Dissolution of (a) Ionic and (b) Molecular Compounds

1. When an ionic compound dissolves in water, ...
2. The water molecules separate and surround the ions.
3. When a molecular compound like methane dissolves in water, no ions are formed.
Most of these are soluble in water.

**Table 5.1 Solubility Rules for Ionic Compounds**

### Usually Soluble

<table>
<thead>
<tr>
<th>Group 1A, ammonium</th>
<th>Nitrates, NO$_3^-$</th>
<th>Chlorides, bromides, iodides, Cl$^-$, Br$^-$, I$^-$</th>
<th>Sulfates, SO$_4^{2-}$</th>
<th>Chlorates, ClO$_3^-$</th>
<th>Perchlorates, ClO$_4^{-}$</th>
<th>Acetates, CH$_3$COO$^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_4^+$, Li$^+$, Na$^+$, K$^+$, Rb$^+$, Cs$^+$, NH$_4^+$</td>
<td>All nitrates are soluble.</td>
<td>All common chlorides, bromides, and iodides are soluble except AgCl, Hg$_2$Cl$_2$, PbCl$_2$, AgBr, Hg$_2$Br$_2$, PbBr$_2$, AgI, HgI$_2$, PbI$_2$.</td>
<td>Most sulfates are soluble; exceptions include CaSO$_4$, SrSO$_4$, BaSO$_4$, and PbSO$_4$.</td>
<td>All chlorates are soluble.</td>
<td>All perchlorates are soluble.</td>
<td>All acetates are soluble.</td>
</tr>
</tbody>
</table>

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Table 5-1a, p.166

Most of these are insoluble in water.

### Usually Insoluble

<table>
<thead>
<tr>
<th>Phosphates, PO$_4^{3-}$</th>
<th>Carbonates, CO$_3^{2-}$</th>
<th>Hydroxides, OH$^-$</th>
<th>Oxalates, C$_2$O$_4^{2-}$</th>
<th>Sulfides, S$^{2-}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All phosphates are insoluble except those of NH$_4^+$ and Group 1A elements (alkali metal cations).</td>
<td>All carbonates are insoluble except those of NH$_4^+$ and Group 1A elements (alkali metal cations).</td>
<td>All hydroxides are insoluble except those of NH$_4^+$ and Group 1A (alkali metal cations). Sr(OH)$_2$, Ba(OH)$_2$, and Ca(OH)$_2$ are slightly soluble.</td>
<td>All oxalates are insoluble except those of NH$_4^+$ and Group 1A (alkali metal cations)</td>
<td>All sulfides are insoluble except those of NH$_4^+$ Group 1A (alkali metal cations), and Group 2A (MgS, CaS, and BaS are sparingly soluble).</td>
</tr>
</tbody>
</table>

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Table 5-1b, p.166
(a) nitrates (soluble)

\[ \text{AgNO}_3 \quad \text{Cu(NO}_3\text{)}_2 \]

(b) hydroxides (insoluble)

\[ \text{Cu(OH)}_2 \quad \text{AgOH} \]
Solubility Rules

1. All nitrates are soluble.
2. All compounds of Group IA metals and the ammonium ion, \( \text{NH}_4^+ \), are soluble.
3. All chlorides are soluble except: AgCl, \( \text{Hg}_2\text{Cl}_2 \) and PbCl₂.
4. All sulfates are soluble except: PbSO₄, \( \text{BaSO}_4 \), and SrSO₄.
Solubility Rules

5. All hydroxides and sulfides are insoluble except those of the Group IA metals and the ammonium ion.
6. All carbonates and phosphates are insoluble except those of the Group IA metals and the ammonium ion.

Precipitation Reactions

The process of separating a substance from a solution as a solid.

The formation of a solid from solution.

The opposite of dissolution.
When aqueous solutions of salts and other ionic compounds are mixed, a solid precipitate may form if swapping the ions produces an insoluble ionic compound.

