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Chapter 4
Aqueous Reactions and Solution Stoichiometry

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Solutions

- **Solutions** are defined as homogeneous mixtures of two or more substances.
- **Solvent**: present in the greater quantities and is used to dissolve the solute.
- All other substances are **solutes**. solutes present in smallest amount and is the substance dissolved in the solvent.
- Example: NaCl dissolved in Water (water = Solvent and NaCl = Solute).

4.5
Concentrations of Solutions

Concentrations of Solutions

Scientists use the term concentration to designate the amount of solute dissolved in a given quantity of solvent or quantity of solution.

Two solutions can contain the same compounds but be quite different because the proportions of those compounds are different.

The greater the amount of solute dissolved in a certain amount of solvent, the more concentrated the resulting solution.

Molarity

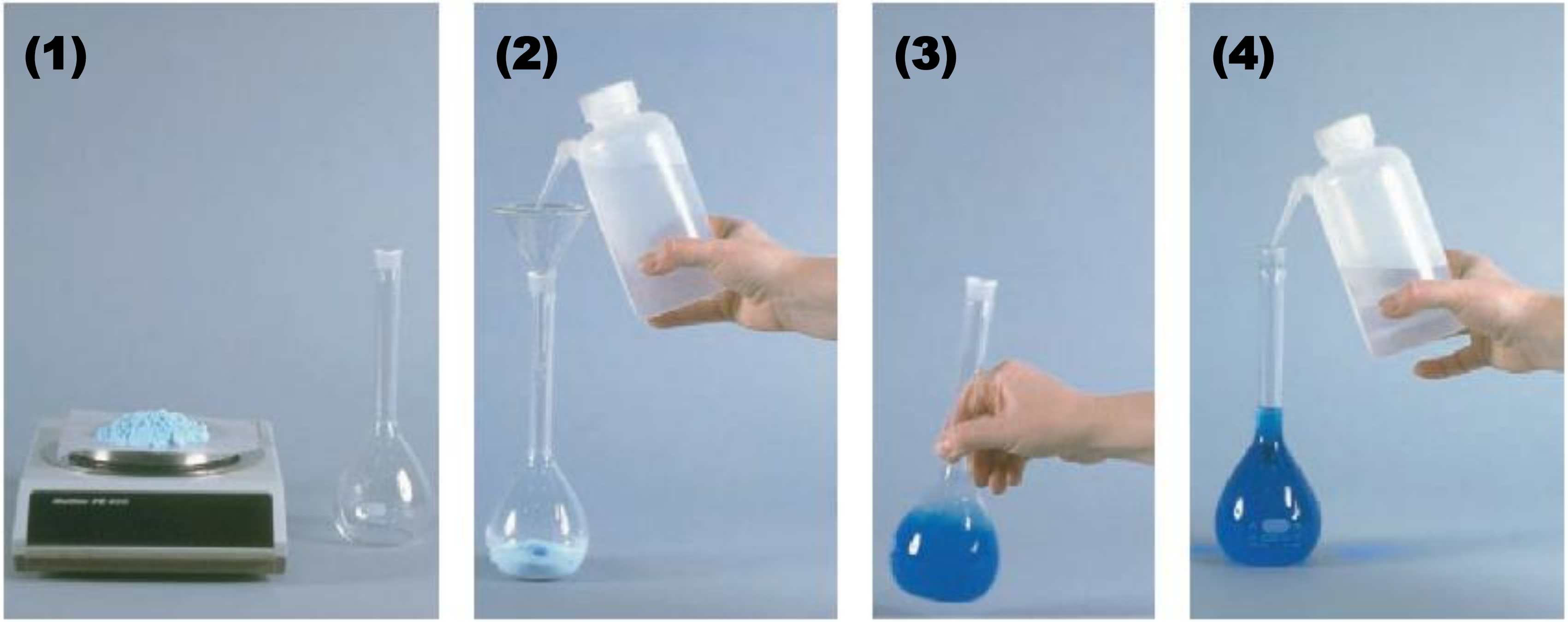
Molarity is one way to measure the concentration of a solution.

Molarity (***M***) expresses the concentration of a solution as the number of moles of solute in a liter of solution:

$$\text{Molarity} = \frac{\text{moles solute}}{\text{volume of solution in liters}}$$

One molar (1.00 *M*) contains 1.00 mole of solute in every liter of solution.

Mixing a Solution



Procedure for preparation of 0.250 L of 1.00 M solution of $CuSO_4$ (MW=159.5 g/mol).

