TYPES OF CHEMICAL REACTION

I. METATHESIS REACTIONS (or DOUBLE DISPLACEMENT RXNS)

- In these reactions the **ions** of the reactants are **exchanged**:

$$A^+B^-\,(aq) \quad + \quad C^+D^-\,(aq) \longrightarrow AD\,(?) \quad + \quad CB\,(?)$$

- Double-Displacement Reactions can be further classified into:

    1. Precipitation Reactions
    2. Acid – Base Reactions
    3. Reactions that form an unstable product

II. REDOX REACTIONS (Oxidation – Reduction Reactions)

- In these reactions an **exchange of electrons** occurs between the reactants.

- Redox Reactions can be further classified into:

    1. Combination Reactions
    2. Decomposition Reactions
    3. Single Replacement Reactions
    4. Combustion Reactions

Each type of these reactions will be discussed in detail.

SOLUBILITY RULES

1. Precipitation Reactions

- In these reactions an insoluble solid (precipitate) forms.
- To better understand these reactions, a knowledge of solubility rules for ionic substances is necessary.
- These solubility rules are summarized in solubility tables (See Table 4.1 in your textbook)

Solubility Rules:

- All compounds of group IA and (NH_4^+) are soluble.
- All nitrates, acetates, and most perchlorates are soluble.
- All chlorides, bromides, and iodides are soluble, except those of Ag^+, Pb^{2+}, Cu^+ and Hg_2^{2+}.
- All sulfates are soluble, except those of Ca^{2+}, Sr^{2+}, Ba^{2+} and Pb^{2+}.

- All metal hydroxides are insoluble, except those of Group IA and larger members of Group 2A.
- All carbonates and phosphates are insoluble, except those of Group IA and (NH_4^+).
- All sulfides are insoluble, except those of Group IA, Group 2A and (NH_4^+).

Examples:

Use solubility table to determine if each of the following substances are soluble or insoluble:

$CaCl_2$ _____

$PbSO_4$ _____

$Mg(OH)_2$ _____

$(NH_4)_2CO_3$ _____

PRECIPITATION REACTIONS

- A solution of silver nitrate is mixed with a solution of sodium chloride. A white precipitate is formed. Write a NET IONIC EQUATION for this reaction.

$$AgNO_3\,(aq) + NaCl\,(aq) \longrightarrow AgCl\,(?) + NaNO_3\,(?)$$

The solubility of each product must be known! Referring to the solubility rules, we find out that:

AgCl is insoluble in water (precipitate):	AgCl(s)
$NaNO_3$ is soluble in water (completely dissociated):	$NaNO_3$(aq)

- **The Molecular Equation becomes**:

$$\mathbf{AgNO_3\,(aq) + NaCl\,(aq) \longrightarrow AgCl\,(s) + NaNO_3\,(aq)}$$

- **The Complete (Total) Ionic Equation is:**

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \longrightarrow \underset{\textbf{ppt}}{AgCl(s)} + Na^+(aq) + NO_3^-(aq)$$

- The Net Ionic Equation is obtained by canceling out the spectator ions:

$$Ag^+(aq) + \underset{\textbf{spectator ion}}{\cancel{NO_3^-(aq)}} + \underset{\textbf{spectator ion}}{\cancel{Na^+(aq)}} + Cl^-(aq) \longrightarrow \underset{\textbf{ppt}}{AgCl(s)} + \underset{\textbf{spectator ions}}{\cancel{Na^+(aq)} + \cancel{NO_3^-(aq)}}$$

- **The NET IONIC EQUATION is:**

$$\mathbf{Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)}$$

Example:
Write balanced molecular and net ionic equations for the reaction of solutions of $Pb(NO_3)_2$ and KI.

