(a) Nonelectrolyte    (b) Weak electrolyte    (c) Strong electrolyte

# Electrolytes. Reactions in Aqueous Solutions



$$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$$

1

# Name the compounds:

$CuSO_4$     $NaOH$     $HNO_3$     $NH_4NO_3$

$Ca(OH)_2$     $H_2SiO_3$     $H_3BO_3$     $KMnO_4$

$Na[Al(OH)_4]$     $NaH_2PO_4$     $Na_2HPO_4$

$PbI_2$     $HNO_2$
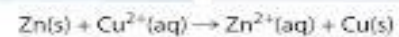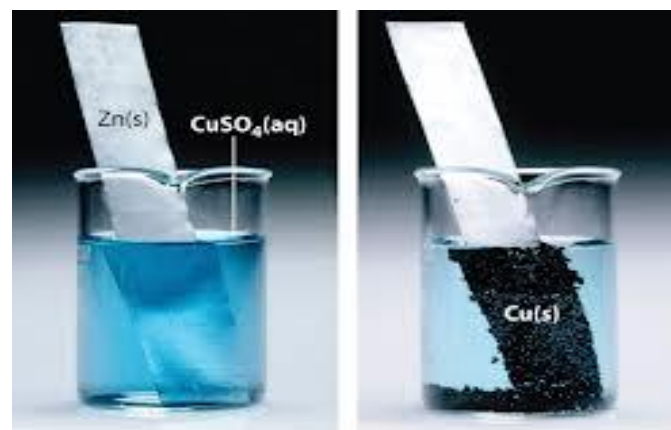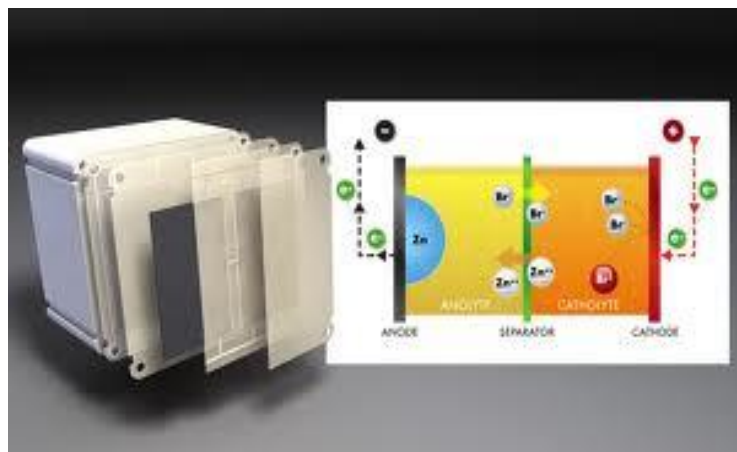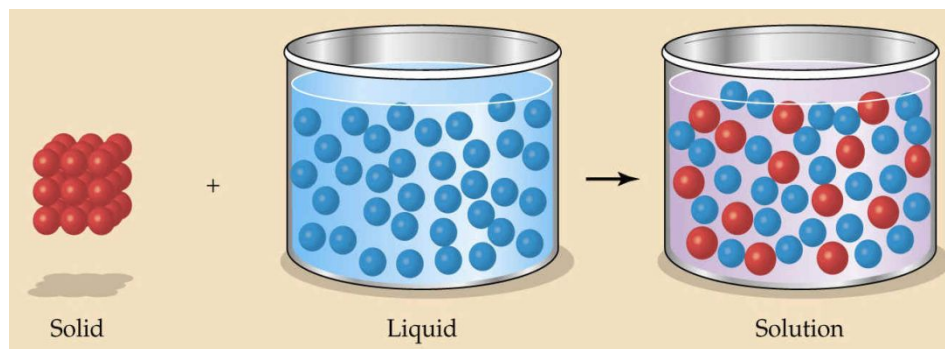
# General Properties of Aqueous Solutions

- **Solution** - a homogeneous mixture

  - **Solute:** the component that is dissolved
  - **Solvent:** the component that does the dissolving

