1.9.5: Molarity

Chemists deal with amounts of molecules every day. Chemical reactions are described as so many molecules of compound A reacting with so many molecules of compound B to form so many molecules of compound C. When we determine how much reagent to use, we need to know the number of molecules in a given volume of the reagent. Percent solutions only tell us the number of grams, not molecules. A $100\ \mathrm{mL}$ solution of $2\%\ \mathrm{NaCl}$ will have a very different number of molecules than a 2% solution of CsCl. So, we need another way to talk about numbers of molecules.

Molarity

Chemists primarily need the concentration of solutions to be expressed in a way that accounts for the number of particles that react according to a particular chemical equation. Since percentage measurements are based on either mass or volume, they are generally not useful for chemical reactions. A concentration unit based on moles is preferable. The **molarity** (M) of a solution is the number of moles of solute dissolved in one liter of solution. To calculate the molarity of a solution, divide the moles of solute by the volume of the solution expressed in liters:

$$\text{Molarity}\ (\mathrm{M}) = \frac{\text{moles of solute}}{\text{liters of solution}} = \frac{\mathrm{mol}}{\mathrm{L}}$$

Note that the volume is in liters of solution and not liters of solvent. When a molarity is reported, the unit is the symbol M and is read as "molar". For example a solution labeled as $1.5\ \mathrm{M}\ \mathrm{NH_3}$ is read as "1.5 molar ammonia solution".

Example 1.9.5.1

A solution is prepared by dissolving $42.23\ \mathrm{g}$ of $\mathrm{NH_4Cl}$ into enough water to make $500.0\ \mathrm{mL}$ of solution. Calculate its molarity.

Solution

Step 1: List the known quantities and plan the problem.

Known

- $\text{Mass} = 42.23\ \mathrm{g\ NH_4Cl}$
- $\text{Molar mass}\ \mathrm{NH_4Cl} = 53.50\ \mathrm{g/mol}$
- $\text{Volume solution} = 500.0\ \mathrm{mL} = 0.5000\ \mathrm{L}$

Unknown

The mass of the ammonium chloride is first converted to moles. Then the molarity is calculated by dividing by liters. Note that the given volume has been converted to liters.

Step 2: Solve.

$$42.23\ \mathrm{g\ NH_4Cl} \times \frac{1\ \mathrm{mol\ NH_4Cl}}{53.50\ \mathrm{g\ NH_4Cl}} = 0.7893\ \mathrm{mol\ NH_4Cl}$$
$$\frac{0.7893\ \mathrm{mol\ NH_4Cl}}{0.5000\ \mathrm{L}} = 1.579\ \mathrm{M}$$

Step 3: Think about your result.

The molarity is $1.579\ \mathrm{M}$, meaning that a liter of the solution would contain $1.579\ \mathrm{mol\ NH_4Cl}$ Four significant figures are appropriate.

In a laboratory situation, a chemist must frequently prepare a given volume of solutions of a known molarity. The task is to calculate the mass of the solute that is necessary. The molarity equation can be rearranged to solve for moles, which can then be converted to grams.

Example 1.9.5.2

A chemist needs to prepare 3.00 L of a 0.250 M solution of potassium permanganate $\left(\text{KMnO}_4\right)$. What mass of KMnO_4 does she need to make the solution?

Solution

Step 1: List the known quantities and plan the problem.

Known

- Molarity $= 0.250 \text{ M}$
- Volume $= 3.00 \text{ L}$
- Molar mass $\text{KMnO}_4 = 158.04 \text{ g/mol}$

Unknown

Moles of solute is calculated by multiplying molarity by liters. Then, moles is converted to grams.

Step 2: Solve.

$$\text{mol KMnO}_4 = 0.250 \text{ M KMnO}_4 \times 3.00 \text{ L} = 0.750 \text{ mol KMnO}_4$$

$$0.750 \text{ mol KMnO}_4 \times \frac{158.04 \text{ g KMnO}_4}{1 \text{ mol KMnO}_4} = 119 \text{ g KMnO}_4$$

Step 3: Think about your result.

When 119 g of potassium permanganate is dissolved into water to make 3.00 L of solution, the molarity is 0.250 M.

Summary

- The molarity (M) of a solution is the number of moles of solute dissolved in one liter of solution.
- Calculations using the concept of molarity are described.