Chapter 16
Solutions

Chapter 16–Assignment A: Characteristics of Solutions

To a chemist, the term solution refers to a homogeneous mixture. This assignment is an introduction to solution characteristics and terminology. Learn the big ideas:

1) The major component of a solution is called the solvent; the minor components are called the solutes. Every solution has one solvent, and one or more solutes.

2) Unlike the composition of a pure substance, the percentage composition of solutions may vary.

3) Two or more substances will mix to form a solution only if the intermolecular attractions in each separate substance is similar.

Learning Procedures

Study Sections 16.1–16.4. Focus on Goals 1–5 as you study.

Strategy This is conceptual material. Learn the definitions of the terms introduced in this assignment, and pay particular attention to Figure 16.3 and its caption.

Answer Questions, Exercises, and Problems 1–16. Check your answers with those at the end of the chapter.

Workbook If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 1–16.

Chapter 16–Assignment B: Solution Concentrations

Solutions are mixtures, not pure substances, so the composition of a solution is not fixed by a molecular formula. We need ways to specify quantitatively the composition of a solution. The textbook identified four ways that are covered in this assignment. Check with your instructor if you are studying all four topics, or only the first two. Look for these new ideas:

1) The percentage concentration of any component in a solution is the mass of that component in a sample divided by the total mass of that sample, all multiplied by 100.
2) Molarity is moles of solute in one liter of solution. Units of molarity are moles per liter, mol/L; the symbol for molarity is M.

3) Molality is moles of solute in one kilogram of solvent. The symbol for molality is m (note that molality is lower case m and molarity is upper case M).

4) One equivalent of an acid is defined as that amount of acid that yields one mole of hydrogen ion in a specific reaction. One equivalent of a base is that amount of base that reacts with one equivalent of an acid.

5) The equivalent mass of a substance is the number of grams of the substance per equivalent.

6) Normality is the number of equivalents of solute in one liter of solution. Units of normality are equivalents per liter, or eq/L. The symbol for normality is N.

Learning Procedures

Study Sections 16.5–16.9. Focus on Goals 6–11 as you study.

Strategy The key to this assignment is to learn the definitions of each of the concentration units and then practice solving a lot of problems.

Answer Questions, Exercises, and Problems 17–41. Check your answers with those at the end of the chapter.

Workbook If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 17–41.

Chapter 16–Assignment C: Solution Dilution and Stoichiometry

Molarity is the most widely used of the four solution concentrations introduced in Assignment B. In this assignment you will learn two important calculation skills involving molarity: (1) given concentrated solutions, add water to make dilute solutions; (2) use molarity in stoichiometry problems such as titrations.

1) Because dilution problems involve adding only water to a solute, the number of moles of solute remains unchanged in the dilution process.

2) The key equation for calculations involving dilution of concentrated solutions is $M_c \cdot V_c = M_d \cdot V_d$, in which M is molarity, V is volume, c is concentrated and d is dilute.

3) The number of moles obtained from molarity and volume data can be used in stoichiometry problems.

4) Titration is the controlled and measured addition of one solution into another.
Learning Procedures


Strategy  Practice by solving lots of problems.

Answer  Questions, Exercises, and Problems 42–52. Check your answers with those at the end of the chapter.

Workbook  If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 42–52.

Chapter 16–Assignment D: Normality Titrations, Colligative Properties (Optional)

With the increasing use of SI units, normality as a concentration unit has become a controversial topic among chemists. The SI system does not acknowledge normality as an acceptable concentration unit. Nevertheless, normality and normality titrations are so convenient for both academic and industrial laboratories that normality will die only after a long hard battle, and perhaps never.

Because it is a mixture, a solution has physical properties that vary with its concentration. The temperature at which a solution freezes or boils depends on the molality of solute in that solution.

The major ideas in this assignment are:

1) In a reaction, the number of equivalents of acid and base that react with each other are equal. This idea of equal numbers of equivalents is the basis of the normality system.

2) For an acid-base titration, \( V_{acid} \times N_{acid} = V_{base} \times N_{base} \).

3) The properties of a solution that depend only on the number of solute particle present, without regard to their identity, are called **colligative properties**.