  Generally, the component present in the greatest quantity is considered to be the solvent. *Aqueous* solutions are those in which *water* is the solvent.
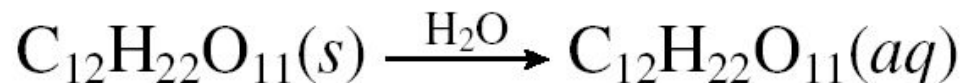
Solid

Liquid

Solution

- **Electrolytes and Nonelectrolytes**
  - *Electrolyte*:  substance that, when dissolved in water, produces a solution that  conducts electricity
    - Contains ions

$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$$

  - *Nonelectrolyte*: substance that, when dissolved in water, produces a solution that does not conduct electricity
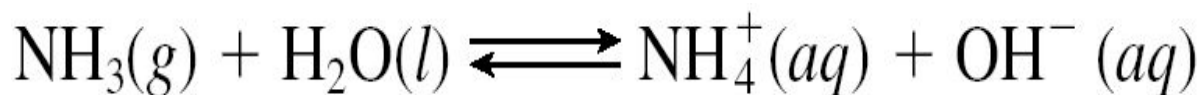    - Does not contain ions

$$C_{12}H_{22}O_{11}(s) \xrightarrow{H_2O} C_{12}H_{22}O_{11}(aq)$$

*Dissociation* - ionic compounds separate into constituent ions when dissolved in solution

$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$$

*Ionization* - formation of ions by molecular compounds when dissolved

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

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

Arrhenius (1883)

- *Hydration*:  process by which water molecules remove and surround individual ions from the solid.

# Acids and Bases

**ACIDS**
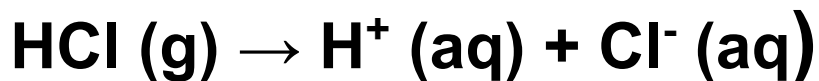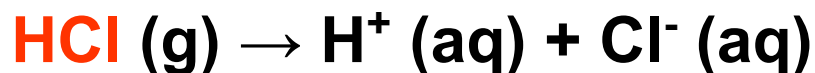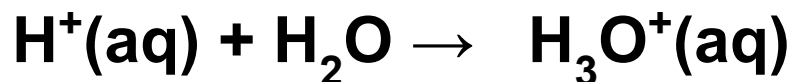
$$HAc \rightarrow H^+ (aq) + Ac^- (aq)$$

