Continued—

Q15. An aqueous solution at 25 °C is in equilibrium with a gaseous mixture containing an equal number of moles of oxygen, nitrogen, and helium. Rank the relative concentrations of each gas in the aqueous solution from highest to lowest.

MISSED THIS? *Read Section 14.4*

a) $[O_2] > [N_2] > [He]$ b) $[He] > [N_2] > [O_2]$
c) $[N_2] > [He] > [O_2]$ d) $[N_2] > [O_2] > [He]$

Answers: **1.** (b) **2.** (b) **3.** (d) **4.** (a) **5.** (c) **6.** (d) **7.** (b) **8.** (a) **9.** (b) **10.** (c) **11.** (c) **12.** (b) **13.** (a) **14.** (a) **15.** (a)

CHAPTER 14 IN REVIEW

TERMS

Section 14.1
solution (580)
solvent (580)
solute (580)

Section 14.2
aqueous solution (581)
solubility (581)
entropy (582)
miscible (583)

Section 14.3
enthalpy of solution (ΔH_{soln}) (587)
heat of hydration ($\Delta H_{hydration}$) (588)

Section 14.4
dynamic equilibrium (590)
saturated solution (590)
unsaturated solution (590)
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recrystallization (591)
Henry's law (593)

Section 14.5
dilute solution (594)
concentrated solution (595)
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Section 14.6
colligative property (601)
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colloidal dispersion (colloid) (616)
Tyndall effect (618)

CONCEPTS

Solutions (14.1, 14.2)
- A solution is a homogeneous mixture of two or more substances. In a solution, the majority component is the solvent, and the minority component is the solute.
- The tendency toward greater entropy (or greater energy dispersal) is the driving force for solution formation.
- In aqueous solutions, water is a solvent, and a solid, liquid, or gas is the solute.

Solubility and Energetics of Solution Formation (14.2, 14.3)
- The solubility of a substance is the amount of the substance that dissolves in a given amount of solvent. The solubility of one substance in another depends on the types of intermolecular forces that exist *between* the substances as well as *within* each substance.
- We can determine the overall enthalpy change upon solution formation by adding the enthalpy changes for the three steps of solution formation: (1) separation of the solute particles, (2) separation of the solvent particles, and (3) mixing of the solute and solvent particles. The first two steps are both endothermic, whereas the last is exothermic.
- In aqueous solutions of an ionic compound, the combined change in enthalpy for steps 2 and 3 is the heat of hydration ($\Delta H_{hydration}$), which is always negative.

Solution Equilibrium (14.4)
- Dynamic equilibrium in a solution occurs when the rates of dissolution and recrystallization in a solution are equal. A solution in this state is saturated. Solutions containing less than or more than the equilibrium amount of solute are unsaturated or supersaturated, respectively.
- The solubility of most solids in water increases with increasing temperature.
- The solubility of gases in water generally decreases with increasing temperature, but it increases with increasing pressure.

Concentration Units (14.5)
- Common units to express solution concentration include molarity (M), molality (m), mole fraction (χ), mole percent (mol %), percent (%) by mass or volume, parts per million (ppm) by mass or volume, and parts per billion (ppb) by mass or volume. Table 14.5 summarizes these units.

Vapor Pressure Lowering, Freezing Point Depression, Boiling Point Elevation, and Osmosis (14.6, 14.7)

- The presence of a nonvolatile solute in a liquid results in a lower vapor pressure of the solution relative to the vapor pressure of the pure liquid. Raoult's law for an ideal solution predicts this lower vapor pressure.
- If the solute–solvent interactions are particularly strong, the actual vapor pressure is lower than that predicted by Raoult's law.
- If the solute–solvent interactions are particularly weak, the actual vapor pressure is higher than that predicted by Raoult's law.
- The addition of a nonvolatile solute to a liquid results in a solution with a lower freezing point and a higher boiling point than those of the pure solvent.
- The flow of solvent from a solution of lower concentration to a solution of higher concentration is osmosis.
- All of these phenomena (vapor pressure lowering, freezing point depression, boiling point elevation, and osmosis) are colligative properties and depend only on the number of solute particles added, not the type of solute particles.
- Electrolyte solutes have a greater effect on these properties than the corresponding amount of a nonelectrolyte solute as specified by the van't Hoff factor.

Colloids (14.8)

- A colloid is a mixture in which a substance is finely divided in a dispersing medium.
- Colloidal mixtures occur when the dispersed substance ranges in size from 1 nm to 1000 nm.
- One way to identify colloidal mixtures is by their tendency to scatter light, known as the Tyndall effect.

EQUATIONS AND RELATIONSHIPS

Henry's Law: Solubility of Gases with Increasing Pressure (14.4)

$$S_{gas} = k_H P_{gas} \ (k_H \text{ is Henry's law constant})$$

Molarity (M) of a Solution (14.5)

$$M = \frac{\text{amount solute (in mol)}}{\text{volume solution (in L)}}$$

Molality (m) of a Solution (14.5)

$$m = \frac{\text{amount solute (in mol)}}{\text{mass solvent (in kg)}}$$

Concentration of a Solution in Parts by Mass and Parts by Volume (14.5)

$$\text{Percent by mass} = \frac{\text{mass solute} \times 100\%}{\text{mass solution}}$$

$$\text{Parts per million (ppm)} = \frac{\text{mass solute} \times 10^6}{\text{mass solution}}$$

$$\text{Parts per billion (ppb)} = \frac{\text{mass solute} \times 10^9}{\text{mass solution}}$$

$$\text{Parts by volume} = \frac{\text{volume solute} \times \text{multiplication factor}}{\text{volume solution}}$$

