Solution Chemistry

Chapter 4
Covalent Molecule Dissolving in Water
Ionic Compound Dissolving in Water

Solid crystal

Dissolved ions
Electrolytes and Nonelectrolytes

Electrolyte and Nonelectrolyte Solutions

Salt solution conducts current. Sugar solution is nonconductive.
# Electrolytes/Nonelectrolytes

<table>
<thead>
<tr>
<th>Type</th>
<th>Dissociation</th>
<th>Electrical Conductivity</th>
<th>Examples</th>
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</thead>
<tbody>
<tr>
<td>Strong Electrolytes</td>
<td>Fully or Mostly (&gt;70%)</td>
<td>Strong</td>
<td>Soluble ionic compounds</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Strong Acids</td>
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<td></td>
<td></td>
<td></td>
<td>Strong Bases</td>
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<tr>
<td>Weak Electrolytes</td>
<td>Some (even very little counts here)</td>
<td>Weak</td>
<td>Weak Acids</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Weak Bases</td>
</tr>
<tr>
<td>Nonelectrolytes</td>
<td>None</td>
<td>None</td>
<td>Organic Molecules</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Sugars, alcohols</td>
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</tbody>
</table>
Ionic Dissociation

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

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

• You should think of ALL AQUEOUS, IONIC compounds as DISSOCIATED.

• AQUEOUS ACIDS may also be considered as DISSOCIATED.
Molarity of Ions

• Calculate the Molarity of a solution if 15.25 g of Mg(NO$_3$)$_2$ is dissolved in water to a final volume of 250 mL.

• Now, calculate the molarity of nitrate ions found in the solution.

• What is the total ion concentration?
Compounds Containing the Following Ions Are Generally Soluble:

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Exceptions</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>
### Compounds Containing the Following Ions Are Generally Insoluble:

<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 slightly soluble)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH&lt;sup&gt;-&lt;/sup&gt;</td>
<td>Li&lt;sup&gt;+&lt;/sup&gt;, Na&lt;sup&gt;+&lt;/sup&gt;, K&lt;sup&gt;+&lt;/sup&gt;, NH&lt;sub&gt;4&lt;/sub&gt;&lt;sup&gt;+&lt;/sup&gt;, Ca&lt;sup&gt;2+&lt;/sup&gt;, Sr&lt;sup&gt;2+&lt;/sup&gt;, Ba&lt;sup&gt;2+&lt;/sup&gt;</td>
</tr>
<tr>
<td>S&lt;sup&gt;2-&lt;/sup&gt;</td>
<td>Li&lt;sup&gt;+&lt;/sup&gt;, Na&lt;sup&gt;+&lt;/sup&gt;, K&lt;sup&gt;+&lt;/sup&gt;, NH&lt;sub&gt;4&lt;/sub&gt;&lt;sup&gt;+&lt;/sup&gt;, Ca&lt;sup&gt;2+&lt;/sup&gt;, Sr&lt;sup&gt;2+&lt;/sup&gt;, Ba&lt;sup&gt;2+&lt;/sup&gt;</td>
</tr>
<tr>
<td>CO&lt;sub&gt;3&lt;/sub&gt;&lt;sup&gt;2-&lt;/sup&gt;, PO&lt;sub&gt;4&lt;/sub&gt;&lt;sup&gt;3-&lt;/sup&gt;</td>
<td>Li&lt;sup&gt;+&lt;/sup&gt;, Na&lt;sup&gt;+&lt;/sup&gt;, K&lt;sup&gt;+&lt;/sup&gt;, NH&lt;sub&gt;4&lt;/sub&gt;&lt;sup&gt;+&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Which of the following salts are soluble in water?

- KOH
- AgBr
- CaCl₂
- Pb(NO₃)₂
- PbI₂
The above chemical reaction is written as a “molecular equation.”