2. Acid – Base Reactions and Acid – Base Concepts

General Properties

	ACIDS	BASES
Taste	sour	bitter
Change color of indicators:	⬇	⬇
Blue Litmus	**Red**	No change
Red Litmus	No change	**Blue**
Phenolphtalein	Colorless	**Pink**
Neutralization	Reacts with bases to produce salt and water	Reacts with acids to produce salt and water

Arrhenius Concept of Acids and Bases

- This definition defines acids and bases in terms of the effect they have on water

ACIDS	BASES
Substances that dissolve in water and increase the concentration of **hydronium** ions ($\mathbf{H_3O^+}$)	Substances that dissolve in water and increase the concentration of **hydroxide** ions ($\mathbf{OH^-}$)
Examples: $HCl\,(g) + H_2O\,(l) \rightarrow \mathbf{H_3O^+}\,(aq) + Cl^-\,(aq)$ Accepted simplification: $HCl\,(g) \xrightarrow{H_2O} \mathbf{H^+}\,(aq) + Cl^-\,(aq)$	**Examples:** $NaOH\,(s) \xrightarrow{H_2O} Na^+\,(aq) + \mathbf{OH^-}\,(aq)$
$HC_2H_3O_2\,(l) + H_2O\,(l) \rightarrow \mathbf{H_3O^+}\,(aq) + C_2H_3O_2^-\,(aq)$ Accepted simplification: $HC_2H_3O_2\,(l) \xrightarrow{H_2O} \mathbf{H^+}\,(aq) + C_2H_3O_2^-\,(aq)$	$Ba(OH)_2\,(s) \xrightarrow{H_2O} Ba^{2+}\,(aq) + 2\,\mathbf{OH^-}\,(aq)$

Limitations of Arrhenius definition:

1. Considers acid-base reactions **only** in aqueous solutions.
2. Singles out the OH^- ion as the source of base character; (other species can play a similar role)

Bronsted-Lowry Concept of Acids and Bases

- This definition defines acids and bases in terms of H^+ (proton) transfer.

ACIDS	BASES
Acids are H^+ (proton donors)	**Bases are H^+ (protons acceptors**
NEUTRALIZATION: A reaction in which a H^+ (proton) is transfered	

Examples of Bronsted-Lowry neutralizations :

1. $HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$

H^+ is transferred from $HCl(aq)$ (acid) to $H_2O(l)$ (base)

$HCl(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$

---

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

H^+ is transferred from $H_2O(l)$ (acid) to $NH_3(g)$ (base)

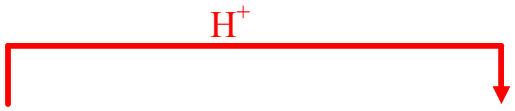
$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

NOTE: - H_2O gains a H^+ and acts as a base with HCl(g)
- H_2O loses a H^+ and acts as an acid with $NH_3(g)$

- A substance that can behave both as a base or an acid depending on the chemical environment is called an **amphiprotic** species.

- H_2O is an **amphiprotic** species.

3. $HC_2H_3O_2(l)$ + $H_2O(l)$ $\rightleftharpoons$ $H_3O^+(aq)$ + $C_2H_3O_2^-(aq)$
   acetic acid — acetate ion



$HC_2H_3O_2(l)$ + $H_2O(l)$ $\rightleftharpoons$ $H_3O^+(aq)$ + $C_2H_3O_2^-(aq)$
acid — base

H_2O is an **amphiprotic** species.

The Bronsted-Lowry Concept of Acids & Bases is more general than the Arrhenius concept:

The Bronsted-Lowry Concept introduces additional points of view:

1. A base is a species that accepts H^+ ions (protons). (OH^- is only one example of a base)
2. Acids and Bases can be ions as well as molecular substances.
3. Acid-Base reactions are not restricted to aqueous solutions.
4. Amphiprotic species (like H_2O) can act as either acids or bases, depending on what the other reactant is.

