SOLUTIONS
2: SOLUTION CONCENTRATIONS

Dr. Sapna Gupta

SOLUTION CONCENTRATIONS

There are a number of ways one can measure concentration of solute in solutions.

- Molarity (M)– commonly used since volumes of solutions are easy to measure.
- Mole fraction (χ) – used for gases and vapor pressures of solutions.
- Molality (*m*) – temperature independent.
- Percent by Mass or volume – temperature independent and need not know molar masses.

Conversion between units requires the use of density if any mass to volume or volume to mass conversion in needed.

VARIOUS UNITS OF SOLUTIONS

- Molarity (mol/L)

$$\text{M} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

- Mass percent (mass/mass; mass/vol; vol/vol – the denominator is solution)

$$\text{Mass percent of solute} = \frac{\text{grams of solute}}{\text{grams of solution}} \times 100\%$$

- Molality (mol/Kg)

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

- Mole fraction

$$\chi = \frac{\text{moles of solute}}{\text{total moles of solution}}$$

- Parts per million

$$ppm = \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^6$$

- Parts per billion

$$ppb = \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^9$$

EXAMPLE 1: MASS PERCENT

An experiment calls for 36.0 g of a 5.00% aqueous solution of potassium bromide. Describe how you would make such a solution.

Answer:

A 5.00% aqueous solution of KBr has 5.00 g KBr per 100. g solution. The remainder of the 100. g is water: 95 g.

We can use this ratio to determine the mass of KBr in 36.0 g solution:

$$36.0 \text{ g solution} \times \frac{5.00 \text{ g KBr}}{100. \text{ g solution}} = 1.80 \text{ g KBr}$$

Since 1.80 g KBr is required for 36.0 g of solution, the remainder consists of 34.2 g water.

$$36.0 \text{ solution} - 1.80 \text{ g KBr} = 34.2 \text{ g } H_2O$$

We make the solution by mixing 1.8 g KBr in 34.2 g water.

EXAMPLE 2: MOLALITY

Iodine dissolves in a variety of organic solvents. For example, in methylene chloride, it forms an orange solution. What is the molality of a solution of 5.00 g iodine, I_2, in 30.0 g of methylene chloride, CH_2Cl_2?

Answer:

Mass of solute = 5.00 g I_2; Mass of solvent = 30.0 g CH_2Cl_2

Strategy: Calculate mols of the solute -> convert the mass of solvent into kg.

You can do this in two steps or one using dimensional analysis.

Two steps: _Step 1_ – find mols of I_2: $5.00\ g\ I_2 \times \frac{1\ mol\ I_2}{253.8\ g\ I_2} = 0.197\ mol\ I_2$

Step 2: Divide mol by kg of solvent: 0.197 mol/0.03 kg = $\boxed{\mathbf{0.657}\ \boldsymbol{m}}$

One step: $$m = \frac{5.00\ \text{g}\ \cancel{\text{I}_2}}{30.0\ \text{g}\ \cancel{\text{solvent}}} \times \frac{1\ \text{mol}\ \text{I}_2}{253.8\ \cancel{\text{g}\ \text{I}_2}} \times \frac{10^3\ \cancel{\text{g}}}{1\ \text{kg}} = \boxed{\frac{0.657 mol}{kg}\ or\ \mathbf{0.657}\ \boldsymbol{m}}$$

EXAMPLE 3: MOL FRACTION

A solution of iodine, I_2, in methylene chloride, CH_2Cl_2, contains 5.00 g I_2 and 56.0 g CH_2Cl_2. What is the mole fraction of each component in this solution?

Answer:

Mass of solute = 5.00 g I_2

Mass of solvent = 56.0 g CH_2Cl_2

Strategy: Find moles of both -> add the moles -> calculate mol fraction of each.

$$\text{Mols solute} \;=\; 5.00\text{ g I}_2 \times \frac{1\text{ mol I}_2}{253.8\text{ g I}_2} = 0.01970\text{ mol}$$

$$\text{Mols solvent} \;=\; 56.0\text{ g I}_2 \times \frac{1\text{ mol CH}_2\text{Cl}_2}{84.93\text{ g CH}_2\text{Cl}_2} = 0.6594\text{ mol}$$

$$\text{Total moles} \;=\; 0.01970\text{ mol} + 0.6594\text{ mol} \;=\; 0.6791\text{ mol}$$

$$\chi_{\text{I}_2} \;=\; \frac{0.01970\text{ mol I}_2}{0.6791\text{ mol total}} = \boxed{\mathbf{0.0290}} \qquad \chi_{\text{CH}_2\text{Cl}_2} \;=\; \frac{0.6594\text{ mol CH}_2\text{CI}_2}{0.6791\text{ mol total}} = \boxed{\mathbf{0.971}}$$

EXAMPLE 4: UNIT CONVERSIONS; MASS % TO MOL FRACTION

A bottle of bourbon is labeled 94 proof, meaning that it is 47% by volume of alcohol in water. What is the mole fraction of ethyl alcohol, C_2H_5OH, in the bourbon? The density of ethyl alcohol is 0.80 g/mL.

Answer:

Strategy: When no volume is given then assume it is 1L. So, there is 470 mL alcohol and 530 mL water. Find masses of both -> convert to mols -> find mol fractions.

$$470\text{ mL } C_2H_5OH \times \frac{0.80\text{ g}}{1\text{ mL}} \times \frac{1\text{ mol}}{46.08\text{ g}} = 8.16\text{ mol}$$

$$530\text{ mL } H_2O \times \frac{1.00\text{ g}}{1\text{ mL}} \times \frac{1\text{ mol}}{18.02\text{ g}} = 29.4\text{ mol}$$

$$\text{Total moles} = 8.16\text{ mol} + 29.4\text{ mol} = 37.6\text{ mol}$$

$$\chi_{\text{ethanol}} = \frac{8.16\text{ mol } C_2H_5OH}{37.6\text{ mol total}} = \boxed{\mathbf{0.22}}$$

EXAMPLE 5: UNIT CONVERSION; MOLALITY TO MOLARITY

Citric acid, $HC_6H_7O_7$, is often used in fruit beverages to add tartness. An aqueous solution of citric acid is 2.331 *m* $HC_6H_7O_7$. What is the molarity of the solution? The density of the solution is 1.135 g/mL.

Answer:

2.331 *m* means – 2.331 mols of citric acid in 1.000 kg ***SOLVENT***; molarity is mols over L of ***SOLUTION***.

Strategy: Convert mols citric acid to mass -> mass of solution -> use *d* to find L of solution.

$$\text{Mass solute} = 2.331\ \text{mol} \times \frac{192.14\ \text{g}}{1\ \text{mol}} = 447.88\ \text{g}$$

$$\text{Mass of solution} = 447.88\ \text{g} + 1000.00\ \text{g} = 1447.88\ \text{g}$$

$$\text{Liters solution} = 1447.88\ \text{g} \times \frac{1\ \text{mL}}{1.135\ \text{g}} \times \frac{10^{-3}\text{L}}{\text{mL}} = 1.267L$$

$$\text{M} = \frac{2.331\ \text{mol}}{1.2761\ \text{L}} = \boxed{\mathbf{1.827}\ \frac{\boldsymbol{mol}}{\boldsymbol{L}}}$$

KEY CONCEPTS

- Know all the units of solutions
- Convert one unit of concentration to another.