0.25 mole of $CuSO_4$ (39.9 g) is weighed out and placed in the volumetric flask. Water is added to dissolve the salt, and the resultant solution is diluted to a total volume of 250.0 mL. the molarity of the solution is:

(0.250 mol $CuSO_4$) / (0.250 L soln) = 1.00 M

Sample Exercise 4.11 Calculating Molarity

Calculate the molarity of a solution made by dissolving 23.4 g of sodium sulfate (Na_2SO_4) in enough water to form 125 mL of solution.

Solution

$$\text{Moles } Na_2SO_4 = (23.4\ \cancel{g\ Na_2SO_4})\left(\frac{1\ \text{mol } Na_2SO_4}{142\ \cancel{g\ Na_2SO_4}}\right) = 0.165\ \text{mol } Na_2SO_4$$

$$\text{Liters soln} = (125\ \cancel{mL})\left(\frac{1\ L}{1000\ \cancel{mL}}\right) = 0.125\ L$$

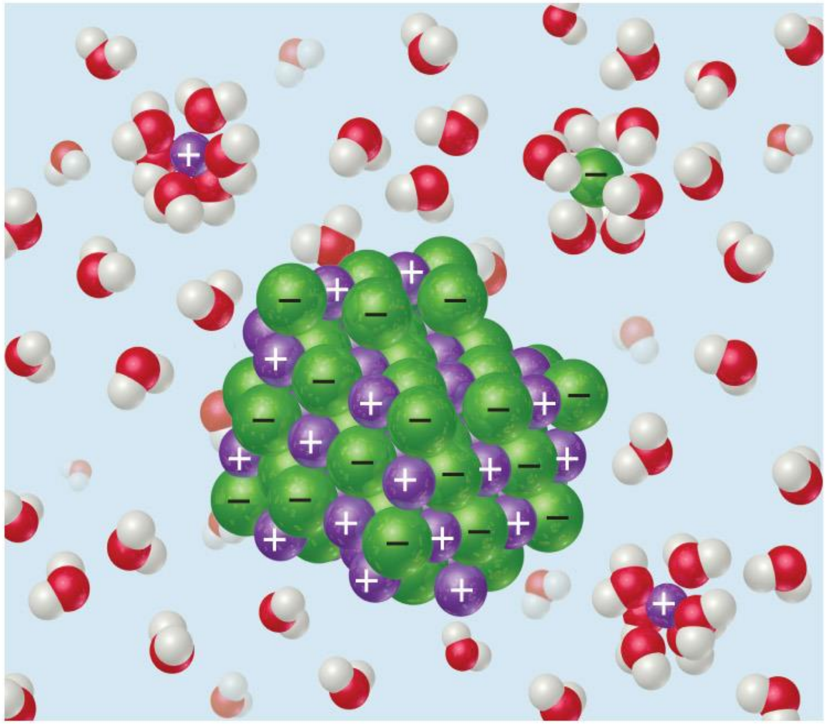
$$\text{Molarity} = \frac{0.165\ \text{mol } Na_2SO_4}{0.125\ \text{L soln}} = 1.32\ \frac{\text{mol } Na_2SO_4}{\text{L soln}} = 1.32\ M$$

Practice Exercise

Calculate the molarity of a solution made by dissolving 5.00 g of glucose ($C_6H_{12}O_6$) in sufficient water to form exactly 100 mL of solution.

Answer: 0.278 *M*

Expressing the Concentration of an Electrolyte



-When an ionic substance dissolves in water, the solvent pulls the individual ions from the crystal and solvates them.

-This process is called **dissociation**.

-An **electrolyte** is a substances that dissociates into ions when dissolved in water.

-A **nonelectrolyte** may dissolve in water, but it does not dissociate into ions when it does so.

Strong and Weak Electrolytes

A **strong electrolyte** dissociates completely when dissolved in water (soluble ionic salts, strong acids and strong bases).
For example:

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

A **weak electrolyte** only dissociates partially when dissolved in water (produce a small concentration of ions when they dissolve, these ions exist in *equilibrium* with the unionized substance).
For example:

$$HC_2H_3O_2(aq) \rightleftharpoons H^+(aq) + C_2H_3O_2^-(aq)$$

When an ionic compound dissolves, the relative concentrations of the ions introduced into the solution depend on the chemical formula of the compound.

For example, a 1.0 M solution of NaCl is 1.0 M in Na^+ ions and 1.0 M in Cl^- ions. Similarly, a 1.0 M solution of Na_2SO_4 is 2.0 M in Na^+ ions and 1.0 M in SO_4^{-2} ions

Sample Exercise 4.12 Calculating Molar Concentrations of Ions

What are the molar concentrations of each of the ions present in a 0.025 *M* aqueous solution of calcium nitrate? ($Ca(NO_3)_2$)

Solution

$Ca(NO_3)_2$ composed of two NO^{3-} ions for each Ca^{2+} ion in the compound, each mole of $Ca(NO_3)_2$ that dissolves dissociates into 1 mol of Ca^{2+} and 2 mol of NO^{3-}.

