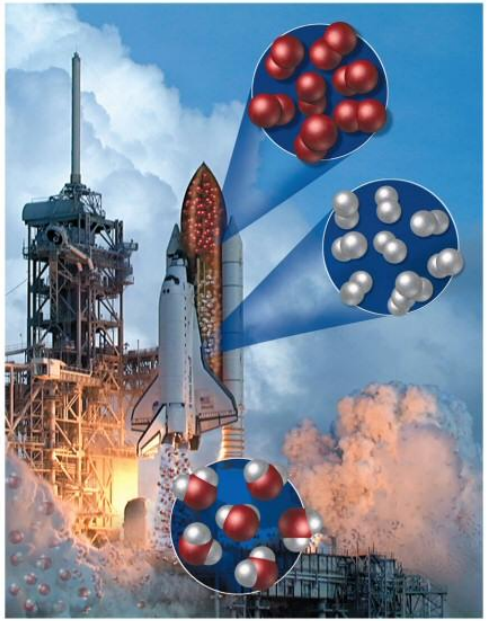
Chemical Reactions



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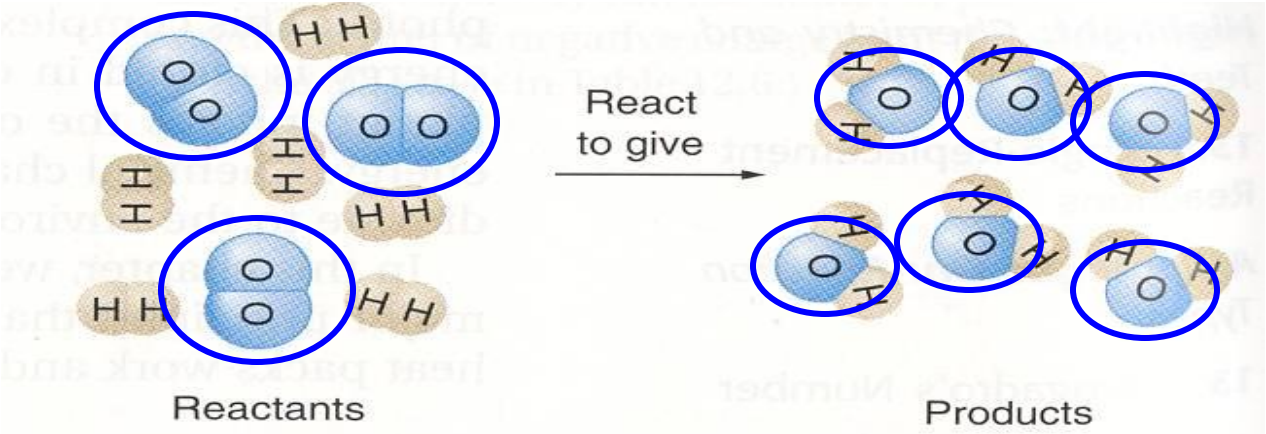
CHAPTER OUTLINE

CHEMICAL REACTIONS

- A chemical reaction is a rearrangement of atoms in which some of the original bonds are broken and new bonds are formed to give different chemical structures.
- In a chemical reaction, atoms are neither created, nor destroyed.
- A chemical reaction, as described above, is supported by Dalton's postulates

CHEMICAL REACTIONS



In a chemical reaction, atoms are neither created, nor destroyed

CHEMICAL REACTIONS

- A chemical reaction can be detected by one of the following evidences:
  1. Change of color
  2. Formation of a solid
  3. Formation of a gas
  4. Exchange of heat with surroundings

Why use Chemical Equations?

1. Shorthand way of describing a reaction
2. Provides information about the reaction
   - Formulas of reactants and products
   - States of reactants and products
   - Relative numbers of reactant and product molecules that are required
   - Can be used to determine amounts of the reactants and products

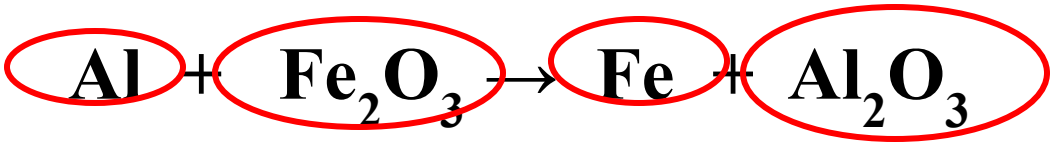
CHEMICAL EQUATIONS

- A chemical equation is a shorthand expression for a chemical reaction.

