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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. agitation (stirring or shaking)

b. temperature

c. particle size

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. true

▶ 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	0.2 g	0.8 g
Determine the total amount that dissolves	36.2 g	

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

9. Look at Figure 16.3 on page 473. Why does the oil float on the vinegar?

Vinegar is water-based, and oil and water are immiscible. The less dense oil floats on the water-based solution.

▶ 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. true

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? barium sulfate

13. How does the solubility of a gas change with an increase in temperature?

As the temperature increases, the solubility of a gas decreases.

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 Henry's law.

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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?

In the closed bottle, the pressure is high and lots of CO_2 is dissolved in the carbonated beverage. Once the cap is removed, the vapor pressure decreases, allowing more CO_2 in the carbonated beverage to escape.

greater pressure and greater solubility | lower pressure and lower solubility

16. How does a solution become supersaturated? If the temperature of a solution having a small excess of solid solute is raised, the solute dissolves. If the solution is then allowed to cool slowly, the excess solute may stay dissolved at a temperature below the temperature at which it would ordinarily crystallize.

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 ___concentration___ of a solution.

2. The most important unit of concentration in chemistry is ___molarity___ .

3. Is the following sentence true or false? Molarity is the number of moles of dissolved solute per liter of solvent. ___false___

4. Look at Figure 16.8 on page 481. Circle the letter of the best procedure for making a 0.50-molar (0.50*M*) 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

2.0 liters of solution

0.50 mol of sodium chloride

Unknown

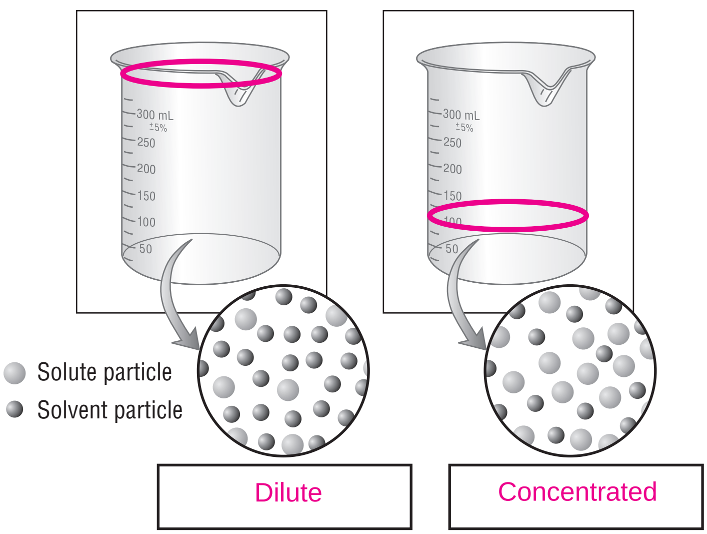
Molarity = ?

$$\text{molarity } (M) = \frac{\text{moles of solute}}{\text{liters of solution}}$$

▶ Making Dilutions (pages 483–484)

6. How do you make a solution less concentrated? Dilute it with solvent.

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.



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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?

The number of moles of solute remains constant.

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 2.00*M* $MgSO_4$ you would need to prepare 100.0 mL of 1.00*M* $MgSO_4$.

Known	Unknown
M_1 = 2.00*M*	V_1 = ? mL of 2.00*M* $MgSO_4$
M_2 = 1.00*M*	
V_2 = 100.0 mL	

$M_1 \times V_1 = M_2 \times V_2$

▶ 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 = 50 mL	% ethanol by volume = ? %
Volume of solution = 250 mL	

$$\%\ (v/v) = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$$

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.

Student summaries should explain that if both the solvent and the solute are liquids, volumes of the solvent and the solution can be measured, and the concentration can be expressed as a percent by volume. If solids are dissolved in liquids, the masses of both the solvent and the solute must be obtained to express the concentration as a percent by mass.

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)

1. 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 colligative properties.