ionization

$$HCl (g) \rightarrow H^+ (aq) + Cl^- (aq)$$

$$HCl (g) \rightarrow H^+ (aq) + Cl^- (aq)$$

**hydronium ion**

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

$$H^+(aq) + H_2O \rightarrow H_3O^+(aq)$$

**BASES**

$$MOH \rightarrow M^+ (aq) + OH^- (aq)$$

$$NaOH (s) \rightarrow Na^+ (aq) + OH^- (aq)$$

$BaCl_2(s)$ dissolves

= $Ba^{2+}$

= $Cl^-$



= Hydrogen

= Oxygen
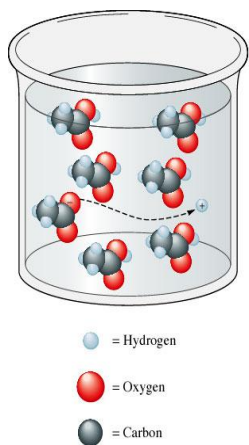
= Carbon
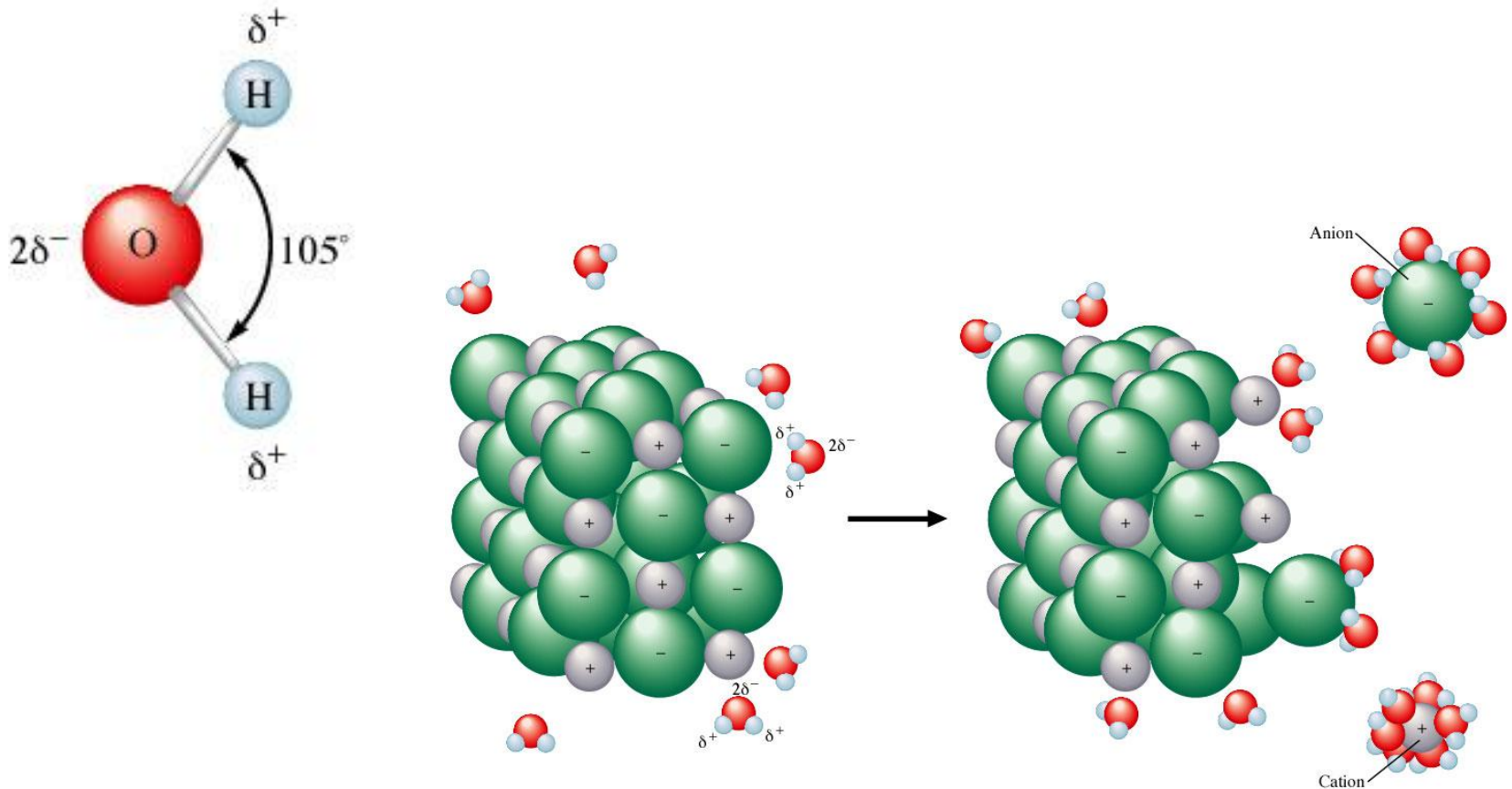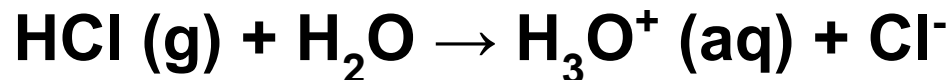
## *Strong Electrolytes*:

## 100% dissociation

- **All water soluble ionic compounds, strong acids and strong bases**
- **Conduct current very efficiently.**

## *Weak electrolytes*

- **Partially ionized in solution**
- **Exist mostly as the molecular form in solution**
- **Weak acids and weak bases**
- **Conduct only a small current.**

