Name _____ Date _____ Period ____
SPIC Chapter 21 Solutions

21:1 Solute -- Solvent

A solution consists of a dissolved substance, the **solute**, and a dissolving medium, the **solvent**. A solution is a homogeneous mixture (has a constant composition throughout). A solute need not be a solid. It can be a gas, such as HCl in hydrochloric acid, or a liquid, such as the ethylene glycol in a car's cooling system. If the solution contains two liquids, the liquid that is in the greater amount is called the solvent. The most common solvent is water.

Knowing the actual strength of a solution is more useful than knowing in general terms that it is dilute or concentrated. The concentration of solutions can be described quantitatively in many ways. Molarity, molality, and mole fraction are discussed in this chapter.

21:2 Molarity

A solution for which a precise concentration is known is called a standard solution. Its strength is often expressed in terms of molarity. A 1 molar solution contains 1 mole of solute dissolved in enough solvent (usually water) to make 1 cubic decimeter of solution.

$$\text{molarity (M)} = \frac{\text{number of moles of solute}}{\text{cubic decimeters of solution}}$$

Chemists express concentration in terms of molarity because they are interested in measuring a certain number of particles. The formula mass of one mole of sodium chloride, NaCl, is 58.5 grams/mole NaCl. If 58.5 grams of NaCl are dissolved in enough water to make 1 cubic decimeter of solution, the solution is a 1 M solution of NaCl. Similarly, if 2 moles of NaCl (117.0 grams/mole NaCl) are dissolved in enough water to make 1 cubic decimeter of solution, the solution is a 2 M solution. Fifty cubic centimeters of a solution with 2 M concentration and 500.0 cubic centimeters of the same solution will have the same concentration, 2 M. The total number of particles changes when the volume is changed but the concentration of particles (the number of particles per unit volume) does not change.

EXAMPLE 1

Calculate the molarity of a 1500.0 cubic centimeter solution that contains 200.0 g of $MgCl_2$.

Solving Process:

The problem requires the calculation of molarity. Molarity is moles of solute per (divided by) dm^3 of solution. Therefore, the data concerning solute is placed in the numerator, and the data concerning the solution in the denominator. The solute data in the numerator is then converted to moles, and the solution data in the denominator to dm^3.

$$\text{molarity} = \frac{200.0 \text{ g } MgCl_2 \;\; | \;\; 1 \text{ mole } MgCl_2 \;\; | \;\; 1000 \text{ cm}^3}{1500.0 \text{ cm}^3 \text{ soln} \;\; | \;\; 95.3 \text{ g } MgCl_2 \;\; | \;\; 1 \text{ dm3}}$$

$$= 1.4 \text{ moles / dm}^3 = 1.4 \text{ M } MgCl_2 \text{ solution}$$

EXAMPLE 2

How many cubic centimeters of a 1.50 M sulfuric acid solution can be made using 36.0 g of sulfuric acid?

Solving Process:

Convert grams of sulfuric acid to moles of sulfuric acid. The moles of H_2SO_4 can be converted to dm^3 of H_2SO_4 using the concentration. Finally, the volume is converted to cubic centimeters.

$$\text{Volume of solution} = \frac{36.0\text{ g } H_2SO_4 \mid 1\text{ mole } H_2SO_4 \mid 1\text{ dm}^3\text{ soln} \mid 1000\text{ cm}^3}{\mid 98.1\text{ g } H_2SO_4 \mid 1.50\text{ mole } H_2SO_4 \mid 1\text{ dm}^3} = 245\text{ cm}^3\ H_2SO_4$$

EXAMPLE 3

Calculate the mass of solute required to make 750.0 cubic centimeters of a 2.50 M sodium chloride solution.

Solving Process:

Convert the volume of solution to moles using the given concentration. The 2.50 M solution contains 2.50 moles NaCl/dm^3 solution. Convert the moles of NaCl to grams of NaCl, using the formula mass of NaCl.