2. Is the following sentence true or false? A nonvolatile substance is one that does not vaporize easily. true

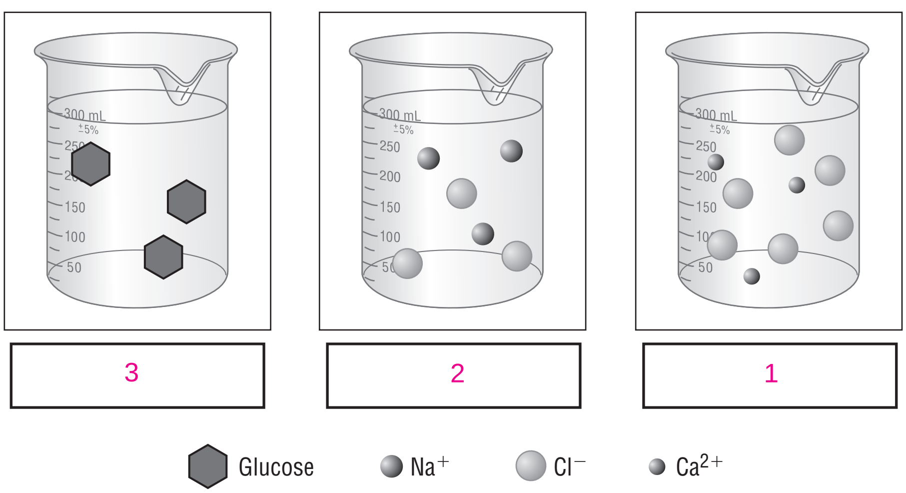
3. Look at Figure 16.13 on page 487. What happens to the vapor pressure equilibrium when a nonvolatile solute is added to a pure solvent?

The equilibrium is disturbed as solvent particles form shells around solute particles. Equilibrium is eventually re-established at a lower vapor pressure.

4. 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?

The decrease in vapor pressure is proportional to the number of particles the solute produces in solution. Solutes with more particles per formula unit produce a larger decrease in vapor pressure.

5. 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).



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▶ 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?

Sodium chloride because it produces twice as many particles per formula unit in solution than glucose.

▶ 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 ___boiling-point elevation___ .

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 ___molality___ .

CHAPTER 16, Solutions *(continued)*

2. Is the following sentence true or false? Molarity and molality are always the same for a solution. false

3. What is the molality of a solution prepared by adding 1.0 mol of sodium chloride to 2.0 kg of water? 0.50*m*

4. The circle graph below shows the ratio of ethylene glycol (EG) to water in one antifreeze solution. Write the mole fractions for each substance.

$$\text{Mole fraction EG} = \frac{1.50}{1.50 + 4.80} = \frac{1.50}{6.30} = 0.240$$

$$\text{Mole fraction } H_2O = \frac{4.80}{1.50 + 4.80} = \frac{4.80}{6.30} = 0.760$$

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

5. Assuming a solute is molecular and not ionic, the magnitude of the boiling-point elevation of the solution, ΔT_b, is directly proportional to the molal concentration of the solute (*m*).

6. Look at Table 16.3 on page 495. What is the molal boiling-point elevation constant, K_b, for water? 0.512°C/*m*

7. You need to find the freezing point of a 1.50*m* aqueous NaCl solution. You calculate ΔT_f to be 1.86°C/*m* × 3.00*m* or 5.86°C. What is the temperature at which the solution freezes? −5.86°C

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GUIDED PRACTICE PROBLEMS

GUIDED PRACTICE PROBLEM 1 (page 477)

1. 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? $\frac{S_1}{P_1} = \frac{S_2}{P_2}$

Step 2. What is this law called? Henry's law

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

P_1 = 104 kPa

S_1 = 0.16 g/L

P_2 = 288 kPa

Step 4. What is the unknown in this problem? S_2

Solve

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

$$S_2 = \frac{S_1 \times P_2}{P_1}$$

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

$$S_2 = \frac{0.16\ \text{g/L} \times 288\ \cancel{\text{kPa}}}{104\ \cancel{\text{kPa}}} = 0.44\ \text{g/L}$$

Evaluate

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

The pressure increased nearly threefold, so the solubility should increase nearly threefold, which it does.