Concentration of a Solution in Mole Fraction (χ) and Mole Percent (14.5)

$$\chi_{solute} = \frac{n_{solute}}{n_{solute} + n_{solvent}}$$

$$\text{Mol \%} = \chi \times 100\%$$

Raoult's Law: Relationship between the Vapor Pressure of a Solution ($P_{solution}$), the Mole Fraction of the Solvent ($\chi_{solvent}$), and the Vapor Pressure of the Pure Solvent ($P^\circ_{solvent}$) (14.6)

$$P_{solution} = \chi_{solvent} P^\circ_{solvent}$$

The Vapor Pressure of a Solution Containing Two Volatile Components (14.6)

$$P_A = \chi_A P^\circ_A$$

$$P_B = \chi_B P^\circ_B$$

$$P_{tot} = P_A + P_B$$

Relationship between Freezing Point Depression (ΔT_f), Molality (m), and Freezing Point Depression Constant (K_f) (14.6)

$$\Delta T_f = m \times K_f$$

Relationship between Boiling Point Elevation (ΔT_b), Molality (m), and Boiling Point Elevation Constant (K_b) (14.6)

$$\Delta T_b = m \times K_b$$

Relationship between Osmotic Pressure (Π), Molarity (M), the Ideal Gas Constant (R), and Temperature (T, in K) (14.6)

$$\Pi = MRT \ (R = 0.08206 \ \text{L} \cdot \text{atm/mol} \cdot \text{K})$$

van't Hoff Factor (i): Ratio of Moles of Particles in Solution to Moles of Formula Units Dissolved (14.7)

$$i = \frac{\text{moles of particles in solution}}{\text{moles of formula units dissolved}}$$

LEARNING OUTCOMES

Chapter Objectives	Assessment
Determine the solubility of a solute (14.2)	Example 14.1 **For Practice** 14.1 **Exercises** 31–34
Analyze energy transfer for the formation of a solution (14.3)	Exercises 35–40
Evaluate the solubility of solids and gases with changing temperature and pressure (14.4)	Example 14.2 **For Practice** 14.2 **Exercises** 41–50

Perform calculations using varying concentration units (14.5)	Examples 14.3, 14.4, 14.5 **For Practice** 14.3, 14.4, 14.5 **For More Practice** 14.3, 14.5 **Exercises** 51–68
Determine colligative properties of solutions containing a nonelectrolyte (14.6)	Examples 14.6, 14.7, 14.8, 14.9, 14.10 **For Practice** 14.6, 14.7, 14.8, 14.9, 14.10 **For More Practice** 14.6 **Exercises** 69–86
Calculate colligative properties of solutions containing an ionic solute (14.7)	Example 14.11 **For Practice** 14.11, 14.12 **Exercises** 87–98

EXERCISES

Mastering Chemistry provides end-of-chapter exercises, feedback-enriched tutorial problems, animations, and interactive activities to encourage problem-solving practice and deeper understanding of key concepts and topics.

REVIEW QUESTIONS

1. Explain why drinking seawater results in dehydration.
2. What is a solution? What are the solute and solvent?
3. What does it mean to say that a substance is soluble in another substance? Which units are used in reporting solubility?
4. Why do two ideal gases thoroughly mix when combined? What drives the mixing?
5. What is entropy? Why is entropy important in discussing the formation of solutions?
6. What kinds of intermolecular forces are involved in solution formation?
7. Explain how the relative strengths of solute–solute interactions, solvent–solvent interactions, and solvent–solute interactions affect solution formation.
8. What does the statement *like dissolves like* mean with respect to solution formation?
9. What are the three steps involved in evaluating the enthalpy changes associated with solution formation?
10. What is the heat of hydration ($\Delta H_{\text{hydration}}$)? How does the enthalpy of solution depend on the relative magnitudes of ΔH_{solute} and $\Delta H_{\text{hydration}}$?
11. Explain dynamic equilibrium with respect to solution formation. What is a saturated solution? An unsaturated solution? A supersaturated solution?
12. How does the solubility of a solid in a liquid depend on temperature? How is this temperature dependence exploited to purify solids through recrystallization?
13. How does the solubility of a gas in a liquid depend on temperature? How does this temperature dependence affect the amount of oxygen available for fish and other aquatic animals?
14. How does the solubility of a gas in a liquid depend on pressure? How does this pressure dependence account for the bubbling that occurs upon opening a can of soda?
15. What is Henry's law? For what kinds of calculations is Henry's law useful?
16. What are the common units for expressing solution concentration?
17. How are parts by mass and parts by volume used in calculations?
18. What is the effect of a nonvolatile solute on the vapor pressure of a liquid? Why is the vapor pressure of a solution different from the vapor pressure of the pure liquid solvent?
19. What is Raoult's law? For what kind of calculations is Raoult's law useful?
20. Explain the difference between an ideal and a nonideal solution.
21. What is the effect on vapor pressure of a solution with particularly *strong* solute–solvent interactions? With particularly *weak* solute–solvent interactions?
22. Explain why the lower vapor pressure for a solution containing a nonvolatile solute results in a higher boiling point and lower melting point compared to the pure solvent.
23. What are colligative properties?
24. What is osmosis? What is osmotic pressure?
25. Explain the meaning of the van't Hoff factor and its role in determining the colligative properties of solutions containing ionic solutes.
26. Describe a colloidal dispersion. What is the difference between a colloidal dispersion and a true solution?
27. What is the Tyndall effect, and how can it be used to help identify colloidal dispersions?
28. What keeps the particles in a colloidal dispersion from coalescing?