Word equation:

Aluminum combines with ferric oxide to form iron and aluminum oxide.

Chemical equation:



CHEMICAL EQUATIONS

- Reactants are separated from products by an arrow.

$$Al + Fe_2O_3 \rightarrow Fe + Al_2O_3$$

- Coefficients are placed in front of substances to balance the equation.

$$2\,Al + Fe_2O_3 \rightarrow 2\,Fe + Al_2O_3$$

Subscripts

CHEMICAL EQUATIONS

- Reaction conditions are placed over the arrow.

$$Al + Fe_2O_3 \xrightarrow{\Delta} Fe + Al_2O_3$$

heat

- The physical state of the substances are indicated by the symbols (s), (l), (g), (aq).

$$2\,Al\,(s) + Fe_2O_3\,(s) \xrightarrow{\Delta} 2\,Fe\,(l) + Al_2O_3\,(s)$$

Symbols Used in Equations

1. energy symbols used above the arrow for decomposition reactions
   - Δ = heat
   - $h\nu$ = light
   - shock = mechanical
   - elec = electrical

BALANCING EQUATIONS

- A balanced equation contains the same number of atoms on each side of the equation, and therefore obeys the law of conservation of mass.
- Many equations are balanced by trial and error; but it must be remembered that coefficients can be changed in order to balance an equation, but not subscripts of a correct formula.

BALANCING EQUATIONS

- The general procedure for balancing equations is:

Write the unbalanced equation:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

Make sure the formula for each substance is correct

BALANCING EQUATIONS

- The general procedure for balancing equations is:

Balance by inspection:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

Count and compare each element on both sides of the equation

1 C	=	1 C
4 H	≠	2 H
2 O	≠	3 O

BALANCING EQUATIONS

- Balance elements that appear only in one substance first.

Balance H

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

$$1\,CH_4 + O_2 \rightarrow CO_2 + 2\,H_2O$$

BALANCING EQUATIONS

Balance O

When finally done, check for the smallest coefficients possible

$$1\ CH_4 + O_2 \rightarrow CO_2 + 2\ H_2O$$

$$1\ CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

Examples:

$$2\ AgNO_3 + H_2S \rightarrow Ag_2S + 2\ HNO_3$$

$$2\ Al(OH)_3 + 3\ H_2SO_4 \rightarrow Al_2(SO_4)_3 + 6\ H_2O$$

$$Fe_3O_4 + 4\ H_2 \rightarrow 3\ Fe + 4\ H_2O$$

$$2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$$

TYPES OF CHEMICAL REACTIONS

- Chemical reactions are can be classified into five types: Based on what the atoms do