SUMMARY OF ACID – BASE CONCEPTS

	ACID	BASE	ACID-BASE REACTION
ARRHENIUS (less general)	Produces H^+ when dissolved in water	Produces OH^- when dissolved in water	$H^+ + OH^- \rightarrow H_2O$
BRONSTED-LOWRY (more general)	Proton donor	Proton acceptor	Proton transfer

CHEMICAL PROPERTIES OF ACIDS AND BASES

- The most important property of ACIDS and BASES is their reaction with each other, called NEUTRALIZATION:

ACID + BASE ⟶ SALT + WATER
(SALT: Ionic Substance)

In General:

$HA + BOH \longrightarrow B^+A^- + H_2O$

B^+: any cation (except H^+)
A^-: any anion (except OH^-)

Examples:

1. $HCl\,(aq) + NaOH\,(aq) \longrightarrow NaCl\,(aq) + H_2O\,(l)$

2. $HCl\,(aq) + Ba(OH)_2\,(aq) \longrightarrow BaCl_2\,(aq) + H_2O\,(l)$
unbalanced

Balanced: $2\,HCl\,(aq) + Ba(OH)_2\,(aq) \longrightarrow BaCl_2\,(aq) + 2\,H_2O\,(l)$

3. $HC_2H_3O_2(aq) + NaOH(aq) \longrightarrow$

4. $H_2SO_4(aq) + NaOH(aq) \longrightarrow$
unbalanced

Balanced: $H_2SO_4(aq) + NaOH(aq) \longrightarrow$

- Note that all SALTS are derived from an ACID and a BASE:

Salt	**Base from which derived**	**Acid from which Derived**
$Fe(NO_3)_3$ iron (III) nitrate	$Fe(OH)_3$ iron (III) hydroxide	HNO_3 nitric acid
$CaCl_2$ calcium chloride	$Ca(OH)_2$ calcium hydroxide	HCl hydrochloric acid
Na_2CO_3 sodium carbonate		
$(NH_4)_2SO_4$ ammonium sulfate		
Na_2S sodium sulfide		
$NaC_2H_3O_2$ sodium acetate		
K_3PO_4 (potassium phosphate)		

STRONG AND WEAK ACIDS AND BASES

- Acids and Bases can be classified according to their ability to ionize or dissociate in aqueous solution:

	ACIDS		BASES	
	STRONG ACIDS	**WEAK ACIDS**	**STRONG BASES**	**WEAK BASES**
Electrolyte strength	Strong electrolytes	Weak electrolytes	Strong electrolytes	Weak electrolytes
Extent of Ionization/ Dissociation	100% Complete Ionization	Less than 100% Partial Ionization	100% Complete Ionization	Less than 100% Partial Ionization
Symbols used to show extent of ionization/ dissociation	$\longrightarrow$	$\rightleftharpoons$	$\longrightarrow$	$\rightleftharpoons$
Particles present in aqueous solution	Ions only	Mostly molecules (a few ions)	Ions only	Mostly molecules (a few ions)
Examples	H^+ (aq) + Cl^- (aq) H^+ (aq) + NO_3^- (aq) H^+ (aq) + HSO_4^- (aq)	$HC_2H_3O_2$ (aq) HF (aq) H_2CO_3 (aq)	Na^+ (aq) + OH^- (aq) K^+ (aq) + OH^- (aq) Ba^{2+} (aq) + 2 OH^- (aq)	NH_4OH (aq) also written NH_3 (aq) + H_2O

SUMMARY OF ACID AND BASE STRENGTHS

- In order to write net ionic equations for acid-base (neutralization reactions), a knowledge of the strength of acids and bases is essential.

I. ACIDS

1. Strong Acids

- are Strong Electrolytes
- are Acids that are completely ionized (100%) in aqueous solution and produce H_3O^+ (H^+) ions and an anion.
- are molecular substances in pure form Ex: HCl(g)

Example: A solution of 0.10 M HCl(aq)

$$\underset{0\ M}{HCl\,(aq)} \longrightarrow \underset{0.1\ M}{H^+\,(aq)} + \underset{0.1\ M}{Cl^-\,(aq)}$$

In General: **$HA(aq) \longrightarrow H^+(aq) + A^-(aq)$**

2. Weak Acids

- are Weak Electrolytes
- are Acids that are partially ionized (less than 100%) in aqueous solution
- molecular substances in pure form Ex: $HC_2H_3O_2(l)$

