

16

SOLUTIONS

SECTION 16.1 PROPERTIES OF SOLUTIONS (pages 471–477)

This section identifies the factors that affect the solubility of a substance and determine the rate at which a solute dissolves.

► Solution Formation (pages 471–472)

Look at Figure 16.1 on page 471 to help you answer Questions 1 and 2.

1. Underline the condition that causes sugar to dissolve *faster* in water.
 - a. as a whole cube or in granulated form?
 - b. when allowed to stand or when stirred?
 - c. at a higher temperature or a lower temperature?

2. Name three factors that influence the rate at which a solute dissolves in a solvent.
 - a. _____
 - b. _____
 - c. _____

3. Is the following sentence true or false? Finely ground particles dissolve more rapidly than larger particles because finer particles expose a greater surface area to the colliding solvent molecules. _____

► Solubility (pages 472–473)

4. Complete the following table showing the steps in a procedure to determine the total amount of sodium chloride that will dissolve in 100 g of water at 25°C.

Procedure	Amount Dissolved	Amount Not Dissolved
Add 36.0 g of sodium chloride to the water	36.0 g	0.0 g
Add an additional 1.0 g of sodium chloride		
Determine the total amount that dissolves		

5. The amount of a substance that dissolves in a given quantity of solvent at a constant temperature is called the substance's _____ at that temperature.

6. If a solution contains the *maximum* amount of solute for a given quantity of solvent at a constant temperature, it is called a(n) _____ solution.

CHAPTER 16, Solutions (continued)

7. Look at Figure 16.2 on page 472. Circle the letter of each sentence that is true about a saturated solution.
- a. The total amount of dissolved solute remains constant.
 - b. The total mass of undissolved crystals remains constant.
 - c. When the rate of solvation equals the rate of crystallization, a state of dynamic equilibrium exists.
 - d. If more solute were added to the container, the total amount of dissolved solute would increase.
8. If two liquids dissolve each other, they are said to be _____ .
9. Look at Figure 16.3 on page 473. Why does the oil float on the vinegar?

► Factors Affecting Solubility (pages 474–477)

10. Is the following sentence true or false? The solubility of sodium chloride in water increases to 39.2 g per 100 g of water at 100°C from 36.2 g per 100 g of water at 25°C. _____
11. Circle the letter of the sentence that best answers the following question. How does the solubility of solid substances change as the temperature of the solvent increases?
- a. The solubility increases for all solids.
 - b. The solubility increases for most solids.
 - c. The solubility remains constant.
12. Look at Table 16.1 on page 474. Which solid substance listed in the table is nearly insoluble at any temperature? _____
13. How does the solubility of a gas change with an increase in temperature?
-

14. The directly proportional relationship between the solubility of a gas in a liquid and the pressure of the gas above the liquid is known as _____ .

15. Describe the two diagrams of a bottled carbonated beverage below as *greater pressure* or *lower pressure*, and then as *greater solubility* or *lower solubility*. How do these two examples illustrate the relationship between the solubility of a gas and its vapor pressure?



16. How does a solution become supersaturated? _____

SECTION 16.2 CONCENTRATIONS OF SOLUTIONS (pages 480–486)

This section explains how to solve problems involving molarity of a solution, how to prepare dilute solutions from more concentrated solutions, and what is meant by percent by volume and percent by mass.

► Molarity (pages 480–482)

1. A measure of the amount of solute dissolved in a given quantity of solvent is the _____ of a solution.
2. The most important unit of concentration in chemistry is _____ .
3. Is the following sentence true or false? Molarity is the number of moles of dissolved solute per liter of solvent. _____

CHAPTER 16, Solutions (continued)

4. Look at Figure 16.8 on page 481. Circle the letter of the best procedure for making a 0.50-molar (0.50M) solution in a 1.0-L volumetric flask.
 - a. Add distilled water exactly to the 1.0-L mark, add 0.50 mol of solute, and then agitate to dissolve the solute.
 - b. Place 0.50 mol of solute in the flask, add distilled water to the 1.0-L mark, and then agitate to dissolve the solute.
 - c. Combine 0.50 mol of water with 0.50 mol of solute in the flask, and then agitate to dissolve the solute.
 - d. Fill the flask with distilled water until it is about half full, add 0.50 mol of solute, agitate to dissolve the solute, and then carefully fill the flask with distilled water to the 1.0-L mark.