1. Synthesis or combination
2. Decomposition
3. Single replacement
4. Double replacement
5. Combustion

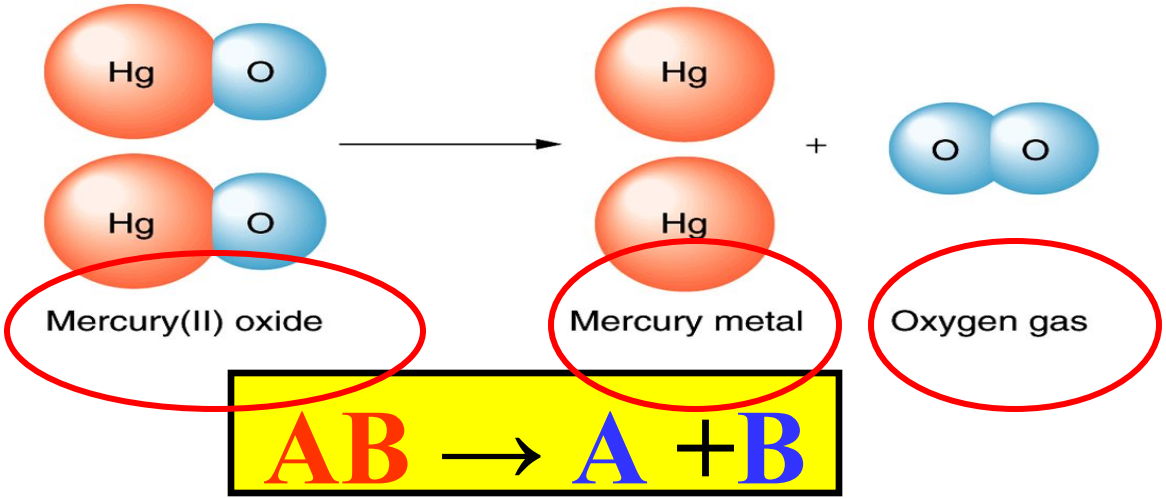
SYNTHESIS or COMBINATION

- In these reactions, 2 elements or compounds combine to form another compound.

A + B → AB

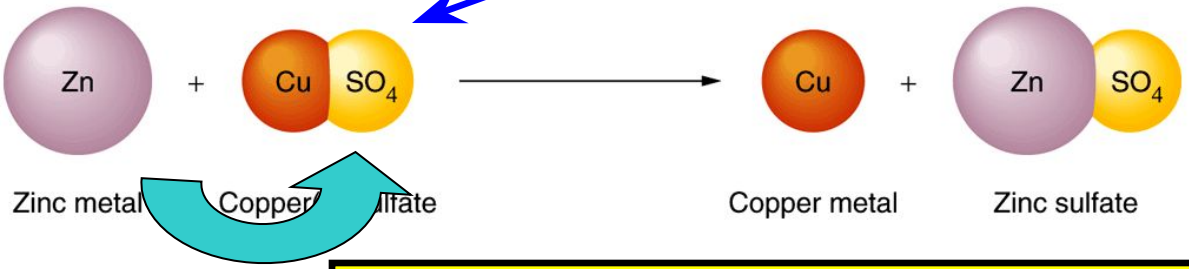
DECOMPOSITION

- **In these reactions, a compound breaks up to form 2 elements or simpler compound.**



SINGLE REPLACEMENT

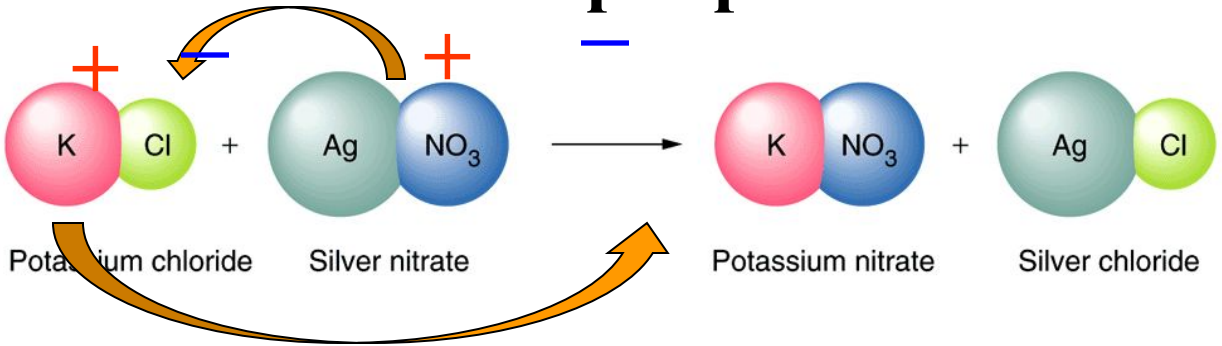
- In these reactions, a more reactive element replaces a less reactive element in a compound.



$$A + BC \rightarrow B + AC$$

DOUBLE REPLACEMENT

- The cation from one compound replaces the cation from another compound.



$$AB + CD \rightarrow AD + CB$$

COMBUSTION

- **A reaction that involves oxygen as a reactant and produces large amounts of heat is classified as a combustion reaction.**

$$CH_4\,(g) + 2\,O_2\,(g) \rightarrow CO_2\,(g) + 2\,H_2O\,(g)$$

Examples:

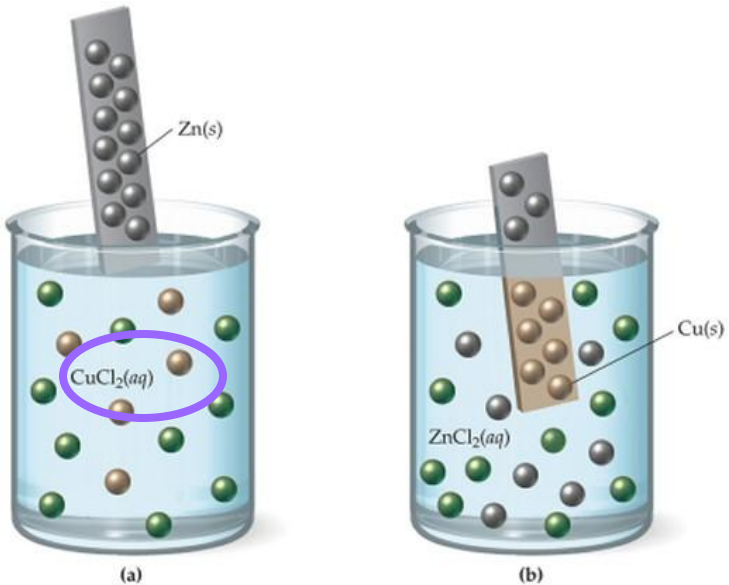
Classify each of the reactions below:

1. $Mg + CuCl_2 \rightarrow MgCl_2 + Cu$
2. $CaCO_3 \rightarrow CaO + CO_2$
3. $2\ HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2\ H_2O$
4. $4\ Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$

Single Displacement

The Zinc Replaces the Copper

$$Zn(s) + CuCl_2(aq) \rightarrow Cu(s) + ZnCl_2$$

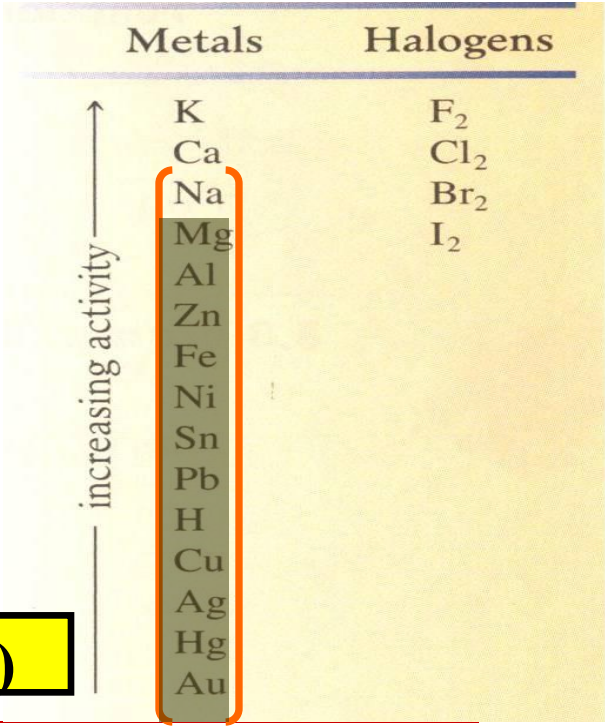


ACTIVITY SERIES OF METALS

- Activity series is a listing of metallic elements in descending order of reactivity.
- Hydrogen is also included in the series since it behaves similar to metals.
- Activity series tables are available in textbooks and other sources.

ACTIVITY SERIES OF METALS

- Elements listed higher will displace any elements listed below them.
- For example Na will displace any elements listed below it from one of its compounds.