PROBLEMS BY TOPIC

Solubility

29. Pick an appropriate solvent from Table 14.3 to dissolve each substance. State the kind of intermolecular forces that would occur between the solute and solvent in each case.
MISSED THIS? *Read Section 14.2*

a. motor oil (nonpolar)
b. ethanol (polar, contains an OH group)
c. lard (nonpolar)
d. potassium chloride (ionic)

30. Pick an appropriate solvent from Table 14.3 to dissolve each substance. State the kind of intermolecular forces that would occur between the solute and solvent in each case.

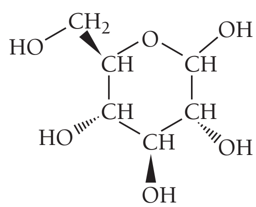
a. isopropyl alcohol (polar, contains an OH group)
b. sodium chloride (ionic)
c. vegetable oil (nonpolar)
d. sodium nitrate (ionic)

31. Which molecule would you expect to be more soluble in water: $CH_3CH_2CH_2OH$ or $HOCH_2CH_2CH_2OH$?
MISSED THIS? *Read Section 14.2*

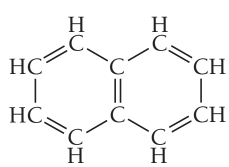
32. Which molecule would you expect to be more soluble in water: CCl_4 or CH_2Cl_2?

33. For each compound, would you expect greater solubility in water or in hexane? Indicate the kinds of intermolecular forces that occur between the solute and the solvent in which the molecule is most soluble. **MISSED THIS?** *Read Section 14.2*

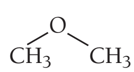
a. glucose



b. naphthalene

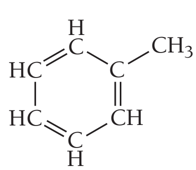


c. dimethyl ether

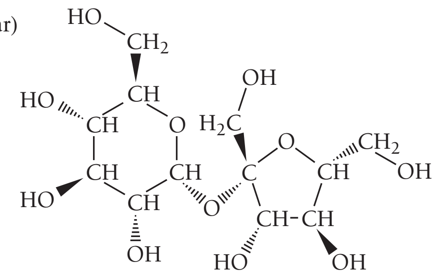


34. For each compound, would you expect greater solubility in water or in hexane? Indicate the kinds of intermolecular forces that would occur between the solute and the solvent in which the molecule is most soluble.

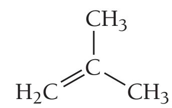
a. toluene



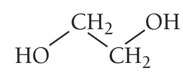
b. sucrose (table sugar)



c. isobutene



d. ethylene glycol



Energetics of Solution Formation

35. When ammonium chloride (NH_4Cl) is dissolved in water, the solution becomes colder. **MISSED THIS?** *Read Section 14.3*

a. Is the dissolution of ammonium chloride endothermic or exothermic?
b. What can you conclude about the relative magnitudes of the lattice energy of ammonium chloride and its heat of hydration?
c. Sketch a qualitative energy diagram similar to Figure 14.7 for the dissolution of NH_4Cl.
d. Why does the solution form? What drives the process?

36. When lithium iodide (LiI) is dissolved in water, the solution becomes hotter.

a. Is the dissolution of lithium iodide endothermic or exothermic?
b. What can you conclude about the relative magnitudes of the lattice energy of lithium iodide and its heat of hydration?
c. Sketch a qualitative energy diagram similar to Figure 14.7 for the dissolution of LiI.
d. Why does the solution form? What drives the process?

37. Silver nitrate has a lattice energy of –820 kJ/mol and a heat of solution of 22.6 kJ/mol. Calculate the heat of hydration for silver nitrate. **MISSED THIS?** *Read Section 14.3*

38. Use the data to calculate the heats of hydration of lithium chloride and sodium chloride. Which of the two cations, lithium or sodium, has stronger ion–dipole interactions with water? Why?

Compound	Lattice Energy (kJ/mol)	ΔH_{soln} (kJ/mol)
LiCl	–834	–37.0
NaCl	–769	+3.88

39. Lithium iodide has a lattice energy of -7.3×10^2 kJ/mol and a heat of hydration of –793 kJ/mol. Find the heat of solution for lithium iodide and determine how much heat is evolved or absorbed when 15.0 g of lithium iodide completely dissolves in water. **MISSED THIS?** *Read Section 14.3*

40. Potassium nitrate has a lattice energy of –163.8 kcal/mol and a heat of hydration of –155.5 kcal/mol. How much potassium nitrate has to dissolve in water to absorb 1.00×10^2 kJ of heat?

Solution Equilibrium and Factors Affecting Solubility

41. A solution contains 25 g of NaCl per 100.0 g of water at 25 °C. Is the solution unsaturated, saturated, or supersaturated? (Use Figure 14.11.) **MISSED THIS?** *Read Section 14.4; Watch KCV 14.4*

42. A solution contains 32 g of KNO_3 per 100.0 g of water at 25 °C. Is the solution unsaturated, saturated, or supersaturated? (Use Figure 14.11.)