Because Pb(NO$_3$)$_2$ and K$_2$CrO$_4$ are strong electrolytes we can write

$$\text{Mg}^2+(aq) + 2 \text{NO}_3^-(aq) + 2 \text{K}^+(aq) + \text{CrO}_4^{2-}(aq) \rightarrow \text{MgCrO}_4(s) + 2 \text{K}^+(aq) + 2 \text{NO}_3^-(aq)$$

This is written now as a “complete ionic equation.”

**Question:** What about K$^+$ and NO$_3^-$ ions?

**Answer:** They are “spectator ions.” These ions DO NOT participate in the reaction.
Complete ionic equation:

\[
\text{Mg}^{2+}(aq) + 2 \text{NO}_3^-(aq) + 2 \text{K}^+(aq) + \text{CrO}_4^{2-}(aq) \rightarrow \text{MgCrO}_4(s) + 2 \text{K}^+(aq) + 2 \text{NO}_3^-(aq)
\]

- Spectator ions are left out when writing net ionic equations.

\[
\text{Mg}^{2+}(aq) + \text{CrO}_4^{2-}(aq) \rightarrow \text{MgCrO}_4(s)
\]

is the **NET IONIC EQUATION** for this reaction.
$\text{K}_2\text{SO}_4(\text{aq}) + 2 \text{AgNO}_3(\text{aq}) \rightarrow \text{Ag}_2\text{SO}_4(\text{s}) + 2 \text{KNO}_3(\text{aq})$

$\text{AlCl}_3(\text{aq}) + \text{NH}_4\text{NO}_3(\text{aq}) \rightarrow \text{Al(NO}_3)_3(\text{aq}) + \text{NH}_4\text{Cl}(\text{aq})$
Evidence of a Reaction

1. Produces Light
2. Absorbs/Gives off Heat
3. Forms Bubbles
4. Forms a Precipitate (solid)
5. Color Change
Reactions in Solution

• Double Displacement Reactions (Exchange of Ions)
  o Precipitation Reactions
    \[ AB(aq) + CD(aq) \rightarrow AD(s) + CB \]
  o Acid/Base Neutralization Reactions
    \[ HA(aq) + MOH(aq) \rightarrow H_2O(l) + MA(aq) \]
  o Gas Evolution Reaction
    \[ AB(aq) + CD(aq) \rightarrow AD(g) + CB \]
Reactions in Solution

• Redox Reactions (Exchange of Electrons)
  o Combustion Reactions

  \[ \text{fuel} + O_2 \rightarrow CO_2 + H_2O \]

  o Single Displacement Reactions (can sometimes be gas evolution reactions when A=H)

  \[ M + AB \rightarrow MB + A \]
Precipitation Reaction

\[
2 \text{KI}(aq) + \text{Pb(NO}_3\text{)}_2(aq) \rightarrow 2 \text{KNO}_3(aq) + \text{PbI}_2(s)
\]

When a potassium iodide solution is mixed with a lead(II) nitrate solution, a yellow lead(II) iodide precipitate forms.
Problem: Write the equation for the precipitation reaction between an aqueous solution of potassium carbonate and an aqueous solution of nickel(II) chloride.

Strategy for writing an equation for a double displacement reaction:

1. Write the formulas of the reactants.
2. Determine the possible products.
   a) Determine the ions present.
   b) Exchange the ions.
   c) Write the formulas of the products.
3. Determine the solubility of each product.
4. If both products soluble, write no reaction.
5. Write (aq) next to soluble products and (s) next to insoluble products.
6. Balance the equation.
Review Problem

• What is the mass and identity of the precipitate formed when you mix 25 mL of 0.150M Fe(NO$_3$)$_3$ and 15mL of 0.204M NaOH?
The “driving force” for many strong acid-strong base reactions is the formation of water.

\[ \text{NaOH}(aq) + \text{HCl}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l) \]

- Net ionic equation:
  \[ \text{OH}^- (aq) + \text{H}^+ (aq) \rightarrow \text{H}_2\text{O}(l) \]

A common product of many acid-base reactions is water and a SALT, \( \text{MX} \).

\[ \text{HX} + \text{MOH} \rightarrow \text{MX} + \text{H}_2\text{O} \]

\( \text{M}^{n+} \) comes from base and \( \text{X}^{n-} \) comes from acid.

