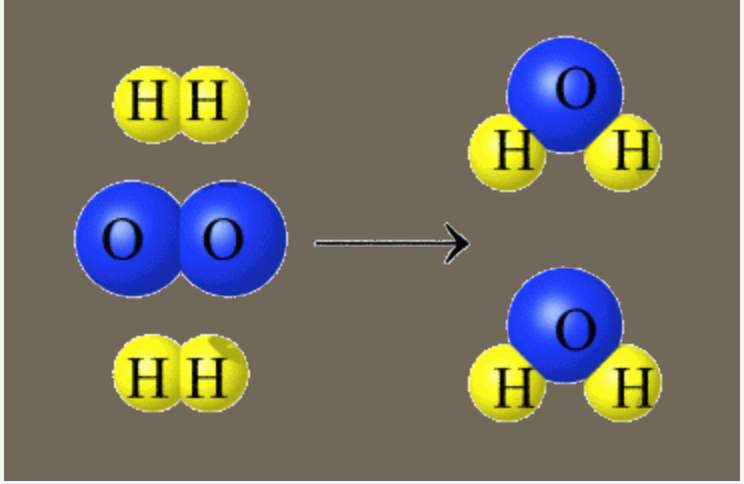
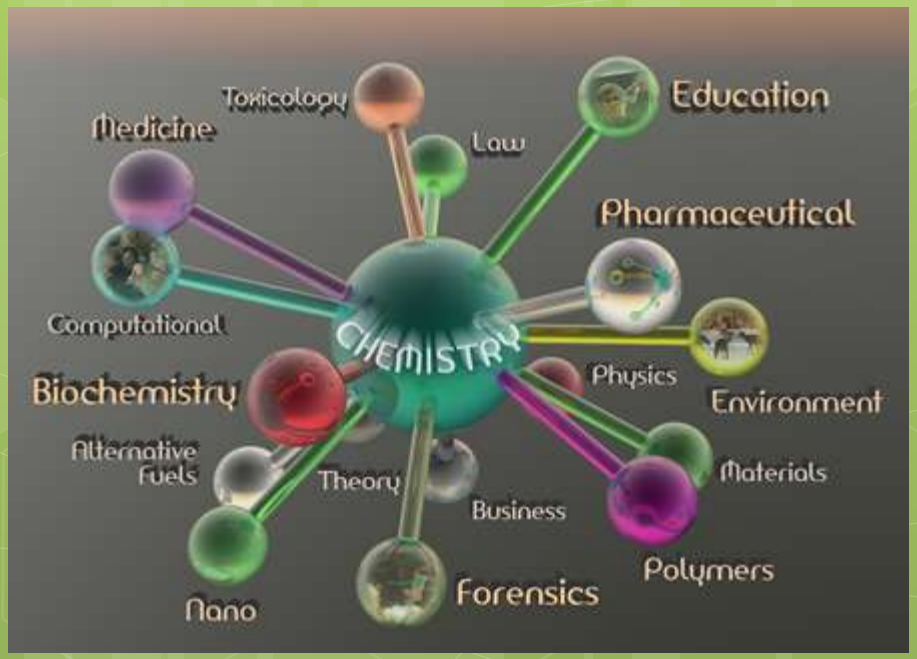


Chapter 11: Chemical Reactions

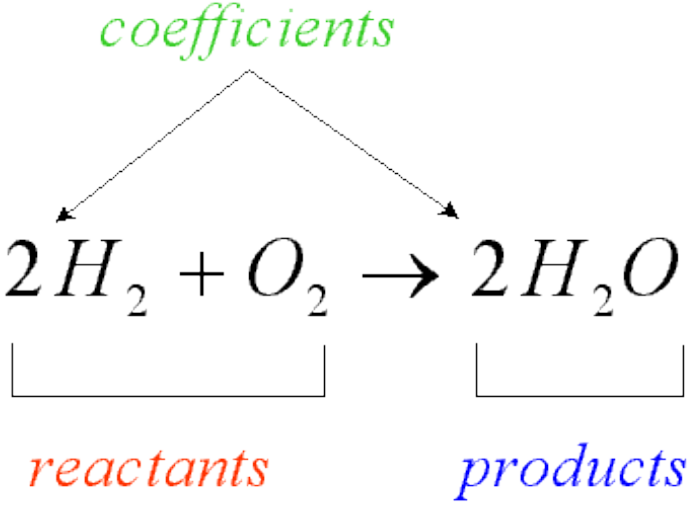
Jennie L. Borders



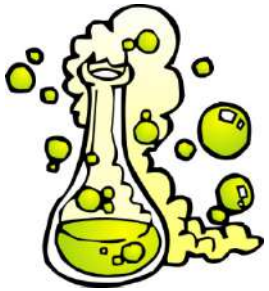
Section 11.1 – Describing Chemical Reactions

- In a chemical reaction, the reactants are written on the left and the products on the right.
- The arrow that separates them is called yield.