Step 8. Are the units correct? Explain.

Yes, because solubility is expressed as grams of gas dissolved per liter of solution.

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?

$$\text{Molarity } (M) = \frac{\text{moles of solute}}{\text{liters of solution}}$$

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

$$36.0 \text{ g} \times \frac{1 \text{ mol}}{180 \text{ g}} = 0.20 \text{ mol glucose}$$

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

$$M = \frac{0.20 \text{ mol}}{2.0 \text{ L}}$$

Step 4. Solve.

M = 0.10 mol/L

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

number of moles of solute = 0.70 mol NaCl

solution volume = 250 mL = 0.250 L

Unknown

solution concentration (molarity) = ? M

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.

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

= 2.8 M

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Evaluate

Step 3. Does the result make sense?

The numerical answer should be 4 times greater than the number of moles of solute, because 250 mL is one-fourth of 1 L.

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

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

$$375\ \cancel{\text{mL}} \times \frac{0.40\ \text{mol}}{1\ \cancel{\text{L}}} \times \frac{1\ \cancel{\text{L}}}{1000\ \cancel{\text{mL}}} = 0.15\ \text{mol}$$

GUIDED PRACTICE PROBLEM 12 (page 484)

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

Analyze

Step 1. List the knowns and the unknown.

Knowns

$M_1 = 4.00M$ KI

M_2 5 $0.760M$ KI

$V_2 = 250.0$ mL

$M_1 \times V_1 = M_2 \times V_2$

Unknown

$V_1 = ?$ mL of $4.00M$ KI

Calculate

Step 2. Solve for the unknown.

Rearranging the equation above will give the result

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

$= $ 47.5 mL of $4.00M$ KI

Step 3. Evaluate Does the result make sense?

The concentration of the initial solution is more than 5 times larger than that of the final solution, so the volume of initial solution should be about one-fifth of the total volume of the diluted solution.

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?

$$\% \text{ (v/v)} = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$$

Step 2. What are the knowns in this problem?

volume of acetone = 10 mL

volume of solution = 200 mL

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

$$\% \text{ (v/v)} = \frac{10 \text{ mL}}{200 \text{ mL}} \times 100\% = 5\ \%$$

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

mass of water = 750 g

solution concentration = 0.400*m*

molar mass NaF = 42.0 g/mol

Unknown

mass of solute = ? g NaF

The final solution must contain 0.400 mol of NaF per 1000 g of water. This information will provide a conversion factor. The process of conversion will be: grams of water → mol NaF → grams NaF

Calculate

Step 2. Solve for the unknown.
Multiply by the appropriate conversion factors:

$$750\ \cancel{g\ H_2O} \times \frac{0.400\ \cancel{mol\ NaF}}{100\cancel{g\ H_2O}} \times \frac{42.0\ g\ NaF}{\cancel{1\ mol\ NaF}}$$

= 12.6 g NaF

Evaluate

Step 3. Does the result make sense?

A one molal NaF solution contains 42.0 g NaF. Given only three-fourths of 1000 g of H_2O and less than half concentration, the result should be less than three-eighths the molar mass.

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 (C_2H_5OH) and 450 g of water?

$$n_{ETH} = 230\ \cancel{g} \times \frac{1\ mol}{46.0\ \cancel{g}} = 5.0\ mol$$

$$n_{WAT} = 450\ \cancel{g} \times \frac{1\ mol}{18.0\ \cancel{g}} = 25\ mol$$

$$X_{ETH} = \frac{5.0\ \cancel{mol}}{5.0\ \cancel{mol} + 25\ \cancel{mol}} = 0.17$$

$$X_{WAT} = \frac{25\ \cancel{mol}}{5.0\ \cancel{mol} + 25\ \cancel{mol}} = 0.83$$

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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

mass of solute = 10.0 g $C_6H_{12}O_6$

mass of solvent = 50.0 g H_2O = 0.0500 kg H_2O

K_f for water = 1.86°C/m

$\_\_T_f = K_f \times m$

Unknown

$\_\_T_f$ = ?°C

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 $C_6H_{12}O_6$: 1mol $C_6H_{12}O_6$ = 180 g

Calculate the number of moles of solute using this conversion:

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

= 0.0556 mol $C_6H_{12}O_6$

Calculate the molality:

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

= 1.11m

Calculate the freezing point depression using the known formula:

$\_\_T_f = K_f \times m = 1.86°\text{C}/m \times 1.11\ m = 2.06°\text{C}$

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Evaluate

Step 3. Does the result make sense?