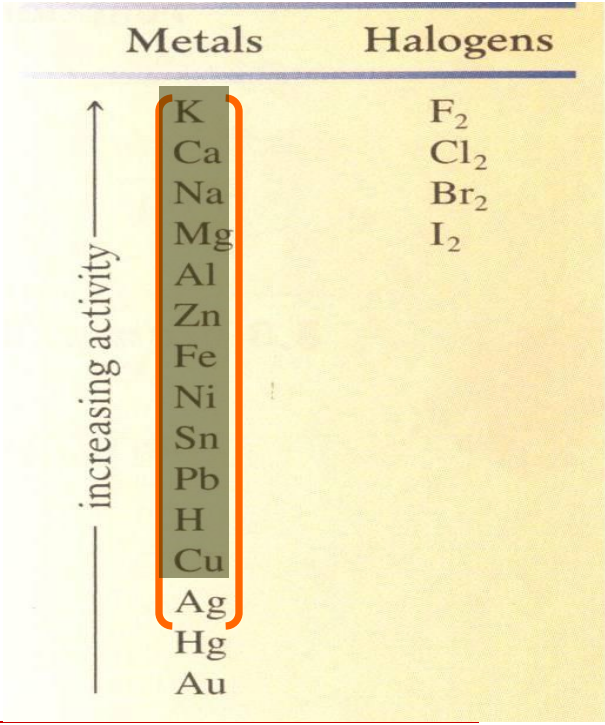


$$2\ Na\ (s) + MgCl_2\ (aq) \rightarrow 2\ NaCl\ (aq) + Mg\ (s)$$

$$2\ Na\ (s) + AgCl\ (aq) \rightarrow NaCl\ (aq) + Ag\ (s)$$

ACTIVITY SERIES OF METALS

- Elements listed lower will not displace any elements listed above them.
- For example Ag cannot displace any elements listed above it from one of its compounds.



$Ag\ (s) + CuCl_2\ (aq) \rightarrow$ No Reaction

$Ag\ (s) + HCl\ (aq) \rightarrow$ No Reaction

Example 1:

Use activity series to complete each reaction below. If no reaction occurs, write "No Reaction".

$$Pb\ (s) + 2\,HCl\ (aq) \rightarrow PbCl_2\ (aq) + H_2\ (g)$$

Pb is more reactive than H

Metals

Fe
Ni
Sn
Pb
H
Cu
Ag

Example 2:

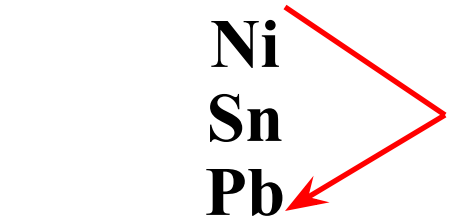
Use activity series to complete each reaction below. If no reaction occurs, write "No Reaction".

$$Ni\ (s) + CuCl_2\ (aq) \rightarrow NiCl_2\ (aq) + Cu\ (s)$$

Ni is more reactive than Cu

Metals

Fe
Ni
Sn
Pb
H
Cu
Ag



AQUEOUS REACTIONS

- Many ionic solids dissolve in water to form ions.
- These substances are called electrolytes.

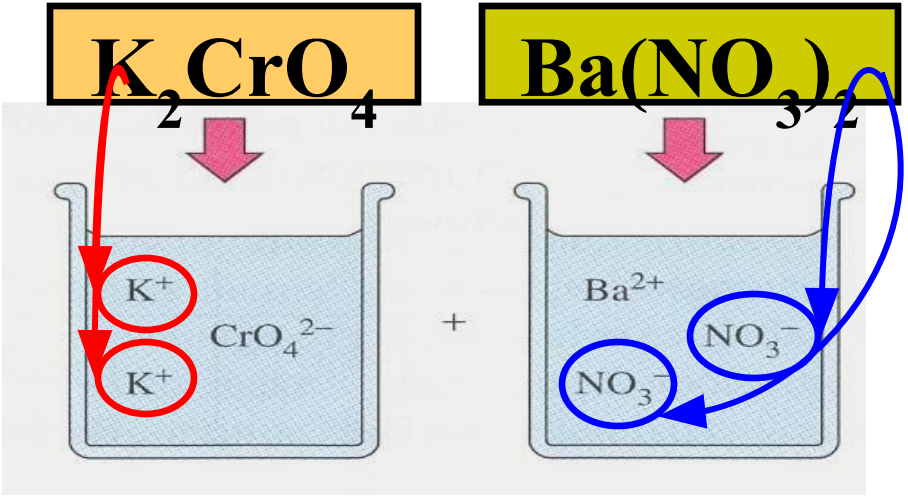
$$NaCl_{(s)} \xrightarrow{H_2O} Na^+_{(aq)} + Cl^-_{(aq)}$$

$$K_2CrO_{4\,(s)} \xrightarrow{H_2O} 2\,K^+_{(aq)} + CrO^{2-}_{4\,(aq)}$$

$$Ba(NO_3)_{2\,(s)} \xrightarrow{H_2O} Ba^{2+}_{(aq)} + 2\,NO^-_{3\,(aq)}$$

AQUEOUS REACTIONS

- When ionic substances dissolve in water they separate into ions.