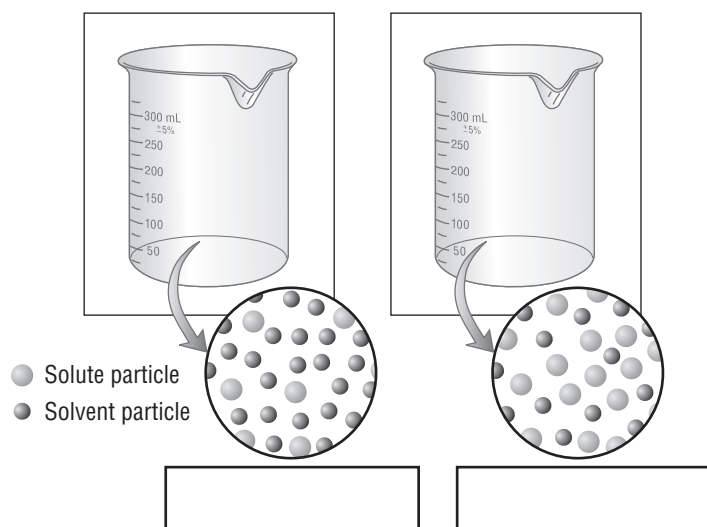
5. List the information needed to find the molarity of a 2.0-L solution containing 0.50 mol of sodium chloride.

Known	Unknown
<div style="border: 1px solid black; width: 100px; height: 20px; margin-bottom: 5px;"></div> of solution	Molarity = ?
<div style="border: 1px solid black; width: 100px; height: 20px; margin-bottom: 5px;"></div> of sodium chloride	
molarity (M) = $\frac{\div style{border: 1px solid black; width: 150px; height: 20px; display: inline-block;">liters of solution$	

► Making Dilutions (pages 483–484)

6. How do you make a solution less concentrated? _____

7. On the diagram below, assume that each beaker contains an equal number of moles of solute. Label each solution as *concentrated* or *dilute*. Then indicate the approximate relative volumes of each solution by drawing in the surface level on each beaker.



Questions 8 and 9 refer to the following situation. Solvent is added to a solution until the total volume of the solution doubles.

8. What happens to the number of moles of solute present in the solution when the volume doubles?

9. Circle the letter of the correct description of the change in molarity of a solution when the volume doubles.

- a. The molarity of the solution is cut in half.
- b. The molarity of the solution doubles.
- c. The molarity of the solution remains constant.
- d. The molarity of the solution increases slightly.

10. List the information you need to find how many milliliters of a stock solution of 2.00M MgSO₄ you would need to prepare 100.0 mL of 1.00M MgSO₄.

Known

Unknown

$M_1 =$ _____

$V_1 = ?$ mL of 2.00M MgSO₄

$M_2 =$ _____

$V_2 =$ _____

$M_1 \times$ _____ $=$ _____ \times _____

► **Percent Solutions (pages 485–486)**

11. List the information needed to find the percent by volume of ethanol in a solution when 50 mL of pure ethanol is diluted with water to a volume of 250 mL.

Known

Unknown

Volume of ethanol = _____

% ethanol by volume = ? %

Volume of solution = _____

% (v/v) = _____



Reading Skill Practice

Writing a summary can help you remember the information you have read. When you write a summary, include only the most important points. Write a summary of the information about percent solutions on pages 485–486. Your summary should be shorter than the text on which it is based. Do your work on a separate sheet of paper.

CHAPTER 16, Solutions (continued)

SECTION 16.3 COLLIGATIVE PROPERTIES OF SOLUTIONS (pages 487–490)

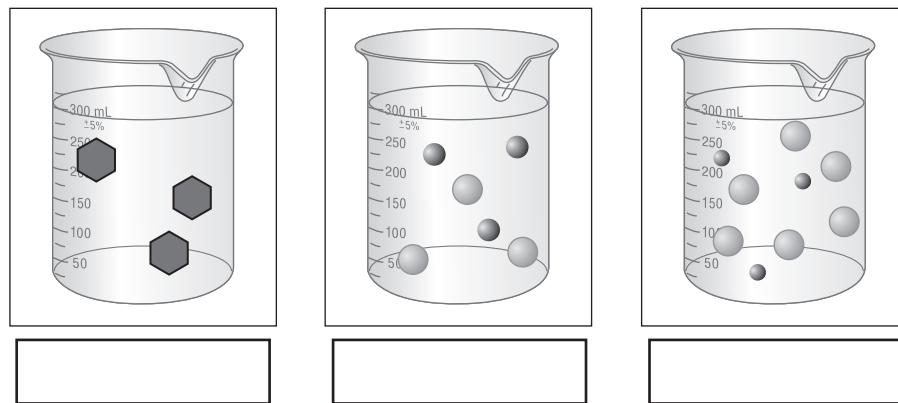
This section explains why a solution has a lower vapor pressure, an elevated boiling point, and a depressed freezing point compared with the pure solvent of that solution.