43. A KNO_3 solution containing 45 g of KNO_3 per 100.0 g of water is cooled from 40 °C to 0 °C. What happens during cooling? (Use Figure 14.11.) **MISSED THIS?** *Read Section 14.4; Watch KCV 14.4*

44. A KCl solution containing 42 g of KCl per 100.0 g of water is cooled from 60 °C to 0 °C. What happens during cooling? (Use Figure 14.11.)

45. Some laboratory procedures involving oxygen-sensitive reactants or products call for using water that has been boiled (and then cooled). Explain.
MISSED THIS? *Read Section 14.4; Watch KCV 14.4*

46. A person preparing a fish tank fills the tank with water that has been boiled (and then cooled). When the person puts fish into the tank, they die. Explain.

47. Scuba divers breathing air at increased pressure can suffer from nitrogen narcosis—a condition resembling drunkenness—when the partial pressure of nitrogen exceeds about 4 atm. What property of gas/water solutions causes this to happen? How can a diver reverse this effect?
MISSED THIS? *Read Section 14.4; Watch KCV 14.4*

48. Scuba divers breathing air at increased pressure can suffer from oxygen toxicity—too much oxygen in their bloodstream—when the partial pressure of oxygen exceeds about 1.4 atm. What happens to the amount of oxygen in a diver's bloodstream when he or she breathes oxygen at elevated pressures? How can this be reversed?

49. Calculate the mass of nitrogen dissolved at room temperature in an 80.0-L home aquarium. Assume a total pressure of 1.0 atm and a mole fraction for nitrogen of 0.78.
MISSED THIS? *Read Section 14.4; Watch KCV 14.4, IWE 14.2*

50. Use Henry's law to determine the molar solubility of helium at a pressure of 1.0 atm and 25 °C.

Concentrations of Solutions

51. An aqueous NaCl solution is made using 112 g of NaCl diluted to a total solution volume of 1.00 L. Calculate the molarity, molality, and mass percent of the solution. (Assume a density of 1.08 g/mL for the solution.)
MISSED THIS? *Read Section 14.5; Watch KCV 14.5, IWE 14.4*

52. An aqueous KNO_3 solution is made using 72.5 g of KNO_3 diluted to a total solution volume of 2.00 L. Calculate the molarity, molality, and mass percent of the solution. (Assume a density of 1.05 g/mL for the solution.)

53. To what volume should you dilute 50.0 mL of a 5.00 M KI solution so that 25.0 mL of the diluted solution contains 3.05 g of KI?
MISSED THIS? *Read Section 14.5; Watch KCV 14.5*

54. To what volume should you dilute 125 mL of an 8.00 M $CuCl_2$ solution so that 50.0 mL of the diluted solution contains 4.67 g $CuCl_2$?

55. Silver nitrate solutions are often used to plate silver onto other metals. What is the maximum amount of silver (in grams) that can be plated out of 4.8 L of an $AgNO_3$ solution containing 3.4% Ag by mass? Assume that the density of the solution is 1.01 g/mL.
MISSED THIS? *Read Section 14.5; Watch KCV 14.5, IWE 14.3*

56. A dioxin-contaminated water source contains 0.085% dioxin by mass. How much dioxin is present in 2.5 L of this water? Assume a density of 1.00 g/mL.

57. A hard water sample contains 0.0085% Ca by mass (in the form of Ca^{2+} ions). How much water (in grams) contains 1.2 g of Ca? (1.2 g of Ca is the recommended daily allowance of calcium for adults between 19 and 24 years old.)
MISSED THIS? *Read Section 14.5; Watch KCV 14.5, IWE 14.3*

58. Lead is a toxic metal that affects the central nervous system. A Pb-contaminated water sample contains 0.0011% Pb by mass. How much of the water (in mL) contains 150 mg of Pb? (Assume a density of 1.0 g/mL.)

59. You can purchase nitric acid in a concentrated form that is 70.3% HNO_3 by mass and has a density of 1.41 g/mL. Describe exactly how you would prepare 1.15 L of 0.100 M HNO_3 from the concentrated solution.
MISSED THIS? *Read Section 14.5; Watch KCV 14.5, IWE 14.3*

60. You can purchase hydrochloric acid in a concentrated form that is 37.0% HCl by mass and that has a density of 1.20 g/mL. Describe exactly how to prepare 2.85 L of 0.500 M HCl from the concentrated solution.

61. Describe how to prepare each solution from the dry solute and the solvent. **MISSED THIS?** *Read Section 14.5; Watch KCV 14.5*
a. 1.00×10^2 mL of 0.500 M KCl
b. 1.00×10^2 g of 0.500 *m* KCl
c. 1.00×10^2 g of 5.0% KCl solution by mass

62. Describe how to prepare each solution from the dry solute and the solvent.
a. 125 mL of 0.100 M $NaNO_3$
b. 125 g of 0.100 *m* $NaNO_3$
c. 125 g of 1.0% $NaNO_3$ solution by mass

63. A solution is prepared by dissolving 28.4 g of glucose ($C_6H_{12}O_6$) in 355 g of water. The final volume of the solution is 378 mL. For this solution, calculate the concentration in each unit.
MISSED THIS? *Read Section 14.5; Watch KCV 14.5, IWE 14.4*
a. molarity **b.** molality
c. percent by mass **d.** mole fraction
e. mole percent

64. A solution is prepared by dissolving 20.2 mL of methanol (CH_3OH) in 100.0 mL of water at 25 °C. The final volume of the solution is 118 mL. The densities of methanol and water at this temperature are 0.782 g/mL and 1.00 g/mL, respectively. For this solution, calculate the concentration in each unit.
a. molarity **b.** molality
c. percent by mass **d.** mole fraction
e. mole percent

65. Household hydrogen peroxide is an aqueous solution containing 3.0% hydrogen peroxide by mass. What is the molarity of this solution? (Assume a density of 1.01 g/mL.)
MISSED THIS? *Read Section 14.5; Watch KCV 14.5, IWE 14.5*

66. One brand of laundry bleach is an aqueous solution containing 4.55% sodium hypochlorite (NaOCl) by mass. What is the molarity of this solution? (Assume a density of 1.02 g/mL.)