AQUEOUS REACTIONS

- **Aqueous reactions occur only when one of the following conditions is present:**

1. **Formation of a solid:** **Precipitation**
2. **Formation of water:** **Neutralization**
3. **Formation of a gas:** **Unstable product**

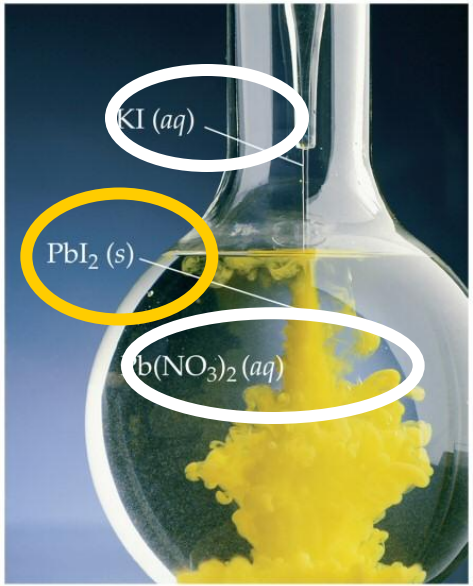
PRECIPITATION REACTIONS

- An aqueous chemical reaction that produces a solid as one of its products is called a precipitation reaction.
- The insoluble solid formed in these reactions is called a precipitate.

$$K_2CrO_{4\,(aq)} + Ba(NO_3)_{2\,(aq)} \longrightarrow BaCrO_{4\,(s)} + 2\,KNO_{3\,(aq)}$$

Example of a Precipitation Reaction

$$Pb(NO_3)_2(aq) + 2\ KI(aq) \rightarrow 2\ KNO_3(aq) + PbI_2(s)$$



SOLUBILITY RULES

SOLUBLE	NO_3^-	No exceptions
	Na^+, K^+ NH_4^+	No exceptions
	Cl^-, Br^-, I^-	Except those containing Ag^+ , Pb^{2+}
	SO_4^{2-}	Except those containing Ba^{2+} , Pb^{2+}, Ca^{2+}

SOLUBILITY RULES

I N S O L	S^{2-}, CO_3^{2-} PO_4^{3-}	Except those containing Na^+ , K^+, NH_4^+
	OH^-	Except those containing Na^+ , K^+, Ca^{2+}, NH_4^+

Example 1:

Write balanced equations for each reactions shown below. Indicate if no reaction occurs.

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

$$NaCl\,(aq) + AgNO_3\,(aq) \rightarrow NaNO_3\,(aq) + AgCl\,(s)$$

soluble

precipitate

Example 2:

Write balanced equations for each reactions shown below. Indicate if no reaction occurs.

$NH_4Cl\ (aq) + KNO_3\ (aq) \rightarrow NH_4NO_3\ (?) + KCl\ (?)$

$NH_4Cl\ (aq) + KNO_3\ (aq) \rightarrow$ No Reaction $KCl\ (aq)$

soluble

Example 3:

Write balanced equations for each reactions shown below. Indicate if no reaction occurs.

$PbCl_2\ (aq) + 2\ NaI\ (aq) \rightarrow PbI_2\ (?) + 2\ NaCl\ (?)$

$PbCl_2\ (aq) + 2\ NaI\ (aq) \rightarrow PbI_2\ (s) + 2\ NaCl\ (aq)$

precipitate

Molecular, Complete Ionic, and Net Ionic Equations

A ***molecular equation*** is a chemical equation showing the complete, neutral formulas for every compound in a reaction.

A ***complete ionic equation*** is a chemical equation showing all of the species as they are actually present in solution.

A ***net ionic equation*** is an equation showing only the species that actually participate in the reaction.

Writing Chemical Equations for Reactions in Solution: Molecular and Complete Ionic Equations

- A **molecular equation** is an equation showing the complete neutral formulas for every compound in the reaction.

$$AgNO_3(aq) + NaCl(aq) \longrightarrow AgCl(s) + NaNO_3(aq)$$

- **Complete ionic equations** show aqueous ionic compounds that normally dissociate in solution as they are actually present in solution.