Reactants → Products



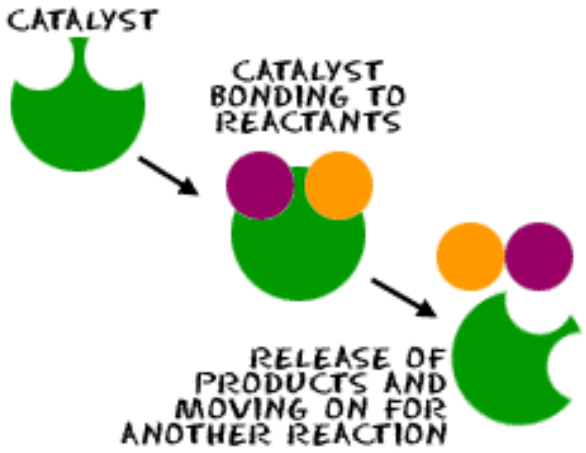
Symbols in Equations

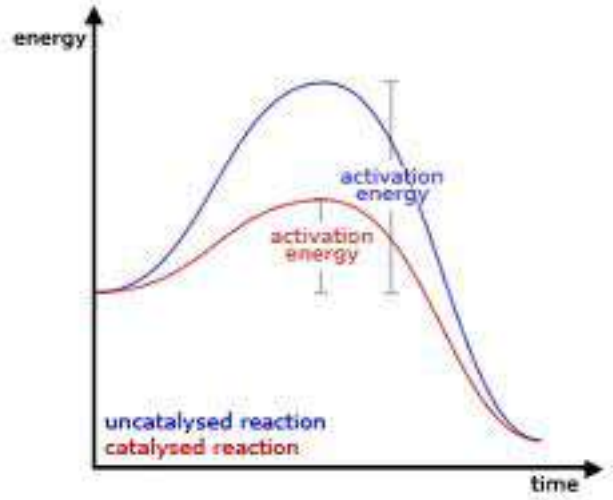


Symbol	Meaning
$\rightarrow$	yields
$\leftrightarrows$	reversible reaction
(s)	solid
(l)	liquid
(g)	gas
(aq)	aqueous
$\xrightarrow{Pt}$	catalyst
$\xrightarrow{\Delta}$	heat

Catalyst

- A catalyst is a substance that speeds up a reaction but is not used up in the reaction.
- A catalyst is neither a reactant nor a product, so its formula is written above the arrow in a chemical equation.





Word Equations

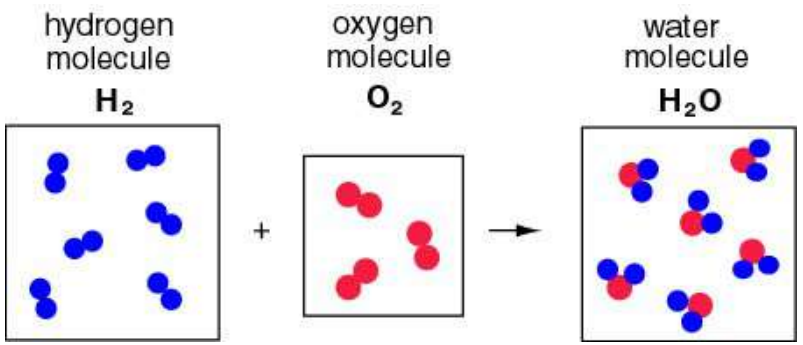
- To write a word equation, write the names of the reactants and products in a sentence form.

Ex: chemical equation

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$$

Ex: word equation

Hydrogen gas and oxygen gas react to form liquid water.



Sample Problem #1

- Write a sentence that describes this chemical reaction:

$$Na_{(s)} + H_2O_{(l)} \rightarrow NaOH_{(aq)} + H_{2(g)}$$

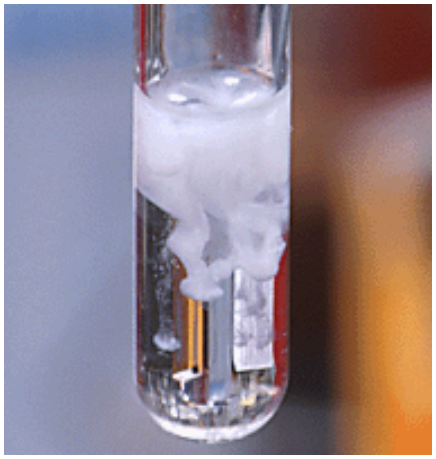
Solid sodium and liquid water react to form aqueous sodium hydroxide and hydrogen gas.

Practice Problem #1

- Write a sentence that describes this reaction:

$H_2SO_{4(aq)} + BaCl_{2(aq)} \rightarrow BaSO_{4(s)} + HCl_{(aq)}$

Aqueous sulfuric acid and aqueous barium chloride react to form solid barium sulfate and aqueous hydrochloric acid.



Sample Problem #2

- Write the chemical equation for the following reaction:

  Hydrochloric acid and solid sodium hydrogen carbonate react to produce aqueous sodium chloride, water, and carbon dioxide.

$HCl_{(aq)} + NaHCO_{3(s)} \rightarrow NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$

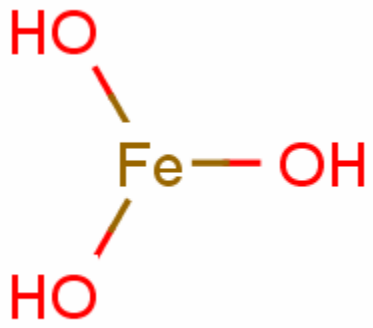
Hint: Acids will always be aqueous unless otherwise stated.

