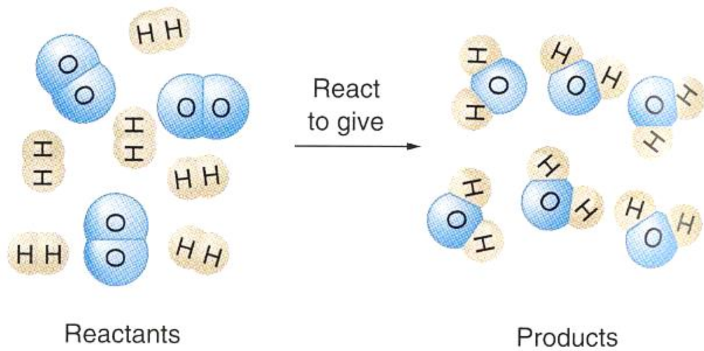
CHEMICAL REACTIONS

- 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***.



- A ***chemical reaction*** can be detected by one of the following changes:

    1. Change of color
    2. Formation of a solid
    3. Formation of gas
    4. Exchange of heat with surroundings

- While the above changes provide evidence of a chemical reaction, they are not ***definitive*** evidence.

- Only chemical analysis showing that the initial substances have changed into other substances conclusively prove that a chemical reaction has occurred.

<u>Examples:</u>
Which changes indicated below involve a chemical reaction?

a) butane burning in a lighter
b) butane evaporating out of a lighter
c) wood burning
d) dry ice subliming

THE CHEMICAL EQUATION

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

Word equation: Methane gas (CH_4) reacts with oxygen gas to produce carbon dioxide and water.

Chemical Equation: $$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

- A chemical equation consists of the following information:

1. ***Reactants*** separated from ***products*** by an arrow (→):

$$\underbrace{CH_4 + O_2}_{\text{reactants}} \longrightarrow \underbrace{CO_2 + H_2O}_{\text{products}}$$

2. ***Coefficients*** are placed in front of substances to ***balance*** the equation:

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$

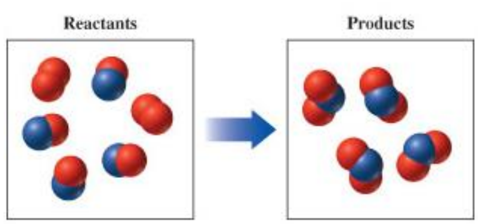
3. Reaction ***conditions*** are placed over the arrow:

$$CH_4 + 2\,O_2 \xrightarrow{\Delta} CO_2 + 2\,H_2O$$

4. The ***physical state*** of the substances are indicated by symbols (s), (l), (g) and (aq):

$$CH_4\,(g) + 2\,O_2\,(g) \xrightarrow{\Delta} CO_2\,(g) + 2\,H_2O\,(g)$$

__**Examples:**__
If red spheres represent oxygen atoms and blue spheres represent nitrogen atoms, write a balanced equation for the reaction shown below.



WRITING & 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.

The general procedure for balancing equations is:

1. ***Write the unbalanced equation***
   - Make sure the formula for each substance is correct

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

2. ***Balance by inspection***
   - ***Count*** and ***compare*** each element on both sides of the equation.

1 C	=	1C
4 H	≠	2H
2O	≠	3O

   - ***Balance*** elements that appear ***only in one substance*** first.

Balance H:

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

Balance O,

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

   - When finally done, check for the ***smallest coefficients*** possible.

Examples:

1) $AgNO_3 + H_2S \rightarrow Ag_2S + HNO_3$

	Ag	H	S	NO_3
Reactant				
Products				

___ $AgNO_3$ + ___$H_2S \rightarrow$ ___Ag_2S + _____ HNO_3

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

	Al	H	O	SO_4
Reactant				
Products				

___ $Al(OH)_3$ + ___ $H_2SO_4 \rightarrow$ ___$Al_2(SO_4)_3$ + _____ H_2O

3) $NH_3 + O_2 \rightarrow NO + H_2O$

	N	O	H
Reactant			
Products			

___NH_3 + ___ $O_2 \rightarrow$ ___ NO + ___ H_2O

4) $C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$

	C	H	O
Reactant			
Products			

___ C_4H_{10} + ___ $O_2 \rightarrow$ ___ CO_2 + ___ H_2O

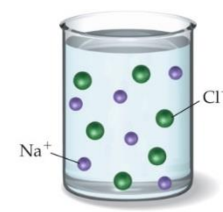
AQUEOUS SOLUTIONS

- Many important chemical reactions occur in water, and are therefore referred to as ***aqueous solutions***.

