Chapter 4

Solutions and Solution Stoichiometry
Solutions

Homogeneous mixtures are called *solutions*.

The component of the solution that changes state is called the *solute*.

The component that keeps its state is called the *solvent*.

If both components start in the same state, the *major component is the solvent*. 
# Kinds of Solutions

<table>
<thead>
<tr>
<th>Type of Solution</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas in gas</td>
<td>Air ($O_2$ in $N_2$)</td>
</tr>
<tr>
<td>Gas in liquid</td>
<td>Carbonated water ($CO_2$ in $H_2O$)</td>
</tr>
<tr>
<td>Gas in solid</td>
<td>$H_2$ in palladium metal</td>
</tr>
<tr>
<td>Liquid in liquid</td>
<td>Gasoline, tequila</td>
</tr>
<tr>
<td>Liquid in solid</td>
<td>Dental amalgam ($Hg$ in $Ag$)</td>
</tr>
<tr>
<td>Solid in liquid</td>
<td>Salt water ($NaCl$ in $H_2O$)</td>
</tr>
<tr>
<td>Solid in solid</td>
<td>Sterling silver ($Cu$ in $Ag$)</td>
</tr>
</tbody>
</table>
Solvent and Solute in an Aqueous Solution
Solvent and Solute in an Aqueous Solution
The Solution Process
What Happens When a Solute Dissolves?

There are attractive forces between the solute particles holding them together. There are also attractive forces between the solvent molecules.

When we mix the solute with the solvent, there are attractive forces between the solute particles and the solvent molecules.

If the attractions between solute and solvent are strong enough, the solute will dissolve.
Each ion is attracted to the surrounding water molecules and pulled off and away from the crystal.
Electrolytes and Nonelectrolytes
Ionic compounds dissociate into ions when they dissolve.

Molecular compounds do not dissociate into ions when they dissolve.
Electrolytes and Nonelectrolytes

Materials that dissolve in water to form a solution that will conduct electricity are called electrolytes.

Materials that dissolve in water to form a solution that will not conduct electricity are called nonelectrolytes.
Acids

Acids are molecular compounds that ionize when they dissolve in water. The molecules are pulled apart by water.

The percentage of molecules that ionize varies.

Acids that ionize virtually 100% are called strong acids.

\[ \text{HCl(aq)} \rightarrow \text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \]

Acids that only ionize a small percentage are called weak acids.

\[ \text{HF(aq)} \leftrightarrow \text{H}^+(\text{aq}) + \text{F}^-(\text{aq}) \]
**Strong and Weak Electrolytes**

*Strong electrolytes* are materials that dissolve completely as ions.

1) ionic compounds and strong acids  
2) The solutions conduct electricity well.

*Weak electrolytes* are materials that dissolve mostly as molecules, but partially as ions.

1) weak acids  
2) The solutions conduct electricity, but not well.
Dissociation vs Ionization

When ionic compounds dissolve in water, the anions and cations are separated from each other. This is called *dissociation*.

\[ \text{Na}_2\text{S}(aq) \rightarrow 2 \text{Na}^+(aq) + \text{S}^{2-}(aq) \]

When compounds containing polyatomic ions dissociate, the polyatomic group stays together as one ion.

\[ \text{Na}_2\text{SO}_4(aq) \rightarrow 2 \text{Na}^+(aq) + \text{SO}_4^{2-}(aq) \]

When strong acids dissolve in water, the molecule *ionizes* into H⁺ and anions.

\[ \text{H}_2\text{SO}_4(aq) \rightarrow 2 \text{H}^+(aq) + \text{SO}_4^{2-}(aq) \]
Write the equation for the process that occurs when the following strong electrolytes dissolve in water:

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCl₂</td>
<td>CaCl₂(aq) ( \rightarrow ) Ca²⁺(aq) + 2 ( \text{Cl}^-)(aq)</td>
</tr>
<tr>
<td>HNO₃</td>
<td>HNO₃(aq) ( \rightarrow ) H⁺(aq) + NO₃⁻(aq)</td>
</tr>
<tr>
<td>((\text{NH}_4\text{)}_2\text{CO}_3)</td>
<td>((\text{NH}_4\text{)}_2\text{CO}_3)(aq) ( \rightarrow ) 2 ( \text{NH}_4^+)(aq) + CO₃²⁻(aq)</td>
</tr>
</tbody>
</table>
The Real Picture of Acid Ionization

HCl + H_2O → H^+ + Cl^−

**strong acid**  **water**

HCl + H_2O → H_3O^+ + Cl^−

**hydronium ion**
Solubility
Solubility of Ionic Compounds

Some ionic compounds, such as NaCl, dissolve very well in water at room temperature.

Other ionic compounds, such as AgCl, dissolve hardly at all in water at room temperature.