# Degree of dissociation

The fraction of total number of total number of molecules of electrolytes dissolved, that ionizes at equilibrium is known as **degree of dissociation or degree of ionization**.
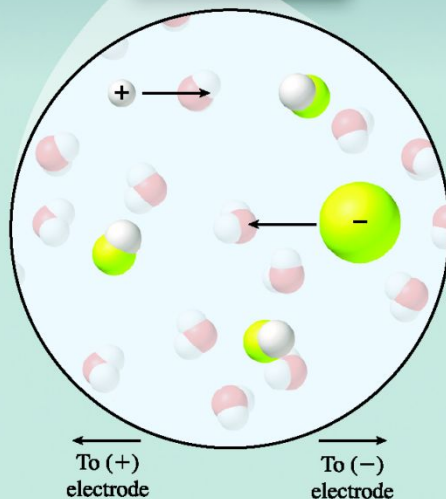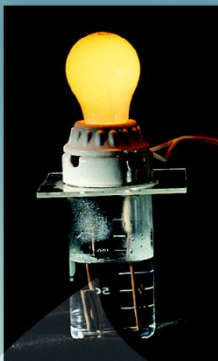
**Degree of dissociation (DOD)**

$α$=amount of substance of the reactant dissociated/amount of substance of the reactant present initially

In case of very strong acids and bases, degree of dissociation will be close to 1. Less powerful acids and bases will have lesser degree of dissociation.
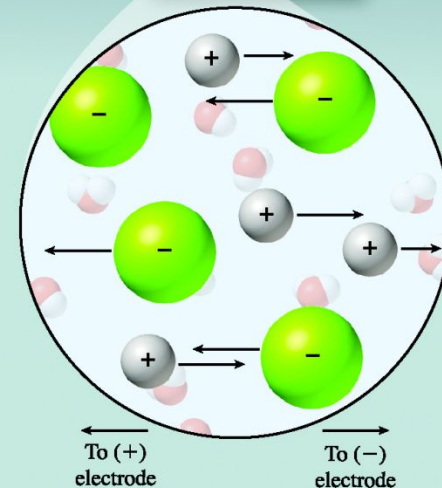
# Method to Distinguish Types of Electrolytes
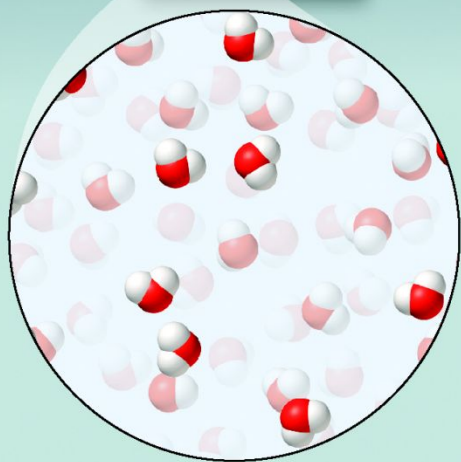


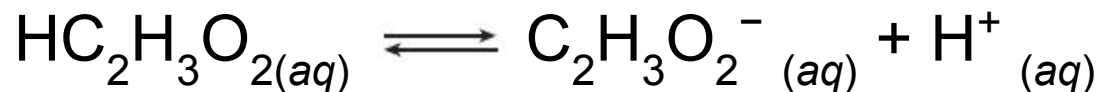nonelectrolyte        weak electrolyte        strong electrolyte