What reaction occurs when aqueous solutions of sodium chloride and calcium nitrate are mixed?

\[
\text{NaCl}(aq) + \text{Ca(NO}_3\text{)}_2 \rightarrow \text{NaNO}_3(aq) + \text{CaCl}_2(aq)
\]

soluble   soluble   soluble   soluble

No reaction occurs

What reaction occurs when aqueous solutions of sodium chloride and silver nitrate are mixed?

\[
\text{NaCl}(aq) + \text{AgNO}_3 \rightarrow \text{NaNO}_3(aq) + \text{AgCl}(aq)
\]

soluble   soluble   soluble   insoluble

A precipitation reaction occurs

Precipitation of Barium Sulfate

\[
\text{BaCl}_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow 2\text{NaCl}(aq) + \text{BaSO}_4(s) \quad \text{precipitate}
\]

Sodium and chloride ions appear on both sides of the equation. They are spectator ions, which assure charge neutrality but do not take part directly in a chemical reaction.
Precipitation of Silver Chloride

\[
\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3
\]

**Precipitate**

Ionic Equations

**Total Ionic Equation:**

\[
\text{Ag}^+ + \text{NO}_3^{-1} + \text{Na}^+ + \text{Cl}^{-1} \rightarrow \text{AgCl} + \text{Na}^+ + \text{NO}_3^{-1}
\]

**Net Ionic Equation:**

\[
\text{Ag}^+ + \text{Cl}^{-1} \rightarrow \text{AgCl}
\]
Ionic Equations

Total Ionic Equation:
$$\text{Ba}^{+2} + 2\text{Cl}^{-1} + 2\text{Na}^{+} + \text{SO}_4^{-2} \rightarrow 2\text{Na}^{+} + \text{Cl}^{-1} + \text{BaSO}_4(s)$$

Net Ionic Equation:
$$\text{Ba}^{+2} + \text{SO}_4^{-2} \rightarrow \text{BaSO}_4$$

Neutralization Reactions

- substance that donates $\text{H}^+$ ions to solution
- sour-tasting substances
- substances whose aqueous solutions are capable of turning blue litmus indicators red
- dissolves certain metals to form salts
- react with bases or alkalis to form salts
Properties of Acids

- Contain at least one hydrogen atom
  - HCl(aq), CH₃COOH(aq), H₂SO₄(aq), H₃PO₄(aq)
- Sour taste, e.g., vinegar contains acetic acid – CH₃COOH
- Dissolve many metals to produce hydrogen gas
  - \[2 \text{HCl(aq)} + \text{Zn(s)} \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g)\]
- React with limestone (CaCO₃) to produce carbon dioxide
  - \[\text{HCl(aq)} + \text{CaCO}_3(s) \rightarrow \text{CaCl}_2(aq) + \text{CO}_2\]
- Change the color of some pigments in specific ways
  - Change litmus paper from blue to red
  - Change pink phenolphthalein solutions clear
- Neutralize bases

Neutralization Reactions

- Base
  - substance that donates a OH⁻ ion to solution
  - hydroxides and oxides of metals
  - bitter tasting, slippery solutions
  - turn litmus blue
  - react with acids to form salts
Properties of Bases

Usually contain the hydroxide anion \( \text{OH}^- \), e.g., NaOH & Ca(OH)_2. Note: NH_3(aq) is an exception

Have a bitter taste (soap), solutions tend to feel slippery

Precipitate many metal ions from solution

\[
\text{Cu(NO}_3\text{)}_2(aq) + 2 \text{NaOH(aq)} \rightarrow \text{Cu(OH)}_2(s) + 2 \text{NaNO}_3(aq)
\]

Change the color of some pigments in specific ways

- Change litmus paper from red to blue
- Change colorless phenolphthalein solutions pink

