

Solutions

WHY?

A solution is a homogeneous combination of two or more substances. The major component is the solvent; the other components are the solutes. Knowledge of the measures of concentration, the factors that determine solubility, and the unique properties of solutions enables scientists, engineers, medical professionals, and you too, to predict properties of unfamiliar solutions.

LEARNING OBJECTIVES

- Identify factors affecting solubility
- Define measures of solution composition
- Learn how a solute affects vapor pressure, boiling point, freezing point, and osmotic pressure

SUCCESS CRITERIA

- Predict solubilities for various substances and situations
- Calculate solution concentrations using different units
- Correctly predict changes in solvent properties caused by a solute

PREREQUISITES

- **Activity 05-2:** *Solution Concentration*
- **Activity 10-1:** *Interactions Between Atoms and Molecules*
- **Activity 10-2:** *Intermolecular Interactions: Water and Organic Compounds*

TASKS

Use your textbook as a reference as you perform the following tasks:

1. Complete Table 1 on factors affecting solubility.
2. Complete Table 2 on measures of solution concentration.
3. Complete Table 3 describing the effects of a solute on solvent properties.

Table 1 Factors Affecting Solubility

Note: In Table 1, identify general trends. Exceptions do sometimes occur; we will learn about those and the reasons they occur later.

Condition	Effect on Solubility
polar solute/polar solvent	<i>The solute dissolves.</i>
nonpolar solute/nonpolar solvent	
polar solute/nonpolar solvent	
nonpolar solute/polar solvent	
increasing the pressure of a gas over a liquid solvent	
increasing the temperature when dissolving a solid	
increasing the temperature when dissolving a gas	

Table 2 Measures of Solution Concentration

Quantity	Formula	Example
mass percent	$= \frac{\text{solute mass}}{\text{total soln mass}} \times 100\%$	20 g of NaCl in 90 g water = (20 g NaCl/110 g soln) × 100% = 18% by mass
mole fraction		0.25 mol NaCl in 5.50 moles water = 0.25 mol NaCl/5.75 total moles = 0.043 mole fraction
molarity (M)		0.25 mol NaCl in 0.50 L of solution = 0.25 mol NaCl/0.5 liter soln = 0.50 M
molality (<i>m</i>)		0.25 moles NaCl in 1.5 kg of water = 0.25 mol NaCl/1.5 kg water = 0.17 <i>m</i>

In Table 3, identify the qualitative effect that the addition of a solute has on the solvent property.

Table 3 Solute Effects

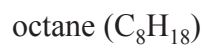
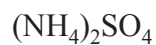
Property	Qualitative Effect of Solute
vapor pressure	reduces vapor pressure
boiling point	
freezing point	
osmotic pressure	increases osmotic pressure

KEY QUESTIONS

1. What general rule can you identify in Table 1, regarding the solubility of polar and nonpolar solutes in polar and nonpolar solvents?
2. What is the difference between solutions of sugar and water that are 1 M and 1 *m* according to Table 2?
3. Why do people put salt on ice in the winter time?
4. Is there a correlation between the effect of a solute on the vapor pressure and the boiling point of a solvent? Explain.

EXERCISES

1. Which solvent, water (H_2O) or hexane (C_6H_{14}), would you use to dissolve the following solutes? Explain.



2. A solution is prepared by dissolving 25.00 g of acetic acid (CH_3COOH) in 750.0 g of water. The density of the resulting solution is 1.105 g/mL.
- a) What is the mass percent of acetic acid in the solution?
- b) What is the molarity of the solution?

c) What is the molality of the solution?

d) What is the mole fraction of acetic acid in the solution?

Colligative Properties

WHY?

Properties of a liquid that depend upon the relative number, and not the identity, of other molecules dissolved in it are called *colligative properties*. You should understand the quantitative as well as the qualitative nature of these properties, as they are important in everyday life as well as in scientific research. For example, salt is thrown on ice to melt it, salty water is used to boil eggs in Denver, and osmotic pressure causes the flow of water through plants, even to the very tops of trees.

