4.3 Precipitation Reactions

- Formation of an insoluble product \textit{(precipitate)} after mixing of two electrolyte solutions
  - The driving force of precipitation reactions is the elimination of ions from the solution by formation of an insoluble product

Example:

When mercury(I) nitrate and potassium phosphate solutions are mixed, mercury(I) phosphate \textit{precipitates}. Write the net ionic equation.

\[
\text{mercury(I)} \rightarrow \text{Hg}_2^{2+} \rightarrow \text{Hg}_2(\text{NO}_3)_2
\]

\(\Rightarrow\) Skeletal eq:

\[
\text{Hg}_2(\text{NO}_3)_2(aq) + \text{K}_3\text{PO}_4(aq) \rightarrow \rightarrow (\text{Hg}_2)_3(\text{PO}_4)_2(s) + \text{KNO}_3(aq)
\]

Predicting the outcome of precipitation

- Precipitation reactions are classified as \textit{double replacement} (metathesis) reactions – exchange of ions leads to an insoluble combination of ions

<table>
<thead>
<tr>
<th>Table 4.1 Solubility Rules for Ionic Compounds in Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soluble Ionic Compounds</strong></td>
</tr>
<tr>
<td>1. All common compounds of Group 1A(1) ions (Li(^+), Na(^+), K(^+), etc.) and ammonium ion (NH(_4^+)) are soluble.</td>
</tr>
<tr>
<td>2. All common nitrates (NO(_3^-)), acetates (CH(_3)COO(^-)) or C(_2)H(_3)O(_2^-)), and most perchlorates (ClO(_4^-)) are soluble.</td>
</tr>
<tr>
<td>3. All common chlorides (Cl(^-)), bromides (Br(^-)), and iodides (I(^-)) are soluble, except those of Ag(^+), Pb(^{2+}), Cu(^{2+}), and Hg(^{2+}).</td>
</tr>
<tr>
<td>4. All common sulfates (SO(_4^{2-})) are soluble, except those of Ca(^{2+}), Sr(^{2+}), Ba(^{2+}), Ag(^+), Pb(^{2+}) and Hg(^{2+}).</td>
</tr>
</tbody>
</table>
**Example:**

Predict the outcome of the mixing of silver nitrate and potassium carbonate solutions.

⇒ Ions present in the solution:

\[ \text{Ag}^+, \text{NO}_3^-, \text{K}^+, \text{CO}_3^{2-} \]

⇒ Consider all possible combinations of ions to find if an insoluble product can form:

\[ \text{Ag}^+ \text{ and } \text{CO}_3^{2-} \text{ form insoluble } \text{Ag}_2\text{CO}_3 \]

⇒ Net ionic eq: \(2\text{Ag}^+ + \text{CO}_3^{2-} \rightarrow \text{Ag}_2\text{CO}_3(s)\)

**Note:** The net ionic equation can be predicted directly from the formula of the precipitate.

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**4.4 Acid-Base Reactions**

- Acids - sharp, sour taste; Bases - soapy, bitter taste

**Arrhenius acids** – release hydrogen ions, \(\text{H}^+(aq)\) [or \(\text{H}_3\text{O}^+(aq)\)], in water solutions

- Acidic hydrogen atoms in molecules
  - can be released as \(\text{H}^+\) ions
  - formulas normally begin with the acidic Hs

**Examples:**

⇒ \(\text{HCl}, \text{H}_2\text{SO}_4, \text{HCN}, \ldots\)

\[
\text{HCl}(g) \xrightarrow{\text{H}_2\text{O}(l)} \text{H}^+ + \text{Cl}^-
\]

\[
\text{HCl}(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-
\]

---

**Arrhenius bases** – release hydroxide ions, \(\text{OH}^-\), in water solutions

**Examples:**

⇒ \(\text{NaOH}\) dissolves in water and dissociates to \(\text{Na}^+\) and \(\text{OH}^-\).

\[\text{NaOH}(s) \xrightarrow{\text{H}_2\text{O}} \text{Na}^+ + \text{OH}^-\]

⇒ Ammonia gas, \(\text{NH}_3\), dissolves in water and produces \(\text{NH}_4^+\) and \(\text{OH}^-\).

\[\text{NH}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{NH}_4^+ + \text{OH}^-\]

---

**Strong acids** – almost completely ionized in aqueous solutions

⇒ \(\text{HBr}(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+ + \text{Br}^-\) (~100% ionized)

- The strong acids in aqueous solution are:
  - \(\text{HCl(aq)}, \text{HBr(aq)}, \text{HI(aq)}, \text{HNO}_3\), \(\text{H}_2\text{SO}_4\), \(\text{HClO}_4\), and \(\text{HClO}_3\)

**Weak acids** – only partially ionized in aqueous solutions (HF, \(\text{H}_2\text{S}\), organic acids ...)

⇒ \(\text{CH}_3\text{COOH(aq)} + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+ + \text{CH}_3\text{COO}^-\) (~1% ionized)
**Strong bases** – almost completely ionized in aqueous solutions (oxides and hydroxides of alkali and alkaline earth metals)

\[ \text{KOH}(s) \rightarrow \text{K}^+ + \text{OH}^- \quad (~100\% \text{ ionized}) \]