Compounds that dissolve in a solvent are said to be **soluble**, whereas those that do not are said to be **insoluble**.
### Solubility Rules

**Compounds that Are Generally **Soluble** in Water**

<table>
<thead>
<tr>
<th>Compounds Containing the Following Ions are Generally Soluble</th>
<th>Exceptions (when combined with ions on the left, the compound is insoluble)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li⁺, Na⁺, K⁺, NH₄⁺</td>
<td>none</td>
</tr>
<tr>
<td>NO₃⁻, C₂H₃O₂⁻</td>
<td>none</td>
</tr>
<tr>
<td>Cl⁻, Br⁻, I⁻</td>
<td>Ag⁺, Hg₂²⁺, Pb²⁺</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>Ag⁺, Ca²⁺, Sr²⁺, Ba²⁺, Pb²⁺</td>
</tr>
</tbody>
</table>
Solubility Rules
Compounds that Are Generally **Insoluble** in Water

<table>
<thead>
<tr>
<th>Compounds Containing the Following Ions are Generally Insoluble</th>
<th>Exceptions (when combined with ions on the left the compound is soluble or <strong>slightly soluble</strong>)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH⁻</td>
<td>Li⁺, Na⁺, K⁺, NH₄⁺, Ca²⁺, Sr²⁺, Ba²⁺</td>
</tr>
<tr>
<td>S²⁻</td>
<td>Li⁺, Na⁺, K⁺, NH₄⁺</td>
</tr>
<tr>
<td>CO₃²⁻, PO₄³⁻</td>
<td>Li⁺, Na⁺, K⁺, NH₄⁺</td>
</tr>
</tbody>
</table>
Practice – Determine if each of the following is soluble in water

KOH is soluble because it contains K

AgBr is insoluble; most bromides are soluble, but AgBr is an exception

CaCl$_2$ is soluble; most chlorides are soluble, and CaCl$_2$ is not an exception

Pb(NO$_3$)$_2$ is soluble because it contains NO$_3^-$

PbSO$_4$ is insoluble; most sulfates are soluble, but PbSO$_4$ is an exception
Solution Concentrations
Qualitatively, solutions are often described as dilute or concentrated.

Dilute solutions have a small amount of solute compared to solvent.

Concentrated solutions have a large amount of solute compared to solvent.
Quantitative Descriptions of Solutions

One method for describing a solution is to quantify the amount of solute in a given amount of solution.
Solution Concentration - Molarity

Moles of solute per 1 liter of solution

Used because it describes how many molecules of solute in each liter of solution

\[
molarity, \ M = \frac{\text{amount of solute (in moles)}}{\text{amount of solution (in L)}}
\]
How to prepare a 1.000 M NaCl solution

First add 1 mole of NaCl.

Add water until solid is dissolved. Then add additional water until the 1 liter mark is reached.

A 1 molar NaCl solution
Find the molarity of a solution that has 25.5 g KBr dissolved in 1.75 L of solution.

\[ \text{molarity, } M = \frac{\text{moles KBr}}{\text{L solution}} = \frac{0.21429 \text{ mol KBr}}{1.75 \text{ L}} = 0.122 \text{ M} \]
What is the molarity of a solution containing 3.4 g of NH₃ (MM 17.03) in 200.0 mL of solution?

\[
3.4 \text{ g NH}_3 \times \frac{1 \text{ mol NH}_3}{17.03 \text{ g NH}_3} = 0.20 \text{ mol}
\]

\[
200.0 \text{ mL} \times \frac{0.001 \text{ L}}{1 \text{ mL}} = 0.2000 \text{ L}
\]

\[
M = \frac{0.20 \text{ mol NH}_3}{0.2000 \text{ L}} = 1.0 \text{ M}
\]
Using Molarity in Calculations

Molarity shows the relationship between the moles of solute and liters of solution.

If a sugar solution concentration is 2.0 M, then 1 liter of solution contains 2.0 moles of sugar.

\[
\frac{2 \text{ mol sugar}}{1 \text{ L solution}} = \frac{1 \text{ L solution}}{2 \text{ mol sugar}}
\]

Questions on might ask:
How many liters....?
How many moles....?
How many grams....?
How would I prepare....?
How many liters of 0.125 M NaOH contain 0.255 mol NaOH?

\[
\text{mol NaOH} \rightarrow \text{L sol’n} \quad \frac{1 \text{L solution}}{0.125 \text{ mol NaOH}}
\]

\[
0.255 \text{ mol NaOH} \times \frac{1 \text{L solution}}{0.125 \text{ mol NaOH}} = 2.04 \text{ L solution}
\]
Determine the mass of CaCl\(_2\) (MM = 110.98) in 1.75 L of 1.50 M solution.

\[
1.75 \text{ L solution} \times \frac{1.50 \text{ mol CaCl}_2}{1 \text{ L}} \times \frac{110.98 \text{ g}}{1 \text{ mol CaCl}_2} = 291 \text{ g CaCl}_2
\]
How would you prepare 250.0 mL of a 1.00 M solution CuSO₄·5 H₂O (MM 249.69)? How many grams of CuSO₄·5 H₂O are required?

Dissolve 62.4 g of CuSO₄·5H₂O in enough water to total 250.0 mL.
Dilution
Dilution

Often, solutions are stored as concentrated stock solutions.