LEARNING OBJECTIVES

- Identify the basic colligative properties
- Determine the effects of solutes on boiling point, freezing point, and osmotic pressure

SUCCESS CRITERIA

- Accurate calculations of freezing-point depression, boiling point elevation, and osmotic pressure
- Determination of the molar mass of a solute based upon its effect on the colligative properties of a solvent

PREREQUISITE

- **Activity 12-1:** *Solutions*

INFORMATION

Colligative properties include the lowering of the vapor pressure, the depression of the freezing point, the elevation of the boiling point, and the osmotic pressure caused by adding a nonvolatile solute to a solvent. These properties are all based on the idea that, because a solution consists of fewer solvent molecules and more nonvolatile solute particles, fewer solvent molecules will reach the surface and escape.

Since the volume of a solution changes with changes in temperature, the molarity of the solution will change as well. Molality is therefore the concentration expression used, because it involves mass instead of volume, and is consequently unaffected by temperature.

MODEL: NOTATION AND EQUATIONS FOR COLLIGATIVE PROPERTIES

ΔT_b = elevation in the boiling point

K_b = molal boiling point elevation constant

c_m = molality of the solution

ΔT_f = depression of the freezing point

K_f = molal freezing-point depression constant

Π = osmotic pressure

R = the ideal gas constant

T = temperature in K

RT = a measure of the average translational energy of a collection of molecules

M = molarity of the solution

i = van 't Hoff factor, which is the ratio of the moles of particles in solution to the moles of solute dissolved

Units of pressure 1 atmosphere = 760 torr

The boiling point is elevated: $\Delta T_b = iK_b c_m$

Freezing point is depressed: $\Delta T_f = iK_f c_m$

Solvent will move from the low solute molarity region to the high solute molarity region, even through a separating membrane, producing an osmotic pressure:

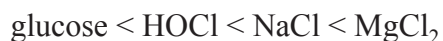
$\Pi = iMRT$

KEY QUESTIONS

1. What colligative properties are included in this activity?
2. Why is molality rather than molarity used as the concentration in the equations for freezing-point depression and boiling point elevation?
3. How can you determine the molar mass of a polymer by measuring the osmotic pressure produced by dissolving some amount of the polymer in a solvent?

EXERCISES

1. Explain why the freezing-point depression of the following compounds in water (each 1.00 m solutions) increases in the indicated order.



2. Determine the boiling point of 1 L of water ($K_b = 0.51^\circ\text{C/m}$) when 1 oz of salt (28 g sodium chloride) is added to it. Does it make sense for people in Denver to add salt to increase the boiling point of water in this mile-high city? Explain.

3. Determine the freezing point of 1 L of water ($K_f = 1.86^\circ\text{C/m}$) when 1 oz of salt (28 g sodium chloride) is added to it.
4. Arrange the following aqueous solutions in order of increasing osmotic pressure:
0.10 M KCl, 0.01 M sucrose, 0.30 M K_2SO_4 , 1.0 M HCl, and 0.01 M CaCl_2 .
5. Calculate the average molar mass of polyethylene when 4.40 g of the polymer is dissolved in benzene to produce 200.0 mL of solution, and the osmotic pressure is found to be 7.60 torr at 25°C .

6. Sulfur exists in many forms with the general molecular formula S_n . If 0.48 g of sulfur are added to 200 g of carbon tetrachloride, and the freezing point of the carbon tetrachloride ($K_f = 30^\circ\text{C}/m$) is depressed by 0.28°C , what is the molar mass and molecular formula of the sulfur?
7. Beaker A contains 100.0 mL 1.0 M salt solution (NaCl). Beaker B contains 100.0 mL pure water. Both beakers are placed inside a large container, which is sealed.
- a) Draw a graph showing how both volumes (solution in beaker A and liquid in beaker B) change with time. Explain.

- b) Draw a graph showing how both concentrations (the solution in beaker A and the liquid in beaker B) change with time. Explain.