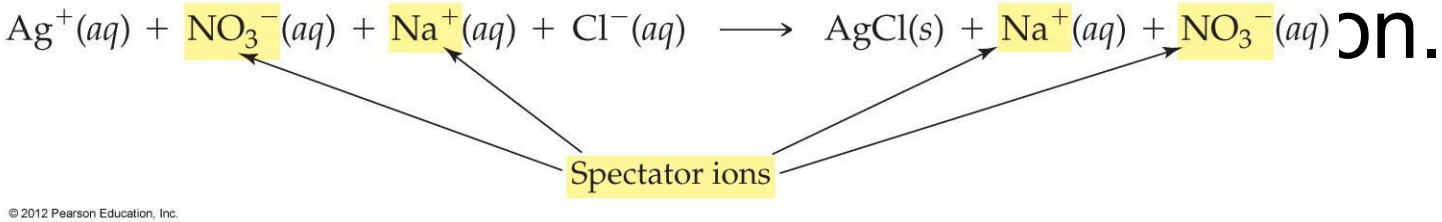
$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \longrightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$$

- When writing complete ionic equations, separate only aqueous ionic compounds into their constituent ions.

- Do NOT separate solid, liquid, or gaseous compounds.

Writing Chemical Equations for Reactions in Solution: Net Ionic Equations

- In the complete ionic equation, some of the ions in solution appear unchanged on both sides of the equation.
- These ions are called **spectator ions** because



on.

Writing Chemical Equations for Reactions in Solution: Proper Net Ionic Equations

- To simplify the equation, and to more clearly show what is happening, spectator ions can be omitted.
- Equations such as this one, which show only the *species* that actually participate in the reaction, are called **net ionic equations**.

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

NEUTRALIZATION REACTIONS

- Salts are ionic substances with the cation donated from the base and the anion donated from the acid.
- The most important reaction of acids and bases is called neutralization.
- In these reactions an acid combines with a base to form a salt and water.

$$HCl\ (aq) + NaOH\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$$

Examples:

Write balanced equations for each of the neutral-ization reactions shown below:

$$2\ HNO_3 + Ba(OH)_2 \rightarrow Ba(NO_3)_2 + 2\ H_2O$$

$$H_2SO_4 + 2\ NaOH \rightarrow Na_2SO_4 + 2\ H_2O$$

GAS FORMING REACTIONS

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

Carbonic acid: $H_2CO_3\ (aq) \rightarrow CO_2\ (g) + H_2O\ (l)$

Sulfurous acid: $H_2SO_3\ (aq) \rightarrow SO_2\ (g) + H_2O\ (l)$

Ammonium: $NH_4OH\ (aq) \rightarrow NH_3\ (g) + H_2O\ (l)$

GAS FORMING REACTIONS

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

$$2\ HCl + Na_2CO_3 \rightarrow 2\ NaCl + H_2CO_3$$

$$2\ HNO_3 + K_2SO_3 \rightarrow 2\ KNO_3 + H_2SO_3$$

$$2\ HNO_3 + Na_2SO_3 \rightarrow 2\ KNO_3 + SO_2\ (g) + H_2O\ (l)$$

Enthalpy: A Measure of the Heat Evolved or Absorbed in a Reaction

- Chemical reactions can be ***exothermic*** (they *emit* thermal energy when they occur).
- Chemical reactions can be ***endothermic*** (they *absorb* thermal energy when they occur).
- The *amount* of thermal energy emitted or absorbed by a chemical reaction, under conditions of constant pressure (which are common for most everyday reactions), can be quantified with a function called **enthalpy**.

Enthalpy: A Measure of the Heat Evolved or Absorbed in a Reaction

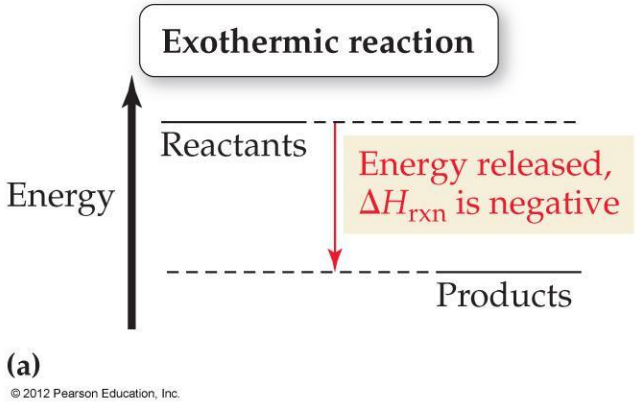
- We define the **enthalpy of reaction**, ΔH_{rxn}, as the amount of thermal energy (or heat) that flows when a reaction occurs at constant pressure.