67. An aqueous solution contains 36% HCl by mass. Calculate the molality and mole fraction of the solution.
MISSED THIS? *Read Section 14.5; Watch KCV 14.5, IWE 14.5*

68. An aqueous solution contains 5.0% NaCl by mass. Calculate the molality and mole fraction of the solution.

Vapor Pressure of Solutions

69. A beaker contains 100.0 mL of pure water. A second beaker contains 100.0 mL of seawater. The two beakers are left side by side on a lab bench for 1 week. At the end of the week, the liquid level in both beakers has decreased. However, the level has decreased more in one of the beakers than in the other. Which one and why? **MISSED THIS?** *Read Section 14.6; Watch KCV 14.6*

70. Which solution has the highest vapor pressure?
- **a.** 20.0 g of glucose ($C_6H_{12}O_6$) in 100.0 mL of water
- **b.** 20.0 g of sucrose ($C_{12}H_{22}O_{11}$) in 100.0 mL of water
- **c.** 10.0 g of potassium acetate $KC_2H_3O_2$ in 100.0 mL of water

71. Calculate the vapor pressure of a solution containing 24.5 g of glycerin ($C_3H_8O_3$) in 135 mL of water at 30.0 °C. The vapor pressure of pure water at this temperature is 31.8 torr. Assume that glycerin is not volatile and dissolves molecularly (i.e., it is not ionic), and use a density of 1.00 g/mL for the water.
MISSED THIS? *Read Section 14.6; Watch KCV 14.6, IWE 14.6*

72. A solution contains naphthalene ($C_{10}H_8$) dissolved in hexane (C_6H_{14}) at a concentration of 12.35% naphthalene by mass. Calculate the vapor pressure at 25 °C of hexane above the solution. The vapor pressure of pure hexane at 25 °C is 151 torr.

73. A solution contains 50.0 g of heptane (C_7H_{16}) and 50.0 g of octane (C_8H_{18}) at 25 °C. The vapor pressures of pure heptane and pure octane at 25 °C are 45.8 torr and 10.9 torr, respectively. Assuming ideal behavior, answer the following:
MISSED THIS? *Read Section 14.6; Watch KCV 14.6*
- **a.** What is the vapor pressure of each of the solution components in the mixture?
- **b.** What is the total pressure above the solution?
- **c.** What is the composition of the vapor in mass percent?
- **d.** Why is the composition of the vapor different from the composition of the solution?

74. A solution contains a mixture of pentane and hexane at room temperature. The solution has a vapor pressure of 258 torr. Pure pentane and hexane have vapor pressures of 425 torr and 151 torr, respectively, at room temperature. What is the mole fraction composition of the mixture? (Assume ideal behavior.)

75. A solution contains 4.08 g of chloroform ($CHCl_3$) and 9.29 g of acetone (CH_3COCH_3). The vapor pressures at 35 °C of pure chloroform and pure acetone are 295 torr and 332 torr, respectively. Assuming ideal behavior, calculate the vapor pressures of each of the components and the total vapor pressure above the solution. The experimentally measured total vapor pressure of the solution at 35 °C is 312 torr. Is the solution ideal? If not, what can you say about the relative strength of chloroform–acetone interactions compared to the acetone–acetone and chloroform–chloroform interactions?
MISSED THIS? *Read Section 14.6; Watch KCV 14.6, IWE 14.6*

76. A solution of methanol and water has a mole fraction of water of 0.312 and a total vapor pressure of 211 torr at 39.9 °C. The vapor pressures of pure methanol and pure water at this temperature are 256 torr and 55.3 torr, respectively. Is the solution ideal? If not, what can you say about the relative strengths of the solute–solvent interactions compared to the solute–solute and solvent–solvent interactions?

Freezing Point Depression, Boiling Point Elevation, and Osmosis

77. A glucose solution contains 55.8 g of glucose ($C_6H_{12}O_6$) in 455 g of water. Determine the freezing point and boiling point of the solution.
MISSED THIS? *Read Section 14.6; Watch KCV 14.6, IWE 14.9*

78. An ethylene glycol solution contains 21.2 g of ethylene glycol ($C_2H_6O_2$) in 85.4 mL of water. Determine the freezing point and boiling point of the solution. (Assume a density of 1.00 g/mL for water.)

79. Calculate the freezing point and boiling point of a solution containing 10.0 g of naphthalene ($C_{10}H_8$) in 100.0 mL of benzene. Benzene has a density of 0.877 g/cm^3.
MISSED THIS? *Read Section 14.6; Watch KCV 14.6, IWE 14.9*

80. Calculate the freezing point and boiling point of a solution containing 7.55 g of ethylene glycol ($C_2H_6O_2$) in 85.7 mL of ethanol. Ethanol has a density of 0.789 g/cm^3.

