$-1.99(0.22) = -0.44$	-115.0	78.4	$1.22(0.22) = 0.27$	78.7
(b)	0.820	-63.5	$-4.68(0.820) = -3.84$	-67.3	61.2	$3.63(0.820) = 2.98$	64.2
(c)	0.205	0.0	$-1.86(0.205) = -0.381$	-0.4	100.0	$0.51(0.205) = 0.10$	100.1
(d)	0.325	0.0	$-1.86(0.325) = -0.605$	-0.6	100.0	$0.51(0.325) = 0.17$	100.2

13.74 $\Delta T = K(m)$; first calculate the molality of the solute particles.

(a) 0.25 m

(b) $\frac{20.0\text{ g C}_{10}\text{H}_{22}}{0.0500\text{ kg CHCl}_3} \times \frac{1\text{ mol C}_{10}\text{H}_{22}}{142.3\text{ g C}_{10}\text{H}_{22}} = 2.811 = 2.81\text{ m}$

(c) $3.50\text{ g NaOH} \times \frac{1\text{ mol NaOH}}{40.00\text{ g NaOH}} \times \frac{2\text{ mol particles}}{1\text{ mol NaOH}} = 0.1750 = 0.175\text{ mol particles}$

$$m = \frac{0.1750\text{ mol NaCl}}{0.175\text{ kg H}_2\text{O}} = 1.000 = 1.00\text{ m}$$

(d) $m = \frac{0.45\text{ mol eg} + 2(0.15)\text{ mol KBr}}{0.150\text{ kg H}_2\text{O}} = \frac{0.75\text{ mol particles}}{0.150\text{ kg H}_2\text{O}} = 5.0\text{ m}$

Then, $f.p. = T_f - K_f(m)$; $b.p. = T_b + K_b(m)$; T in $^{\circ}\text{C}$

	m	T_f	$-K_f(m)$	f.p.	T_b	$+K_b(m)$	b.p.
(a)	0.25	-114.6	$-1.99(0.25) = -0.50$	-115.1	78.4	$1.22(0.25) = 0.31$	78.7
(b)	2.81	-63.5	$-4.68(2.81) = -13.2$	-76.7	61.2	$3.63(2.81) = 10.2$	71.4
(c)	1.00	0.0	$-1.86(1.00) = -1.86$	-1.9	100.0	$0.51(1.00) = 0.51$	100.5
(d)	5.0	0.0	$-1.86(5.0) = -9.3$	-9.3	100.0	$0.51(5.0) = 2.6$	102.6

13.75 *Analyze.* Given freezing point of solution and mass of solvent, calculate mass of solute.

Plan. Reverse the logic in Sample Exercise 13.8. Use $\Delta T_f = K_f(m)$ to calculate the required molality, and then apply the definition of molality to calculate moles and grams of $C_2H_6O_2$.

Solve. f.p. of solution = $-5.00^\circ C$; f.p. of solvent (H_2O) = $0.0^\circ C$

$$\Delta T_f = 5.00^\circ C = K_f(m); 5.00^\circ C = 1.86^\circ C/m(m)$$

$$m = \frac{5.00^\circ C}{1.86^\circ C/m} = 2.688 = 2.69 m C_2H_6O_2$$

$$m = \frac{\text{mol } C_2H_6O_2}{\text{kg } H_2O} = C_2H_6O_2 = m \times \text{kg } H_2O$$

$$2.688 m C_2H_6O_2 \times 1.00 \text{ kg } H_2O = 2.688 = 2.69 \text{ mol } C_2H_6O_2$$

$$2.688 m C_2H_6O_2 \times \frac{62.07 \text{ g } C_2H_6O_2}{1 \text{ mol}} = 166.84 = 167 \text{ g } C_2H_6O_2$$

13.76 Use ΔT_b = find m of aqueous solution, and then use m to calculate ΔT_f and freezing point. $K_b = 0.51$, $K_f = 1.86$.

$$\text{b.p.} = 105.0^\circ C; \Delta T_b = 105.0^\circ C - 100.0^\circ C = 5.0^\circ C$$

$$\Delta T_b = K_b(m); m = \frac{\Delta T_b}{K_b} = \frac{5.0^\circ C}{0.51} = 9.804 = 9.8 m$$

$$\Delta T_f = 1.86^\circ C/m \times 9.804 m = 18.24 = 18^\circ C; \text{freezing point} = 0.0^\circ C - 18.24^\circ C = -18^\circ C$$

