Module 3: Representing Amounts of Substances

Solutions and Concentration

Fundamentals of Chemistry Open Course

Learning Objectives | Module 3

1. Explain the significance of Avogadro's number and why the value $6.022 \times 10^{23}\ mol^{-1}$ is a convenient definition of the mole.

2. Use average atomic masses to calculate the molar mass of a substance with given chemical formula.

3. Apply molar mass to determine amount of substance from mass and *vice versa*.

4. Define mass density and molar volume; apply them in calculations.

5. Visualize liquid solutions at the submicroscopic level; identify the components of a solution.

6. Define concentration and recognize common units of concentration.

7. Define molarity and apply it to calculate amount of solute from volume of a solution and *vice versa*.

8. Recognize quantities in the ideal gas law and their associated units.

9. Apply the ideal gas law to calculate the amount of a gas from pressure, volume, and temperature.

Solutions are Homogeneous Mixtures

- A **solution** is a homogeneous mixture of two or more components.
  - The major component of a solution is called the **solvent**.
  - The minor components are called **solutes**.
  - In all solutions, we say that the solutes **dissolve** in (or are dissolved in) the solvent.

- The components of a solution may be in any of the three states of matter: solid, liquid, or gas.

- Very commonly, the solute is a liquid and the solution has the appearance of a liquid.

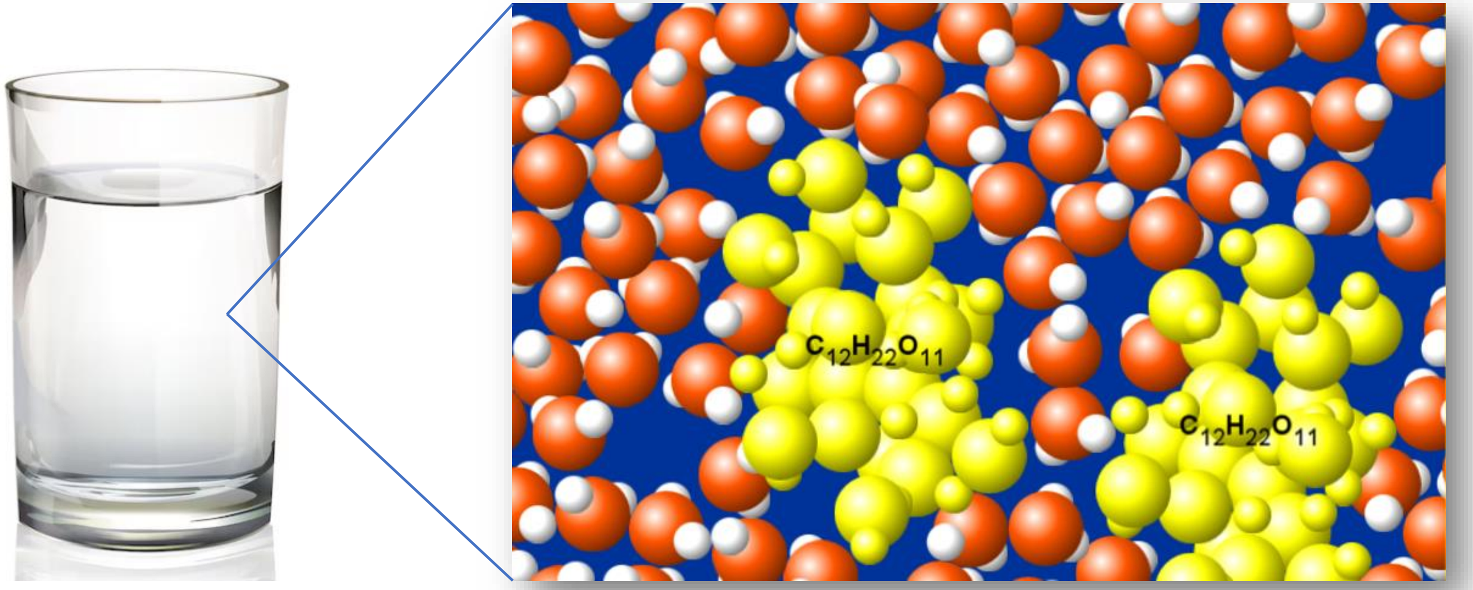

Figure. In a solution of sucrose ($C_{22}H_{22}O_{11}$) in water, solute sucrose molecules are surrounded by solvent water molecules.

Aqueous Solutions

- Liquid solutions in which water (H_2O) is the solvent are called **aqueous solutions**.
- Solutes dissolved in water are given the phase designator (*aq*) in chemical equations, indicating that they are in aqueous solutions.
- For example, the sucrose molecules in a solution of sucrose in water are denoted $C_{12}H_{22}O_{11}(aq)$. This symbolic representation may also refer to the solution as a whole—consider the context.

