Chapter 17. Solutions

17.1. Molecular Mixtures

A **chemical solution** is a mixture of molecules, called *components* of the mixture. Two-component solutions are called **binary solutions**, the focus of this chapter. The relative amounts of the various components are called their respective **concentrations**. The term **solvent** is usually applied to the substance in greatest concentration, although it is sometimes used to describe a substance that can dissolve other substances without regard to the amount. Minor components are called **solutes**.

17.2. Concentration Units

A variety of solutions concentration units are used for different applications in chemistry. It is useful to know how to convert between various concentration units and to have a feeling for the relative magnitudes of the different units for a given solution. Conversion formulas are based on concentration unit definitions, and the process of converting from one set of units to another can be systematized into useful algorithms.

Table 17.1 Concentration Unit Definitions

Name	*Definition*	*Common Uses*
Mass percent	$\%_{\text{mass}_i} = 100\,\frac{\text{mass}_i}{\text{mass}_{\text{total}}}$	liquid and solid solutions
Volume percent	$\%_{\text{volume}_i} = 100\,\frac{\text{volume}_i}{\text{volume}_{\text{total}}}$	liquid solutions
Molarity	$M_i = \frac{\text{mols}_i}{\text{liters}_{\text{solution}}}$	liquid solutions
Normality	$N_i = \frac{\text{equivalents}_i}{\text{liters}_{\text{solution}}}$	titrations
Molality	$m_i = \frac{\text{mols}_i}{\text{kg}_{\text{solvent}}}$	colligative properties
Mole fraction	$X_i = \frac{\text{mols}_i}{\text{mols}_{\text{total}}}$	gas solutions

Note that since concentrations are fractions, converting between different concentration units may require converting numerator and/or denominator units. Molar mass, density and percentage conversion factors are useful for these conversions. Since solution conversion calculations just apply the definitions, no general algorithm is needed. However, a useful heuristic is to assume 100 g of the solution to handle mass percentage concentration conveniently.

Example 17.1 What is the molarity, mol fraction, and molality of a $4\%_{\text{mass}}$ aqueous solution of CH_3CO_2H? (Density of solution = 1.0058 g/mL.)

100 g solution contains 4 g CH_3CO_2H plus 96 g H_2O. Also, we will need the molar mass of CH_3CO_2H, 60 g/mol.

$$M_{CH_3CO_2H} = \frac{4/60\text{ mol}}{100\text{ g }(\frac{10^{-3}\text{L}}{1.0058\text{ g}})} = 0.670\text{mol/L}$$

$$X_{CH_3CO_2H} = \frac{4/60\ \text{mol}}{(4/60\ \text{mol} + 96/18\ \text{mol})} = 0.0123$$

$$m_{CH_3CO_2H} = \frac{4/60\ \text{mol}}{96 \times 10^{-3}\text{Kg}} = 0.694\ \text{kg/mol}$$

17.3. Concentrations as Conversion Factors

Concentrations are fractional quantities with units in numerator and denominator. Thus they serve to convert between various measures of amounts matter in solution. They are commonly used to connect the amount of solute with the amount of solution. Because chemists frequently work with solutions, measuring volumes may be easier or more accurate than measuring masses.

Example 17.2 How many grams of table salt, NaCl should be weighed out to make 500 mL of a 0.10 M salt solution?

Molarity has mols of solute and liters of solution. Mols of NaCl can be converted to grams through molar mass.

$$500\ \text{mL}_{soln} \times \left(\frac{1\text{L}_{soln}}{1000\ \text{mL}_{soln}}\right) \times \left(\frac{0.10\ \text{mol}_{NaCl}}{1\text{L}_{soln}}\right) \times \left(\frac{58.5\ \text{g}_{NaCl}}{1\ \text{mol}_{NaCl}}\right) = 2.93\ \text{g}_{NaCl}$$

17.4. Solubility

The degree to which substances dissolve is called **solubility**. Since gas molecules are widely separated, all gases dissolve in each other in any amount. The molecules in condensed phases interact closely, and dissolution depends on the mutual interactions. Essentially, substances which are attracted equally or more to other substances than to each other will tend to dissolve. This leads to the heuristic, *like dissolves like*.

Solubility Heuristic

Purpose: To determine the solubility of a given substance in another.

Procedure:

1. Determine the type of bonding which may exist between the atoms and molecules of the given substance from the Basic Bonding and Phase of Matter Heuristics.
2. Assume the more similar the substances, the greater they dissolve.

   Gases are completely soluble in gases.

   Metals are quite soluble in metals (alloys).

   Polar substances are soluble in polar substances, and non-polar in non-polar. Salts with low ionic charges are usually soluble in water. Salts with high ionic charges are usually insoluble in water.

Example 17.3 Discuss the solubilities of methane, hydrogen chloride, sodium chloride, silver chloride, red rust and sugar in water and in gasoline.

1. Methane, or natural gas, CH_4, is a non-polar covalent gas. Hydrogen chloride, HCl, is a polar covalent gas. Sodium chloride, or table salt, NaCl, is an ionic solid with low ionic charges. Silver chloride, AgCl, is a more covalent solid with low ionic charges. Red rust, an iron oxide, Fe_2O_3, and is an ionic solid with high ionic charges. Sugar, a carbohydrate, $C_6H_{12}O_6$, is a polar covalent solid. Water, H_2O, is a polar covalent liquid. Gasoline, a mixture of hydrocarbons, may be represented by octane, C_8H_{18}, a non-polar liquid.
2. Non-polar methane does not dissolve appreciably in water, but dissolves easily in gasoline. Hydrogen chloride gas dissolves in water, and undergoes chemical ionization to produce hydrochloric acid. Polar hydrogen chloride is quite insoluble in gasoline. Sodium chloride is polar like water and dissolves appreciably in water, but not octane. Silver chloride is just the opposite and does not dissolve appreciably in water, but does in octane. Iron oxide has high charges (+2 or +3), and is insoluble in water and non-polar octane. Sugar hydrogen bonds like water and is soluble in

water, but insoluble in nonpolar gasoline.

Substances which ionize in solution can carry electrical current and are called **electrolytes**. Hydrochloric acid and salt are strong electrolytes, while methane and sugar are nonelectrolytes.

Summary

Chemical solutions are molecular mixtures of variable composition. The relative amounts of the components is specified by the concentration, a fraction with units that can be used as a conversion factor.

SOLUTION STATE EXERCISES

1. What are the mole fractions of a 50% gaseous solution?
2. What are the mass percentages of a 50% gaseous solution of Ar and Xe?

SOLUTION STATE EXERCISE HINTS

1. Consider the definitions of concentration.
2. Consider the definitions of concentration.