Practice Problem #2

- Write the chemical equation for the following reaction:

  Solid iron(III)hydroxide is heated to form solid iron(III)oxide and water

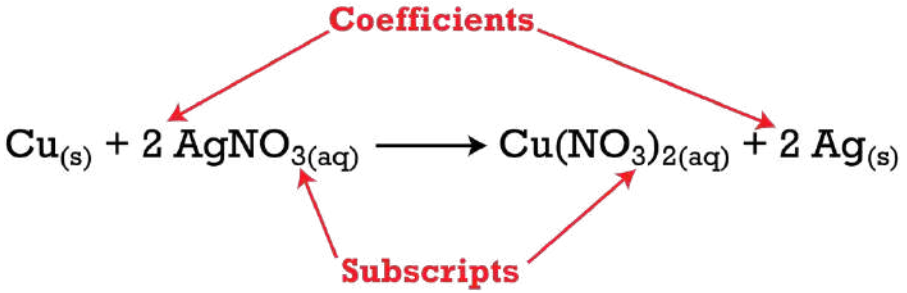
$$Fe(OH)_{3(s)} \xrightarrow{\Delta} Fe_2O_{3(s)} + H_2O_{(l)}$$



Balancing Chemical Equations

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$$

- Coefficients are the numbers in front of a chemical formula.
- Subscripts are numbers that show the number of atoms in a compound.
- When balancing reactions, you can only change the coefficients, **not** the subscripts.
- A skeleton equation is an equation that has no coefficients.



Balancing Chemical Equations

- To balance a chemical equation, you add coefficients to the substances so that the reactant and product side of the equation contain equals numbers and types of atoms.
- Coefficients are added so that the equation follows the law of conservation of mass.

Rules for Balancing Equations

- Balance hydrogen and oxygen last.
- Count a polyatomic ion as a single unit if it appears unchanged on both sides of the equation.
- If you end up with an odd number, you can double all of the coefficients.
- Make sure to reduce the coefficients to the lowest whole-number ratio.
- A coefficient of one is understood and does not need to be written.

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

C=1		C=1
H=4	=	H=4
O=4		O=4

Sample Problems

Balance the following equations:

1. ___H_2 + ___O_2 → ___H_2O

   2 H_2 + ___O_2 → 2 H_2O

2. ___$AgNO_3$ + ___H_2S → ___Ag_2S + ___HNO_3

   2 $AgNO_3$ + ___H_2S → ___Ag_2S + 2 HNO_3

3. ___$Zn(OH)_2$ + ___H_3PO_4 → ___$Zn_3(PO_4)_2$ + ___H_2O

   3 $Zn(OH)_2$ + 2 H_3PO_4 → ___$Zn_3(PO_4)_2$ + 6 H_2O

Practice Problems

1. ___$FeCl_3$ + ___NaOH → ___$Fe(OH)_3$ + ___NaCl

   ___$FeCl_3$ + 3 NaOH → ___$Fe(OH)_3$ + 3 NaCl

2. ___CS_2 + ___Cl_2 → ___CCl_4 + ___S_2Cl_2

   ___CS_2 + 3 Cl_2 → ___CCl_4 + ___S_2Cl_2

3. ___C_2H_6 + ___O_2 → ___CO_2 + ___H_2O

   2 C_2H_6 + 7 O_2 → 4 CO_2 + 6 H_2O

Section 11.1 Assessment

1. Describe the steps in writing a balanced chemical equation.
2. Write the skeleton equation for the following reactions:
   a. Heating solid copper(II)sulfide in the presence of oxygen gas produces pure copper and sulfur dioxide gas.

$$CuS_{(s)} + O_{2(g)} \xrightarrow{\Delta} Cu_{(s)} + SO_{2(g)}$$

   b. Iron metal and chlorine gas react to form solid iron(III)chloride.

$$Fe_{(s)} + Cl_{2(g)} \rightarrow FeCl_{3(s)}$$

Section 11.1 Assessment

c. Solid aluminum carbonate decomposes to form solid aluminum oxide and carbon dioxide gas.

$$Al_2(CO_3)_{3(s)} \rightarrow Al_2O_{3(s)} + CO_{2(g)}$$

d. Solid magnesium reacts with aqueous silver(I)nitrate to form solid silver and aqueous magnesium nitrate.

$$Mg_{(s)} + AgNO_{3(aq)} \rightarrow Ag_{(s)} + Mg(NO_3)_{2(aq)}$$

Section 11.1 Assessment

3. Balance the following equations:

a. $\_2\_ SO_2 + \_\_\_ O_2 \rightarrow \_2\_ SO_3$

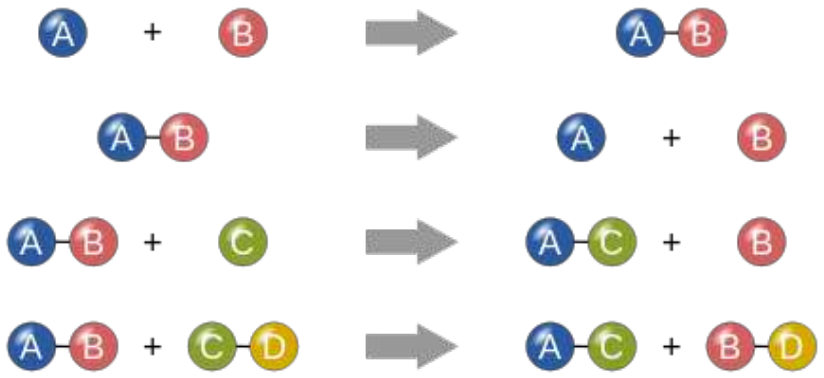
b. $\_\_\_ Fe_2O_3 + \_3\_ H_2 \rightarrow \_2\_ Fe + \_3\_ H_2O$

c. $\_4\_ P + \_5\_ O_2 \rightarrow \_\_\_ P_4O_{10}$

d. $\_2\_ Al + \_\_\_ N_2 \rightarrow \_2\_ AlN$

Section 11.2 – Types of Chemical Reactions

- The five general types of reactions are synthesis, decomposition, single displacement, double displacement, and combustion.



