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16 Solutions

Big idea THE MOLE AND QUANTIFYING MATTER

16.1 Properties of Solutions

For students using the Foundation edition, assign problems 1–12, 14, 15.

Essential Understanding The properties of solutions depend on the amount of solute dissolved in the solvent or the concentration of particles in the solution.

Lesson Summary

Solution Formation Agitation, temperature, and particle size all affect the speed at which a solute dissolves in a solvent.

- Agitation (stirring or shaking) increases the speed at which a solute dissolves.
- In general, increasing temperature increases how quickly a solute dissolves, and decreasing temperature decreases the rate.
- The smaller the particles, the quicker the rate of dissolving.

Solubility Solubility reflects the amount of solute that will dissolve in a certain amount of solvent at a specified temperature.

- A solution that can hold no more of the solute at a particular temperature is said to be a saturated solution at that temperature.
- An unsaturated solution is a solution that contains less solute than is required to saturate it at that temperature.
- Miscible liquids are capable of mixing in any ratio without separation of two phases.

Factors Affecting Solubility Temperature and pressure can affect the solubility of a solute in a solvent.

- A supersaturated solution contains more solute than usually would dissolve at that temperature.
- In general, increasing temperature increases the solubility of a solid in a liquid and decreases the solubility of a gas in a liquid.
- Increased pressure increases the solubility of a gas in a liquid but does not affect the solubility of a liquid or a solid in a liquid.

Henry's Law	Cause	Effect
$\frac{S_1}{S_2} = \frac{P_1}{P_2}$	increased pressure above solution decreased pressure above solution	increased solubility of gas decreased solubility of gas

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After reading Lesson 16.1, answer the following questions.

Solution Formation

Look at Figure 16.1 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 <u>in granulated form</u>?

b. when allowed to stand or <u>when stirred</u>?

c. <u>at a higher temperature</u> or at 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

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.

7. Look at Figure 16.2. 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***.

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9. Look at Figure 16.4. Why does the oil float on water?

Oil and water are immiscible. The less dense oil floats on the water.

Factors Affecting Solubility

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. Which solid substance listed in the table is nearly insoluble at any temperature? ***barium sulfate***

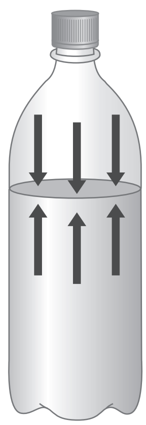
13. How does the solubility of a gas change with an increase in temperature?

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

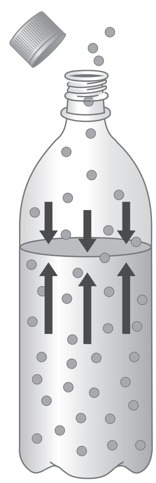
14. The directly proportional relationship between the solubility of a gas in a liquid and the pressure of the gas above the liquid is known as ***Henry's law***.

15. Describe the two diagrams of a bottled carbonated beverage shown 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

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16. How does a solution become supersaturated?

If you raise the temperature of a solution containing a small excess of solid solute, the solute dissolves. If you then allow the solution to cool slowly, the excess solute may stay dissolved at a temperature below the temperature at which it would ordinarily crystallize.