Thus, a solution that is 0.025 *M* in $Ca(NO_3)_2$ is 0.025 *M* in Ca^{2+} and 2 × 0.025 *M* = 0.050 *M* in NO_3^-:

$$\frac{\text{mol } NO_3^-}{\text{L}} = \left(\frac{0.025 \text{ mol } Ca(NO_3)_2}{\text{L}}\right)\left(\frac{2 \text{ mol } NO_3^-}{1 \text{ mol } Ca(NO_3)_2}\right) = 0.050\ M$$

The concentration of NO^{3-} ions is twice that of Ca^{2+} ions, as the subscript 2 after the NO^{3-} in the chemical formula $Ca(NO_3)_2$ suggests it should be.

Practice Exercise

What is the molar concentration of K^+ ions in a 0.015 *M* solution of potassium carbonate? (K_2CO_3)

Answer: 0.030 *M* K^+

Interconverting Molarity, Moles and Volume

Sample Exercise 4.13 Using Molarity to Calculate Grams of Solute

How many grams of Na_2SO_4 are required to make 0.350 L of 0.500 *M* Na_2SO_4?

Solution

$$M_{Na_2SO_4} = \frac{\text{moles } Na_2SO_4}{\text{liters soln}}$$

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$$\text{moles } Na_2SO_4 = \text{liters soln} \times M_{Na_2SO_4}$$

$$= (0.350 \text{ L soln})\left(\frac{0.500 \text{ mol } Na_2SO_4}{1 \text{ L soln}}\right)$$

$$= 0.175 \text{ mol } Na_2SO_4$$

Because each mole of Na_2SO_4 weighs 142 g, the required number of grams of Na_2SO_4 is

$$\text{grams } Na_2SO_4 = (0.175 \text{ mol } Na_2SO_4)\left(\frac{142 \text{ g } Na_2SO_4}{1 \text{ mol } Na_2SO_4}\right) = 24.9 \text{ g } Na_2SO_4$$

Practice Exercise

(a) How many grams of Na_2SO_4 are there in 15 mL of 0.50 *M* Na_2SO_4? **(b)** How many milliliters of 0.50 *M* Na_2SO_4 solution are needed to provide 0.038 mol of this salt?

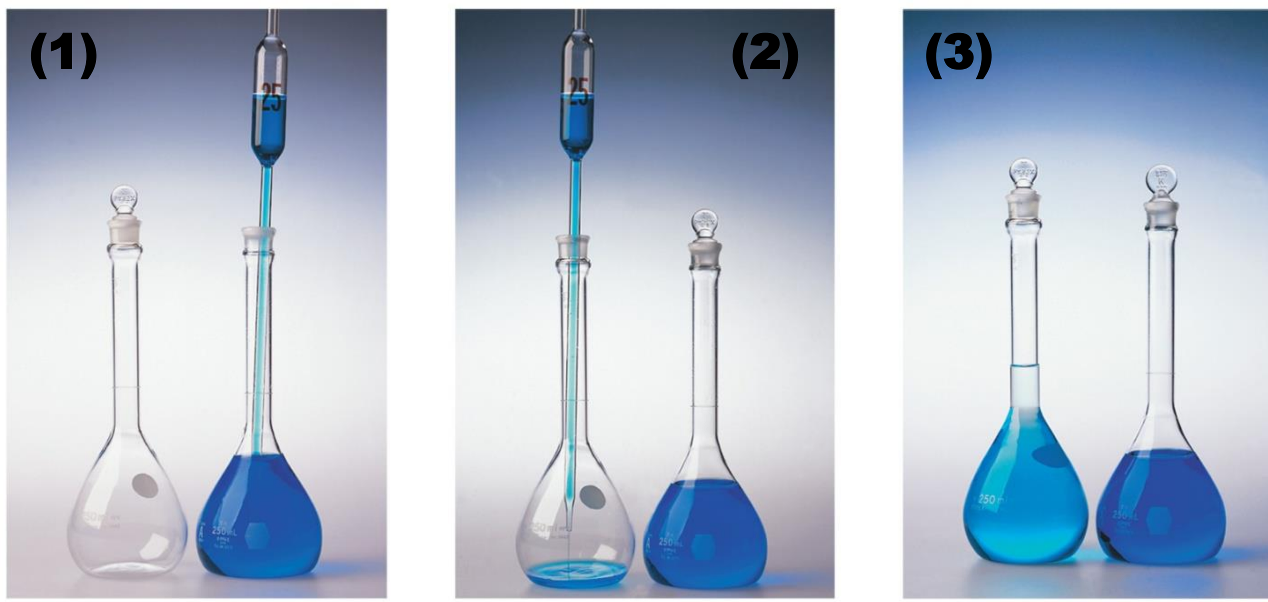
Answers: **(a)** 1.1 g, **(b)** 76 mL

Dilution

One can also dilute a more concentrated solution by:

- Using a pipet to deliver a volume of the solution to a new volumetric flask, and
- Adding solvent to the line on the neck of the new flask.