4) **Freezing point depression** and **boiling point elevation** are colligative properties that are directly proportional to the molal concentration of any solute. These proportionality constants are called the molal freezing point constant and the molal boiling point constant, respectively. The values of these constants depend only on the chemical identity of the solvent in the solution.

5) For freezing point depression, \( \Delta T_f = K_f m \); for boiling point elevation, \( \Delta T_b = K_b m \).

6) Freezing point depression experiments are often used to determine molar mass.

Learning Procedures


Strategy  As with Assignment C, practice by solving lots of problems.
Answer Questions, Exercises, and Problems 53–65. Check your answers with those at the end of the chapter.

Workbook If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 53–65.

Chapter 16–Assignment E: Summary and Review

Learn well the language of solutions and use it correctly. In addition to the terms at the beginning of the chapter, know exactly what is meant by percentage and molarity, and, if included in your course, molality and normality. Knowing “exactly what is meant” includes the units in which these concentrations are expressed. If the units are known, understood, and used in calculation setups, you will enjoy much more success in solving solution problems.

When predicting solubility of one substance in another, remember that a solution is more likely to develop between substances with similar intermolecular attractions and molecular size. This is often expressed in the phrase “Like dissolves like,” which suggests that similar molecules dissolve in each other.

In solving molarity and normality problems, note that both concentrations are defined in liters. If a question gives milliliters, the volume must be converted to liters.

If you have trouble remembering how freezing and boiling points of solutions change compared to pure solvents, think of automobile anti-freeze. It is actually a winter anti-freeze and summer coolant. The solute in the anti-freeze, ethylene glycol, is mixed with water in your radiator. This causes the freezing point of the solution to decrease and the boiling point of the solution to increase when compared with water by itself. The engine is therefore protected against winter freezing and summer boil-over. Adding a solute to a solvent stretches the temperature range between freezing and boiling. Thus it is freezing point depression and boiling point elevation.

In solving freezing point depression or boiling point elevation problems, note that the temperature term obtained is the change from the normal freezing or boiling point. This is particularly troublesome with the freezing of water. The 0.0°C freezing point of water tends to blur the difference between the new freezing point, $T_f$, and the term found from the equation, $\Delta T_f$.

Learning Procedures

Review your lecture and textbook notes.

the Chapter in Review and the Key Terms and Concepts, and read the Study Hints and Pitfalls to Avoid.
Answer  Concept-Linking Exercises 1–4. Complete Concept-Linking Exercise 5 if Section 16.8 was assigned. Complete Concept-Linking Exercise 6 if Section 16.14 was assigned. Check your answers with those at the end of the chapter.

Questions, Exercises, and Problems 66–68. Include Questions 69–77 if assigned by your instructor. Check your answers with those at the end of the chapter.

Workbook  If your instructor recommends the Active Learning Workbook, do Questions, Exercises, and Problems 66–67. Include Questions 68–77 if assigned by your instructor.

Take  the chapter summary test that follows. Check your answers with those at the end of this assignment.

Chapter 16 Sample Test

Instructions: You may use a “clean” periodic table. Sample test questions for the optional sections on molality, normality, and colligative properties follow this test.

1) A solution that can dissolve more of a substance than it currently contains is said to be _____.
   a) supersaturated   b) saturated   c) unsaturated   d) immiscible   e) miscible

2) When undissolved solute is present in an unsaturated solution, the rate of dissolving is _____ the rate of crystallization.
   a) greater than   b) equal to   c) less than

3) The time required between adding excess solute to a solvent and reaching equilibrium with a saturated solution can be reduced by all of the following except:
   a) raising the temperature   b) stirring the mixture   c) illuminating the solution   d) reducing solute particle size

4) Considering the structural formulas of CH₃OH and CH₃CH₂OH, it is logical to expect these liquids are:
   a) miscible because their intermolecular attractions are similar
   b) immiscible because one molecule is highly polar and the other nonpolar
   c) immiscible because one molecule has hydrogen bonding and the other does not
   d) immiscible because their molecular masses and sizes are so different

5) A cylinder contains liquid water and nitrogen, oxygen, and carbon dioxide gases. Only carbon dioxide dissolves appreciably in the water, and there is an equilibrium between the dissolved and undissolved carbon dioxide. More nitrogen gas is forced into this cylinder, at constant temperature. The solubility of the carbon dioxide in the water _____.
   a) increases greatly   b) increases slightly
   c) remains unchanged   d) decreases slightly
6) How would you make 312 grams of a 0.90% sodium chloride solution?