Acid-base reactions are referred to as NEUTRALIZATION reactions.
HCl(aq) + NaOH(aq) → H₂O(l) + NaCl(aq)
Gas Evolution Reactions

• Direct Formation
  – Acid + metal sulfide $\rightarrow$ H$_2$S (g)

• Indirect Formation
  – When H$_2$SO$_3$, H$_2$CO$_3$, or NH$_4$OH are formed by a Double Displacement Rxn, they decompose forming a gas.
Other Patterns in Reactions: Transfer of electrons rather than ions

• The precipitation, acid/base, and gas-evolving reactions are all involved in exchanging the ions in the solution.

• Other kinds of reactions involve transferring electrons from one atom to another; these are called oxidation–reduction reactions.

  – Known as **redox reactions**
  – Many involve the reaction of a substance with O$_2$(g)

    $4 \text{Fe}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Fe}_2\text{O}_3(s)$
1. Oxidation number of a free atom or an atom in its elemental state is 0.
2. The oxidation number of a monatomic ion is the same as its charge.
3. The sum of oxidation numbers in a polyatomic ion or compound usually has the same oxidation number it would have if it were a monatomic ion.
   a) Hydrogen is +1 with nonmetals, -1 if bound to a metal.
   b) Oxygen is always -2 unless in a peroxide
   c) Halogens are usually -1, unless bound to oxygen
4. The sum of the oxidation numbers of all elements is equal to the compound/ion’s charge.
Problem:
Assign an oxidation state to each element in the following:

- $\text{Br}_2$
- $\text{K}^+$
- LiF
- $\text{H}_2\text{O}_2$
- $\text{CO}_2$
- $\text{SO}_4^{2-}$
- $\text{Na}_2\text{Cr}_2\text{O}_7$
Oxidation and Reduction Reactions

**Oxidation:**
- The process that occurs when
  - the oxidation number of an element increases
  - an element loses electrons

  **OXIDIZING AGENT** is an electron acceptor; it causes another species to be OXIDIZED but it (agent) is being reduced.

**Reduction:**
- The process that occurs when
  - the oxidation number of an element decreases
  - an element gains electrons

  **REDUCING AGENT** is an electron donor; it causes another species to be REDUCED but it (agent) is being oxidized.
Oxidation and Reduction

- Oxidation and reduction MUST occur simultaneously.

- Oxidation occurs when an atom’s oxidation state increases during a reaction.

- Reduction occurs when an atom’s oxidation state decreases during a reaction.

\[
\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}
\]
Oxidation–Reduction Reaction

\[ 2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g) \]

Hydrogen and oxygen in the balloon react to form gaseous water.

\[ 2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g) \]
Redox without Oxygen

\[ 2 \text{Na} (s) + \text{Cl}_2 (g) \rightarrow \text{NaCl} (s) \]

Electron transfer
Combustion Reactions

\[ 2 \text{C}_8\text{H}_{18}(g) + 25 \text{O}_2(g) \rightarrow 16 \text{CO}_2(g) + 18 \text{H}_2\text{O}(g) \]

- Reactions in which \(\text{O}_2(g)\) is a reactant are called combustion reactions.

- Combustion reactions release lots of energy.

- Combustion reactions are a subclass of oxidation–reduction reactions.
Problem: Complete and balance the following reactions.

1. Combustion of acetic acid, $\text{HC}_2\text{H}_3\text{O}_2(\ell)$

2. Combustion of isopropyl alcohol, $\text{C}_3\text{H}_7\text{OH}(\ell)$