16.2 Concentrations of Solutions

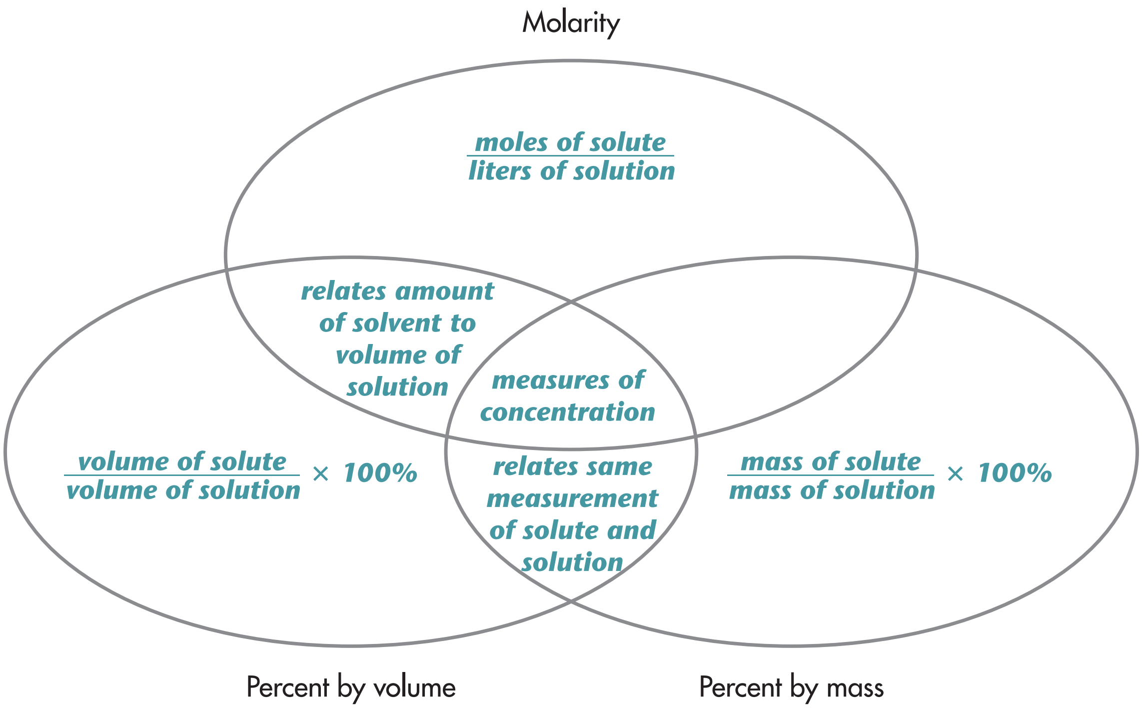
For students using the Foundation edition, assign problems 1–7, 9–11.

Essential Understanding The concentration of a solution can be expressed in several ways, including molarity, percent by mass, and percent by volume.

Reading Strategy

Venn Diagram A Venn diagram is a useful tool in visually organizing related information. A Venn diagram shows which characteristics the concepts share and which characteristics are unique to each concept.

As you read Lesson 16.2, use the Venn diagram below. Fill in the diagram to compare and contrast different measures of concentration by percent.



EXTENSION **Choose one measure of concentration. Explain how diluting a solution affects the calculation of that measure of concentration.**

For each measure of concentration, dilution increases the volume of the solution without changing the amount of solute present.

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Lesson Summary

Molarity The most important quantitative unit of concentration in chemistry is molarity.

- Molarity is the number of moles of solute dissolved per liter of solution.

Making Dilutions Diluting a solution involves adding additional solvent, which decreases the amount of solute per volume of solution.

- Diluting a solution does not affect the amount of solute in the solution, just the volume of solution.
- Because the amount of solute does not change, the product of the molarity and the volume before dilution equals the product of the molarity and the volume after dilution.

Percent Solutions Concentration can also be measured as percent by volume or percent by mass.

- Percent by volume equals the volume of solute divided by the volume of solution, multiplied by 100%.
- Percent by mass equals the mass of solute divided by the mass of the solution, multiplied by 100%.

BUILD Math Skills

Calculating Solubility of a Gas When you talk about the solubility of a gas, you are saying how much mass of the gas you need to dissolve it in a given amount of liquid, which is typically water. The solubility amount for a gas is dependent on the pressure that it is subjected to, so the solubility amount may change if the pressure changes. If you know the initial solubility and pressure, a simple mathematical equation enables you to determine what the solubility is at a different pressure. That equation is:

$\frac{S_1}{P_1} = \frac{S_2}{P_2}$. S is solubility, and P is pressure.

To determine solubility, follow a few simple steps:

- Write out all given information in terms of the variables mentioned above.
- Make sure that all units are the same.
- Rearrange the above equation for the desired variable.
- Plug in all known information, and solve the equation.

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Sample Problem A gas has a solubility of 0.83 g/L in water at a pressure of 1.5 atm. What is the solubility of the gas at a pressure of 0.23 atm?

Write out the given information in terms of the appropriate variables.

$S_1 = 0.83$ g/L;

$P_1 = 1.5$ atm;

$P_2 = 0.23$ atm

You are trying to find S_2, so the equation should be rearranged for S_2.

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

Plug in the known information, and solve.

$$S_2 = \frac{(0.83 \times 0.23)}{1.5} = 0.1272\overline{6} \text{ g/L}$$

Report your answer to the correct number of significant figures.

Since all of the given information has 2 significant digits, $S_2 = 0.13$ g/L

Hint: Remember to report your answer with the correct number of significant figures.

Now it's your turn to practice determining solubility. Remember to check that all information is given in the same units.

1. A gas has a solubility of 0.67 g/L at a pressure of 2.3 atm. If the pressure changes to 0.78 atm, what is the new solubility of the gas?

0.23 g/L

2. At a pressure of 1.13 atm, a gas has a solubility of 0.13 g/L. If the solubility changes to 0.543 g/L, what has the pressure changed to?