7) How many mL of 0.415 M $\text{H}_2\text{SO}_4$ do you need to have 0.716 mole $\text{H}_2\text{SO}_4$?

8) A 62.5 mL sample of 12.0 M $\text{HNO}_3$ is diluted to a final concentration of 0.812 M. What is the final volume of this solution?
Questions 9–12 refer to the equation

$$\text{Na}_2\text{CO}_3(\text{aq}) + 2 \text{HCl(aq)} \rightarrow \text{CO}_2(\text{g}) + 2 \text{NaCl(aq)} + \text{H}_2\text{O(ℓ)}$$

9) What volume of CO$_2$(g), measured at 756 torr and 23°C, is obtained from the reaction of 24.16 mL of 0.0872 M Na$_2$CO$_3$ with excess HCl?

10) What volume of 0.123 M HCl is needed to react with 14.27 mL of 0.102 M Na$_2$CO$_3$?
11) What is the molarity of the HCl if 19.46 mL react with 0.317 grams of sodium carbonate?

12) What is the molarity of the HCl if 22.4 mL react with 11.7 mL of 0.113 M Na$_2$CO$_3$?
Answers to Chapter 16 Sample Test

1) c  
2) a  
3) c  
4) a  
5) c

6) \[ \text{Given: } 312 \text{ g solution} \quad \text{Wanted: } \text{g NaCl; g H}_2\text{O} \]

\[ \text{Per/Path: } \text{g solution} \quad \frac{0.90 \text{ g NaCl}}{100 \text{ g solution}} = 2.8 \text{ g NaCl} \]

\[ \text{g H}_2\text{O} = \text{g solution} - \text{g solute} = 312 \text{ g} - 2.8 \text{ g} = 309 \text{ g} \]

7) \[ \text{Given: } 0.716 \text{ mole H}_2\text{SO}_4 \quad \text{Wanted: } \text{mL} \]

\[ \text{Per/Path: } \text{mol H}_2\text{SO}_4 \quad \frac{0.415 \text{ mol H}_2\text{SO}_4}{L} \quad \frac{L}{1000 \text{ mL}} = \frac{1.73 \times 10^3 \text{ mL}}{L} \]

8) \[ \text{Given: } V_c = 62.5 \text{ mL} \quad M_c = 12.0 \text{ M} \quad M_d = 0.812 \text{ M} \quad \text{Wanted: } V_d \text{ (assume mL)} \]

\[ \text{Equation: } V_d = \frac{M_c \cdot V_c}{M_d} = \frac{12.0 \text{ M} \cdot 62.5 \text{ mL}}{0.812 \text{ M}} = 924 \text{ mL} \]

9) \[ \text{Given: } 24.16 \text{ mL } 0.0872 \text{ M } \text{Na}_2\text{CO}_3 \quad \text{Wanted: } \text{mol CO}_2 \]

\[ \text{Per/Path: } \text{mL} \quad \frac{0.0872 \text{ mol Na}_2\text{CO}_3}{1000 \text{ mL}} \quad \frac{\text{mol Na}_2\text{CO}_3}{\text{mol CO}_2} \quad \frac{1 \text{ mol CO}_2}{1 \text{ mol Na}_2\text{CO}_3} \]

\[ 24.16 \text{ mL} \cdot \frac{0.0872 \text{ mol Na}_2\text{CO}_3}{1000 \text{ mL}} \cdot \frac{1 \text{ mol CO}_2}{1 \text{ mol Na}_2\text{CO}_3} = 0.00211 \text{ mol CO}_2 \]

**Ideal Gas Equation Method:**

\[ \text{Given: } 756 \text{ torr; } 0.00211 \text{ mol CO}_2; 23 + 273 = 296 \text{ K} \quad \text{Wanted: } V \text{ (assume L)} \]

\[ \text{Equation: } V = \frac{nRT}{P} = 0.00211 \text{ mol CO}_2 \cdot \frac{62.4 \text{ L} \cdot \text{torr}}{\text{mol} \cdot \text{K}} \cdot 296 \text{ K} \cdot \frac{1}{756 \text{ torr}} = \frac{1}{0.0516 \text{ L CO}_2} \]
Molar Volume Method:

**GIVEN:** 0.00211 mol CO₂  
**WANTED:** Volume CO₂ at STP

**PER/PATH:**  

\[
\text{mol CO}_2 \quad \times \quad \frac{22.4 \text{ L CO}_2}{\text{mol CO}_2} \quad = \quad \text{L CO}_2
\]

0.00211 mol CO₂ \( \times \frac{22.4 \text{ L CO}_2}{\text{mol CO}_2} \) = 0.0473 L CO₂ at STP

**GIVEN:** \( P_1 = 760 \) torr; \( V_1 = 0.0473 \) L; \( T_1 = 273 \) K; \( P_2 = 756 \) torr; \( T_2 = 23 + 273 = 296 \) K  
**WANTED:** \( V_2 \)

**EQUATION:**  
\[
V_2 = \frac{P_1 V_1 T_2}{P_2 T_1} = \frac{760 \text{ torr} \times 0.0473 \text{ L} \times 296 \text{ K}}{756 \text{ torr} \times 273 \text{ K}} = 0.0516 \text{ L CO}_2
\]

10) **GIVEN:** 14.27 mL 0.102 M Na₂CO₃  
**WANTED:** Volume HCl (assume mL)

**PER/PATH:**  

\[
\text{mL Na}_2\text{CO}_3 \quad \times \quad \frac{0.102 \text{ mol Na}_2\text{CO}_3}{1000 \text{ mL Na}_2\text{CO}_3} \quad \times \quad \frac{2 \text{ mol HCl}}{1 \text{ mol Na}_2\text{CO}_3} \quad = \quad \text{mol HCl} \quad \text{per mL Na}_2\text{CO}_3
\]

14.27 mL Na₂CO₃ \( \times \frac{0.102 \text{ mol Na}_2\text{CO}_3}{1000 \text{ mL Na}_2\text{CO}_3} \) \( \times \frac{2 \text{ mol HCl}}{1 \text{ mol Na}_2\text{CO}_3} \) = 0.00598 mol HCl

**EQUATION:**  
\[
M = \frac{\text{mol HCl}}{L} = \frac{0.00598 \text{ mol HCl}}{19.46 \text{ mL}} \times \frac{1000 \text{ mL HCl}}{L \text{ HCl}} = 0.307 \text{ M HCl}
\]

11) **GIVEN:** 0.317 g Na₂CO₃; 19.46 mL HCl  
**WANTED:** mol HCl

**PER/PATH:**  

\[
\text{g Na}_2\text{CO}_3 \quad \times \quad \frac{105.99 \text{ g Na}_2\text{CO}_3}{1 \text{ mol Na}_2\text{CO}_3} \quad \times \quad \frac{2 \text{ mol HCl}}{1 \text{ mol Na}_2\text{CO}_3} \quad = \quad \text{mol HCl}
\]

0.317 g Na₂CO₃ \( \times \frac{105.99 \text{ g Na}_2\text{CO}_3}{1 \text{ mol Na}_2\text{CO}_3} \) \( \times \frac{2 \text{ mol HCl}}{1 \text{ mol Na}_2\text{CO}_3} \) = 0.00598 mol HCl

**EQUATION:**  
\[
M = \frac{\text{mol HCl}}{L} = \frac{0.00598 \text{ mol HCl}}{19.46 \text{ mL}} \times \frac{1000 \text{ mL HCl}}{L \text{ HCl}} = 0.307 \text{ M HCl}
\]
12) **GIVEN:** 11.7 mL 0.113 M Na$_2$CO$_3$; 22.4 mL HCl  

**WANTED:** M HCl 

**PER/PATH:** 
11.7 mL Na$_2$CO$_3$ \( \times \) \[ \frac{0.113 \text{ mol Na}_2\text{CO}_3}{1000 \text{ mL Na}_2\text{CO}_3} \] \( \div \) 2 mol HCl/1 mol Na$_2$CO$_3$ \( \times \) mol HCl 

\[ \frac{11.7 \text{ mL Na}_2\text{CO}_3}{1000 \text{ mL Na}_2\text{CO}_3} \times \frac{0.113 \text{ mol Na}_2\text{CO}_3}{1 \text{ mol Na}_2\text{CO}_3} \times \frac{2 \text{ mol HCl}}{1 \text{ mol Na}_2\text{CO}_3} = 0.00264 \text{ mol HCl} \]

