4.3 Precipitation Reactions

- Formation of an insoluble product (**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 **precipitates**. Write the net ionic equation.

mercury(I) → $\mathbf{Hg_2^{2+}}$ → $\mathbf{Hg_2(NO_3)_2}$

⇒Skeletal eq:

$$\mathbf{Hg_2(NO_3)_2(aq) + K_3PO_4(aq) \rightarrow}$$

$$\mathbf{\rightarrow (Hg_2)_3(PO_4)_2(s) + KNO_3(aq)}$$

⇒Overall balanced eq:

$$\mathbf{3Hg_2(NO_3)_2(aq) + 2K_3PO_4(aq) \rightarrow}$$

$$\mathbf{\rightarrow (Hg_2)_3(PO_4)_2(s) + 6KNO_3(aq)}$$

⇒Complete ionic eq:

$$\mathbf{3Hg_2^{2+} + 6NO_3^- + 6K^+ + 2PO_4^{3-} \rightarrow}$$

$$\mathbf{\rightarrow (Hg_2)_3(PO_4)_2(s) + 6K^+ + 6NO_3^-}$$

⇒Net ionic eq:

$$\mathbf{3Hg_2^{2+} + 2PO_4^{3-} \rightarrow (Hg_2)_3(PO_4)_2(s)}$$

Predicting the outcome of precipitation

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

Table 4.1 Solubility Rules for Ionic Compounds in Water

Soluble Ionic Compounds	Insoluble Ionic Compounds
1. All common compounds of Group 1A(1) ions (Li^+, Na^+, K^+, etc.) and ammonium ion (NH_4^+) are soluble.	1. All common metal hydroxides are insoluble, *except* those of Group 1A(1) and the larger members of Group 2A(2) (beginning with Ca^{2+}).
2. All common nitrates (NO_3^-), acetates (CH_3COO^- or $C_2H_3O_2^-$), and most perchlorates (ClO_4^-) are soluble.	2. All common carbonates (CO_3^{2-}) and phosphates (PO_4^{3-}) are insoluble, *except* those of Group 1A(1) and NH_4^+.
3. All common chlorides (Cl^-), bromides (Br^-), and iodides (I^-) are soluble, *except* those of Ag^+, Pb^{2+}, Cu^+, and Hg_2^{2+}.	3. All common sulfides are insoluble *except* those of Group 1A(1), Group 2A(2), and NH_4^+.
4. All common sulfates (SO_4^{2-}) are soluble, *except* those of Ca^{2+}, Sr^{2+}, Ba^{2+}, Ag^+, Pb^{2+} and Hg_2^{2+}.	

Example:

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

⇒Ions present in the solution:

Ag^+, NO_3^-, K^+, CO_3^{2-}

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

Ag^+ and CO_3^{2-} form insoluble Ag_2CO_3

⇒Net ionic eq: $2Ag^+ + CO_3^{2-} \rightarrow Ag_2CO_3(s)$

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

4.4 Acid-Base Reactions

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

- **Arrhenius acids** – release hydrogen ions, **$H^+(aq)$** [or **$H_3O^+(aq)$**], in water solutions
- Acidic hydrogen atoms in molecules
  - can be released as H^+ ions
  - formulas normally begin with the acidic Hs

Examples:

⇒ **HCl, H_2SO_4, HCN, ….**

$$HCl(g) \xrightarrow{H_2O} H^+ + Cl^-$$

$$HCl(g) + H_2O(l) \rightarrow H_3O^+ + Cl^-$$

- **Arrhenius bases** – release hydroxide ions, **OH^-**, in water solutions

Examples:

⇒**NaOH** dissolves in water and dissociates to **Na^+** and **OH^-**.

$$NaOH(s) \xrightarrow{H_2O} Na^+ + OH^-$$

⇒Ammonia gas, **NH_3**, dissolves in water and produces **NH_4^+** and **OH^-**.

$$NH_3(g) + H_2O(l) \rightarrow NH_4^+ + OH^-$$

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

⇒$HBr(g) + H_2O(l) \rightarrow H_3O^+ + Br^-$

(~100% ionized)

- The strong acids in aqueous solution are: HCl(aq), HBr(aq), HI(aq), HNO_3, H_2SO_4, $HClO_4$, and $HClO_3$
- **Weak acids** – only partially ionized in aqueous solutions (HF, H_2S, organic acids ...)

⇒$CH_3COOH(aq) + H_2O(l) \rightarrow$

$\rightarrow H_3O^+ + CH_3COO^-$ **(~1% ionized)**

- **Strong bases** – almost completely ionized in aqueous solutions (oxides and hydroxides of alkali and alkaline earth metals)

$\Rightarrow KOH(s) \xrightarrow{H_2O} K^+ + OH^-$ (~100% 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, …)

$\Rightarrow NH_3(aq) + H_2O(l) \rightarrow NH_4^+ + OH^-$

(~1% ionized)

Neutralization

acid + base → salt + water (or other products)

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

$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$

- 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.

$H_2CO_3(aq) + Ca(OH)_2(aq) \rightarrow CaCO_3(s) + 2H_2O$

Proton Transfer

- Net ionic equations for reactions between strong acids and bases

$HCl(aq) + KOH(aq) \rightarrow KCl(aq) + H_2O(l)$

$H^+ + Cl^- + K^+ + OH^- \rightarrow K^+ + Cl^- + H_2O(l)$

$\Rightarrow H^+ + OH^- \rightarrow H_2O(l)$

– H^+ is present in the form of H_3O^+

$\Rightarrow H_3O^+ + OH^- \rightarrow 2H_2O(l)$

Net ionic equation for all strong acid/strong base reactions (transfer of a proton from H_3O^+ to OH^-)

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

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

Example:

$HF(aq) + NaOH(aq) \rightarrow NaF(aq) + H_2O(l)$

$HF(aq)$ → weak acid (only partially ionized)

$HF(aq) + Na^+ + OH^- \rightarrow Na^+ + F^- + H_2O(l)$

$\Rightarrow HF(aq) + OH^- \rightarrow F^- + H_2O(l)$

⇒transfer of a proton from HF to OH^-

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

Example:

$HCl(aq) + NH_3(aq) \rightarrow NH_4Cl\ (aq)$

$NH_3(aq) \rightarrow$ **weak base (only partially ionized)**

$H^+ + Cl^- + NH_3(aq) \rightarrow NH_4^+ + Cl^-$

$\Rightarrow H^+ + NH_3(aq) \rightarrow NH_4^+$

– H^+ is present in the form of H_3O^+

$\Rightarrow H_3O^+ + NH_3(aq) \rightarrow NH_4^+ + H_2O(l)$

$\Rightarrow$ **transfer of a proton from H_3O^+ to NH_3**

Gas Formation Reactions

- Reactions of salts of weak or volatile acids with strong acids

Example:

$ZnS(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2S(g)$

$ZnS(s) + 2H^+ + 2Cl^- \rightarrow Zn^{2+} + 2Cl^- + H_2S(g)$

$\Rightarrow ZnS(s) + 2H^+ \rightarrow Zn^{2+} + H_2S(g)$

– **H^+ is present in the form of H_3O^+**

$\Rightarrow ZnS(s) + 2H_3O^+ \rightarrow Zn^{2+} + H_2S(g) + 2H_2O(l)$

$\Rightarrow$ **transfer of a proton from H_3O^+ to S^{2-}**