Problems

1. Calculate the molarity of the following solutions.
    a. 825 cm^3 that contains 300 g of acetic acid (CH_3COOH)
    b. 2050 cm^3 that contains 49.0 g of phosphoric acid (H_3PO_4)
    c. 1.50 dm^3 that contains 102 g of potassium hydroxide
2. How many cubic decimeters of solution can be made from each of the following?
    a. 2.00 M solution using 80.0 g sodium hydroxide
    b. 0.500 M solution using 80.0 g sodium hydroxide
    c. 6.00 M solution using 126 g nitric acid
3. Calculate the mass of solute in the following solutions.
    a. 75.0 cm^3 of $CaCl_2$ solution that is 0.500 M $CaCl_2$ solution
    b. 3000.0 cm^3 of a KOH solution that is 2.50 M KOH solution
    c. 250.0 cm^3 of a Na_2SO_4 solution that is 2.00 M Na_2SO_4 solution

21.3 Molality

Some properties of a solution depend only on the number of particles, not on the type of particles. These properties are called **colligative properties**. The number of particles in a mass of solvent can affect the boiling or freezing point of the solvent. Molality is used in place of molarity when dealing with colligative properties. **Molality (*m*)** is the number of moles of solute per 1000 grams or 1 kilogram of solvent. A two molal (2 *m*) solution contains two moles of solute dissolved in each kilogram of solvent. Note that the unit is a lower case "m", like meters and milli-, and is therefore expressed in italics or cursive.

EXAMPLE 4

Calculate the molality of a solution made by dissolving 45.0 g of glucose, $C_6H_{12}O_6$, in 500.0 g of water.

Solving Process:

Convert grams of glucose to moles of glucose. The molality expression gives the number of moles of solute per kilogram of solvent (water). The molecular mass of glucose is 180.0 g/mole $C_6H_{12}O_6$.

$$\text{molality} = \frac{45.0 \text{ g } C_6H_{12}O_6}{500.0 \text{ g } H_2O} \mid \frac{100 \text{ g } H_2O}{1 \text{ kg } H_2O} \mid \frac{1 \text{ mole } C_6H_{12}O_6}{180.0 \text{ g } C_6H_{12}O_6} = \frac{0.500 \text{ moles } C_6H_{12}O_6}{1 \text{ kg } H_2O} = 0.500 \textit{ m } C_6H_{12}O_6 \text{ soln.}$$

EXAMPLE 5

Calculate the mass of ethanol that must be dissolved in 750.0 g of water to make a 2.00 *m* ethanol solution.

Solving Process:

The concentration unit 2.00 *m* ethanol solution can be written as

$$\frac{2.00 \text{ moles } CH_3CH_2OH}{1000.0 \text{ g } H_2O}$$

To obtain the mass of CH_3CH_2OH, multiply the mass of water by the concentration unit and then convert to grams of ethanol by using the molecular mass of the solute, 46.1 grams CH_3CH_2OH.

$$\text{Mass of solute} = \frac{750.0 \text{ g } H_2O}{1000.0 \text{ g } H_2O} \mid \frac{2.00 \text{ mole } CH_3CH_2OH}{1 \text{ mole } CH_3CH_2OH} \mid \frac{46.1 \text{ g } CH_3CH_2OH}{} = 69.2 \text{ g } CH_3CH_2OH$$

Problems

4. Calculate the molality of the following solutions.
   a. 1.50 moles $NaCH_3COO$ dissolved in 750.0 g water
   b. 3.00 moles H_2SO_4 dissolved in 1250.0 g water
   c. 50.0 g acetic acid, CH_3COOH, dissolved in 500.0 g water
5. Determine the grams of solute required to prepare the following solutions
   a. 3.00 *m* solution of KOH containing 1500.0 g of water
   b. 0.500 *m* solution CH_3COOH containing 750.0 g of water
6. Calculate the grams of water required to make a 0.500 *m* solution that contains 20.0 g of NaCl

21:4 Mole Fraction

Another way to express solution concentration is mole fraction. The mole fraction (X) of a substance in a solution is defined as the moles of substance divided by the moles of solution (sum of moles of solute + moles of solvent). Mole fraction is a ratio and the units cancel out in the answer.

$$X = \frac{\text{moles solute}}{(\text{moles of solute} + \text{moles of solvent})}$$

The sum of the mole fractions of all the components of a solution equals the total of all the moles present or the "whole". If one multiplies the mole fraction by 100%, you will have the mole percent. In the following example, 99.4% of the molecules in the solution are H_2O.

EXAMPLE 6

What are the mole fractions of glucose and water in a solution made of 7.59 g of glucose, $C_6H_{12}O_6$, dissolved in 125 g of water?