Neutralize acids

---

Common Acids and Bases

<table>
<thead>
<tr>
<th>Strong acids (strong electrolytes)</th>
<th>Strong bases (strong electrolytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{HCl} )</td>
<td>( \text{LiOH} )</td>
</tr>
<tr>
<td>( \text{HNO}_3 )</td>
<td>( \text{NaOH} )</td>
</tr>
<tr>
<td>( \text{H}_2\text{SO}_4 )</td>
<td>( \text{KOH} )</td>
</tr>
<tr>
<td>( \text{HClO}_3 )</td>
<td>( \text{Ca(OH)}_2 )</td>
</tr>
<tr>
<td>( \text{HBr} )</td>
<td>( \text{Ba(OH)}_2 )</td>
</tr>
<tr>
<td>( \text{HIO} )</td>
<td>( \text{Sr(OH)}_2 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weak acids* (weak electrolytes)</th>
<th>Weak bases† (weak electrolytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H}_3\text{PO}_4 )</td>
<td>( \text{NH}_3 )</td>
</tr>
<tr>
<td>( \text{CH}_3\text{COOH} )</td>
<td>( \text{CH}_3\text{NH}_2 )</td>
</tr>
<tr>
<td>( \text{H}_2\text{CO}_3 )</td>
<td>( \text{NH}_3 )</td>
</tr>
<tr>
<td>( \text{HCN} )</td>
<td>( \text{CH}_3\text{NH}_2 )</td>
</tr>
<tr>
<td>( \text{HCOOH} )</td>
<td>( \text{NH}_3 )</td>
</tr>
<tr>
<td>( \text{C}_2\text{H}_3\text{COOH} )</td>
<td>( \text{NH}_3 )</td>
</tr>
</tbody>
</table>

*Many organic carboxylic acids are weak acids.
† Many organic amines (related to ammonia) are weak bases.
<table>
<thead>
<tr>
<th>Acids</th>
<th>Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>All hydroxides</td>
</tr>
<tr>
<td>HCl</td>
<td>Most common due to solubility:</td>
</tr>
<tr>
<td>HBr</td>
<td>NaOH sodium hydroxide</td>
</tr>
<tr>
<td>HI</td>
<td>KOH potassium hydroxide</td>
</tr>
<tr>
<td>HClO</td>
<td>Ammonia and amines</td>
</tr>
<tr>
<td>HClO₂</td>
<td>NH₃ aqueous ammonia</td>
</tr>
<tr>
<td>HClO₃</td>
<td>CH₃NH₂ methylamine</td>
</tr>
<tr>
<td>HClO₄</td>
<td></td>
</tr>
<tr>
<td>H₂SO₃</td>
<td></td>
</tr>
<tr>
<td>H₂SO₄</td>
<td></td>
</tr>
<tr>
<td>HNO₃</td>
<td></td>
</tr>
<tr>
<td>H₃PO₄</td>
<td></td>
</tr>
<tr>
<td>CH₃COOH</td>
<td></td>
</tr>
</tbody>
</table>
Neutralization Reactions

salt
• substances produced by the reaction of an acid with a base
• characterized by ionic bonds, relatively high melting points, electrical conductivity when melted or when in solution, and a crystalline structure when in the solid state

Neutralization Reactions between Acids & Bases

Aqueous acids and bases react to form a salt and water:

\[
\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}
\]

\[
\begin{align*}
\text{HBr(aq)} & \quad + \quad \text{NaOH(aq)} \quad \rightarrow \quad \text{NaBr(aq)} + \quad \text{H}_2\text{O(ℓ)} \\
\text{H}_2\text{SO}_4(aq) & \quad + \quad 2\ \text{KOH(aq)} \quad \rightarrow \quad \text{K}_2\text{SO}_4(aq) + \quad 2\ \text{H}_2\text{O(ℓ)}
\end{align*}
\]

Salt: Substance produced by an acid-base reaction

- NaCl is produced by NaOH and HCl
- NH₄I is produced by NH₃ and HI
- Al(NO₃)₃ is produced by Al(OH)₃ and HNO₃
- NaHCO₃ is produced by NaOH and H₂CO₃

Isolated compounds are solids, ionic compounds

- atomic or molecular ions are bonded through ionic bonds
- high melting points
- liquids conduct electricity