13.77 *Analyze/Plan.* $\Pi = MRT$; $T = 25^\circ C + 273 = 298 \text{ K}$; $M = \text{mol } C_9H_8O_4/\text{L soln}$ *Solve.*

$$M = \frac{44.2 \text{ mg } C_9H_8O_4}{0.358 \text{ L}} \times \frac{1 \text{ g}}{1000 \text{ mg}} \times \frac{1 \text{ mol } C_9H_8O_4}{180.2 \text{ g } C_9H_8O_4} = 6.851 \times 10^{-4} = 6.85 \times 10^{-4} M$$

$$\Pi = \frac{6.851 \times 10^{-4} \text{ mol}}{\text{L}} \times \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298 \text{ K} = 0.01675 = 0.0168 \text{ atm} = 12.7 \text{ torr}$$

13.78 $\Pi = MRT$; $T = 20^\circ C + 273 = 293 \text{ K}$

$$M(\text{of ions}) = \frac{\text{mol NaCl} \times 2}{\text{L soln}} = \frac{3.4 \text{ g NaCl}}{1 \text{ L soln}} \times \frac{1 \text{ mol NaCl}}{58.4 \text{ g NaCl}} \times \frac{2 \text{ mol ions}}{1 \text{ mol NaCl}} = 0.116 = 0.12 M$$

$$\Pi = \frac{0.116 \text{ mol}}{\text{L}} \times \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 293 \text{ K} = 2.8 \text{ atm}$$

13.79 *Analyze/Plan.* Follow the logic in Sample Exercise 13.11 to calculate the molar mass of adrenaline based on the boiling point data. Use the structure to obtain the molecular formula and molar mass. Compare the two values. *Solve.*

$$\Delta T_b = K_b m; \quad m = \frac{\Delta T_b}{K_b} = \frac{+0.49}{5.02} = 0.0976 = 0.098 \text{ } m \text{ adrenaline}$$

$$m = \frac{\text{mol adrenaline}}{\text{kg CCl}_4} = \frac{\text{g adrenaline}}{\text{MM adrenaline} \times \text{kg CCl}_4}$$

$$\text{MM adrenaline} = \frac{\text{g adrenaline}}{m \times \text{kg CCl}_4} = \frac{0.64 \text{ g adrenaline}}{0.0976 \text{ } m \times 0.0360 \text{ kg CCl}_4} = 1.8 \times 10^2 \text{ g/mol adrenaline}$$

Check. The molecular formula is $\text{C}_9\text{H}_{13}\text{NO}_3$, $\text{MM} = 183 \text{ g/mol}$. The values agree to 2 sig figs, the precision of the experimental value.

$$13.80 \quad \Delta T_f = 5.5 - 4.1 = 1.4; \quad m = \frac{\Delta T_f}{K_f} = \frac{1.4}{5.12} = 0.273 = 0.27 \text{ } m$$

$$\text{MM lauryl alcohol} = \frac{\text{g lauryl alcohol}}{m \times \text{kg C}_6\text{H}_6} = \frac{5.00 \text{ g lauryl alcohol}}{0.273 \times 0.100 \text{ kg C}_6\text{H}_6} = 1.8 \times 10^2 \text{ g/mol lauryl alcohol}$$

13.81 *Analyze/Plan.* Follow the logic in Sample Exercise 13.12. *Solve.*

$$\Pi = MRT; \quad M = \frac{\Pi}{RT}; \quad T = 25^\circ\text{C} + 273 = 298 \text{ K}$$

$$M = 0.953 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} \times \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} \times \frac{1}{298 \text{ K}} = 5.128 \times 10^{-5} = 5.13 \times 10^{-5} \text{ } M$$

$$\text{mol} = M \times L = 5.128 \times 10^{-5} \times 0.210 \text{ L} = 1.077 \times 10^{-5} = 1.08 \times 10^{-5} \text{ mol lysozyme}$$

$$\text{MM} = \frac{\text{g}}{\text{mol}} = \frac{0.150 \text{ g}}{1.077 \times 10^{-5} \text{ mol}} = 1.39 \times 10^4 \text{ g/mol lysozyme}$$

$$13.82 \quad M = P/RT = \frac{0.605 \text{ atm}}{298 \text{ K}} \times \frac{\text{mol} \cdot \text{K}}{0.08206 \text{ L} \cdot \text{atm}} = 0.02474 = 0.0247 \text{ } M$$

$$\text{MM} = \frac{\text{g}}{M \times L} = \frac{2.35 \text{ g}}{0.02474 \text{ } M \times 0.250 \text{ L}} = 380 \text{ g/mol}$$