• The strong bases in aqueous solution are: Group I hydroxides, Ca(OH)_2, Sr(OH)_2, and Ba(OH)_2

• **Weak bases** – only partially ionized in aqueous solutions (ammonia, amines, …)

\[ \text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightarrow \text{NH}_4^+ + \text{OH}^- \quad (~1\% \text{ ionized}) \]

**Neutralization**

\[ \text{acid} + \text{base} \rightarrow \text{salt} + \text{water (or other products)} \]

• **Salt** – an ionic compound with a cation from the base and an anion from the acid

\[ \text{H}_2\text{SO}_4(aq) + 2\text{KOH}(aq) \rightarrow \text{K}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l) \]

• Neutralization reactions are also viewed as double replacement (metathesis) reactions – exchange of ions leads to a salt and water

**Example:** Predict the products of the reaction between carbonic acid and calcium hydroxide.

\[ \text{H}_2\text{CO}_3(aq) + \text{Ca(OH)}_2(aq) \rightarrow \text{CaCO}_3(s) + 2\text{H}_2\text{O} \]

**Proton Transfer**

• Net ionic equations for reactions between strong acids and bases

\[ \text{HCl}(aq) + \text{KOH}(aq) \rightarrow \text{KCl}(aq) + \text{H}_2\text{O}(l) \]
\[ \text{H}^+ + \text{Cl}^- + \text{K}^+ + \text{OH}^- \rightarrow \text{K}^+ + \text{Cl}^- + \text{H}_2\text{O}(l) \]

\[ \Rightarrow \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}(l) \]

– \text{H}^+ is present in the form of \text{H}_3\text{O}^+

\[ \Rightarrow \text{H}_3\text{O}^+ + \text{OH}^- \rightarrow 2\text{H}_2\text{O}(l) \]

Net ionic equation for all strong acid/strong base reactions (transfer of a proton from \text{H}_3\text{O}^+ to \text{OH}^-)

• Net ionic equations for reactions between weak acids and strong bases

**Example:**

\[ \text{HF}(aq) + \text{NaOH}(aq) \rightarrow \text{NaF}(aq) + \text{H}_2\text{O}(l) \]
\[ \text{HF}(aq) \rightarrow \text{weak acid (only partially ionized)} \]

\[ \text{HF}(aq) + \text{Na}^+ + \text{OH}^- \rightarrow \text{Na}^+ + \text{F}^- + \text{H}_2\text{O}(l) \]

\[ \Rightarrow \text{HF}(aq) + \text{OH}^- \rightarrow \text{F}^- + \text{H}_2\text{O}(l) \]

– The driving force of strong acid-base reactions is the elimination of ions (\text{H}^+ and \text{OH}^-) from the solution by formation of water

• Net ionic equations for reactions between weak acids and strong bases

**Example:**

\[ \text{HF}(aq) + \text{NaOH}(aq) \rightarrow \text{NaF}(aq) + \text{H}_2\text{O}(l) \]
\[ \text{HF}(aq) \rightarrow \text{weak acid (only partially ionized)} \]

\[ \text{HF}(aq) + \text{Na}^+ + \text{OH}^- \rightarrow \text{Na}^+ + \text{F}^- + \text{H}_2\text{O}(l) \]

\[ \Rightarrow \text{HF}(aq) + \text{OH}^- \rightarrow \text{F}^- + \text{H}_2\text{O}(l) \]

– transfer of a proton from HF to OH^-
• Net ionic equations for reactions between strong acids and weak bases

**Example:**

\[
\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4\text{Cl (aq)}
\]

\[
\text{NH}_3(\text{aq}) \rightarrow \text{weak base (only partially ionized)}
\]

\[
\text{H}^+ + \text{Cl}^- + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4^+ + \text{Cl}^-
\]

\[
\Rightarrow \text{H}^+ + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4^+
\]

– H\(^+\) is present in the form of H\(_3\)O\(^+\)

\[
\Rightarrow \text{H}_3\text{O}^+ + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4^+ + \text{H}_2\text{O(l)}
\]

– transfer of a proton from H\(_3\)O\(^+\) to NH\(_3\)

<table>
<thead>
<tr>
<th>Gas Formation Reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reactions of salts of weak or volatile acids with strong acids</td>
</tr>
</tbody>
</table>

**Example:**

\[
\text{ZnS(s)} + 2\text{HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2\text{S(g)}
\]

\[
\text{ZnS(s)} + 2\text{H}^+ + 2\text{Cl}^- \rightarrow \text{Zn}^{2+} + 2\text{Cl}^- + \text{H}_2\text{S(g)}
\]

\[
\Rightarrow \text{ZnS(s)} + 2\text{H}^+ \rightarrow \text{Zn}^{2+} + \text{H}_2\text{S(g)}
\]

– H\(^+\) is present in the form of H\(_3\)O\(^+\)

\[
\Rightarrow \text{ZnS(s)} + 2\text{H}_3\text{O}^+ \rightarrow \text{Zn}^{2+} + \text{H}_2\text{S(g)} + 2\text{H}_2\text{O(l)}
\]

– transfer of a proton from H\(_3\)O\(^+\) to S\(^2-\)