► **Vapor Pressure Lowering** (pages 487–488)

- Properties of a solution that depend only on the number of particles dissolved, but not the identity of solute particles in the solution are called _____.
- Is the following sentence true or false? A nonvolatile substance is one that does not vaporize easily. _____
- Look at Figure 16.13 on page 487. What happens to the vapor pressure equilibrium when a nonvolatile solute is added to a pure solvent?

- How is the decrease in vapor pressure of a solution with a nonvolatile solute related to the number of particles per formula unit of solute?

- Assume 3 mol each of three different solutes have been added to three identical beakers of water as shown below. If the beakers are covered to form closed systems at constant temperature, rank the vapor pressures in each container from 1 (lowest) to 3 (highest).



► Freezing-Point Depression (pages 488–489)

6. Circle the letter of each sentence that is true about the freezing point of a solution formed by a liquid solvent and nonvolatile solute.
- a. When a substance freezes, the arrangement of its particles becomes less orderly.
 - b. The presence of a solute in water disrupts the formation of orderly patterns as the solution is cooled to the freezing point of pure water.
 - c. More kinetic energy must be withdrawn from a solution than from a pure solvent in order for the solution to solidify.
 - d. The freezing point of the solution is lower than the freezing point of the pure solvent.
7. One mole of which substance, glucose or sodium chloride, will produce more freezing-point depression when added to equal amounts of water? Why?
- _____
- _____

► Boiling-Point Elevation (page 490)

8. Circle the letter next to each sentence that is true concerning the boiling point of a solution formed by a liquid solvent and a nonvolatile solute.
- a. The boiling point is the temperature at which the vapor pressure equals atmospheric pressure.
 - b. Adding a nonvolatile solute decreases the vapor pressure.
 - c. Because of the decrease in vapor pressure, additional kinetic energy must be added to raise the vapor pressure of the liquid phase to atmospheric pressure.
 - d. The boiling point of the solution is higher than the boiling point of the pure solvent.
9. The difference between the boiling point of a solution and that of the pure solvent is called the _____.

SECTION 16.4 CALCULATIONS INVOLVING COLLIGATIVE PROPERTIES (pages 491–496)

This section explains how to calculate the molality and mole fraction of a solution, and how to use molality to calculate the freezing-point depression or boiling-point elevation of a solution.

► Molality and Mole Fraction (pages 491–493)

1. For a solution, the ratio of moles of solute to mass of solvent in kilograms, represented by m , is the solution's _____.

CHAPTER 16, Solutions (continued)

- Is the following sentence true or false? Molarity and molality are always the same for a solution. _____
- What is the molality of a solution prepared by adding 1.0 mol of sodium chloride to 2.0 kg of water? _____
- The circle graph below shows the ratio of ethylene glycol (EG) to water in one antifreeze solution. Write the mole fractions for each substance.

$$\text{Mole fraction EG} = \frac{\boxed{}}{\boxed{} + \boxed{}} = \frac{\boxed{}}{\boxed{}} = \boxed{}$$

$$\text{Mole fraction H}_2\text{O} = \frac{\boxed{}}{\boxed{} + \boxed{}} = \frac{\boxed{}}{\boxed{}} = \boxed{}$$



► **Freezing-Point Depression and Boiling-Point Elevation** (pages 494–496)

- Assuming a solute is molecular and not ionic, the magnitude of the boiling-point elevation of the solution, ΔT_b , is directly proportional to _____.
- Look at Table 16.3 on page 495. What is the molal boiling-point elevation constant, K_b , for water? _____
- You need to find the freezing point of a 1.50*m* aqueous NaCl solution. You calculate ΔT_f to be $1.86^\circ\text{C}/m \times 3.00m$ or 5.86°C . What is the temperature at which the solution freezes? _____

GUIDED PRACTICE PROBLEMS

GUIDED PRACTICE PROBLEM 1 (page 477)

- The solubility of a gas in water is 0.16 g/L at 104 kPa of pressure. What is the solubility when the pressure of the gas is increased to 288 kPa? Assume the temperature remains constant.