Example: A solution of 0.10 M $HC_2H_3O_2(aq)$

$$\underset{\approx 0.099\ M}{HC_2H_3O_2\,(aq)} \rightleftharpoons \underset{\approx 0.001\ M}{H^+\,(aq)} + \underset{\approx 0.001\ M}{C_2H_3O_2^-\,(aq)}$$

In General: **$HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$**

II. BASES

1. Strong Bases

- are Strong Electrolytes
- are Bases that are completely dissociated (100%) in aqueous solution and produce a metallic cation and OH^- ions
- are ionic substances in pure form(all soluble metallic hydroxides) Ex: $Na^+ OH^-$ (s)
  $K^+ OH^-$ (s)

Example: A solution of 0.10 M NaOH(aq)

$$\underset{0\ M}{NaOH(aq)} \longrightarrow \underset{0.1\ M}{Na^+(aq)} + \underset{0.1\ M}{OH^-(aq)}$$

Example: A solution of 0.10 M $Ba(OH)_2$(aq)

$$\underset{0\ M}{Ba(OH)_2(aq)} \longrightarrow \underset{0.1\ M}{Ba^{2+}(aq)} + \underset{0.2\ M}{2OH^-(aq)}$$

In General: **$BOH(aq) \longrightarrow B^+(aq) + OH^-(aq)$**

2. Weak Bases

- are Weak Electrolytes
- are Bases that are partially ionized (less than 100%) in aqueous solution
- molecular substances in pure form Ex: $NH_3(g)$

Example: A solution of 0.10 M NH_3(aq)

$$\underset{\approx 0.099\ M}{NH_3(aq) + H_2O(l)} \rightleftharpoons \underset{\approx 0.001\ M}{NH_4^+(aq)} + \underset{\approx 0.001\ M}{OH^-}$$

In General: **$B(aq) + H_2O(l) \rightleftharpoons BH^+(aq) + OH^-(aq)$**

COMMON ACIDS AND BASES

Strong Acids

- Completely ionized and written in their ionic forms

$HI(aq) \longrightarrow H^+(aq) + I^-(aq)$
$HBr(aq) \longrightarrow H^+(aq) + Br^-(aq)$
$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$
$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$
$H_2SO_4(aq) \longrightarrow 2H^+(aq) + SO_4^{2-}(aq)$
$HClO_4(aq) \longrightarrow H^+(aq) + ClO_4^-(aq)$
$HClO_3(aq) \longrightarrow H^+(aq) + ClO_3^-(aq)$

Weak Acids

- Partially ionized and written in their molecular forms

$H_2C_2H_3O_2(aq)$
$HF(aq)$
$H_2S(aq)$
$HCN(aq)$

Strong Bases

- Completely ionized and written in their ionic forms

$LiOH(aq) \longrightarrow Li^+(aq) + OH^-(aq)$
$NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$
$KOH(aq) \longrightarrow K^+(aq) + OH^-(aq)$
$Ba(OH)_2(aq) \longrightarrow Ba^{2+}(aq) + 2OH^-(aq)$
$Sr(OH)_2(aq) \longrightarrow Sr^{2+}(aq) + 2OH^-(aq)$
$Ca(OH)_2(aq) \longrightarrow Ca^{2+}(aq) + 2OH^-(aq)$

Weak Bases

- Partially ionized and written in their molecular forms

NH_3 or NH_4OH
CH_3NH_2
$CO(NH_2)_2$

WRITING NET IONIC EQUATIONS FOR NEUTRALIZATION REACTIONS

Recall:

$$\text{ACID} + \text{BASE} \xrightarrow{\text{neutralization}} \text{SALT} + \text{WATER}$$

- Neutralization Reactions can be classified according to the type of acid and base (strong or weak) reacting with each other.