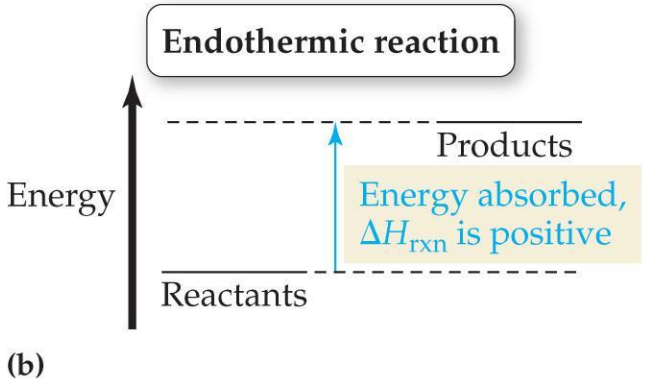
Sign of ΔH_{rxn}

- The *sign* of ΔH_{rxn} (positive or negative) depends on the *direction* in which thermal energy flows when the reaction occurs.
- Energy flowing *out* of the chemical system is like a withdrawal and carries a negative sign.
- Energy flowing *into* the system is like a deposit and carries a positive sign.

Exothermic and Endothermic reactions

- **(a)** In an exothermic reaction, energy is released into the surroundings. **(b)** In an endothermic reaction, energy is absorbed from the surroundings.





HEAT IN CHEMICAL REACTIONS

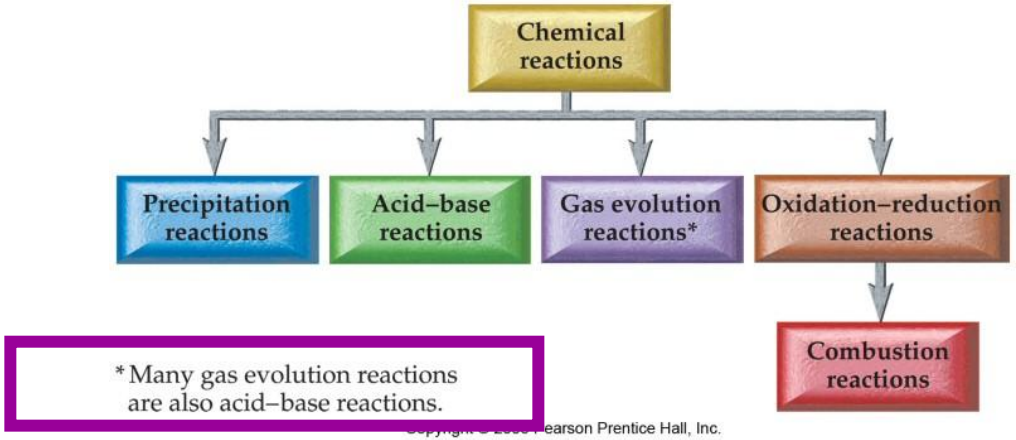
- In exothermic reaction, heat is produced and can be written as a product.
- In endothermic reaction, heat is required and can be written as a reactant.
- Reactions that release heat are classified as exothermic.
- Reactions that absorb heat are classified as endothermic.

$$H_2\,(g) + Cl_2\,(g) \rightarrow 2\,HCl\,(g) + 185\ kJ$$

$$N_2\,(g) + O_2\,(g) + 181\ kJ \rightarrow 2\,NO\,(g)$$

Classifying Reactions

- Also we can classify reactions by what happens:
- Redox reactions are the exchange of e^-
- Redox are all reactions except?



OXIDATION-REDUCTION REACTIONS

- Reactions known as oxidation and reduction (redox) have many important applications in our everyday lives.
- Rusting of a nail or the reaction within your car batteries are two examples of redox reactions.
- In an oxidation-reduction reaction, electrons are transferred from one substance to another.
- If one substance loses electrons, another substance must gain electrons.