- An aqueous solution is a homogeneous mixture of a substance with water. For example, a NaCl solution is composed of sodium chloride dissolved in water.

- When soluble ionic substances dissolve in water, they dissociate into their component ions.

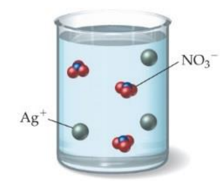
- For example, a sodium chloride solution, represented as NaCl (aq) consists of sodium ions and chloride ions.



A sodium chloride solution contains independent **Na$^+$** and **Cl$^-$** ions.

$$NaCl\ (aq) \rightarrow Na^+\ (aq) + Cl^-\ (aq)$$

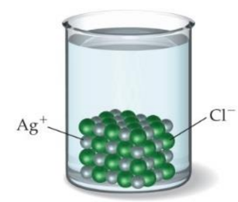
- Similarly, when silver nitrate dissolves, the solution contains Ag^+ and nitrate (NO_3^-) ions.



A silver nitrate solution contains independent **Ag$^+$** and **NO$_3^-$** ions.

$$AgNO_3\ (aq) \rightarrow Ag^+\ (aq) + NO_3^-\ (aq)$$

- Some ionic substances do not dissolve in water and are insoluble. If these substances are added to water, they remain undissolved and as a solid. For example, AgCl is an insoluble salt and when added to water, it remains as a white solid at the bottom of the beaker.



When silver chloride is added to water, it remains as solid AgCl—it does not dissolve into independent ions.

$$AgCl\ (s) \rightarrow AgCl\ (s)$$

<u>Examples:</u>

1. Identify the ions and number of each present in each compound below:

   a) $AlCl_3$

   b) $Mg(NO_3)_2$

   c) Na_3PO_4

SOLUBLE AND INSOLUBLE SALTS

- Many ionic solids ***dissolve*** in water and are called ***soluble salts***. However, some ionic solids ***do not dissolve*** in water and do not form ions in solution. These salts are called ***insoluble salts*** and remain solid in solution.
- Chemists use a set of ***solubility rules*** to ***predict*** whether a salt is ***soluble or insoluble***. These rules are summarized below:

Compounds containing the following ions		Exceptions
SOLUBLE	**NO_3^- , $C_2H_3O_2^-$**	**None**
	Na^+, K^+, NH_4^+	**None**
	Cl^-, Br^-, I^-	**Those containing Ag^+, Hg_2^{2+}, Pb^{2+}**
	SO_4^{2-}	**Those containing Ba^{2+}, Ca^{2+}, Pb^{2+}, Sr^{2+}**
INSOLUBLE	**CO_3^{2-}, PO_4^{3-}, CrO_4^{2-}**	**Those containing Na^+, K^+, NH_4^+**
	OH^-, S^{2-}	**Those containing Na^+, K^+, NH_4^+**
	S^{2-}	**Those containing Ca^{2+}, Sr^{2+}, Ba^{2+}**
	OH^-	**Those containing Ca^{2+}, Sr^{2+}, Ba^{2+} (slightly soluble)**

Examples:

1. Use the solubility rules to determine if each of the following salts are soluble or insoluble:

   a) K_3PO_4 ______________________

   b) $CaCO_3$ ______________________

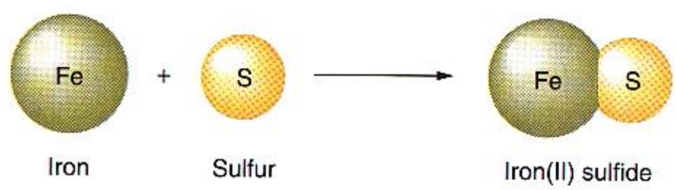
   c) $Pb(NO_3)_2$ _____________________

   d) $PbSO_4$ _____________________

CLASSIFYING CHEMICAL REACTIONS

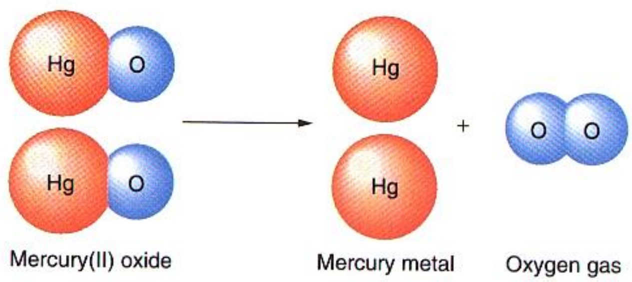
- Chemical reactions are classified into ***five types***:

1. Synthesis or combination **(A + B → AB)**



- Two ***elements or compound*** combine to form another compound.

