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Theodore L. Brown; H. Eugene LeMay, Jr.; Bruce E. Bursten; Catherine J. Murphy

Chapter 13
Properties of Solutions

Ahmad Aqel Ifseisi
Assistant Professor of Analytical Chemistry
College of Science, Department of Chemistry
King Saud University
P.O. Box 2455 Riyadh 11451 Saudi Arabia
Building: 05, Office: 1A7 & AA53
Tel. 014674198, Fax: 014675992
Web site: http://fac.ksu.edu.sa/aifseisi
E-mail: ahmad3qel@yahoo.com
aifseisi@ksu.edu.sa

كرسي أبحاث المواد المتقدمة
Advanced Materials Research Chair
AMRC

جامعة الملك سعود
King Saud University

Solutions

- **Solutions** are homogeneous mixtures of two or more pure substances.
- In a solution, the **solute** is dispersed uniformly throughout the **solvent**.

State of Solution	State of Solvent	State of Solute	Example
Gas	Gas	Gas	Air
Liquid	Liquid	Gas	Oxygen in water
Liquid	Liquid	Liquid	Alcohol in water
Liquid	Liquid	Solid	Salt in water
Solid	Solid	Gas	Hydrogen in palladium
Solid	Solid	Liquid	Mercury in silver
Solid	Solid	Solid	Silver in gold

13.4
Ways of Expressing Concentration

Ways of Expressing Concentration

The concentration of a solution can be expressed either:

- **Qualitatively**, or
- **Quantitatively**.

The terms **dilute** and **concentrated** are used to describe a solution qualitatively.

Several different ways used to express concentration quantitatively, such as

- **Mass percentage**,
- **Mole fraction**,
- **Molarity**, and
- **Molality**.

Mass Percentage, ppm and ppb

$$\text{Mass \% of component} = \frac{\text{mass of component in soln}}{\text{total mass of soln}} \times 100$$

A solution of hydrochloric acid with 36% **HCl** by mass contains 36 g of **HCl** for each 100 g of solution.

Solute weight = 36 g
Solvent weight = 64 g
Total solution weight = 100 g

The concentrations of very dilute solution often express in parts per million (**ppm**) or part per billion (**ppb**).

1 ppm = 1000 ppb

$$\text{ppm of component} = \frac{\text{mass of component in soln}}{\text{total mass of soln}} \times 10^6$$

A solution whose solute concentration is 1 ppm contains 1 g of solute for each million (10^6) grams of solution.

This equivalent 1 mg of solute per kilogram of solution (**mg / kg**).

For aqueous solutions, because the density of water is 1 g/mL, this equivalent 1 mg of solute per liter of solution (**mg / L**).

The acceptable maximum concentrations of toxic or carcinogenic substances in the environment are often expressed in ppm or ppb. For example, the maximum allowable concentration of arsenic in drinking water in USA is 0.010 ppm; that is 0.010 mg of arsenic per liter of water, this corresponds to 10 ppb.

Sample Exercise 13.4 Calculation of Mass-Related Concentrations

(a) A solution is made by dissolving 13.5 g of glucose ($C_6H_{12}O_6$) in 0.100 kg of water. What is the mass percentage of solute in this solution? **(b)** A 2.5-g sample of groundwater was found to contain 5.4 μg of Zn^{2+}. What is the concentration of Zn^{2+} in parts per million?

Solution

(a) The mass percentage of water in this solution is (100 – 11.9)% = 88.1%.

Solve: $$\text{Mass \% of glucose} = \frac{\text{mass glucose}}{\text{mass soln}} \times 100 = \frac{13.5\text{ g}}{13.5\text{ g} + 100\text{ g}} \times 100 = 11.9\%$$

(b) In this case we are given the number of micrograms of solute. Because 1 μg is 1×10^{-6} g, 5.4 μg = 5.4×10^{-6} g.

Solve: $$\text{ppm} = \frac{\text{mass of solute}}{\text{mass of soln}} \times 10^6 = \frac{5.4 \times 10^{-6}\text{ g}}{2.5\text{ g}} \times 10^6 = 2.2\text{ ppm}$$

Practice Exercise

(a) Calculate the mass percentage of NaCl in a solution containing 1.50 g of NaCl in 50.0 g of water. **(b)** A commercial bleaching solution contains 3.62 mass % sodium hypochlorite, NaOCl. What is the mass of NaOCl in a bottle containing 2.50 kg of bleaching solution?

Answer: **(a)** 2.91%, **(b)** 0.0905 kg NaOCl (90.5 g).

Mole Fraction, Molarity and Molality

$$\text{Mole fraction of component} = \frac{\text{moles of component}}{\text{total moles of all components}}$$

The symbol ***X*** is commonly used for mole fraction, with a subscript to indicate the component of interest.

$$X_A = \frac{\textbf{moles of A}}{\textbf{total moles in solution}}$$

For example; a solution containing 1.00 mol of HCl (36.5 g) and 8.00 mol water (144 g) has a mole fraction of HCl and water:

$\boldsymbol{X_{HCl}}$ **= (1.00 mol) / (1.00 mol + 8.00 mol) = 0.111**

$\boldsymbol{X_{H2O}}$ **= (8.00 mol) / (1.00 mol + 8.00 mol) = 0.889 or 1.00 – 0.111 = 0.889**

Mole fraction has no unit (the units in the numerator and the denominator cancel).
The sum of the mole fractions of all components of a solution must equal 1.