81. An aqueous solution containing 17.5 g of an unknown molecular (nonelectrolyte) compound in 100.0 g of water has a freezing point of −1.8 °C. Calculate the molar mass of the unknown compound. **MISSED THIS?** *Read Section 14.6; Watch KCV 14.6*

82. An aqueous solution containing 35.9 g of an unknown molecular (nonelectrolyte) compound in 150.0 g of water has a freezing point of −1.3 °C. Calculate the molar mass of the unknown compound.

83. Calculate the osmotic pressure of a solution containing 24.6 g of glycerin ($C_3H_8O_3$) in 250.0 mL of solution at 298 K.
MISSED THIS? *Read Section 14.6; Watch KCV 14.6*

84. What mass of sucrose ($C_{12}H_{22}O_{11}$) would you combine with 5.00×10^2 g of water to make a solution with an osmotic pressure of 8.55 atm at 298 K? (Assume a density of 1.0 g/mL for the solution.)

85. A solution containing 27.55 mg of an unknown protein per 25.0 mL solution was found to have an osmotic pressure of 3.22 torr at 25 °C. What is the molar mass of the protein?
MISSED THIS? *Read Section 14.6; Watch KCV 14.6*

86. Calculate the osmotic pressure of a solution containing 18.75 mg of hemoglobin in 15.0 mL of solution at 25 °C. The molar mass of hemoglobin is 6.5×10^4 g/mol.

87. Calculate the freezing point and boiling point of each aqueous solution, assuming complete dissociation of the solute.
MISSED THIS? *Read Section 14.7*
- **a.** 0.100 *m* K_2S
- **b.** 21.5 g of $CuCl_2$ in 4.50×10^2 g water
- **c.** 5.5% $NaNO_3$ by mass (in water)

88. Calculate the freezing point and boiling point in each solution, assuming complete dissociation of the solute.
- **a.** 10.5 g $FeCl_3$ in 1.50×10^2 g water
- **b.** 3.5% KCl by mass (in water)
- **c.** 0.150 m MgF_2

89. What mass of salt (NaCl) should you add to 1.00 L of water in an ice-cream maker to make a solution that freezes at −10.0 °C? Assume complete dissociation of the NaCl and density of 1.00 g/mL for water. **MISSED THIS?** *Read Section 14.7*

90. Determine the required concentration (in percent by mass) for an aqueous ethylene glycol ($C_2H_6O_2$) solution to have a boiling point of 104.0 °C.

91. Use the van't Hoff factors in Table 14.9 to calculate each colligative property: **MISSED THIS?** *Read Section 14.7*
- **a.** the melting point of a 0.100 *m* iron(III) chloride solution
- **b.** the osmotic pressure of a 0.085 M potassium sulfate solution at 298 K
- **c.** the boiling point of a 1.22% by mass magnesium chloride solution

92. Using the van't Hoff factors in Table 14.9, calculate the mass of solute required to make each aqueous solution:

a. a sodium chloride solution containing 1.50×10^2 g of water that has a melting point of -1.0 °C

b. 2.50×10^2 mL of a magnesium sulfate solution that has an osmotic pressure of 3.82 atm at 298 K

c. an iron(III) chloride solution containing 2.50×10^2 g of water that has a boiling point of 102 °C

93. A 1.2 *m* aqueous solution of an ionic compound with the formula MX_2 has a boiling point of 101.4 °C. Calculate the van't Hoff factor (*i*) for MX_2 at this concentration.
MISSED THIS? *Read Section 14.7*

94. A 0.95 *m* aqueous solution of an ionic compound with the formula MX has a freezing point of -3.0 °C. Calculate the van't Hoff factor (*i*) for MX at this concentration.

95. A 0.100 M ionic solution has an osmotic pressure of 8.3 atm at 25 °C. Calculate the van't Hoff factor (*i*) for this solution.
MISSED THIS? *Read Section 14.7*

96. A solution contains 8.92 g of KBr in 500.0 mL of solution and has an osmotic pressure of 6.97 atm at 25 °C. Calculate the van't Hoff factor (*i*) for KBr at this concentration.

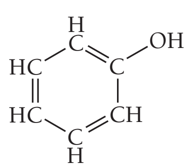
97. Calculate the vapor pressure at 25 °C of an aqueous solution that is 5.50% NaCl by mass. (Assume complete dissociation of the solute.)
MISSED THIS? *Read Section 14.7; Watch IWE 14.12*

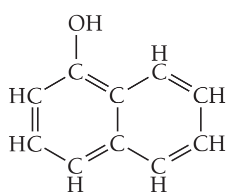
98. An aqueous $CaCl_2$ solution has a vapor pressure of 81.6 mmHg at 50 °C. The vapor pressure of pure water at this temperature is 92.6 mmHg. What is the concentration of $CaCl_2$ in mass percent? (Assume complete dissociation of the solute.)

CUMULATIVE PROBLEMS

99. The solubility of carbon tetrachloride (CCl_4) in water at 25 °C is 1.2 g/L. The solubility of chloroform ($CHCl_3$) at the same temperature is 10.1 g/L. Why is chloroform almost ten times more soluble in water than carbon tetrachloride?

100. The solubility of phenol in water at 25 °C is 87 g/L. The solubility of naphthol at the same temperature is only 0.74 g/L. Examine the structures of phenol and naphthol shown here and explain why phenol is so much more soluble than naphthol.