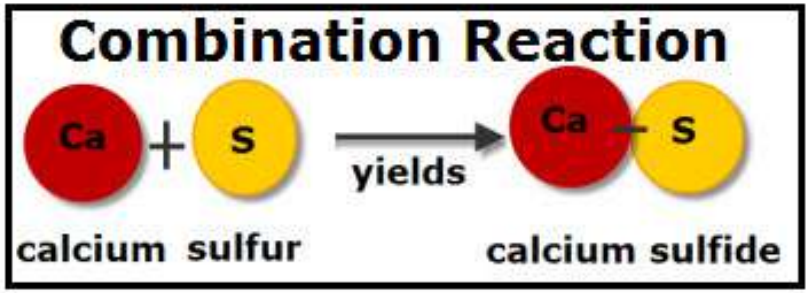
Synthesis Reactions

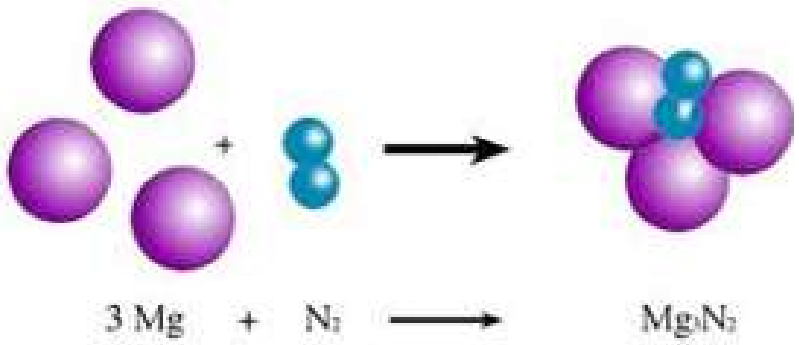
- In a synthesis reaction, two or more substances react to form one product.
- Generic Reaction:

$$A + B \rightarrow AB$$

- Actual Example:

$$2Mg + O_2 \rightarrow 2MgO$$





Predicting Products

- Predict the products for the following reactions:

1. $Cu + S \rightarrow$ (Hint: copper is +1)

   $2Cu + S \rightarrow Cu_2S$

2. $Be + O_2 \rightarrow$

   $2Be + O_2 \rightarrow 2BeO$

3. $Fe + S \rightarrow$ (Hint: iron is +3)

   $2Fe + 3S \rightarrow Fe_2S_3$

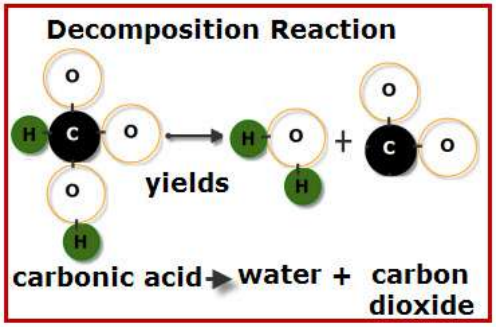
Decomposition Reactions

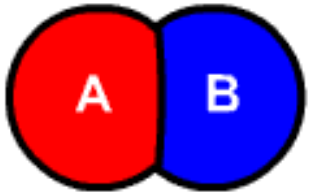
- A decomposition reaction occurs when a single reactant breaks down into two or more products.
- Generic Reaction:

$$AB \rightarrow A + B$$

- Actual Example:

$$2HgO \rightarrow 2Hg + O_2$$





Predicting Products

- Predict the products for the following reactions:

1. $H_2O \rightarrow$

$$2H_2O \rightarrow 2H_2 + O_2$$

2. $HI \rightarrow$

$$2HI \rightarrow H_2 + I_2$$

3. $NH_3 \rightarrow$

$$2NH_3 \rightarrow N_2 + 3H_2$$

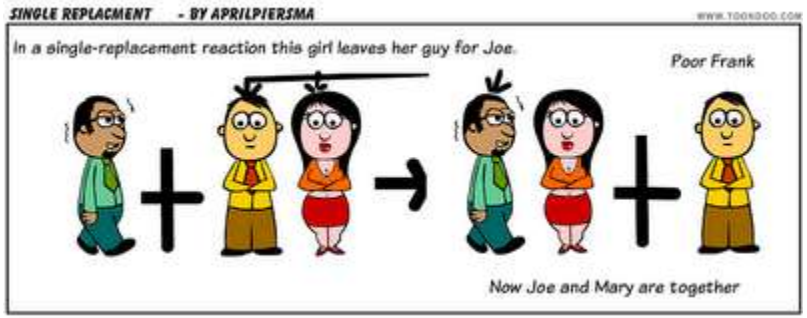
Single Displacement Reactions

- A single displacement reaction occurs when one element replaces a second element in a compound.
- Generic Reaction:

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

- Actual Example:

$$Zn + Cu(NO_3)_2 \rightarrow Cu + Zn(NO_3)_2$$



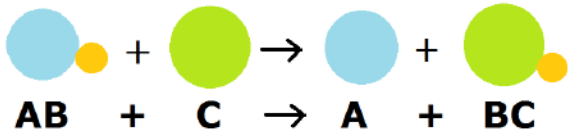


Figure 2.5

Predicting Products

- Predict the products for the following reactions:

1. $Br_2 + NaI \rightarrow$

$$Br_2 + 2NaI \rightarrow 2NaBr + I_2$$

2. $Fe + Pb(NO_3)_2 \rightarrow$ (Hint: iron is +3)

$$2Fe + 3Pb(NO_3)_2 \rightarrow 2Fe(NO_3)_3 + 3Pb$$

3. $Zn + H_2SO_4 \rightarrow$ (Hint: zinc is +2)