Solving Process:

The molecular mass of glucose is 180.0 g/mole $C_6H_{12}O_6$. Find the moles of glucose.

$$\text{moles glucose} = \frac{7.59 \text{ g } C_6H_{12}O_6}{1 \text{ mole } C_6H_{12}O_6} = 0.0422 \text{ moles } C_6H_{12}O_6$$

The molecular mass of H_2O is 18.0 g/mole H_2O.

$$\text{moles water} = \frac{125 \text{ g } H_2O}{18.0 \text{ g } H_2O \mid 1 \text{ mole } H_2O} = 6.94 \text{ moles } H_2O$$

Determine the mole fraction of $C_6H_{12}O_6$.

$$\text{mole fraction of } C_6H_{12}O_6 = \frac{\text{moles solute}}{(\text{moles solute} + \text{moles solvent})}$$

$$= \frac{0.0422 \text{ moles } C_6H_{12}O_6}{(0.0422 \text{ moles } C_6H_{12}O_6 + 6.94 \text{ moles } C_6H_{12}O_6)} = \frac{0.422}{6.98} = 00.605$$

Determine the mole fraction of H_2O.

$$\text{mole fraction } H_2O = \frac{6.94 \text{ moles } H_2O}{(0.0422 \text{ moles } C_6H_{12}O_6 + 6.94 \text{ moles } C_6H_{12}O_6)} = \frac{6.94}{6.98} = 0.994$$

To determine percent

$$\frac{0.994}{1} \mid \frac{100\% \text{ water}}{} = 99.4\% \text{ water}$$

Problems

Calculate the mole fraction for both components in the following solutions.

7. 22.5 g CH_3CH_2OH in 1.00 x 10^2 g H_2O
8. 39.5 g $C_6H_5CH_3$, toluene, in 1.50 x 10^2 g C_6H_6, benzene

Chapter Review Problems

1. Calculate the molarity of the following solutions.
   a. 500.0 cm^3 that contains 82.0 g calcium nitrate
   b. 250.0 cm^3 that contains 50.0 g copper II sulfate pentahydrate
   c. 1000.0 cm^3 that contains 116 g sodium carbonate heptahydrate
2. Calculate the mass of solute in the following solutions.
   a. 250.0 cm^3 of $Na_2SO_4 \cdot 7\ H_2O$ solution that is 2.00 M $Na_2SO_4 \cdot 7\ H_2O$ solution
   b. 1500.0 dm^3 of KH_2PO_4 solution that is 0.240 M KH_2PO_4 solution
   c. 2500.0 cm^3 of a HNO_3 solution that is 4.00 M HNO_3 solution

3. How many cubic decimeters of solution can be made from each of the following"
    a. 0.100 M solution using 117 g sodium chloride
    b. 1.00 M solution using 50.0 g copper II sulfate pentahydrate
    c. 0.200 M solution using 200.0 g sodium sulfide
4. How many grams of lead II acetate, $Pb(CH_3COO)_2$, must be used to make 500.0 cm^3 of a solution that is to contain 10.0 mg/cm^3 of lead ions? What is the molarity of this solution?
5. Calculate the molality of the following solutions.
    a. 15.0 g ethanol dissolved in 250.0 g water
    b. 10.0 g glucose $C_6H_{12}O_6$, dissolved in 500.0 g water
    c. 1.204×10^{24} molecules CH_3COOH dissolved in 1500.0 g water
6. Determine the grams of solute required to prepare each of the following solutions.
    a. 2.50 *m* solution of $C_6H_{12}O_6$ containing 2000.0 g water
    b. 1.25 *m* solution of NaCl containing 250.0 g water
7. Determine the mass of ethylene glycol, $C_2H_4(OH)_2$, which must be dissolved in 2500.0 g water to make a 4.00 *m* $C_2H_4(OH)_2$ solution.
8. Calculate the mole fraction of methanol, CH_3OH, when 3.20 g of methanol are dissolved in 4.61 g of ethanol CH_3CH_2OH.
9. A laboratory experiment requires 0.100 M $Pb(NO_3)_2$. How many grams of $Pb(NO_3)_2$ are needed to make 175 cm^3 of the $Pb(NO_3)_2$ solution?
10. A teacher needs to prepare 15 sets of solutions for a chemistry lab. Each set must have 70.0 cm^3 of 0.200 M $FeSO_4 \cdot 7\ H_2O$ solution. What mass of $FeSO_4 \cdot 7\ H_2O$ is required to prepare enough solution for the class?

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