| TABLE 4.1 | The Strong Acids |
|-----------|------------------|

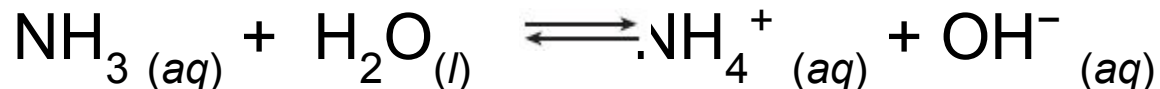| Acid | Ionization Equation |
|------|---------------------|
| Hydrochloric acid | $HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$ |
| Hydrobromic acid | $HBr(aq) \longrightarrow H^+(aq) + Br^-(aq)$ |
| Hydroiodic acid | $HI(aq) \longrightarrow H^+(aq) + I^-(aq)$ |
| Nitric acid | $HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$ |
| Chloric acid | $HClO_3(aq) \longrightarrow H^+(aq) + ClO_3^-(aq)$ |
| Perchloric acid | $HClO_4(aq) \longrightarrow H^+(aq) + ClO_4^-(aq)$ |
| Sulfuric acid* | $H_2SO_4(aq) \longrightarrow H^+(aq) + HSO_4^-(aq)$ |
|  | $HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$ |

*Note that although each sulfuric acid molecule has two ionizable hydrogen atoms, it only undergoes the first ionization completely, effectively producing one $H^+$ ion and one $HSO_4^-$ ion per $H_2SO_4$ molecule. The second ionization happens only to a very small extent.

- **Examples of weak electrolytes**

  – **Weak acids**

  $$HC_2H_3O_{2(aq)} \rightleftharpoons C_2H_3O_2^-{}_{(aq)} + H^+{}_{(aq)}$$

  – **Weak bases**

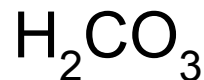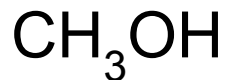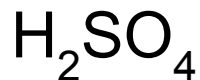  $$NH_{3\ (aq)} + H_2O_{(l)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

(Note: double arrows indicate a reaction that occurs in both directions - a state of *dynamic equilibrium* exists)

Classify the following as nonelectrolyte, weak electrolyte or strong electrolyte

$H_2SO_4$ $\qquad\qquad$ $CH_3OH$ $\qquad\qquad$ $H_2CO_3$

# Precipitation Reactions

- ***Precipitation*** (formation of a solid from two aqueous solutions) occurs when product is insoluble

- Produce insoluble ionic compounds

- Double replacement (or metathesis reaction)

- ***Solubility*** is the maximum amount of a solid that can dissolve in a given amount of solvent at a specified temperature

- Prediction based on solubility rules

# Simple Rules for Solubility

1. **Most nitrate ($NO_3^-$) salts** **are soluble.**

2. **Most alkali metals (group 1A) salts and $NH_4$** **are soluble.**

3. **Most $Cl^-$, $Br^-$, and $I^-$ salts** **are soluble**
   **NOT** **$Ag^+$, $Pb^{2+}$, $Hg_2^{2+}$**

4. **Most sulfate salts** **are soluble**
   **NOT** **$BaSO_4$, $PbSO_4$, $HgSO_4$, $CaSO_4$**

5. **Most bases** **are only slightly soluble** **NaOH, KOH** **are soluble**, **$Ba(OH)$ , $Ca(OH)_2$** **are marginally soluble**

6. **Most $S^{2-}$, $CO_3^{2-}$, $CrO_4^{2-}$, $PO_4^{3-}$ salts** **are only slightly soluble.**

## Identify the Precipitate

$$Pb(NO_3)_2(aq) + 2NaI(aq) \rightarrow 2NaNO_3^{(?)}(aq) + PbI_2^{(?)}(s)$$
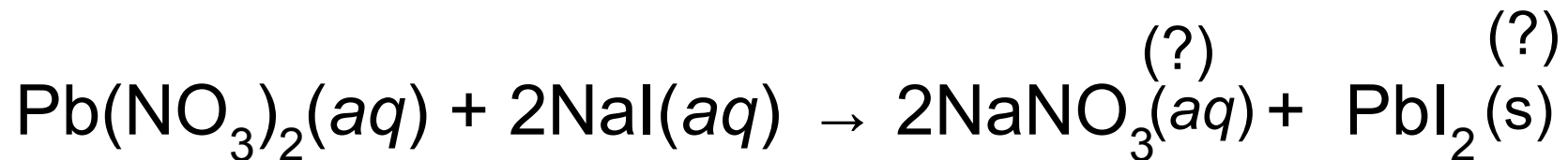
# Mixing Solutions of $Pb(NO_3)_2$ and NaCl



Na+

I−
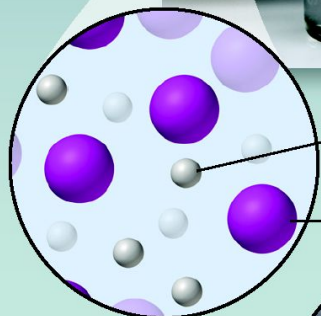
The addition of a colorless NaI(*aq*) solution...