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

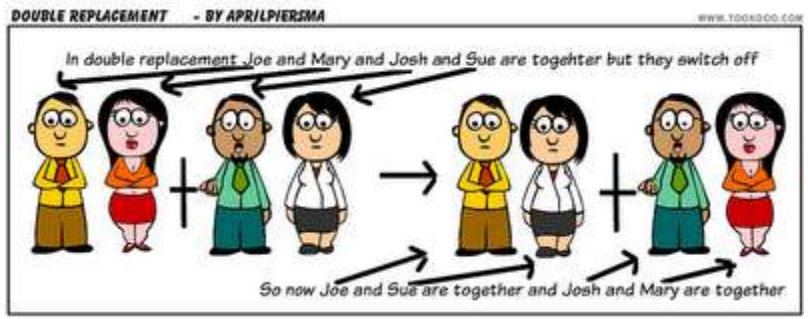
Double Displacement Reactions

- A double displacement reaction involves the exchange of two positive ions between two compounds.
- Generic Reaction:

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

- Actual Example:

$$2NaCN + H_2SO_4 \rightarrow 2HCN + Na_2SO_4$$



Predicting Products

- Predict the products for the following reactions:

1. $CaBr_2 + AgNO_3 \rightarrow$

   $CaBr_2 + 2AgNO_3 \rightarrow 2AgBr + Ca(NO_3)_2$

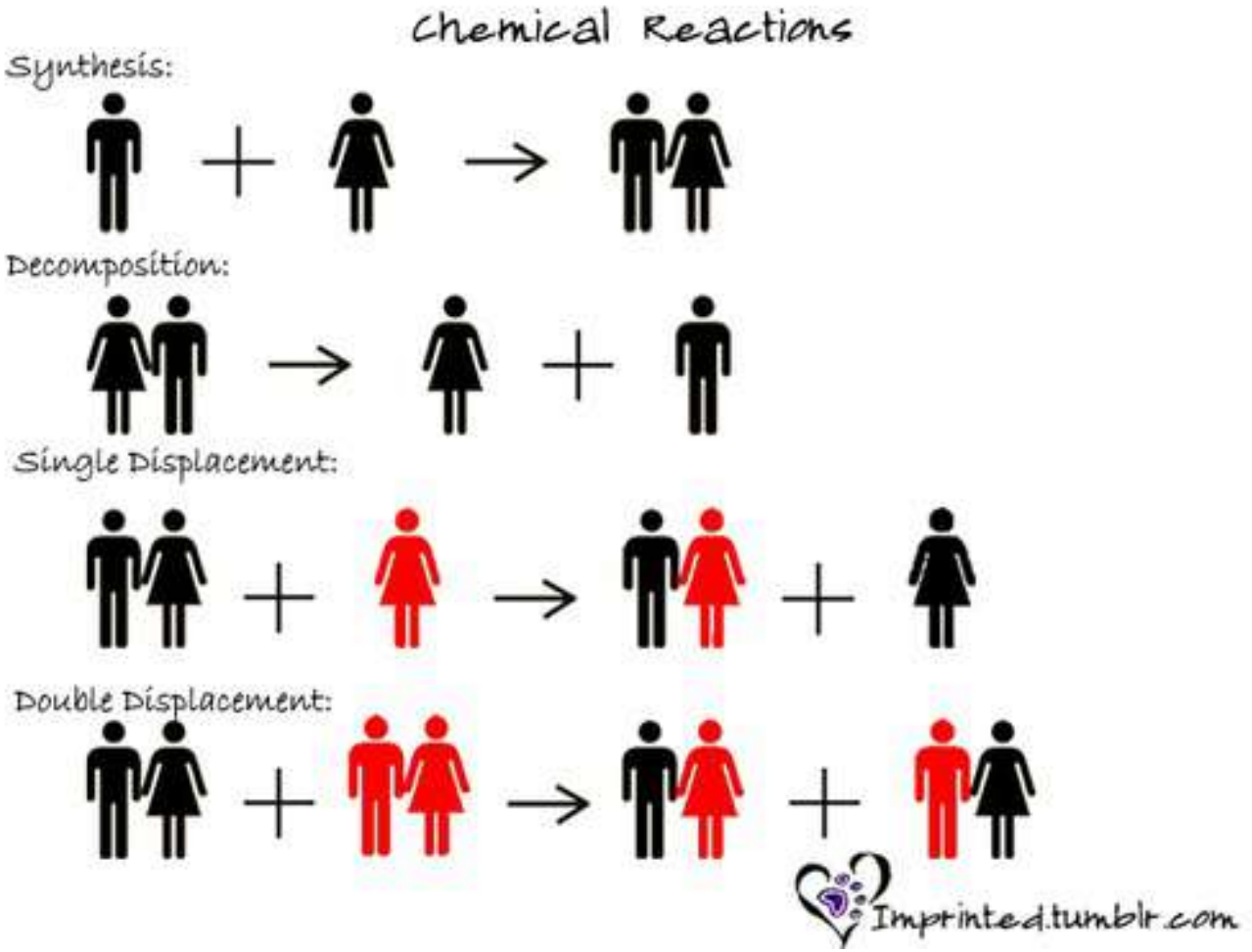
2. $FeS + HCl \rightarrow$

   $FeS + 2HCl \rightarrow FeCl_2 + H_2S$

3. $NaOH + Fe(NO_3)_3 \rightarrow$

   $3NaOH + Fe(NO_3)_3 \rightarrow Fe(OH)_3 + 3NaNO_3$

Relationships and Reactions



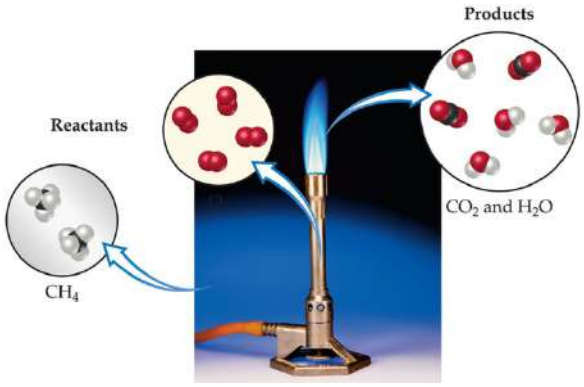
Combustion Reactions

- A combustion reaction occurs when a substance burns in oxygen and produces a lot of heat and light.
- Generic Reaction:

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

- Actual Example:

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$



Predicting Products

- Predict the products for the following reactions:

1. $C_6H_6 + O_2 \rightarrow$

   $2C_6H_6 + 15O_2 \rightarrow 12CO_2 + 6H_2O$

2. $C_7H_{16} + O_2 \rightarrow$

   $C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$

3. $C_6H_{12}O_6 + O_2 \rightarrow$

   $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

Section 11.2 Assessment

1. What are the five types of chemical reactions?