Phenol


Naphthol

101. Potassium perchlorate ($KClO_4$) has a lattice energy of -599 kJ/mol and a heat of hydration of -548 kJ/mol. Find the heat of solution for potassium perchlorate and determine the temperature change that occurs when 10.0 g of potassium perchlorate is dissolved with enough water to make 100.0 mL of solution. (Assume a heat capacity of 4.05 J/g · °C for the solution and a density of 1.05 g/mL.)

102. Sodium hydroxide (NaOH) has a lattice energy of -887 kJ/mol and a heat of hydration of -932 kJ/mol. How much solution could be heated to boiling by the heat evolved by the dissolution of 25.0 g of NaOH? (For the solution, assume a heat capacity of 4.0 J/g · °C, an initial temperature of 25.0 °C, a boiling point of 100.0 °C, and a density of 1.05 g/mL.)

103. A saturated solution forms when 0.0537 L of argon, at a pressure of 1.0 atm and a temperature of 25 °C, is dissolved in 1.0 L of water. Calculate the Henry's law constant for argon.

104. A gas has a Henry's law constant of 0.112 M/atm. What total volume of solution is needed to completely dissolve 1.65 L of the gas at a pressure of 725 torr and a temperature of 25 °C?

105. The Safe Drinking Water Act (SDWA) sets a limit for mercury—a toxin to the central nervous system—at 0.0020 ppm by mass. Water suppliers must periodically test their water to ensure that mercury levels do not exceed this limit. Suppose water becomes contaminated with mercury at twice the legal limit (0.0040 ppm). How much of this water would a person have to consume to ingest 50.0 mg of mercury?

106. Water softeners often replace calcium ions in hard water with sodium ions. Since sodium compounds are soluble, the presence of sodium ions in water does not cause the white, scaly residues caused by calcium ions. However, calcium is more beneficial to human health than sodium because calcium is a necessary part of the human diet, while high levels of sodium intake are linked to increases in blood pressure. The U.S. Food and Drug Administration (FDA) recommends that adults ingest less than 2.4 g of sodium per day. How many liters of softened water, containing a sodium concentration of 0.050% sodium by mass, would a person have to consume to exceed the FDA recommendation? (Assume a water density of 1.0 g/mL.)

107. An aqueous solution contains 12.5% NaCl by mass. What mass of water (in grams) is contained in 2.5 L of the vapor above this solution at 55 °C? The vapor pressure of pure water at 55 °C is 118 torr. (Assume complete dissociation of NaCl.)

108. The vapor above an aqueous solution contains 19.5 mg water per liter at 25 °C. Assuming ideal behavior, what is the concentration of the solute within the solution in mole percent?

109. What is the freezing point of an aqueous solution that boils at 106.5 °C?

110. What is the boiling point of an aqueous solution that has a vapor pressure of 20.5 torr at 25 °C? (Assume a nonvolatile solute.)

111. An isotonic solution contains 0.90% NaCl mass to volume. Calculate the percent mass to volume for isotonic solutions containing each solute at 25 °C. Assume a van't Hoff factor of 1.9 for all *ionic* solutes.

a. KCl **b.** NaBr **c.** glucose ($C_6H_{12}O_6$)

112. Magnesium citrate, $Mg_3(C_6H_5O_7)_2$, belongs to a class of laxatives called *hyperosmotics*, which cause rapid emptying of the bowel. When a concentrated solution of magnesium citrate is consumed, it passes through the intestines, drawing water and promoting diarrhea, usually within 6 hours. Calculate the osmotic pressure of a magnesium citrate laxative solution containing 28.5 g of magnesium citrate in 235 mL of solution at 37 °C (approximate body temperature). Assume complete dissociation of the ionic compound.

113. A solution is prepared from 4.5701 g of magnesium chloride and 43.238 g of water. The vapor pressure of water above this solution is 0.3624 atm at 348.0 K. The vapor pressure of pure water at this temperature is 0.3804 atm. Find the value of the van't Hoff factor (*i*) for magnesium chloride in this solution.

114. When HNO_2 is dissolved in water, it partially dissociates according to the equation $HNO_2 \rightleftharpoons H^+ + NO_2^-$. A solution is prepared that contains 7.050 g of HNO_2 in 1.000 kg of water. Its freezing point is −0.2929 °C. Calculate the fraction of HNO_2 that has dissociated.

115. A solution of a nonvolatile solute in water has a boiling point of 375.3 K. Calculate the vapor pressure of water above this solution at 338 K. The vapor pressure of pure water at this temperature is 0.2467 atm.

116. The density of a 0.438 M solution of potassium chromate (K_2CrO_4) at 298 K is 1.063 g/mL. Calculate the vapor pressure of water above the solution. The vapor pressure of pure water at this temperature is 0.0313 atm. (Assume complete dissociation of the solute.)

117. The vapor pressure of carbon tetrachloride, CCl_4, is 0.354 atm, and the vapor pressure of chloroform, $CHCl_3$, is 0.526 atm at 316 K. A solution is prepared from equal masses of these two compounds at this temperature. Calculate the mole fraction of the chloroform in the vapor above the solution. If the vapor above the original solution is condensed and isolated into a separate flask, what will the vapor pressure of chloroform be above this new solution?

118. Distillation is a method of purification based on successive separations and recondensations of vapor above a solution. Use the result of the previous problem to calculate the mole fraction of chloroform in the vapor above a solution obtained by three successive separations and condensations of the vapors above the original solution of carbon tetrachloride and chloroform. Show how this result explains the use of distillation as a separation method.