(A) Reaction of a Strong Acid with a Strong Base

Hydrochloric acid + Sodium hydroxide ⟶ Sodium chloride + Water

Molecular Equation:

$$HCl\,(aq) + NaOH\,(aq) \longrightarrow NaCl\,(aq) + H_2O\,(l)$$

Strong Electrolyte (completely ionized) Ions only	Strong Electrolyte (completely ionized) Ions only	Strong Electrolyte (completely ionized) Ions only	Non- Electrolyte (un-ionized) Molecules only

Total Ionic Equation:

$$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \longrightarrow Na^+(aq) + Cl^-(aq) + H_2O(l)$$

Net Ionic Equation:
is obtained after canceling out the spectator ions from the Total Ionic Equation:

$$H^+(aq) + \cancel{Cl^-(aq)} + \cancel{Na^+(aq)} + OH^-(aq) \longrightarrow \cancel{Na^+(aq)} + \cancel{Cl^-(aq)} + H_2O(l)$$

spectator ions spectator ions

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

Example:
Write net ionic equation for the reaction of nitric acid and barium hydroxide.

(B) Reaction of a Weak Acid with a Strong Base

Acetic Acid + Sodium hydroxide ⟶ Sodium Acetate + Water

Molecular Equation:

$$HC_2H_3O_2(aq) + NaOH(aq) \longrightarrow NaC_2H_3O_2(aq) + H_2O(l)$$

Weak Electrolyte (partially ionized) Mostly molecules	Strong Electrolyte (completely ionized) Ions only	Strong Electrolyte (completely ionized) Ions only	Non- Electrolyte (un-ionized) Molecules only

Total Ionic Equation:

$$HC_2H_3O_2(aq) + Na^+(aq) + OH^-(aq) \longrightarrow Na^+(aq) + C_2H_3O_2(aq)^-(aq) + H_2O(l)$$

$$HC_2H_3O_2(aq) + \cancel{Na^+(aq)} + OH^-(aq) \longrightarrow \cancel{Na^+(aq)} + C_2H_3O_2(aq)^- + H_2O(l)$$

spectator ion spectator ion

Net Ionic Equation:

$$HC_2H_3O_2(aq) + OH^-(aq) \longrightarrow C_2H_3O_2(aq)^- + H_2O(l)$$

Example:
Write net ionic equation for the reaction of hydrosulfuric acid and potassium hydroxide.

(C) Reaction of a Strong Acid with a Weak Base

Hydrochloric Acid + Ammonium hydroxide ⟶ Ammonium Chloride + Water

Molecular Equation:

$$HCl(aq) + NH_4OH(aq) \longrightarrow NH_4Cl(aq) + H_2O(l)$$

Strong Electrolyte (completely ionized) Ions only	Weak Electrolyte (partially ionized) Mostly molecules	Strong Electrolyte (completely ionized) Ions only	Non- Electrolyte (un-ionized) Molecules only

Total Ionic Equation:

$$H^+(aq) + Cl^-(aq) + NH_4OH(aq) \longrightarrow NH_4^+(aq) + Cl(aq)^-(aq) + H_2O(l)$$

also written: $NH_3(aq) + H_2O(l)$

$$H^+(aq) + Cl^-\cancel{(aq)} + NH_4OH(aq) \longrightarrow NH_4^+(aq) + Cl^-(aq)^- + H_2O(l)$$

$(NH_3(aq) + H_2O(l)$

spectator ion spectator ion

Net Ionic Equation:

$$H^+(aq) + NH_4OH(aq) \longrightarrow NH_4^+(aq) + H_2O(l)$$

OR

$$H^+(aq) + NH_3(aq) \longrightarrow NH_4^+(aq)$$

Example:
Write net ionic equation for the reaction of sulfuric acid and ammonia.

(D) Reaction of a Weak Acid with a Weak Base

Acetic Acid + Ammonium hydroxide ⟶ Ammonium acetate + Water

Molecular Equation:

$$HC_2H_3O_2(aq) + NH_4OH(aq) \longrightarrow NH_4C_2H_3O_2(aq) + H_2O(l)$$

Weak Electrolyte (partially ionized) Mostly molecules	Weak Electrolyte (partially ionized) Mostly molecules	Strong Electrolyte (completely ionized) Ions only	Non- Electrolyte (un-ionized) Molecules only

Total Ionic Equation:

$$HC_2H_3O_2(aq) + NH_4OH(aq) \longrightarrow NH_4^+(aq) + C_2H_3O_2(aq)^- + \cancel{H_2O(l)}$$

also written: $NH_3(aq) + \cancel{H_2O(l)}$

NO SPECTATOR IONS ARE PRESENT!