The Molarity ***M*** of a solute in a solution is defined as:

$$\boxed{\text{Molarity} = \frac{\text{moles solute}}{\text{liters soln}}}$$

Since volume is temperature-dependent, molarity can change with temperature.

The Molality ***m*** of a solution, defined as:

$$\boxed{\text{Molality} = \frac{\text{moles of solute}}{\text{kilograms of solvent}}}$$

Since both moles and mass do not change with temperature, molality (unlike molarity) is *not* temperature-dependent. Thus molality is often the concentration unit of choice when a solution is to be used over a range of temperatures.

Sample Exercise 13.5 Calculation of Molality

A solution is made by dissolving 4.35 g glucose ($C_6H_{12}O_6$) in 25.0 mL of water at 25 ^oC. Calculate the molality of glucose in the solution. Water has a density of 1.00 g/mL.

Solution

Use the molar mass of glucose, 180.2 g/mL, to convert grams to moles:

$$\text{Mol } C_6H_{12}O_6 = (4.35 \text{ g } C_6H_{12}O_6)\left(\frac{1 \text{ mol } C_6H_{12}O_6}{180.2 \text{ g } C_6H_{12}O_6}\right) = 0.0241 \text{ mol } C_6H_{12}O_6$$

Because water has a density of 1.00 g/mL, the mass of the solvent is

$$(25.0 \text{ mL})(1.00 \text{ g/mL}) = 25.0 \text{ g} = 0.0250 \text{ kg}$$

Finally, the molality:

$$\text{Molality of } C_6H_{12}O_6 = \frac{0.0241 \text{ mol } C_6H_{12}O_6}{0.0250 \text{ kg } H_2O} = 0.964\ m$$

Practice Exercise

What is the molality of a solution made by dissolving 36.5 g of naphthalene ($C_{10}H_8$) in 425 g of toluene (C_7H_8)?

Answer: 0.670 *m*

Conversion of Concentration units

Sample Exercise 13.6 Calculation of Mole Fraction and Molality

An aqueous solution of hydrochloric acid contains 36% HCl by mass. **(a)** Calculate the mole fraction of HCl in the solution. **(b)** Calculate the molality of HCl in the solution.

Solution

(a) To calculate the mole fraction of HCl, we convert the masses of HCl and H_2O to moles:

$$\text{Moles HCl} = (36\text{ g HCl})\left(\frac{1\text{ mol HCl}}{36.5\text{ g HCl}}\right) = 0.99\text{ mol HCl}$$

$$\text{Moles H}_2\text{O} = (64\text{ g H}_2\text{O})\left(\frac{1\text{ mol H}_2\text{O}}{18\text{ g H}_2\text{O}}\right) = 3.6\text{ mol H}_2\text{O}$$

$$X_{\text{HCl}} = \frac{\text{moles HCl}}{\text{moles H}_2\text{O} + \text{moles HCl}} = \frac{0.99}{3.6 + 0.99} = \frac{0.99}{4.6} = 0.22$$

(b) To calculate the molality of HCl in the solution, We use the calculated number of moles of HCl in part (a), and the mass of solvent is 64 g = 0.064 kg:

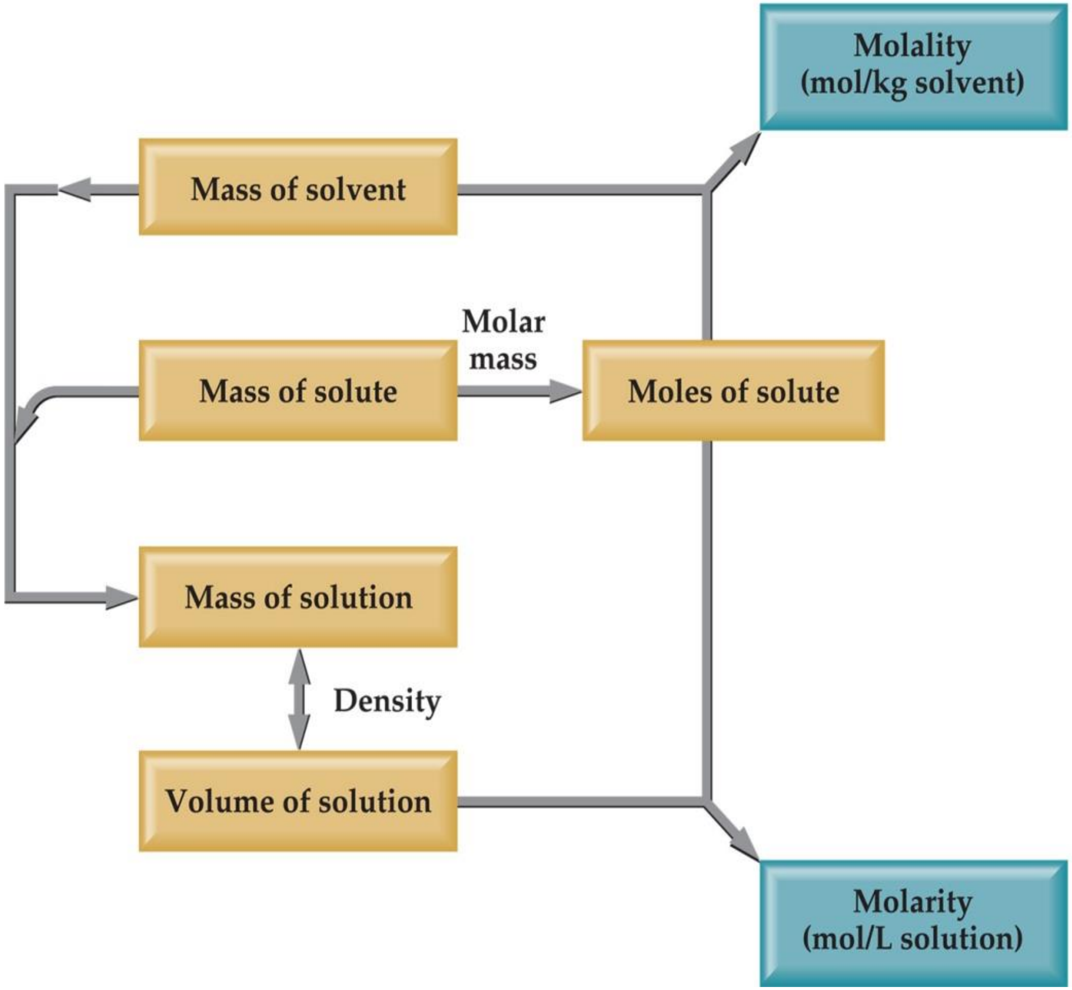
$$\text{Molality of HCl} = \frac{0.99\text{ mol HCl}}{0.064\text{ kg H}_2\text{O}} = 15\ m$$

Practice Exercise

A commercial bleach solution contains 3.62 mass % NaOCl in water. Calculate **(a)** the mole fraction and **(b)** the molality of NaOCl in the solution.

Answer: **(a)** 9.00×10^{-3}, **(b)** 0.505 *m*.

Changing Molarity to Molality



If we know the **density** of the solution, we can calculate the molality from the molarity and vice versa.

Sample Exercise 13.7 Calculation of Molality Using the Density of a Solution

A solution with a density of 0.876 g/mL contains 5.0 g of toluene (C_7H_8) and 225 g of benzene. Calculate the molarity of the solution.

Solution

The volume of the solution is obtained from the mass of the solution (mass of solute + mass of solvent = 5.0 g + 225 g = 230 g) and its density.

$$\text{Moles } C_7H_8 = (5.0\text{ g } C_7H_8)\left(\frac{1\text{ mol } C_7H_8}{92\text{ g } C_7H_8}\right) = 0.054\text{ mol}$$

The density of the solution is used to convert the mass of the solution to its volume:

$$\text{Milliliters soln} = (230\text{ g})\left(\frac{1\text{ mL}}{0.876\text{ g}}\right) = 263\text{ mL}$$

Molarity is moles of solute per liter of solution:

$$\text{Molarity} = \left(\frac{\text{moles } C_7H_8}{\text{liter soln}}\right) = \left(\frac{0.054\text{ mol } C_7H_8}{263\text{ mL soln}}\right)\left(\frac{1000\text{ mL soln}}{1\text{ L soln}}\right) = 0.21\ M$$

Comment: Because the mass of the solvent (0.225 kg) and the volume of the solution (0.263 L) are similar in magnitude, the molarity and molality are also similar in magnitude:

$$(0.054\text{ mol } C_7H_8)/(0.225\text{ kg solvent}) = 0.24\ m$$

Practice Exercise

A solution containing equal masses of glycerol ($C_3H_8O_3$) and water has a density of 1.10 g/mL. Calculate **(a)** the molality of glycerol, **(b)** the mole fraction of glycerol, **(c)** the molarity of glycerol in the solution.

Answer: **(a)** 10.9 m, **(b)** X_{C3H8O3}= 0.163, **(c)** 5.97 M

Q & A

A solution of SO_2 in water contains 0.00023 g of SO_2 per milli liter of solution. What is the concentration of SO_2 in ppm? In ppb?

0.00023 g / mL = 230 mg / L = 230 ppm

1 ppm = 1000 ppb

230 ppm = 23×10^4 ppb

The molality of a solution is found by dividing the amount of solute in moles by the:

a. volume of the solution in liters
b. mass of the solvent in kilograms
c. mass of the solution in kilograms
d. total number of moles

When concentration is expressed in units of __________ , changing temperature will affect the solution concentration.

- molality
- molarity
- ppm
- molarity and molality
- molarity, molality, and ppm


Thank You!