Analyze

Step 1. What is the equation for the relationship between solubility and pressure? _____

Step 2. What is this law called? _____

Step 3. What are the known values in this problem?

$$P_1 = \boxed{}$$

$$S_1 = \boxed{}$$

$$\boxed{} = 288 \text{ kPa}$$

Step 4. What is the unknown in this problem? _____

Solve

Step 5. Rearrange the equation to solve for the unknown.

$$S_2 = \boxed{}$$

Step 6. Substitute the known values into the equation and solve.

$$S_2 = \frac{\boxed{} \text{ g/L} \times \boxed{} \text{ kPa}}{\boxed{} \text{ kPa}} = \boxed{}$$

Evaluate

Step 7. How do you know that your answer is correct?

Step 8. Are the units correct? Explain.

CHAPTER 16, Solutions (continued)

GUIDED PRACTICE PROBLEM 8 (page 481)

8. A solution has a volume of 2.0 L and contains 36.0 g of glucose. If the molar mass of glucose is 180 g/mol, what is the molarity of the solution?

Step 1. What is the equation for molarity of a solution?

$$\text{Molarity } (M) = \frac{\text{moles of solute}}{\text{volume of solution in L}}$$

Step 2. How many moles of glucose are in the solution?

$$\boxed{} \text{ g} \times \frac{1 \text{ mol}}{\boxed{} \text{ g}} = \boxed{} \text{ mol glucose}$$

Step 3. Substitute the known values into the equation for molarity.

$$M = \frac{\boxed{}}{2.0 \boxed{}}$$

Step 4. Solve.

$$M = \underline{\hspace{2cm}}$$

GUIDED PRACTICE PROBLEM 9 (page 481)

9. A solution has a volume of 250 mL and contains 0.70 mol NaCl. What is its molarity?

Analyze

Step 1. List the knowns and the unknown.

Knowns

Unknown

The units of molarity, M , is mol solute/L solution.

Calculate

Step 2. Solve for the unknown.

As long as the units are correct, division gives the result.

$$\text{molarity} = \frac{\text{mol solute}}{\text{solution volume}} = \frac{0.70 \text{ mol NaCl}}{0.250 \text{ L}}$$

$$= \underline{\hspace{2cm}}$$

Evaluate

Step 3. Does the result make sense?

EXTRA PRACTICE (similar to Practice Problem 10, page 482)

10. How many moles of ammonium nitrate are in 375 mL of 0.40M NH_4NO_3 ?

GUIDED PRACTICE PROBLEM 12 (page 484)

12. How many milliliters of a solution of 4.00M KI is needed to prepare 250.0 mL of 0.760M KI?

Analyze

Step 1. List the knowns and the unknown.

Knowns

Unknown

Calculate

Step 2. Solve for the unknown.

Rearranging the equation above will give the result

$$V_1 = \frac{M_2 \times V_2}{M_1} = \frac{0.760M \text{ KI} \times 250.0 \text{ mL}}{4.00M \text{ KI}}$$

= _____

CHAPTER 16, Solutions (continued)

Step 3. Evaluate Does the result make sense?

GUIDED PRACTICE PROBLEM 14 (page 485)

14. If 10 mL of pure propanone (or acetone) is diluted with water to a total solution volume of 200 mL, what is the percent by volume of acetone in the solution?

Step 1. What is the equation for calculating percent by volume?

$$\% (v/v) = \frac{\quad}{\quad} \times 100\%$$

Step 2. What are the knowns in this problem?

Step 3. Substitute the known values into the equation and solve.

$$\% (v/v) = \frac{\boxed{\quad} \text{ mL}}{\boxed{\quad} \text{ mL}} \times 100\% = \boxed{\quad} \%$$

GUIDED PRACTICE PROBLEM 29 (page 492)

29. How many grams of sodium fluoride are needed to prepare a 0.400*m* NaF solution that contains 750 g of water?

Analyze

Step 1. List the knowns and the unknown.

Knowns

Unknown

The final solution must contain 0.400 mol of NaF per 100 g of water. This information will provide a conversion factor. The process of conversion will be: grams of water \square mol NaF \square grams NaF

Calculate

Step 2. Solve for the unknown.

Multiply by the appropriate conversion factors:

$$750 \text{ g H}_2\text{O} \times \frac{0.400 \text{ mol NaF}}{100 \text{ g H}_2\text{O}} \times \frac{42.0 \text{ g NaF}}{1 \text{ mol NaF}}$$

= _____

Evaluate

Step 3. Does the result make sense?