2. Decomposition **(AB → A + B)**



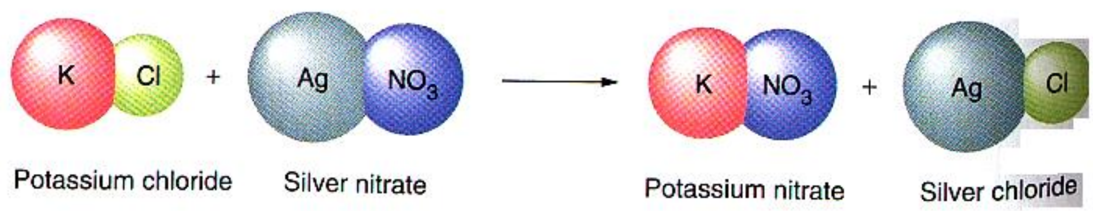
- A compound breaks up to form ***elements or simpler compound***.

3. Single Replacement **(A + BC → B + AC)**

- A ***more reactive element*** replaces a ***less reactive element*** in a compound.

CLASSIFYING CHEMICAL REACTIONS

4. Double Replacement (AB + CD → AD + BC)



- ***Two compounds*** interact to form two ***new compounds***.

5. Combustion Reactions:

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

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

Examples:

Classify each of the reactions below:

1. $Mg + CuCl_2 \rightarrow MgCl_2 + Cu$ ____________________________

2. $CaCO_3 \rightarrow CaO + CO_2$ ____________________________

3. $2\,HCl + Ca(OH)_2 \rightarrow CaCl_2 + H_2O$ ____________________________

4. $C_3H_8 + 5\,O_2 \rightarrow 3\,CO_2 + 4\,H_2O$ ____________________________

5. $4\,Fe + 3\,O_2 \rightarrow 2\,Fe_2O_3$ ____________________________

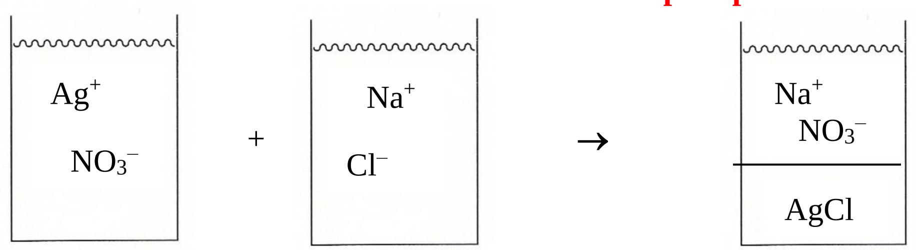
PRECIPITATION REACTIONS

- Solubility rules can be used to predict whether a solid, called a ***precipitate***, can be formed when two solutions of ionic compounds are mixed.

- A solid is formed when two ions of an insoluble salt come in contact with one another.

- For example, when a solution of $AgNO_3$ is mixed with a solution of NaCl , a white insoluble salt AgCl is produced.

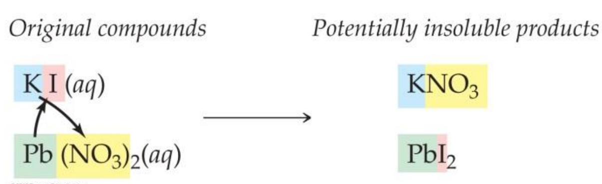
$AgNO_3$ (aq) + NaCl (aq) → AgCl (s) + $NaNO_3$ (aq)
precipitate



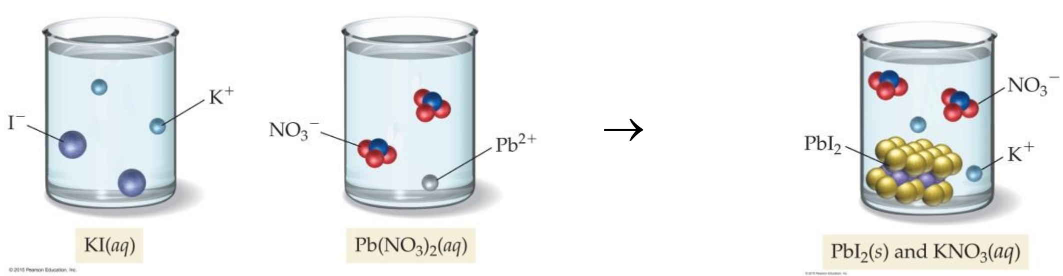
- Double replacement reactions in which a precipitate is formed are called ***precipitation*** reactions.