**EQUATION:** 
\[ M = \frac{\text{mol HCl}}{22.4 \text{ mL}} = \frac{0.00264 \text{ mol HCl}}{22.4 \text{ mL}} = 0.118 \text{ M HCl} \]

**Chapter 16 Molality and Colligative Properties Sample Test**

**Instructions:** You may use a “clean” periodic table.

1) Adding 1.60 g acetic acid, HC$_2$H$_3$O$_2$, to 21.47 g of solvent raises the boiling point of a solution 3.14°C. What is K$_b$ for this solvent?

2) If 5.22 grams of naphthalene, C$_{10}$H$_8$, are dissolved in 35.81 grams of cyclohexane, C$_6$H$_{10}$, what is the molality of the resulting solution?
3) If pure cyclohexane freezes at 6.5°C and the molal freezing point constant $K_f$ is 20.2°C/m for cyclohexane, what is the freezing point of the solution made in Question 2?

4) A solution is made by dissolving 4.18 g of an unknown solid in 19.89 g solvent. The freezing point falls by 4.31°C. If $K_f$ for the solvent is 5.48°C/m, what is the molar mass of the unknown solid?
Answers to Chapter 16 Molality and Colligative Properties Sample Test

1) \( \text{GIVEN:} \ 1.60 \text{ g HC}_2\text{H}_3\text{O}_2; \ 21.47 \text{ g solvent; } \Delta T_b = 3.14°C \) \( \text{WANTED:} \ K_b \)

\( \text{PER/PATH:} \ g \text{ HC}_2\text{H}_3\text{O}_2 \times \frac{1 \text{ mol HC}_2\text{H}_3\text{O}_2}{60.05 \text{ g HC}_2\text{H}_3\text{O}_2} = 0.0266 \text{ mol HC}_2\text{H}_3\text{O}_2 \)

\[ m = \frac{\text{mol solute}}{\text{kg solvent}} = \frac{0.0266 \text{ mol HC}_2\text{H}_3\text{O}_2}{21.47 \text{ g solvent}} \times \frac{1000 \text{ g solvent}}{1 \text{ kg solvent}} = 1.24 \text{ m HC}_2\text{H}_3\text{O}_2 \]

\[ EQUATION: \ K_b = \frac{\Delta T_b}{m} = \frac{3.14°C}{1.24 \text{ m}} = 2.53°C/m \]

2) \( \text{GIVEN:} \ 5.22 \text{ g C}_{10}\text{H}_8; \ 35.81 \text{ g C}_6\text{H}_6 \) \( \text{WANTED:} \ m \text{ C}_{10}\text{H}_8 \)

\( \text{PER/PATH:} \ g \text{ C}_{10}\text{H}_8 \times \frac{1 \text{ mol C}_{10}\text{H}_8}{128.16 \text{ g C}_{10}\text{H}_8} = 0.0407 \text{ mol C}_{10}\text{H}_8 \)

\[ m = \frac{\text{mol solute}}{\text{kg solvent}} = \frac{0.0407 \text{ mol C}_{10}\text{H}_8}{35.81 \text{ g C}_6\text{H}_6} \times \frac{1000 \text{ g C}_6\text{H}_6}{1 \text{ kg C}_6\text{H}_6} = 1.14 \text{ m C}_6\text{H}_6 \]

3) \( \text{GIVEN:} \ \text{fp C}_6\text{H}_6 = 6.5°C; \ K_f = 20.2°C/m \) \( \text{WANTED:} \ \text{fp of 1.14 m C}_6\text{H}_6 \)

\[ EQUATION: \ \Delta T_f = K_f m = \frac{20.2°C}{m} \times 1.14 \text{ m} = 23.0°C \]

\[ 6.5°C – 23.0°C = –16.5°C \]
4)  