13.83 (a) *Analyze/Plan.* $i = \Pi$ (measured) / Π (calculated for a nonelectrolyte);

$$\Pi \text{ (calculated)} = MRT. \quad \textit{Solve.}$$

$$\Pi \text{ (calculated)} = \frac{0.010 \text{ mol}}{\text{L}} \times \frac{0.08206 \text{ L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \times 298 \text{ K} = 0.2445 = 0.24 \text{ atm}$$

$$i = 0.674 \text{ atm} / 0.2445 \text{ atm} = 2.756 = 2.8$$

(b) The van't Hoff factor is the effective number of particles per mole of solute. The closer the measured i value is to a theoretical integer value, the more ideal the solution. Ion-pairing and other interparticle attractive forces reduce the effective number of particles in solution and reduce the measured value of i . The more concentrated the solution, the greater the ion-pairing and the smaller the measured value of i .

13.84 If these were ideal solutions, they would have equal ion concentrations and equal ΔT_i values. Data in Table 13.4 indicates that the van't Hoff factors (i) for both salts are less than the ideal values. For $0.030 \text{ } m \text{ NaCl}$, i is between 1.87 and 1.94, about 1.92. For

0.020 *m* K₂SO₄, *i* is between 2.32 and 2.70, about 2.62. From Equation 13.15,

$$\Delta T_f (\text{measured}) = i \times \Delta T_f (\text{calculated for nonelectrolyte})$$

$$\text{NaCl: } \Delta T_f (\text{measured}) = 1.92 \times 0.030 \text{ m} \times 1.86 \text{ }^\circ\text{C/m} = 0.11 \text{ }^\circ\text{C}$$

$$\text{K}_2\text{SO}_4: \Delta T_f (\text{measured}) = 2.62 \times 0.020 \text{ m} \times 1.86 \text{ }^\circ\text{C/m} = 0.097 \text{ }^\circ\text{C}$$

0.030 *m* NaCl would have the larger ΔT_f .

The deviations from ideal behavior are due to ion-pairing in the two electrolyte solutions. K₂SO₄ has more extensive ion-pairing and a larger deviation from ideality because of the higher charge on SO₄²⁻ relative to Cl⁻.

Colloids (section 13.6)

- 13.85 (a) In the gaseous state, the particles are far apart and intermolecular attractive forces are small. When two gases combine, all terms in Equation [13.1] are essentially zero and the mixture is always homogeneous.
- (b) The outline of a light beam passing through a colloid is visible, whereas light passing through a true solution is invisible unless collected on a screen. This is the Tyndall effect. To determine whether Faraday's (or anyone's) apparently homogeneous dispersion is a true solution or a colloid, shine a beam of light on it and see if the light is scattered.
- 13.86 (a) Suspensions are classified as solutions or colloids according to the size of the dispersed particles. Solute particles have diameters less than 5 nm (50 Å); suspended colloid particles range from 5-1000 nm. Proteins with molecular masses of 30,000 amu or greater are likely to have dimensions in the colloid range. The aqueous suspensions are colloids because of the size of protein molecules. (Large protein molecules remain homogeneously suspended in water because of their many hydrogen bonding interactions with water.)
- (b) Emulsion. An *emulsifying agent* is one that aids in the formation of an emulsion. It usually has a polar part and a nonpolar part, to facilitate mixing of immiscible liquids with very different molecular polarities.
- 13.87 (a) hydrophobic (b) hydrophilic (c) hydrophobic
- (d) hydrophobic (but stabilized by adsorbed charges)
- 13.88 (a) When the colloid *particle mass* becomes large enough so that gravitational and interparticle attractive forces are greater than the kinetic energies of the particles, settling and aggregation can occur.
- (b) *Hydrophobic* colloids do not attract a sheath of water molecules around them and thus tend to aggregate from aqueous solution. They can be stabilized as colloids by adsorbing charges on their surfaces. The charged particles interact with solvent water, stabilizing the colloid.
- (c) *Charges on colloid particles* can stabilize them against aggregation. Particles carrying like charges repel one another and are thus prevented from aggregating and settling out.