4.7 atm

3. At a pressure of 1.56 atm, the solubility of a gas in unknown. It is known that at a pressure of 1.05 atm, the solubility is 1.68 g/L. What is the initial solubility?

2.50 g/L

4. A gas has a solubility of 0.89 g/L at an unknown pressure. The same gas has a solubility of 0.34 g/L at a pressure of 2.0 atm. What is the unknown pressure?

5.2 atm

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After reading Lesson 16.2, answer the following questions.

Molarity

5. A measure of the amount of solute dissolved in a given quantity of solvent is the ***concentration*** of a solution.

6. The most important unit of concentration in chemistry is ***molarity***.

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

8. Look at Figure 16.8. Circle the letter of the best procedure for making a 0.50-molar (0.50*M*) solution in a 1-L volumetric flask.

a. Add distilled water exactly to the 1-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-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-L mark.

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

Knowns	**Unknown**
2.0 liters of solution	molarity = ?
0.50 mol of sodium chloride	

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

Making Dilutions

10. How do you make a solution less concentrated?

Dilute it with solvent.

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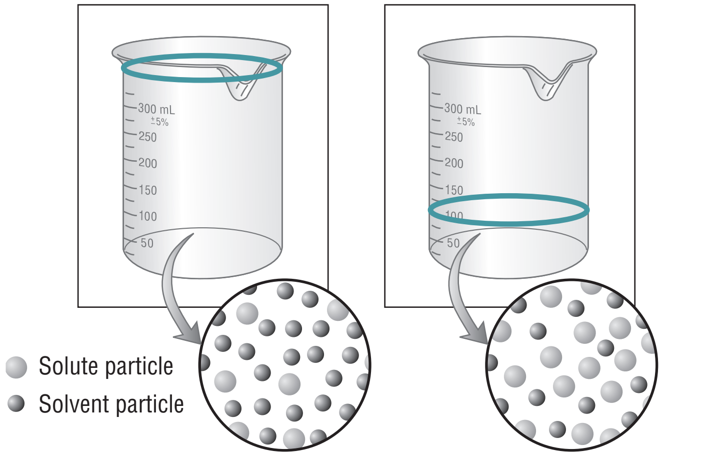
11. On the diagrams below, assume that each beaker contains an equal number of moles of solute. Label each solution as *concentrated* or *dilute*. Then indicate the approximate relative volumes of each solution by drawing in the surface level on each beaker.



dilute	concentrated

Questions 12 and 13 refer to the following situation. Solvent is added to a solution until the total volume of the solution doubles.

12. 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.

13. 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.

14. 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* $MgSO_4$.

Knowns

M_1 = ***2.00M***

M_2 = ***1.00M***

V_2 = ***100.0 mL***

$M_1 \times$ ***V_1*** $=$ ***M_2*** $\times$ ***V_2***

Unknown

V_1 = ? mL of 2.00*M* $MgSO_4$

Percent Solutions

15. 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.

Knowns

Volume of ethanol = ***50 mL***

Volume of solution = ***250 mL***

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

Unknown

% ethanol by volume = ? %

16.3 Colligative Properties of Solutions

For students using the Foundation edition, assign problems 1–3, 5, 6, 8.

Essential Understanding Some colligative properties of solutions that depend on the number of solute particles are vapor pressure, boiling point, and freezing point.

Lesson Summary

Describing Colligative Properties Colligative properties depend on the number of solute particles present in solution.

- It is the number of particles, not the identity of the solute, that changes the colligative property.
- Increasing the amount of solute in solution decreases the vapor pressure, decreases the freezing point, and increases the boiling point of the solution.

After reading Lesson 16.3, answer the following questions.

Describing Colligative Properties

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 16.11. 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 reestablished at a lower vapor pressure.

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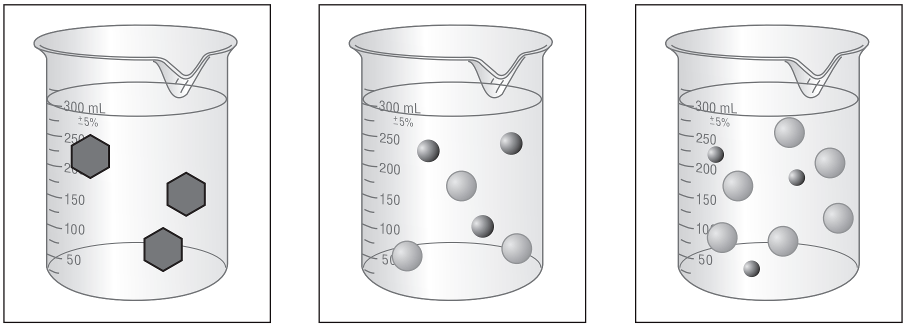
4. How is the decrease in vapor pressure of a solution with a nonvolatile solute related to the number of particles per formula unit of solute?