2. Classify the following skeleton reactions:
   a. $C_3H_6 + O_2 \rightarrow CO_2 + H_2O$
   b. $Al(OH)_3 \rightarrow Al_2O_3 + H_2O$
   c. $Li + O_2 \rightarrow Li_2O$
   d. $Zn + AgNO_3 \rightarrow Ag + Zn(NO_3)_2$

Section 11.2 Assessment

1. Complete and balance each equation:

b. $CaI_2 + Hg(NO_3)_2 \rightarrow$

$CaI_2 + Hg(NO_3)_2 \rightarrow Ca(NO_3)_2 + HgI_2$

c. $Al + Cl_2 \rightarrow$

$2Al + 3Cl_2 \rightarrow 2AlCl_3$

d. $Ag + HCl \rightarrow$ (Hint: silver is +1)

$2Ag + 2HCl \rightarrow H_2 + 2AgCl$

e. $C_2H_2 + O_2 \rightarrow$

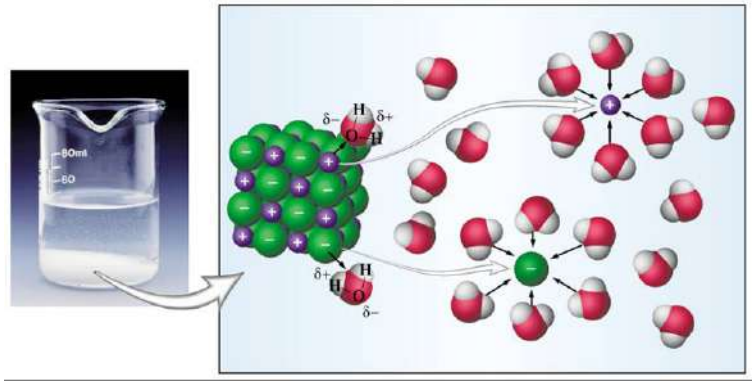
$2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O$

f. $MgCl_2 \rightarrow$

$MgCl_2 \rightarrow Mg + Cl_2$

Section 11.3 – Reactions in Aqueous Solution

- A complete ionic equation is an equation that shows dissolved ionic compounds as dissociated free ions.
- A spectator ion is an ion that is not directly involved in a reaction.
- Compounds that are aqueous will break into ions, and compounds that are solid will remain bonded.

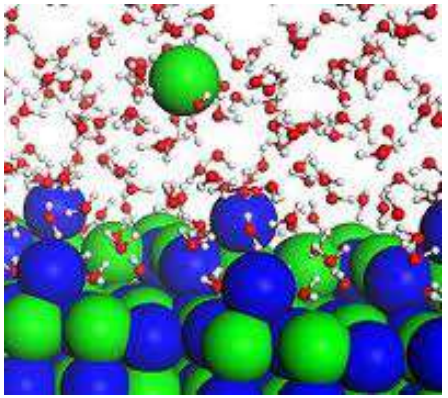


Aqueous Ions

- When a compound is aqueous it breaks into its ions.

- Ex:

$NaCl$ =	Na^{+} and Cl^{-}
$MgBr_2$ =	Mg^{+2} and $2Br^{-}$
Al_2O_3 =	$2Al^{+3}$ and $3O^{-2}$
$LiNO_3$ =	Li^{+} and NO_3^{-}
K_2CO_3 =	$2K^{+}$ and CO_3^{-2}
$Sr(NO_2)_2$ =	Sr^{+2} and $2NO_2^{-}$



Rules for Writing Complete Ionic Equations

1. Balance the equation.
2. Separate all aqueous substances into ions.
3. Leave any non-aqueous substances or precipitates together.