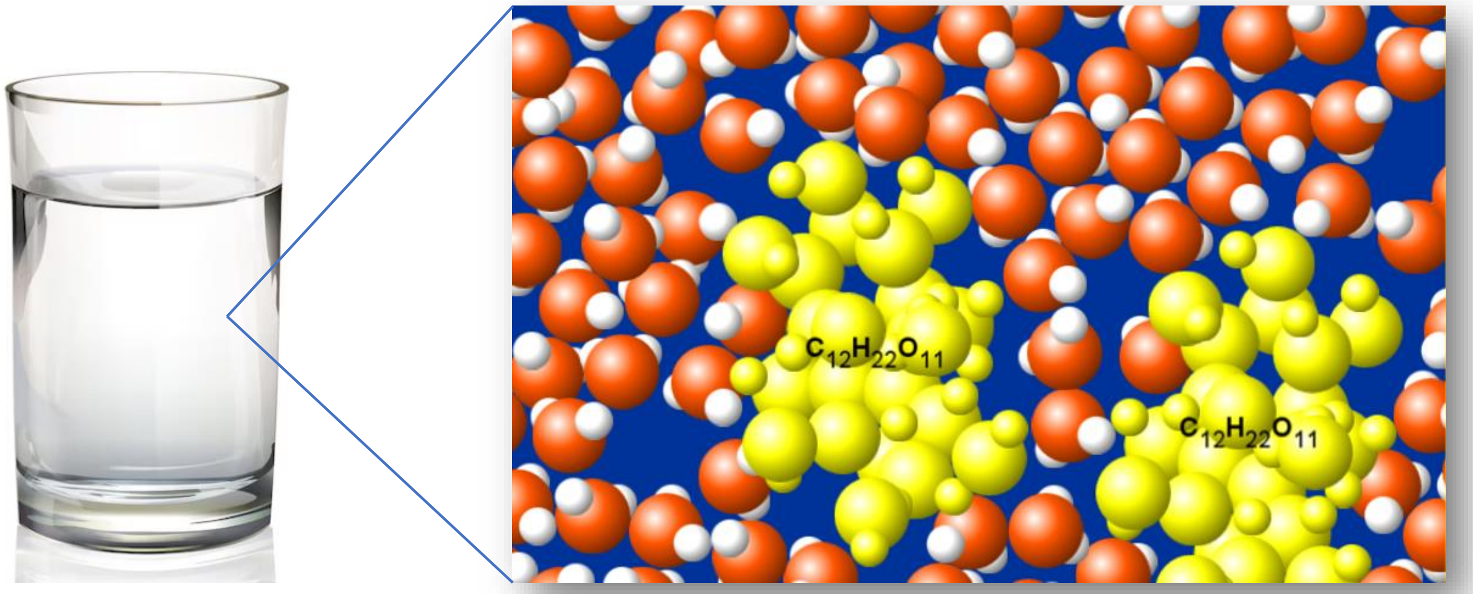

Figure. In a solution of sucrose ($C_{22}H_{22}O_{11}$) in water, solute sucrose molecules are surrounded by solvent water molecules.

Concentration is a Measure of Solute "Density"

- **Concentration** is the amount, mass, or volume of a solute in a fixed amount, mass, or volume of solvent or solution. Higher concentration is associated with a greater density of solute species in the solution.