**GIVEN:** $\Delta T_f = 4.31^\circ C; \quad K_f = 5.48^\circ C/m \quad \text{WANTED: } m \text{ (mol solute/kg solvent)}

**EQUATION:**

$$m = \frac{\Delta T_f}{K_f} = \frac{4.31^\circ C}{5.48^\circ C} = 0.786 \text{ m} = \frac{0.786 \text{ mol solute}}{\text{kg solvent}}

**GIVEN:** 19.89 g solvent \quad \text{WANTED: } \text{mol solute}

**PATH:**

$$g \text{ solvent} \quad \frac{1000 \text{ g solvent}}{\text{kg solvent}} \quad \frac{0.786 \text{ mol solute}}{\text{kg solvent}} \quad \text{mol solute}

19.89 \text{ g solvent} \times \frac{1 \text{ kg solvent}}{1000 \text{ g solvent}} \times \frac{0.786 \text{ mol solute}}{\text{kg solvent}} = 0.0156 \text{ mol solute}

**GIVEN:** 0.0156 mol solute; 4.18 g solute \quad \text{WANTED: } \text{MM}

**EQUATION:**

$$\text{MM} = \frac{g}{\text{mol}} = \frac{4.18 \text{ g}}{0.0156 \text{ mol}} = 268 \text{ g/mol}

---

**Chapter 16 Normality Sample Test**

**Instructions:** You may use a “clean” periodic table. All questions refer to the equation

$$\text{Na}_2\text{CO}_3(\text{aq}) + 2 \text{HCl(}aq\text{)} \rightarrow \text{CO}_2(\text{g}) + 2 \text{NaCl(}aq\text{)} + \text{H}_2\text{O(}l\text{)}$$

1)  What is the equivalent mass of sodium carbonate?

2)  A volume of 17.9 mL 0.119 N Na$_2$CO$_3$ contains how many equivalents of base?
3) What is the normality of the hydrochloric acid if 21.42 mL react with 0.288 grams of sodium carbonate?

4) What is the normality of the sodium carbonate if 11.3 mL react with 25.1 mL of 0.0995 N HCl?

Answers to Chapter 16 Normality Sample Test

1) From the equation, there are 2 eq/mol Na₂CO₃,

\[
\frac{105.99 \text{ g Na}_2\text{CO}_3}{\text{mol Na}_2\text{CO}_3} \cdot \frac{1 \text{ mol Na}_2\text{CO}_3}{2 \text{ eq}} = 52.995 \text{ g Na}_2\text{CO}_3/\text{eq}
\]

2) \text{GIVEN:} 17.9 \text{ mL 0.119 N Na}_2\text{CO}_3 \text{ WANTED: eq base, Na}_2\text{CO}_3

\text{PER/PATH:} \text{ mL} \div \frac{1000 \text{ mL/L}}{\text{L}} \cdot \text{ L} \div \frac{0.119 \text{ eq Na}_2\text{CO}_3/\text{L}}{\text{L}} = 0.00213 \text{ eq Na}_2\text{CO}_3
3) **GIVEN:** 0.288 g Na$_2$CO$_3$; 21.42 mL HCl  

**WANTED:** eq HCl

*PER/PATH:*  

\[ \frac{\text{g Na}_2\text{CO}_3}{105.99 \text{ g Na}_2\text{CO}_3} \times \frac{1 \text{ mol Na}_2\text{CO}_3}{2 \text{ eq Na}_2\text{CO}_3} = 0.00543 \text{ eq Na}_2\text{CO}_3 \]

*EQUATION:*  

\[ \frac{\text{eq}}{L} = \frac{0.00543 \text{ eq Na}_2\text{CO}_3 \text{ or HCl}}{21.42 \text{ mL}} \times \frac{1000 \text{ mL}}{L} = 0.253 \text{ N HCl} \]

4) **GIVEN:** $V_1 = 25.1 \text{ mL}$  

$N_1 = 0.0995 \text{ N}$  

$V_2 = 11.3 \text{ mL}$  

**WANTED:** $N_2$

*EQUATION:*  

\[ N_2 = \frac{V_1N_1}{V_2} = \frac{25.1 \text{ mL} \times 0.0995 \text{ N}}{11.3 \text{ mL}} = 0.221 \text{ N Na}_2\text{CO}_3 \]