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 greater 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).



3	*2*	*1*

Glucose Na^+ Cl^- Ca^{2+}

6. Circle the letter of each sentence that is true about the freezing point of a solution formed by a liquid solvent and a 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 does because it produces twice as many particles per formula unit in solution than does glucose.

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***.

16.4 Calculations Involving Colligative Properties

For students using the Foundation edition, assign problems 4–7.

Essential Understanding The colligative properties of a solution can be quantified by using the number of solute particles produced in solution, the amount of solution, and certain constants.

Lesson Summary

Molality and Mole Fraction Both the molality and mole fraction relate the ratio of solute to solvent in a solution.

- Molality is the number of moles of solute per kilogram of solvent.
- Mole fraction is the ratio of moles of solute to total moles of solute and solvent.

Freezing-Point Depression and Boiling-Point Elevation The amount a freezing point is lowered or a boiling point is elevated depends on the molality of the solution and related constants.

- The freezing-point depression of a solution is the product of the molality of the solution and the molal freezing-point depression constant.
- The boiling-point elevation of a solution is the product of the molality of the solution and the molal boiling-point elevation constant.

After reading Lesson 16.4, answer the following questions.

Molality and Mole Fraction

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

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? ***0.50M***

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.

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

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

Freezing-Point Depression and Boiling-Point Elevation

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 16.2. 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

Answer the following questions about Practice Problem 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

Calculate

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.

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

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.

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Answer the following questions about Practice Problem 10.

A solution has a volume of 2.0 L and contains 36.0 g of glucose ($C_6H_{12}O_6$). 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?

Molarity (M) = $\dfrac{\textit{moles of solute}}{\textit{liters of solution}}$

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

36.0 g × $\dfrac{1 \text{ mol}}{\textbf{180} \text{ g}}$ = **0.20** mol glucose

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

$M = \dfrac{\textbf{0.20 mol}}{2.0 \ \textbf{L}}$

Step 4. Solve.

M = ***0.10 mol/L***

Answer the following questions about Practice Problem 11.

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.

$$\text{Molarity} = \frac{\text{mol solute}}{\text{solution volume}} = \frac{0.70 \text{ mol NaCl}}{0.250 \text{ L}} = \textbf{2.8}\boldsymbol{M}$$

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.

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Answer the following questions about Practice Problem 14.

How many milliliters of a solution of 4.00*M* KI are 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

$M_2 = 0.760M$ KI

$V_2 = 250.0$ mL

$M_1V_1 = M_2V_2$

Unknown

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

Calculate

Step 2. Solve for the unknown.

Rearranging the equation above will give the result

$$V_1 = \frac{M_2V_2}{M_1} = \frac{0.760M\text{ KI} \times 250.0\text{ mL}}{4.00M\text{ KI}} = 47.5\text{ mL of }4.00M\text{ KI}$$

Evaluate

Step 3. Does the result make sense?

The concentration of the initial solution is more than 5 times greater 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.

Answer the following questions about Practice Problem 16.

If 10 mL of propanone (or acetone, [C_3H_6O]) is diluted with water to a total solution volume of 200 mL, what is the percent by volume of propanone in the solution?

Step 1. What is the equation for calculating percent by volume?	$\%\ (v/v) = \frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$
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.	$\%\ (v/v) = \frac{10\text{ mL}}{200\text{ mL}} \times 100\% = 5\ \%$

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Answer the following questions about Practice Problem 34.

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 = 0.400m

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:

$$750\ \text{g H}_2\text{O} \times \frac{0.400\ \text{mol NaF}}{100\ \text{g H}_2\text{O}} \times \frac{42.0\ \text{g NaF}}{1\ \text{mol NaF}} = \textit{12.6 g NaF}$$

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.

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Answer the following questions about Practice Problem 38.

What is the freezing-point depression of an aqueous solution of 10.0 g of 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

$\Delta T_f = K_f \times m$

Unknown

ΔT_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:

$$1 \text{ mol } C_6H_{12}O_6 = 10.0 \cancel{\text{ g } C_6H_{12}O_6} \times \frac{1 \text{ mol } C_6H_{12}O_6}{180 \cancel{\text{ g } C_6H_{12}O_6}} = \mathbf{0.0556 \text{ mol } C_6H_{12}O_6}$$

Calculate the molality:

$$m = \frac{\text{mol solute}}{\text{kg solvent}} = \frac{0.0556 \text{ mol } C_6H_{12}O_6}{0.0500 \text{ kg } H_2O} = \mathbf{1.11m}$$

Calculate the freezing-point depression using the known formula:

$\Delta T_f = K_f \times m$ = 1.86°C/m × 1.11m = 2.06°C

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 a concentration about one-tenth greater should decrease the freezing point further by about one-tenth of K_f.

