Precipitation Reactions and Solubility Rules

To PREDICT whether a precipitation will occur on mixing solutions of two substances, you must know the solubility's of the potential products. If the salt has a low solubility it will precipitate out of solution; if the salt has a high solubility it will not.

\[ AB_{(aq)} + CD_{(aq)} \rightarrow AD_{(s ?)} + CB_{(s ?)} \]

There are three classes of salts:

1. **Salts which are always soluble:**
   - all alkali salts; Cs⁺, Rb⁺, K⁺, Na⁺, Li⁺
   - all ammonium (NH₄⁺) salts
   - all salts of the NO₃⁻, ClO₃⁻, ClO₄⁻, HCO₃⁻, C₂H₃O₂⁻

2. **Salts which are soluble with exceptions:**
   - Cl⁻, Br⁻, I⁻ ion salts except with Ag⁺, Pb²⁺, & Hg₂²⁺
   - SO₄²⁻ ion salts except with Ag⁺, Pb²⁺, Hg₂²⁺, Ca²⁺, Sr²⁺, & Ba²⁺

3. **Salts which are insoluble with exceptions:**
   - O²⁻ & OH⁻ ion salts except with the alkali metal ions, and Ca²⁺, Sr²⁺, & Ba²⁺ ions
   - CO₃²⁻, PO₄³⁻, S²⁻, CrO₄²⁻, & SO₃²⁻ ion salts except with the alkali metal ions and the ammonium ion
**Problem:**
Which of the following are insoluble in water?
NaCl, BaCO₃, PbI₂, CaSO₄, KNO₃, PbSO₄, RbOH, Ca(OH)₂, Ag₂CO₃, Na₂S, CdS, (NH₄)₂ CO₃, MgO, HgCl₂, CuCO₃

**STRATEGY IN PREDICTING WHETHER A PRECIPITATION REACTION WILL OCCUR.**
1) Given the reactants, write out a possible molecular chemical equation.
2) Identify the two potential products and predict the solubility of each using the SOLUBILITY RULES.
3) If one product is insoluble then a precipitation reaction occurs and you should be able to write out the net ionic equation by canceling out the spectator ions.

**Example:**
Solutions of Pb(NO₃)₂ and (NH₄)₂SO₄ are mixed together. Will a precipitate reaction occur? If so, write down the molecular, total ionic and net ionic equation.

Two possible products are PbSO₄ and NH₄NO₃. PbSO₄ is insoluble in water.

Molecular eq: Pb(NO₃)₂ (aq) + (NH₄)₂SO₄ (aq) → 2 NH₄NO₃ (aq) + PbSO₄ (s)

Total ionic eq:
Pb²⁺ (aq) + 2NO₃⁻ (aq) + 2NH₄⁺ (aq) + SO₄²⁻ (aq) → 2 NH₄⁺ (aq) + 2NO₃⁻ (aq) + PbSO₄ (s)

Net ionic eq: spectator ions are NH₄⁺ (aq) and NO₃⁻ (aq)
Pb²⁺ (aq) + SO₄²⁻ (aq) → PbSO₄ (s)

**Problem:**
Predict whether a precipitation reaction will occur for the following: If there is a reaction write down the balanced net ionic equation.

(a) mixing aqueous solution of NaNO₃ and BaCl₂
(b) mixing aqueous solutions of SnCl₂ and NaOH
Acids, Bases and Neutralization Reactions

Definitions of Acids and Bases

**Arrhenius Acid:** A substance which dissociates to form hydrogen ions (H\(^+\)) in solution.

**Arrhenius Base:** A substance that dissociates in, or reacts with, water to form hydroxide ions (OH\(^-\)).

**Brensted Acid:** Can donate protons (H\(^+\)) to another substance in solution.

**Brensted Base:** Can accept protons (H\(^+\)) from another substance in solution.

\[
\text{HA} + \text{B} \rightleftharpoons \text{BH}^+ + \text{A}^-
\]

Conjugate acid–base pairs

**Acids**

**Strong acids** - fully dissociated, are strong electrolytes

Examples: HClO\(_4\), H\(_2\)SO\(_4\), HBr, HCl, HNO\(_3\)

\[
\text{HA} + \text{H}_2\text{O} \rightarrow \text{A}^- + \text{H}_3\text{O}^+ \\
(> 95\%)
\]

**Weak acids** - mostly undissociated; are weak electrolytes

Examples: H\(_3\)PO\(_4\), HF, H\(_2\)S, CH\(_3\)CO\(_2\)H (acetic acid)

\[
\text{HA} + \text{H}_2\text{O} \rightleftharpoons \text{A}^- + \text{H}_3\text{O}^+ \\
(> 95 \%) \quad (< 5\%)\n\]

**Polyprotic acids** - acids with more than one acidic hydrogen:

Examples: H\(_3\)PO\(_4\), H\(_2\)SO\(_4\), H\(_2\)SO\(_3\), H\(_2\)CO\(_3\), H\(_2\)CrO\(_4\)

dissociates in steps

\[
\text{H}_2\text{SO}_4 (aq) + \text{H}_2\text{O} (l) \rightarrow \text{HSO}_4^- (aq) + \text{H}_3\text{O}^+ (aq) \\
\text{HSO}_4^- (aq) + \text{H}_2\text{O} (l) \rightarrow \text{SO}_4^{2-} (aq) + \text{H}_3\text{O}^+ (aq)
\]
**Bases**

**Strong Bases** - fully dissociates, strong electrolytes
- examples: Ca(OH)$_2$, Ba(OH)$_2$, NaOH, KOH

\[
\text{NaOH} \rightarrow \text{Na}^+ (aq) + \text{OH}^- (aq) \quad (>95\%)
\]

**Weak bases** - reacts with water to a **small extent** produce OH$^-$
- examples: NH$_3$, CH$_3$NH$_2$ (*amines*), CaCO$_3$

\[
\text{NH}_3 (aq) + \text{H}_2\text{O} (l) \rightarrow \text{NH}_4^+ (aq) + \text{OH}^- (aq) \quad (<5\%)
\]

**Neutralization reaction**
A reaction between an acid and a base which produces water (or a gas) and a salt

\[
\text{HA} \quad + \quad \text{XOH} \rightarrow \text{H}_2\text{O} \quad + \quad \text{XA}
\]

“Net ionic equation” of **strong acid** with **strong base**:

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

“Net ionic equation” of **weak acid** with **strong base**:

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

[where **A** is the anion of the weak acid]

**Problems**
Write the “balanced” total ionic and net ionic equations for the following neutralization reactions:

(a) Ca(OH)$_2$(aq) + CH$_3$CO$_2$H(aq) →

(b) HCl(aq) + Ba(OH)$_2$(aq) →

(c) HCl(aq) + NH$_3$(aq) →

(d) CaCO$_3$(aq) + HCl(aq) →
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