Because a one molal solution decreases the freezing point of water by 1.86°C, a solution with concentration about one-tenth larger should decrease the freezing point further by about one-tenth of K_f.

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?

$$\frac{1.25 \text{ mol}}{\boxed{1400}\text{ g}} \times \frac{\boxed{1000}\text{ g}}{1 \text{ kg}} = \boxed{0.89}\ m$$

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

$CaCl_2(s) \longrightarrow Ca^{+} + \boxed{2}\ Cl^{-}$, therefore 3 particles are produced.

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

3 $\times\ 0.89m = 2.7m$

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

K_b (water) = 0.512 °C/m

Step 5. Calculate the boiling point elevation.

ΔT_b = 0.512 °C/m × 2.7 m

= 1.4 °C

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

1.4 °C + 100°C = 101.4 °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.

Knowns

mass of solvent = 1.000 kg H_2O

K_f for water = 1.86°C/m

$\_\_T_b$ = 2.00°C

$\_\_T_b = K_b \times m$

Unknown

mass of solute = 10.0 g NaCl

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 $\_\_T_b = K_b \times m$:

$$m = \_\_T_b/K_b = \frac{2.00°\text{C}}{1.86°\text{C}/m}$$

= 1.08m

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

= 5.85×10^{-2} kg NaCl

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

$$\text{moles NaCl} = \text{mass of solvent} \times \text{molality} = 1.000 \text{ kg } H_2O \times \frac{1.08 \text{ mol NaCl}}{1 \text{ kg } H_2O}$$

= 1.08 mol NaCl

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

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

= 6.32×10^{-2} kg NaCl

Evaluate

Step 3. Does the result make sense?

Because the solution's molality is slightly more than one, the mass of solute should be slightly more than one times the numerical value of molar mass.

Chap 16 - Solutions

PP #12, 19-23

(12) $M_1 \times V_1 = M_2 \times V_2$

$M_1 = 4.0\ M\ KI$ $V_1 = ?$

$M_2 = .760\ M$ $V_2 = 250\ mL$

$4.0 \times V_1 = (.760\ M)(250.0\ mL)$

$V_1 = 47.5\ mL$

(19) 400g $CuSO_4$ in 4.00 L

63.55
32.07
64
159.6

$M = \frac{n\ (mols)}{V\ (L)}$

$400g \times \frac{1\ mol}{159.6} = 2.5\ mols\ CuSO_4$

$M = \frac{2.5\ mols}{4.0\ L} =$ **.63 M**

(20) $M = \frac{n}{V} \Rightarrow n = M(V) = (.2M)(.05\ L) =$ **.01 moles**

(21) $M_1 \times V_1 = M_2 \times V_2$

$M_1 = 2M$ $V_1 = ?$ $M_2 = .15\ M\ KNO_3$ $V_2 = 100\ mL$

$2M \times V_1 = (.15M)(100\ mL)$

$V_1 = 7.5\ mL$

(22) $\%V = \frac{\text{volume solute}}{\text{volume of solution}} \times 100\% =$

Volume of solute = 50 mL = .050 L

Volume of solution = 2.5 L

$\frac{.05\text{ L}}{2.5\text{ L}} \times 100\% = \boxed{2\%}$

(23) $\%\text{ mass} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$

? = mass of solute   % = 5%

1500 g = mass of solution

$\frac{5\%}{100\%} = \frac{?}{1500\text{ g}}$

$\boxed{? = 75\text{ g of } K_2SO_4}$

Mead