Net Ionic Equation:

$$HC_2H_3O_2(aq) + NH_4OH(aq) \longrightarrow NH_4^+(aq) + C_2H_3O_2(aq)^- + H_2O(l)$$

Note: this is the same as the Total Ionic Equation

OR

$$HC_2H_3O_2(aq) + NH_3(aq) \longrightarrow NH_4^+(aq) + C_2H_3O_2^-(aq)$$

Example:
Write net ionic equation for the reaction of hydrofluoric acid and ammonia.

3. Reactions that form an unstable product

- Some chemical reactions produce gas because one of the products formed in the reaction is unstable.
- Three such substances that readily decompose are:

$H_2CO_3(aq) \longrightarrow CO_2(g) + H_2O(l)$
(carbonic acid)

$H_2SO_3(aq) \longrightarrow SO_2(g) + H_2O(l)$
(sulfurous acid)

$NH_4OH(aq) \longrightarrow NH_3(g) + H_2O(l)$
ammonium hydroxide → ammonia

- When any of these products appears in a chemical reaction, they should be replaced with their decomposition products.

Example 1:

$Na_2CO_3(aq) + 2\,HCl(aq) \longrightarrow NaCl(aq) + \mathbf{H_2CO_3(aq)}$ **unstable**

$Na_2CO_3(aq) + \mathbf{2}\,HCl(aq) \longrightarrow \mathbf{2}\,NaCl(aq) + \mathbf{H_2CO_3(aq)}$

$\mathbf{H_2CO_3(aq)} \rightarrow \mathbf{CO_2(g)} + \mathbf{H_2O(l)}$

$Na_2CO_3(aq) + \mathbf{2}\,HCl(aq) \longrightarrow \mathbf{2}\,NaCl(aq) + \mathbf{CO_2(g)} + \mathbf{H_2O(l)}$

Total Ionic Equation:

$2Na^+(aq) + CO_3^{2-}(aq) + 2H^+(aq) + 2Cl^-(aq) \rightarrow 2Na+(aq) + 2Cl^-(aq) + CO_2(g) + H_2O(l)$

Net Ionic Equation:

$2Na^+(aq) + CO_3^{2-}(aq) + 2H^+(aq) + 2Cl^-(aq) \rightarrow 2Na+(aq) + 2Cl^-(aq) + CO_2(g) + H_2O(l)$

$CO_3^{2-}(aq) + 2H^+(aq) \longrightarrow CO_2(g) + H_2O(l)$

Example 2:

$CaCO_3(s) + 2\ HNO_3(aq) \longrightarrow Ca(NO_3)_2(aq) + \mathbf{H_2CO_3(aq)}$ **unstable**

$CaCO_3(s) + \mathbf{2}\ HNO_3(aq) \longrightarrow Ca(NO_3)_2(aq) + \mathbf{H_2CO_3(aq)}$

$\mathbf{H_2CO_3(aq)} \rightarrow \mathbf{CO_2(g)} + \mathbf{H_2O(l)}$

$CaCO_3(s) + \mathbf{2}\ HNO_3(aq) \longrightarrow Ca(NO_3)_2(aq) + \mathbf{CO_2(g)} + \mathbf{H_2O(l)}$

Total Ionic Equation:

$CaCO_3(s) + 2H^+(aq) + 2NO_3^-(aq) \longrightarrow Ca^{2+}(aq) + 2NO_3^-(aq) + CO_2(g) + H_2O(l)$

Net Ionic Equation:

$CaCO_3(s) + 2H^+(aq) + 2NO_3^-(aq) \longrightarrow Ca^{2+}(aq) + 2NO_3^-(aq) + CO_2(g) + H_2O(l)$

$CaCO_3(s) + 2H^+(aq) \longrightarrow Ca^{2+}(aq) + CO_2(g) + H_2O(l)$

Example 3:

Write a balanced net ionic equation for the reaction of sodium sulfite and hydrobromic acid.