Procedure for sample dilution



Solutions purchased or prepared in concentrated form called stock solutions. Example: 12 *M* HCl (concentrated HCl).

Solutions of lower concentrations are prepared by adding more solvent (e.g., water), a process called **dilution**.

The number of moles are the same in dilute and concentrated solutions (remains unchanged). Hence,

$$\text{Moles solute before dilution} = \text{moles solute after dilution}$$

Mole = molarity x soln volume (L)

$$\text{moles solute in conc soln} = \text{moles solute in dil soln}$$

$$M_{\text{conc}} \times V_{\text{conc}} = M_{\text{dil}} \times V_{\text{dil}}$$

Where, M_{conc} and M_{dil} are the molarity of the concentrated and dilute solutions, respectively, and V_{conc} and V_{dil} are the volumes of the two solutions.

M_{conc} is always larger than M_{dil}, because V_{dil} is always larger than V_{conc}.

Sample Exercise 4.14 Preparing A solution by Dilution

How many milliliters of 3.0 M H_2SO_4 are needed to make 450 mL of 0.10 M H_2SO_4?

Solution

Calculating the moles of H_2SO_4 in the dilute solution:

$$\text{moles } H_2SO_4 \text{ in dilute solution} = (0.450 \cancel{\text{L soln}})\left(\frac{0.10 \text{ mol } H_2SO_4}{1 \cancel{\text{L soln}}}\right) = 0.045 \text{ mol } H_2SO_4$$

Calculating the volume of the concentrated solution that contains 0.045 mol H_2SO_4:

$$\text{L conc soln} = (0.045 \cancel{\text{mol } H_2SO_4})\left(\frac{1 \text{ L soln}}{3.0 \cancel{\text{mol } H_2SO_4}}\right) = 0.015 \text{ L soln}$$

Converting liters to milliliters gives 15 mL.

If we apply dilution low, we get the same result:

$$(3.0\ M)(V_{\text{conc}}) = (0.10\ M)(450 \text{ mL})$$

$$(V_{\text{conc}}) = \frac{(0.10\ \cancel{M})(450 \text{ mL})}{3.0\ \cancel{M}} = 15 \text{ mL}$$

Either way, we see that if we start with 15 mL of 3.0 M H_2SO_4 and dilute it to a total volume of 450 mL, the desired 0.10 M solution will be obtained.

Q & A

Which is more concentrated, a 1.00×10^{-2} *M* solution of sucrose or a 1.00×10^{-4} *M* solution of sucrose?

Answer: 1.00×10^{-2} *M*

How is the molarity of a 0.50 *M* **KBr** solution changed when water is added to double its volume?

Answer: 0.25 *M*

Example: $0.5 \times 10 = M_{dil} \times 20$

$$M_{dil} = 0.25\ M$$

How many grams of **NaOH** are required to make a 250 mL of 0.500 *M* **NaOH**? (MW **NaOH** = 40.0 g/mol).

Answer: 5.0 g

When **$Fe(NO_3)_2$** dissolves in water, what particles are present in the solution?

a. Fe^{+} and $(NO_3)_2^{-}$
b. Fe^{2+} and $2\ NO_3^{-}$
c. Fe and $2\ NO_3$
d. Fe and N_2 and $3\ O_2$

How many milliliters of a 6.00 *M* **NaCl** solution are needed to make 250.0 milliliters of a 0.500 *M* **NaCl** solution?

a. 20.8
b. 41.7
c. 500.0
d. 3000.0

Which will have the highest concentration of **Na^+**?

- 0.35 *M* Na_2SO_4
- 0.40 *M* Na_3PO_4
- 0.50 *M* $NaNO_3$
- 0.80 *M* NaOH
- 1.00 *M* NaCl

(a) What volume of 2.50 *M* lead(II) nitrate solution contains 0.0500 mol of Pb^{2+}?

(b) How many milliliters of 5.0 *M* $K_2Cr_2O_7$ solution must be diluted to prepare 250 mL of 0.10 *M* solution?

(c) If 10.0 mL of a 10.0 *M* stock solution of NaOH is diluted to 250 mL, what is the concentration of the resulting stock solution?

Answers: **(a)** 0.0200 L = 20.0 mL, **(b)** 5.0 mL, **(c)** 0.40 *M*


Thank You!