119. A solution of 49.0% H_2SO_4 by mass has a density of 1.39 g/cm^3 at 293 K. A 25.0-cm^3 sample of this solution is mixed with enough water to increase the volume of the solution to 99.8 cm^3. Find the molarity of sulfuric acid in this solution.

120. Find the mass of urea (CH_4N_2O) needed to prepare 50.0 g of a solution in water in which the mole fraction of urea is 0.0770.

121. A solution contains 10.05 g of unknown compound dissolved in 50.0 mL of water. (Assume a density of 1.00 g/mL for water.) The freezing point of the solution is −3.16 °C. The mass percent composition of the compound is 60.97% C, 11.94% H, and the rest is O. What is the molecular formula of the compound?

122. The osmotic pressure of a solution containing 2.10 g of an unknown compound dissolved in 175.0 mL of solution at 25 °C is 1.93 atm. The combustion of 24.02 g of the unknown compound produced 28.16 g CO_2 and 8.64 g H_2O. What is the molecular formula of the compound (which contains only carbon, hydrogen, and oxygen)?

123. A 100.0-mL aqueous sodium chloride solution is 13.5% NaCl by mass and has a density of 1.12 g/mL. What would you add (solute or solvent), and what mass of it, to make the boiling point of the solution 104.4 °C? (Use $i = 1.8$ for NaCl.)

124. A 50.0-mL solution is initially 1.55% $MgCl_2$ by mass and has a density of 1.05 g/mL. What is the freezing point of the solution after you add an additional 1.35 g $MgCl_2$? (Use $i = 2.5$ for $MgCl_2$.)

CHALLENGE PROBLEMS

125. The small bubbles that form on the bottom of a water pot that is being heated (before boiling) are due to dissolved air coming out of solution. Use Henry's law and the solubilities given to calculate the total volume of nitrogen and oxygen gas that should bubble out of 1.5 L of water upon warming from 25 °C to 50 °C. Assume that the water is initially saturated with nitrogen and oxygen gas at 25 °C and a total pressure of 1.0 atm. Assume that the gas bubbles out at a temperature of 50 °C. The solubility of oxygen gas at 50 °C is 27.8 mg/L at an oxygen pressure of 1.00 atm. The solubility of nitrogen gas at 50 °C is 14.6 mg/L at a nitrogen pressure of 1.00 atm. Assume that the air above the water contains an oxygen partial pressure of 0.21 atm and a nitrogen partial pressure of 0.78 atm.

126. The vapor above a mixture of pentane and hexane at room temperature contains 35.5% pentane by mass. What is the mass percent composition of the solution? Pure pentane and hexane have vapor pressures of 425 torr and 151 torr, respectively, at room temperature.

127. A 1.10-g sample contains only glucose ($C_6H_{12}O_6$) and sucrose ($C_{12}H_{22}O_{11}$). When the sample is dissolved in water to a total solution volume of 25.0 mL, the osmotic pressure of the solution is 3.78 atm at 298 K. What is the mass percent composition of glucose and sucrose in the sample?

128. A solution is prepared by mixing 631 mL of methanol with 501 mL of water. The molarity of methanol in the resulting solution is 14.29 M. The density of methanol at this temperature is 0.792 g/mL. Calculate the difference in volume between this solution and the total volume of water and methanol that were mixed to prepare the solution.

129. Two alcohols, isopropyl alcohol and propyl alcohol, have the same molecular formula, C_3H_8O. A solution of the two that is two-thirds by mass isopropyl alcohol has a vapor pressure of 0.110 atm at 313 K. A solution that is one-third by mass isopropyl alcohol has a vapor pressure of 0.089 atm at 313 K. Calculate the vapor pressure of each pure alcohol at this temperature. Explain the difference given that the formula of propyl alcohol is $CH_3CH_2CH_2OH$ and that of isopropyl alcohol is $(CH_3)_2CHOH$.

130. A metal, M, of atomic mass 96 amu reacts with fluorine to form a salt that can be represented as MF_x. In order to determine x and therefore the formula of the salt, a boiling point elevation experiment is performed. A 9.18-g sample of the salt is dissolved in 100.0 g of water, and the boiling point of the solution is found to be 374.38 K. Find the formula of the salt. (Assume complete dissociation of the salt in solution.)

131. Sulfuric acid in water dissociates completely into H^+ and HSO_4^- ions. The HSO_4^- ion dissociates to a limited extent into H^+ and SO_4^{2-}. The freezing point of a 0.1000 m solution of sulfuric acid in water is 272.76 K. Calculate the molality of SO_4^{2-} in the solution, assuming ideal solution behavior.

132. A solution of 75.0 g of benzene (C_6H_6) and 75.0 g of toluene (C_7H_8) has a total vapor pressure of 80.9 mmHg at 303 K. Another solution of 100.0 g benzene and 50.0 g toluene has a total vapor pressure of 93.9 mmHg at this temperature. Find the vapor pressure of pure benzene and pure toluene at 303 K.

133. A solution is prepared by dissolving 11.60 g of a mixture of sodium carbonate and sodium bicarbonate in 1.00 L of water. A 300.0 cm^3 sample of the solution is treated with excess HNO_3 and boiled to remove all the dissolved gas. A total of 0.940 L of dry CO_2 is collected at 298 K and 0.972 atm. Find the molarity of the carbonate and bicarbonate in the solution.