$Pb^{2+}$

$NO_3^-$
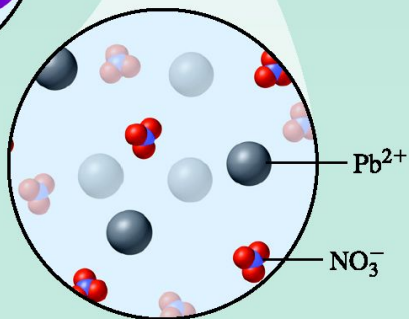
to a colorless $Pb(NO_3)_2$(*aq*) solution...
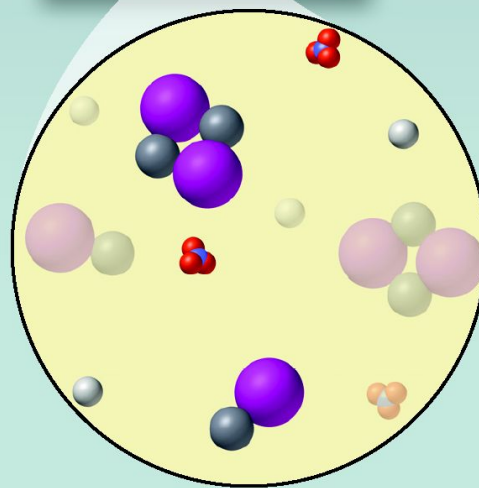
produces $PbI_2$(*s*), a yellow precipitate...
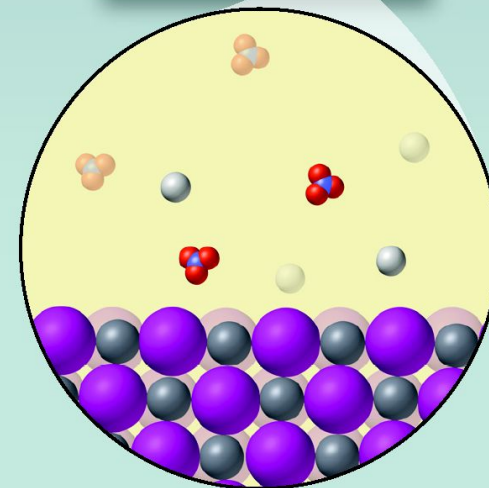
which settles out of solution. The remaining solution contains $Na^+$ and $NO_3^-$ ions.

- ***Molecular equation*****:** shows all compounds represented by their chemical formulas

$$Na_2SO_4(aq) + Ba(OH)_2(aq) \longrightarrow 2NaOH(aq) + BaSO_4(s)$$
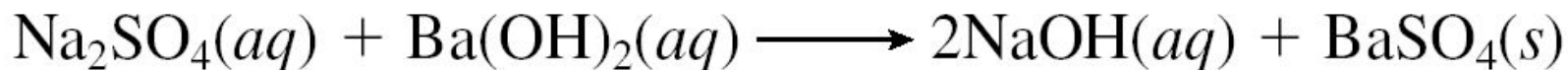
- ***Ionic equation*****:** shows all strong electrolytes as ions and all other substances (non-electrolytes, weak electrolytes, gases) by their chemical formulas

$$Na_2SO_4(aq) \longrightarrow 2Na^+(aq) + SO_4^{2-}(aq)$$

$$Ba(OH)_2(aq) \longrightarrow Ba^{2+}(aq) + 2OH^-(aq)$$

$$NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$$

Molecular equation:

$$Na_2SO_4(aq) + Ba(OH)_2(aq) \longrightarrow 2NaOH(aq) + BaSO_4(s)$$

Ionic equation:

$$2Na^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + 2OH^-(aq) \longrightarrow 2Na^+(aq) + 2OH^-(aq) + BaSO_4(s)$$
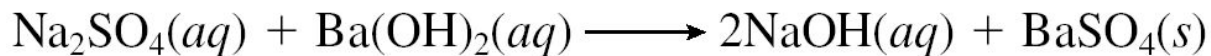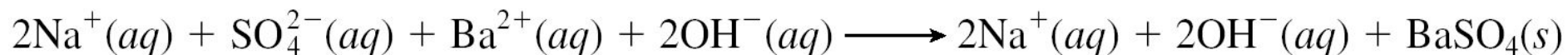
- **Net Ionic equation**: shows only the reacting species in the chemical equation
  - Eliminates spectator ions

$$2Na^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + 2OH^-(aq) \longrightarrow 2Na^+(aq) + 2OH^-(aq) + BaSO_4(s)$$

Net ionic equation:

$$Ba^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow BaSO_4(s)$$
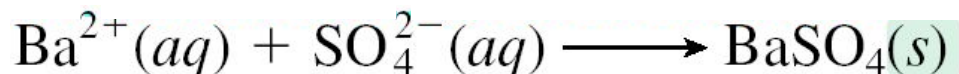
# **Steps in writing a net ionic equation**

- Write the balanced molecular equation.
  - Predict products by exchanging cations and anions in reactants.
- Separate strong electrolytes into ions.
- Cancel spectator ions.
- Use the remaining species to write the net ionic equation.

**Aqueous solutions of silver nitrate and sodium sulfate are mixed. Write the net ionic reaction.**

$2AgNO_3(aq) + Na_2SO_4(aq) \rightarrow 2NaNO_3(?) + Ag_2SO_4(?)$

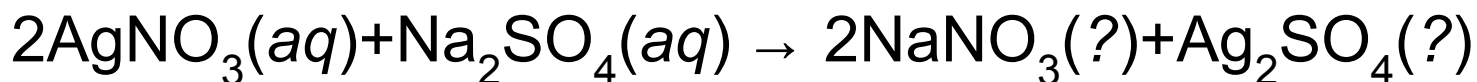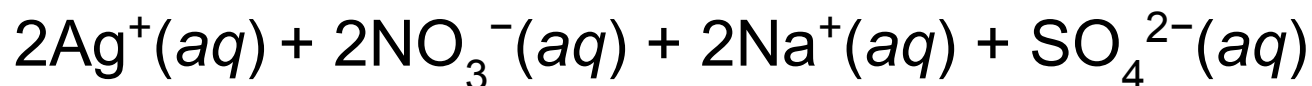All nitrates are soluble but silver sulfate is insoluble.

$2Ag^+(aq) + 2NO_3^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq)$

● $\rightarrow 2Na^+(aq) + 2NO_3^-(aq) + Ag_2SO_4(s)$

Cancel spectators.

$2Ag^+(aq) + 2NO_3^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq)$

$\rightarrow 2Na^+(aq) + 2NO_3^-(aq) + Ag_2SO_4(s)$

Write the net ionic reaction.

$2Ag^+(aq) + SO_4^{2-}(aq) \rightarrow Ag_2SO_4(s)$
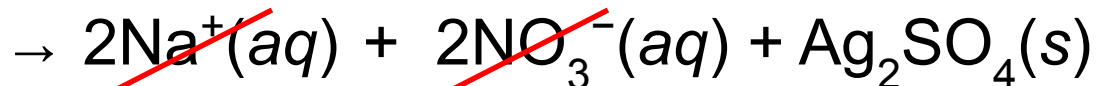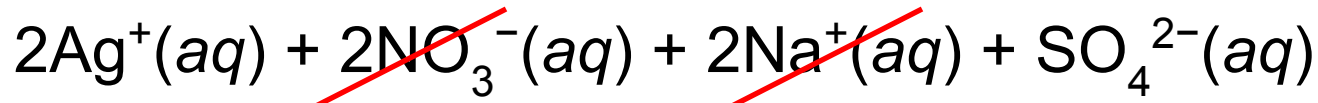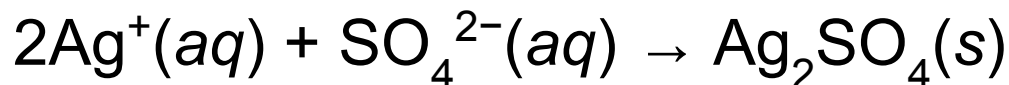
# Aqueous Reactions and Chemical Analysis