- The solubility rules can be used to predict whether a precipitate forms when two solutions of ionic compounds are mixed together.

- For example, when solutions of KI and $Pb(NO_3)_2$ are mixed together, two potentially insoluble products are formed (KNO_3 and PbI_2).



- If the potentially insoluble products are both soluble, then no reaction occurs. If, on the other hand, one of these products is insoluble, then a precipitation reaction occurs.



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

MOLECULAR, COMPLETE IONIC & NET IONIC EQUATIONS

- When writing equations for precipitation reactions, the equation is usually written as a ***molecular equation***, showing each compound in the reaction as a molecule.

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

- This equation can also be written in a way to show the aqueous solutions as they really exist as ions, and is called ***complete ionic equation***.

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

- In the equation above, notice that some of the ions appear in the same form on the reactant and product side. These ions do not participate in the reaction and are called ***spectator ions***.

- The complete ionic equation can be simplified by omitting the spectator ions. The resulting equation is called ***net ionic equation***.

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

- To summarize:

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

  - A ***complete ionic equation*** is a chemical equation showing all 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.

PRECIPITATION REACTIONS

- Double replacement reactions in which a precipitate is formed are called ***precipitation*** reactions.

- To predict whether a precipitation reaction occurs or not, the following stepwise process should be followed:

    1. Write the ***molecular equation*** for the reaction by predicting the products formed from the combination of the reactants. Use the solubility rules to determine if any of the products are insoluble. Label all the states and balance the equation.

    2. Using the molecular equation above, write the ***complete ionic equation*** by breaking all of the soluble compounds into their corresponding ions; leave the precipitate compound together as molecular.

    3. Using the complete ionic equation above, write the ***net ionic equation (NIE)*** by cancelling all ions that appear as the same on both sides of the equation. These ions are called ***spectator*** ions.

    Note: If no precipitate forms in step 2, write "NO REACTION" after the arrow and stop.

Examples:
Predict the products for each reaction shown below and write molecular, complete ionic and net ionic equations. If no reaction occurs, write "No Reaction" after the arrow.

1. Na_2SO_4 (aq) + $Pb(NO_3)_2$ (aq) $\rightarrow$???????

    Step 1:

    Step 2

    Step 3:

2. $Pb(C_2H_3O_2)_2$ (aq) + KI (aq) $\rightarrow$???????????

<u>Step 1:</u>

<u>Step 2:</u>

<u>Step 3:</u>

3. NH_4Cl (aq) + KNO_3 (aq) $\rightarrow$???????????

ACID-BASE & GAS EVOLUTION REACTIONS

- In addition to precipitation reactions, double replacement reactions can be subdivided into two other reaction types:

1. ***<u>Acid-Base Neutralization:</u>***
   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**. For example:

$$\underset{\text{acid}}{\mathbf{HCl\ (aq)}} + \underset{\text{base}}{\mathbf{NaOH\ (aq)}} \longrightarrow \underset{\text{salt}}{\mathbf{NaCl\ (aq)}} + \underset{\text{water}}{\mathbf{H_2O\ (l)}}$$

   Salts are ***ionic*** substances with the ***cation*** donated from the ***base*** and the ***anion*** donated from the ***acid***. In the laboratory, neutralization reactions are observed by an increase in temperature (exothermic reaction).

2. ***<u>Gas Evolution:</u>***
   Some chemical reactions ***produce gas*** because one of the products formed in the reaction is ***unstable***. Three such products are listed below:

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

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

$$2\ HCl\ (aq) + Na_2CO_3\ (aq) \rightarrow 2\ NaCl\ (aq) + \underset{\textbf{(unstable)}}{H_2CO_3\ (aq)}$$

$$2\ HCl\ (aq) + Na_2CO_3\ (aq) \rightarrow 2\ NaCl\ (aq) + CO_2\ (g) + H_2O\ (l)$$

Examples:
Complete and balance each neutralization reaction below:

1. HNO_3 (aq) + $Ba(OH)_2$ (aq) $\rightarrow$

2. H_2SO_4 (aq) + NaOH (aq) $\rightarrow$

3. $HC_2H_3O_2$ (aq) + KOH (aq) $\rightarrow$

Complete and balance the unstable product reaction shown below:

4. HNO_3 (aq) + K_2SO_3 (aq) $\rightarrow$

5. NH_4NO_3 (aq) + NaOH (aq) $\rightarrow$