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Answer the following questions about Practice Problem 40.

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 *m* 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 $CaCl_2$?	$CaCl_2(s) \rightarrow Ca^{2+} + \boxed{2}\ Cl^-$ Therefore, __3__ particles are produced.
Step 3. What is the total molality of the solution?	__3__ $\times$ 0.89*m* = 2.7*m*
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* $\times$ 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

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Answer the following questions about Practice Problem 41.

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	Unknown
mass of solvent = 1.000 kg H_2O	***mass of solute = 10.0 g NaCl***
K_f for water = 1.86°C/m	
ΔT_b = 2.00°C	
$\Delta T_b = K_b \times m$	

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 $\Delta T_b = K_b \times m$:

$m = \Delta T_b/K_b = \dfrac{2.00°C}{1.86°C/m} =$ ***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:

moles NaCl = mass of solvent × molality

$= 1.000 \text{ kg } H_2O \times \dfrac{1.08 \text{ mol NaCl}}{1 \text{ kg } H_2O} =$ ***1.08 mol NaCl***

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

$1.08 \text{ mol NaCl} \times \dfrac{5.85 \times 10^{-2} \text{ kg NaCl}}{1 \text{ mol NaCl}} =$ ***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 the solute should be slightly more than one times the numerical value of molar mass.

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Apply the Big idea

When is the molarity of a solution the same as its molality? When are they different? Explain your answer.

If water is the solvent, 1 kg of water = 1L of water, so molarity and molality are basically the same. For other solvents, the mass-volume relationship is different, so molarity and molality differ.

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16 Self-Check Activity

For Questions 1–9, complete each statement by writing the correct word or words. If you need help, you can go online.

16.1 Properties of Solutions

1. A solute dissolves faster if it is stirred, temperature is ***increased***, or particle size is ***reduced***.

2. If the temperature stays the same in a(n) ***saturated*** solution, a dynamic equilibrium exists between any undissolved solute and the solution.

3. ***Temperature*** affects the solubility of any solute, but ***pressure*** affects solubility only if the solute is a gas.

16.2 Concentrations of Solutions

4. The number of moles of solute divided by the ***volume of solution in liters*** is equal to molarity.

5. Diluting a solution increases the ***volume*** of the solution, but the amount of ***solute*** in the solution stays the same.

6. Percent by ***volume*** is the ratio of the volume of solute to the volume of solution.

16.3 Colligative Properties of Solutions

7. Vapor-pressure lowering, freezing-point depression, and boiling-point elevation are all ***colligative*** properties.

16.4 Calculations Involving Colligative Properties

8. The ratio of solute to solvent is expressed as ***molality*** or mole fraction.

9. The amount that freezing point is depressed or boiling point is elevated is proportional to the ***molality*** of the solution.

If You Have Trouble With…

Question	1	2	3	4	5	6	7	8	9
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Review Key Equations

Match each formula in the first column with what it is used to calculate in the second column.

e 1. $\frac{\text{moles of solute}}{\text{kilogram of solvent}}$

g 2. $\Delta T_f = K_f \times m$

c 3. $\frac{S_1}{P_1} = \frac{S_2}{P_2}$

d 4. $\frac{\text{moles of solute}}{\text{liter of solution}}$

f 5. $\frac{n_A}{(n_A + n_B)}$

a 6. $\Delta T_b = K_b \times m$

b 7. $\frac{\text{volume of solute}}{\text{volume of solution}} \times 100\%$

a. boiling-point elevation

b. percent by volume

c. Henry's law

d. molarity

e. molality

f. mole fraction

g. freezing-point depression

Review Vocabulary

Look at the groups of terms below. Three of the terms in each group are related, while one does not belong. Circle the one that does not belong, and explain the relationship among the others.

1. moles, molarity, mass, volume

Molarity is expressed as moles per volume.

2. solute addition, elevation, freezing point, depression

When more solute is added, the freezing point of a solution is depressed.

3. saturated, mole, dissolved, solubility

A saturated solution has the maximum amount of solute dissolved and has reached its solubility limit.

4. solubility, freezing point, colligative, vapor pressure

Colligative properties, such as freezing-point lowering and vapor-pressure raising, are not dependent on the identity of the substance.