**Types of quantitative analysis**

- **Gravimetric analysis (mass analysis)**
  - **Example:  precipitation reaction**
- **Volumetric analysis (volume analysis)**
  - **Example:  titration**

# Gravimetric Analysis

- One form: isolation of a precipitate
- Typical steps:
  - Determine mass of unknown solid
  - Dissolve unknown in water
  - Combine with excess amount of known substance to form a precipitate (excess drives reaction to completion)
  - Filter, dry and weigh the precipitate
  - Use formula and mass of ppt to find % of ion in unknown solid

A 0.825 g sample of an ionic compound containing chloride ions and an unknown metal is dissolved in water and treated with excess silver nitrate. If 1.725 g of AgCl precipitate forms, what is the percent by mass of Cl in the original sample?

## Steps in solution:

- Find the % of Cl in AgCl

- Multiply the % of Cl by the mass of the precipitate to obtain the Cl in the sample

- Divide the mass of Cl in sample by total mass of sample (multiply by 100 for %)

$$\% \ Cl = \frac{35.45 \ gCl}{143.35 \ g \ AgCl} \times 100 = 24.7\%$$

$$0.247 \times 1.725g \ AgCl \ ppt = 0.427 \ g \ Cl \ in \ sample$$

$$\% \ Cl \ in \ unknown = \frac{0.427 \ g \ Cl}{0.825 \ g \ sample} \times 100 = 51.7\% \ Cl$$

- **Volumetric analysis**
  - Commonly accomplished by *titration*
    - Addition of a solution of known concentration (standard solution) to another solution of unknown concentration.
  - *Standardization is* the determination of the exact concentration of a solution.
  - *Equivalence point* represents completion of the reaction.
  - *Endpoint* is where the titration is stopped.
  - An *indicator* is used to signal the endpoint.

# Apparatus for Titration

A student measured exactly 15.0 mL of an unknown monoprotic acidic solution and placed in an Erlenmeyer flask. An indicator was added to the flask. At the end of the titration the student had used 35.0 mL of 0.12 $M$ NaOH to neutralize the acid. Calculate the molarity of the acid.

$$0.035 \text{ L NaOH} \times \frac{0.12 \text{ mol NaOH}}{1 \text{ L}} \times \frac{1 \text{ mol acid}}{1 \text{ mol base}} = 0.0042 \text{ mol acid}$$

$$M = \frac{0.0042 \text{ mol}}{0.015 \text{L}} = 0.28 \text{ M acid}$$

Calculate the molarity of 25.0 mL of a monoprotic acid if it took 45.50 mL of 0.25 *M* KOH to neutralize the acid.

$$\frac{0.25\,\text{mol KOH}}{\text{L}} \times 0.04550\,\text{L} \times \frac{1\,\text{mol acid}}{1\,\text{mol KOH}} = 0.01338\,\text{mol acid}$$

$$\frac{0.01338\,\text{mol acid}}{0.0250\,\text{L}} = 0.455\,M$$

# Home task

- Read and memorize:
Pp. 282-285, pp. 286-291

- Write all the possible equations in molecular and ionic forms:

$CuSO_4 \rightarrow Cu(OH)_2 \rightarrow CuCl_2 \rightarrow CuS \rightarrow H_2S \rightarrow Na_2S \rightarrow Na_2SO_4 \rightarrow BaSO_4$