To make solutions of lower concentrations from these stock solutions, more solvent is added.

The amount of solute doesn’t change, just the volume of solution.

moles solute in solution 1 = moles solute in solution 2

\[(\text{mol/L}) \cdot \text{L} = (\text{mol/L}) \cdot \text{L}\]

\[M_1 \cdot V_1 = M_2 \cdot V_2\]
What is the concentration of a solution prepared by diluting 45.0 mL of 8.25 M HNO₃ to 135.0 mL?

\[ M_1 V_1 = M_2 V_2 \]

\[ \frac{M_1 \cdot V_1}{V_2} = M_2 \]

\[ \left(8.25 \frac{\text{mol}}{\text{L}}\right) \cdot \left(45.0 \text{ mL}\right) \left(\frac{\text{L}}{135.0 \text{ mL}}\right) = 2.75 \frac{\text{mol}}{\text{L}} = 2.75 \text{ M} \]
To what volume should you dilute 0.200 L of 15.0 M NaOH to make 3.00 M NaOH?

\[
M_1 V_1 = M_2 V_2
\]

\[
\frac{M_1 \cdot V_1}{M_2} = V_2
\]

\[
\frac{15.0 \text{ mol/L}}{3.00 \text{ mol/L}} \cdot (0.200 \text{ L}) = 1.00 \text{ L}
\]
How would you prepare 200.0 mL of 0.25 M NaCl solution from a 2.0 M solution?

\[ M_1 V_1 = M_2 V_2 \]

\[ V_1 = \frac{M_2 \cdot V_2}{M_1} \]

\[
\left( \frac{0.25 \text{ mol}}{L} \right) \cdot \left( 200.0 \text{ mL} \right) = 25 \text{ mL}
\]

Dilute 25 mL of 2.0 M solution up to 200.0 mL.
Serial Dilution

- Full Strength Stock: 1 stock/ml
- Actual Stock Dilution: 1/10

1ml
- + 9ml
  - Concentration: 1/10 (1/100)
  - .1 stock/ml
- + 9ml
  - Concentration: .01/10 (1/1000)
  - .01 stock/ml
- + 9ml
  - Concentration: .001/10 (1/10000)
  - .001 stock/ml
- + 9ml
  - Concentration: .0001 stock/ml
Solution Stoichiometry

Because molarity relates the moles of solute to the liters of solution, it can be used to convert between amount of reactants and/or products in a chemical reaction.
What volume of 0.150 M KCl is required to completely react with 0.150 L of 0.175 M Pb(NO$_3$)$_2$ in the reaction

$$2 \text{ KCl}(aq) + \text{ Pb(NO}_3)_2(aq) \rightarrow \text{ PbCl}_2(s) + 2 \text{ KNO}_3(aq)$$

\[
\begin{align*}
0.175 \text{ mol} & \quad \frac{2 \text{ mol KCl}}{1 \text{ mol Pb(NO}_3)_2} \\
1 \text{ L Pb(NO}_3)_2 & \quad \frac{1 \text{ L KCl}}{0.150 \text{ mol}} \\
\end{align*}
\]

\[
\begin{align*}
0.150 \text{ L Pb(NO}_3)_2 & \times \frac{0.175 \text{ mol}}{1 \text{ L Pb(NO}_3)_2} \times \frac{2 \text{ mol KCl}}{1 \text{ mol Pb(NO}_3)_2} \times \frac{1 \text{ L KCl}}{0.150 \text{ mol}} \\
= 0.350 \text{ L KCl} \\
\end{align*}
\]
43.8 mL of 0.107 M HCl is needed to neutralize 37.6 mL of Ba(OH)$_2$ solution. What is the molarity of the base?

\[ 2 \text{ HCl(aq)} + \text{Ba(OH)$_2$(aq)} \rightarrow \text{BaCl$_2$(aq)} + 2 \text{ H}_2\text{O(aq)} \]

\[
0.0438 \text{ L HCl} \times \frac{0.107 \text{ mol HCl}}{1 \text{ L}} \times \frac{1 \text{ mol Ba(OH)$_2$}}{2 \text{ mol HCl}} = 0.00234 \text{ mol Ba(OH)$_2$}
\]

\[
\frac{0.00234 \text{ mol Ba(OH)$_2$}}{0.0376 \text{ L Ba(OH)$_2$}} = 0.0623 \text{ M Ba(OH)$_2$}
\]
The Big Picture of Stoichiometry

- **Liters of a Solution of A** → **Molarity** → **Moles of A** → **Avogadro's Number** → **Particles of A**
- **Liters of a Solution of B** → **Molarity** → **Moles of B** → **Avogadro's Number** → **Particles of B**
- **Moles of A** → **Molar Mass** → **Grams of A**
- **Moles of B** → **Molar Mass** → **Grams of B**
- **Particles of A** ↔ **Particles of B**
- **Coefficients**

This diagram illustrates the relationships between different quantities in stoichiometry, such as moles, grams, particles, and solutions, and how they can be converted using molar mass and Avogadro's number.