EXTRA PRACTICE (similar to Practice Problem 31, page 493)

31. What is the mole fraction of each component in a solution made by mixing 230 g of ethanol ($\text{C}_2\text{H}_5\text{OH}$) and 450 g of water?

$$n_{\text{ETH}} = \underline{\hspace{10em}}$$

$$n_{\text{WAT}} = \underline{\hspace{10em}}$$

$$X_{\text{ETH}} = \underline{\hspace{10em}}$$

$$X_{\text{WAT}} = \underline{\hspace{10em}}$$

CHAPTER 16, Solutions (*continued*)**GUIDED PRACTICE PROBLEM 33** (page 495)

33. What is the freezing point depression of an aqueous solution of 10.0 g glucose ($C_6H_{12}O_6$) in 50.0 g H_2O ?

Analyze

Step 1. List the knowns and the unknown.

Knowns

Unknown

To use the given equation, first convert the mass of solute to the number of moles, then calculate the molality, m .

Calculate

Step 2. Solve for the unknown.

Calculate the molar mass of $C_6H_{12}O_6$: $1 \text{ mol } C_6H_{12}O_6 =$ _____

Calculate the number of moles of solute using this conversion:

$$\text{mol } C_6H_{12}O_6 = 10.0 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{180 \text{ g } C_6H_{12}O_6}$$

$$= \underline{\hspace{2cm}}$$

Calculate the molality:

$$m = \frac{\text{mol solute}}{\text{kg solvent}} = \frac{0.0556 \text{ mol } C_6H_{12}O_6}{0.0500 \text{ kg } H_2O}$$

$$= \underline{\hspace{2cm}}$$

Calculate the freezing point depression using the known formula:

Evaluate

Step 3. Does the result make sense?

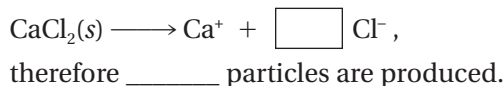
GUIDED PRACTICE PROBLEM 35 (page 496)

35. What is the boiling point of a solution that contains 1.25 mol CaCl_2 in 1400 g of water?

Step 1. What is the concentration of the CaCl_2 solution?

$$\frac{1.25 \text{ mol}}{\boxed{} \text{ g}} \times \frac{\boxed{} \text{ g}}{1 \text{ kg}} = \boxed{} m$$

Step 2. How many particles are produced by the ionization of each formula unit of CaCl_2 ?



Step 3. What is the total molality of the solution?

$$\underline{\hspace{2cm}} \times 0.89m = 2.7m$$

Step 4. What is the molal boiling point elevation constant (K_b) for water?

$$K_b (\text{water}) = \underline{\hspace{2cm}} \text{ } ^\circ\text{C}/m$$

Step 5. Calculate the boiling point elevation.

$$\begin{aligned} \Delta T_b &= \underline{\hspace{2cm}} \text{ } ^\circ\text{C}/m \times 2.7 \underline{\hspace{2cm}} \\ &= 1.4 \underline{\hspace{2cm}} \end{aligned}$$

Step 6. Add ΔT_b to 100°C to find the new boiling point.

$$\underline{\hspace{2cm}} \text{ } ^\circ\text{C} + 100^\circ\text{C} = \underline{\hspace{2cm}} \text{ } ^\circ\text{C}$$

GUIDED PRACTICE PROBLEM 36 (page 496)

33. What mass of NaCl would have to be dissolved in 1.000 kg of water to raise the boiling point by 2.00°C ?

Analyze

Step 1. List the knowns and the unknown.

CHAPTER 16, Solutions (*continued*)**Knowns**

Unknown

First calculate the molality, m , using the given equation. Then use a molar mass conversion to determine the mass of solute.

Calculate

Step 2. Solve for the unknown.

Calculate the molality by rearranging $\Delta T_b = K_b \times m$:

$$m = \frac{\Delta T_b / K_b}{1.86^\circ\text{C}/m} = \frac{2.00^\circ\text{C}}{1.86^\circ\text{C}/m}$$

$$= \underline{\hspace{2cm}}$$

Calculate the molar mass of NaCl: 1 mol NaCl = 58.5 g

$$= \underline{\hspace{2cm}} \text{ kg NaCl}$$

Determine the number of moles of solute using the molality and the amount of solvent:

$$\text{moles NaCl} = \text{mass of solvent} \times \text{molality} = 1.000 \text{ kg H}_2\text{O} \times \frac{1.08 \text{ mol NaCl}}{1 \text{ kg H}_2\text{O}}$$

$$= \underline{\hspace{2cm}}$$

Finally, convert the number of moles of NaCl to mass:

$$1.08 \text{ mol NaCl} \times \frac{5.85 \times 10^{-2} \text{ kg NaCl}}{1 \text{ mol NaCl}}$$

$$= \underline{\hspace{2cm}}$$

Evaluate

Step 3. Does the result make sense?