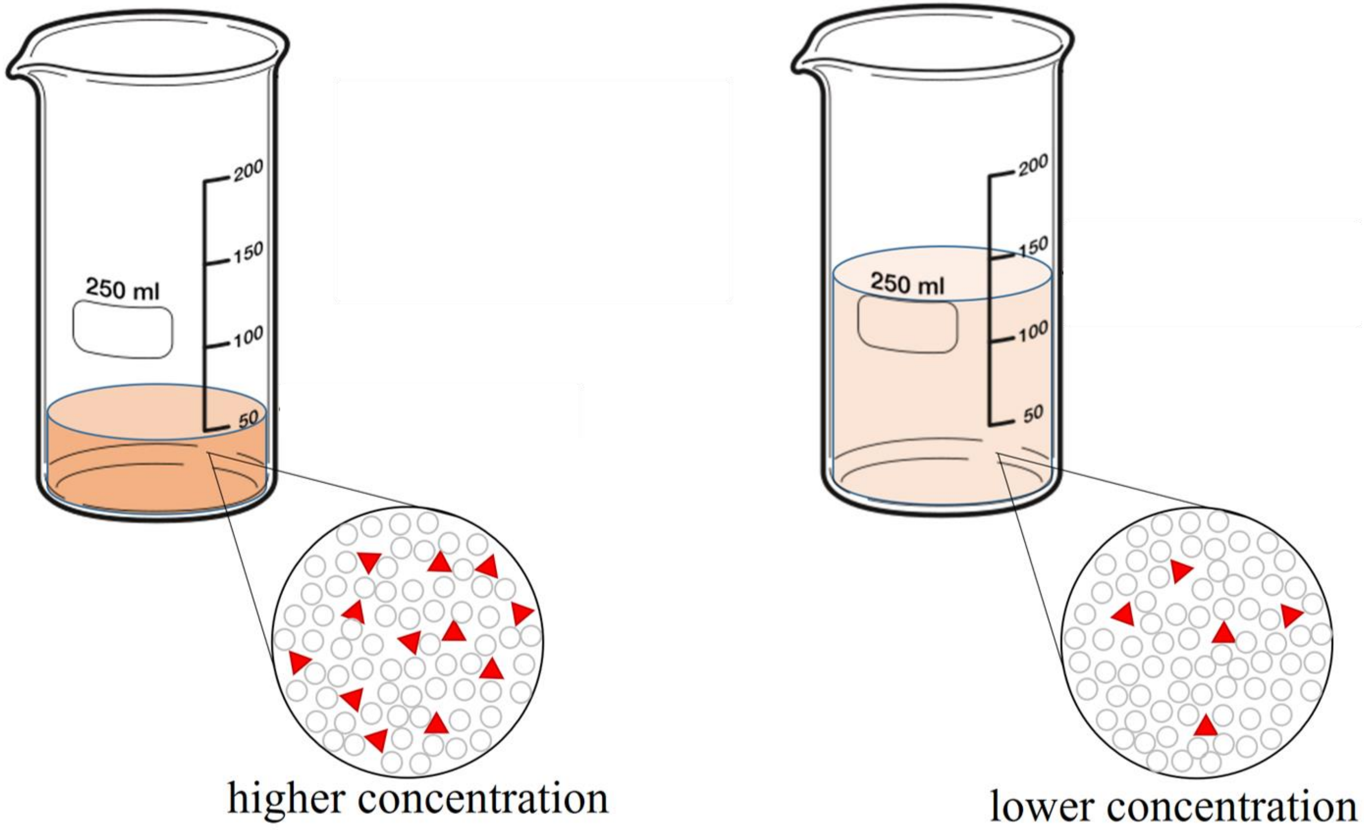

Figure. A solution of higher concentration (left) contains a greater density of solvent species (red triangles) than a solution of lower concentration (right). See concentration and dilution on Wikipedia.

Measures of Concentration

- Concentrations can be expressed in a variety of units; all have the form of amount of solute divided by amount of solution or (rarely) solvent.

  - **Percent by mass (%w/w):** the mass of solute per unit mass of solution times 100%
  - **Percent by volume (%v/v):** the volume of solute per unit volume of solution times 100%
  - **Mass-volume percentage (%w/v):** the mass of solute per unit volume of solution times 100% (e.g., g/mL)
  - **Mole fraction (*x*):** the number of solute particles divided by the total number of particles in the solution

- Concentrations reflect the proportionality between amount of solute and amount of solution in a homogeneous solution. We can use them to find amount of solute from amount of solution or *vice versa*!

Example. Concentrated hydrochloric acid, $HCl(aq)$, has a concentration of 37.2% by mass. What mass of HCl is present in a sample of concentrated hydrochloric acid weighing 85.0 g?

The density of concentrated hydrochloric acid is 1.19 g/mL. What is the concentration of this solution in units of grams per milliliter (g/mL)?

Molarity

- For chemists, the most important unit of concentration is **molarity (mol/L, M)**: moles of solute per liter of solution.

- Molarity reflects the proportionality between the amount in moles of a solute and the volume of the solution. With molarity, we can use volume to count numbers of solute particles!

Example. Given that concentrated hydrochloric acid, HCl(aq), has a concentration of 0.443 g/mL, what is the molarity of HCl in concentrated hydrochloric acid?

Example. Using the result above, how many moles of HCl are present in a concentrated hydrochloric acid solution with a volume of 375 mL?

Lingering Questions

- What other units of concentration are in common use? What about the very small units parts per million (ppm) and parts per billion (ppb)?
- When an ionic salt is dissolved in water, the ions **dissociate**. How does dissociation affect the molarities of ions? Are the molarities of ions in a solution always equal to the molarity of the formula unit?
- What properties of solutions are related to molarity? How can we use measurement of these properties to determine molarity?