Chapter 4
Reactions in Aqueous Solutions
A solution is a homogenous mixture of 2 or more substances.

The solute is(are) the substance(s) present in the smaller amount(s).

The solvent is the substance present in the larger amount.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Solvent</th>
<th>Solute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft drink</td>
<td>H₂O</td>
<td>Sugar, CO₂</td>
</tr>
<tr>
<td>Air</td>
<td>N₂</td>
<td>O₂, Ar, CH₄</td>
</tr>
</tbody>
</table>

Aqueous solutions of KMnO₄

**Precipitation Reactions**

- Molecular equation:
  \[
  \text{Pb(NO}_3\text{)}_2 (aq) + 2\text{NaI (aq)} \rightarrow \text{PbI}_2 (s) + 2\text{NaNO}_3 (aq)
  \]

- Ionic equation:
  
  \[
  \text{Pb}^{2+} + 2\text{I}^- \rightarrow \text{PbI}_2 (s)
  \]

- Net ionic equation:
  
  \[
  \text{Pb}^{2+} + 2\text{I}^- \rightarrow \text{PbI}_2 (s)
  \]

**Neutralization Reaction**

- acid + base → salt + water

- \[
  \text{HCl (aq)} + \text{NaOH (aq)} \rightarrow \text{NaCl (aq)} + \text{H}_2\text{O}
  \]
Oxidation-Reduction Reactions
(electron transfer reactions)

\[ 2Mg \rightarrow 2Mg^{2+} + 4e^- \quad \text{Oxidation half-reaction (lose } e^-) \]
\[ O_2 + 4e^- \rightarrow 2O^{2-} \quad \text{Reduction half-reaction (gain } e^-) \]

\[ 2Mg + O_2 + 4e^- \rightarrow 2Mg^{2+} + 2O^{2-} + 4e^- \]
\[ 2Mg + O_2 \rightarrow 2MgO \]

The Oxidation Numbers of Elements in their Compounds
1. Combination Reactions

A *combination reaction* is a reaction in which two or more substances combine to form a single product.

\[ \text{A + B} \rightarrow \text{C} \]

\[ 2\text{Al} + 3\text{Br}_2 \rightarrow 2\text{AlBr}_3 \]

2. Decomposition Reactions

- Decomposition reactions are the opposite of combination reactions.
- A *decomposition reaction* is the breakdown of a compound into two or more components.

\[ \text{C} \rightarrow \text{A + B} \]

\[ 2\text{KClO}_3 \rightarrow 2\text{KCl} + 3\text{O}_2 \]
Types of Oxidation-Reduction Reactions

3. Combustion Reactions

A combustion reaction is a reaction in which a substance reacts with oxygen, usually with the release of heat and light to produce a flame.

\[ A + O_2 \rightarrow B \]

\[ S + O_2 \rightarrow SO_2 \]

\[ 2Mg + O_2 \rightarrow 2MgO \]

Concentration of solution

The concentration of a solution is the amount of solute present in a given quantity of solvent or solution.

Molarity (M), or molar concentration, which is the number of moles of solute per liter of solution.

\[ M = \text{molarity} = \frac{\text{moles of solute}}{\text{liters of solution}} \]

\[ M = \frac{n}{V} \]

where \( n \) denotes the number of moles of solute. \( V \) is the volume of the solution in liters.
What mass of KI is required to make 500. mL of a 2.80 \( M \) KI solution?

\[
\text{volume of KI solution} \quad \frac{M \text{ KI}}{\text{mole KI}} \quad \frac{M \text{ KI}}{\text{grams KI}}
\]

\[
500 \, \text{mL} \times \frac{1 \text{ L}}{1000 \, \text{mL}} \times \frac{2.80 \text{ mol KI}}{1 \, \text{L soln}} \times \frac{166 \text{ g KI}}{1 \, \text{mol KI}} = 232 \, \text{g KI}
\]
Concentration of solution

**EXAMPLE 4.6**

How many grams of potassium dichromate (K₂Cr₂O₇) are required to prepare a 250-mL solution whose concentration is 2.16 M?

**Strategy** How many moles of K₂Cr₂O₇ does a 1-L (or 1000 mL) 2.16 M K₂Cr₂O₇ solution contain? A 250-mL solution? How would you convert moles to grams?

**Solution** The first step is to determine the number of moles of K₂Cr₂O₇ in 250 mL or 0.250 L of a 2.16 M solution. Rearranging Equation (4.1) gives

\[
\text{moles of solute} = \text{molarity} \times \text{L soln}
\]

Thus,

\[
\text{moles of K}_2\text{Cr}_2\text{O}_7 = \frac{2.16 \text{ mol K}_2\text{Cr}_2\text{O}_7}{1 \text{ L soln}} \times 0.250 \text{ L soln} = 0.540 \text{ mol K}_2\text{Cr}_2\text{O}_7
\]

The molar mass of K₂Cr₂O₇ is 294.2 g, so we write

\[
\text{grams of K}_2\text{Cr}_2\text{O}_7 \text{ needed} = 0.540 \text{ mol K}_2\text{Cr}_2\text{O}_7 \times \frac{294.2 \text{ g K}_2\text{Cr}_2\text{O}_7}{1 \text{ mol K}_2\text{Cr}_2\text{O}_7} = 159 \text{ g K}_2\text{Cr}_2\text{O}_7
\]

**Check** As a ball-park estimate, the mass should be given by [molarity (mol/L) × volume (L) × molar mass (g/mol)] or [2 mol/L × 0.25 L × 300 g/mol] = 150 g. So the answer is reasonable.

**Practice Exercise** What is the molarity of an 85.0-mL ethanol (C₂H₅OH) solution containing 1.77 g of ethanol?

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**EXAMPLE 4.7**

In a biochemical assay, a chemist needs to add 3.81 g of glucose to a reaction mixture. Calculate the volume in milliliters of a 2.53 M glucose solution she should use for the addition.

**Strategy** We must first determine the number of moles contained in 3.81 g of glucose and then use Equation (4.2) to calculate the volume.

**Solution** From the molar mass of glucose, we write

\[
3.81 \text{ g C}_6\text{H}_{12}\text{O}_6 \times \frac{1 \text{ mol C}_6\text{H}_{12}\text{O}_6}{180.2 \text{ g C}_6\text{H}_{12}\text{O}_6} = 2.114 \times 10^{-2} \text{ mol C}_6\text{H}_{12}\text{O}_6
\]

Next, we calculate the volume of the solution that contains \(2.114 \times 10^{-2}\) mol of the solute. Rearranging Equation (4.2) gives

\[
V = \frac{n}{M} = \frac{2.114 \times 10^{-2} \text{ mol C}_6\text{H}_{12}\text{O}_6}{2.53 \text{ mol C}_6\text{H}_{12}\text{O}_6/\text{L soln}} \times \frac{1000 \text{ mL soln}}{1 \text{ L soln}} = 8.36 \text{ mL soln}
\]

**Check** One liter of the solution contains 2.53 moles of C₆H₁₂O₆. Therefore, the number of moles in 8.36 mL or 8.36 \(\times\) 10⁻³ L is (2.53 mol \(\times\) 8.36 \(\times\) 10⁻³) or 2.12 \(\times\) 10⁻² mol. The small difference is due to the different ways of rounding off.

**Practice Exercise** What volume (in milliliters) of a 0.315 M NaOH solution contains 6.22 g of NaOH?