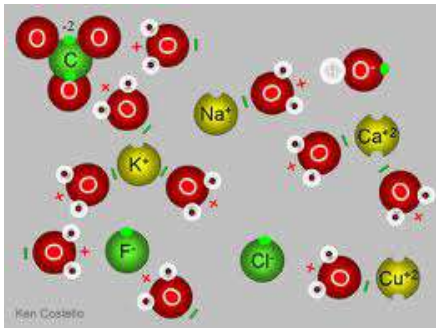
Complete Ionic Equations

- Regular Equation:

$$AgNO_{3(aq)} + NaCl_{(aq)} \rightarrow AgCl_{(s)} + NaNO_{3(aq)}$$

- Complete Ionic Equation:

$$Ag^{+}_{(aq)} + NO_{3}^{-}{}_{(aq)} + Na^{+}_{(aq)} + Cl^{-}_{(aq)} \rightarrow AgCl_{(s)} + Na^{+}_{(aq)} + NO_{3}^{-}{}_{(aq)}$$



Sample Problem

- Write the complete ionic equation for the following reaction:

$$FeCl_{3(aq)} + KOH_{(aq)} \rightarrow Fe(OH)_{3(s)} + KCl_{(aq)}$$

First balance the equation:

$$FeCl_{3(aq)} + \mathbf{3}KOH_{(aq)} \rightarrow Fe(OH)_{3(s)} + \mathbf{3}KCl_{(aq)}$$

Then write the complete ionic equation:

$$Fe^{+3}_{(aq)} + 3Cl^{-}_{(aq)} + 3K^{+}_{(aq)} + 3OH^{-}_{(aq)} \rightarrow$$

$$Fe(OH)_{3(s)} + 3K^{+}_{(aq)} + 3Cl^{-}_{(aq)}$$

Practice Problems

- Write the complete ionic equation for the following reaction:

$NaOH_{(aq)} + Fe(NO_3)_{3(aq)} \rightarrow Fe(OH)_{3(s)} + NaNO_{3(aq)}$

First balance the equation:

$\mathbf{3}NaOH_{(aq)} + Fe(NO_3)_{3(aq)} \rightarrow Fe(OH)_{3(s)} + \mathbf{3}NaNO_{3(aq)}$

Then write the complete ionic equation:

$3Na^{+}_{(aq)} + 3OH^{-}_{(aq)} + Fe^{+3}_{(aq)} + 3NO_{3}^{-}{}_{(aq)} \rightarrow$
$Fe(OH)_{3(s)} + 3Na^{+}_{(aq)} + 3NO_{3}^{-}{}_{(aq)}$

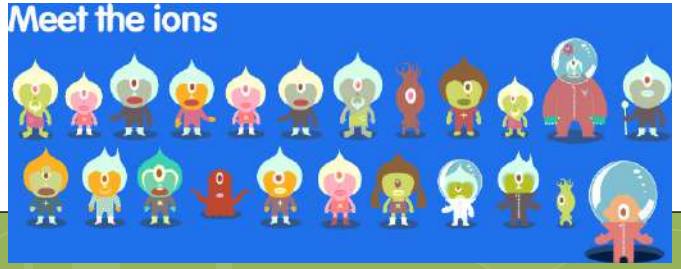
Net Ionic Equations

- A net ionic equation shows only those particles involved in the reaction.
- The spectator ions have been removed.
- Ex: complete ionic equation

$$3Na^{+}_{(aq)} + 3OH^{-}_{(aq)} + Fe^{+3}_{(aq)} + 3NO_{3}^{-}{}_{(aq)} \rightarrow Fe(OH)_{3(s)} + 3Na^{+}_{(aq)} + 3NO_{3}^{-}{}_{(aq)}$$

- When the spectator ions are removed, you are left with the net ionic equation:

$$Fe^{+3}_{(aq)} + 3OH^{-}_{(aq)} \rightarrow Fe(OH)_{3(s)}$$



Sample Problems

- To write a net ionic equation, you only consider non-aqueous substances and the ions that form them.

$$Bi(NO_3)_{3(aq)} + H_2S_{(aq)} \rightarrow Bi_2S_{3(s)} + HNO_{3(aq)}$$

- First, balance the equation:

$$2Bi(NO_3)_{3(aq)} + 3H_2S_{(aq)} \rightarrow Bi_2S_{3(s)} + 6HNO_{3(aq)}$$

- Write only the ions involved in the reaction:

$$2Bi^{+3}_{(aq)} + 3S^{-2}_{(aq)} \rightarrow Bi_2S_{3(s)}$$

Practice Problems

1. Write the net ionic equation for the following reaction:

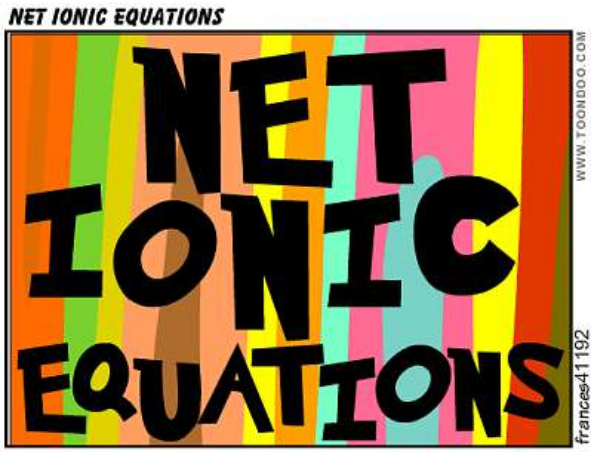
   $Pb(NO_3)_{2(aq)} + H_2SO_{4(aq)} \rightarrow PbSO_{4(s)} + HNO_{3(aq)}$

First balance the equation:

$Pb(NO_3)_{2(aq)} + H_2SO_{4(aq)} \rightarrow PbSO_{4(s)} + \mathbf{2}HNO_{3(aq)}$

Write the net ionic equation:

$Pb^{+2}_{(aq)} + SO_4^{-2}{}_{(aq)} \rightarrow PbSO_{4(s)}$



Practice Problems

- Write the net ionic equation for the following equation:

$$Na_3PO_{4(aq)} + FeCl_{3(aq)} \rightarrow NaCl_{(aq)} + FePO_{4(s)}$$

First, balance the equation:

$$Na_3PO_{4(aq)} + FeCl_{3(aq)} \rightarrow \mathbf{3}NaCl_{(aq)} + FePO_{4(s)}$$

Write the net ionic equation:

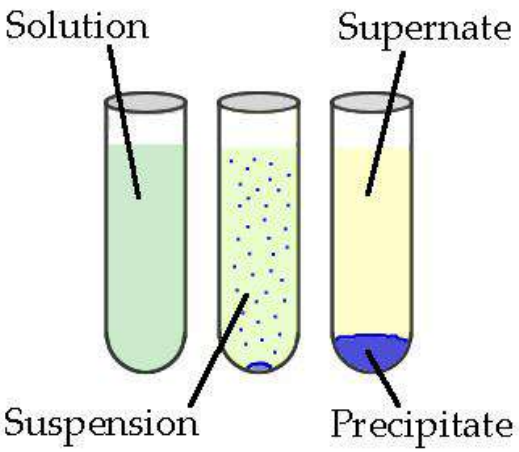
$$PO4^{-3}{}_{(aq)} + Fe^{+3}{}_{(aq)} \rightarrow FePO_{4(s)}$$

Predicting Precipitates

- You can predict whether a precipitate forms by using solubility rules.
- If a substance is soluble, then it will dissolve in water and be aqueous.
- If a substance is insoluble, then it will bond with another ion and will be a solid.

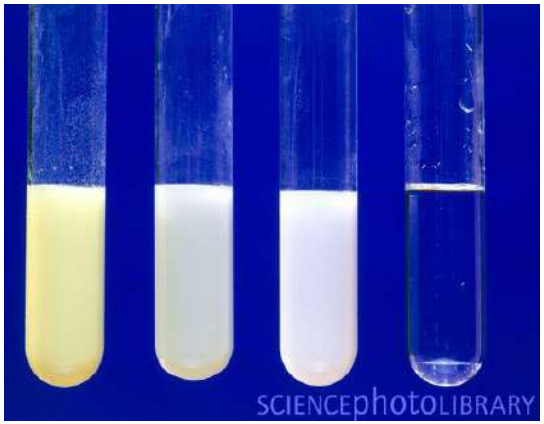
Solubility Rules

alkali metals - Group 1	soluble
NH_4^+	soluble
NO_3^-	soluble
ClO_3^-	soluble
SO_4^{-2} (except with Pb^{+2}, Ag^+, Hg_2^{+2}, Ba^{+2}, Sr^{+2}, and Ca^{+2})	soluble
Cl^- (exception Ag^+, Pb^{+2}, Hg_2^{+2})	soluble
CO_3^{-2}, PO_4^{-3}, CrO_4^{-2}, S^{-2}, and OH^-	insoluble



Soluble or Insoluble?

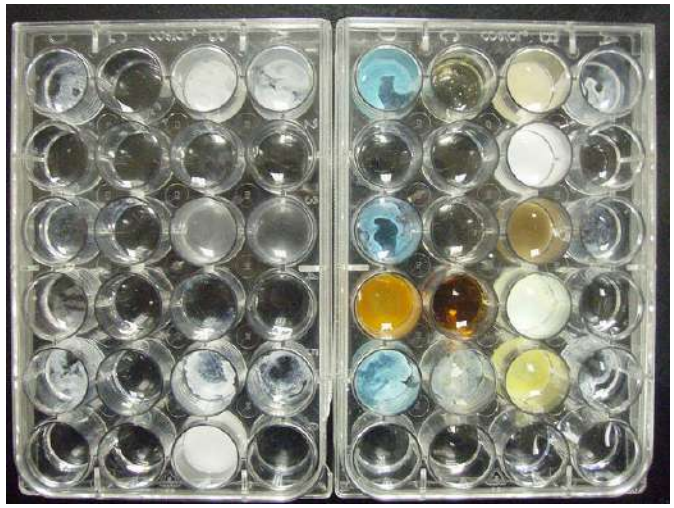
- If any part of a compound is soluble, then the compound will be soluble.
- NH_4Cl Soluble/Aqueous
- $BaSO_4$ Insoluble/Solid
- Na_2SO_4 Soluble/Aqueous
- $Ca(OH)_2$ Insoluble/Solid
- K_3PO_4 Soluble/Aqueous
- $Mg(NO_3)_2$ Soluble/Aqueous
- $AgCl$ Insoluble/Solid
- $NiCrO_4$ Insoluble/Solid



Predicting Precipitates

Rules for Predicting Precipitates

1. Switch the ions and balance the charges to form the products.
2. Balance the equation.
3. Identify whether the products are solid or aqueous.



Sample Problem

- Predict the products for the following reaction:

$$HCl_{(aq)} + AgNO_{3(aq)} \rightarrow$$

First, form the products:

$HCl_{(aq)} + AgNO_{3(aq)} \rightarrow$ **HNO_3 + AgCl**

Then, balance the equation:

$HCl_{(aq)} + AgNO_{3(aq)} \rightarrow HNO_3 + AgCl$

Finally, list states of matter:

$HCl_{(aq)} + AgNO_{3(aq)} \rightarrow HNO_{3}$**$_{(aq)}$** $+ AgCl$**$_{(s)}$**

Practice Problems

1. Predict the products for the following reaction:

$$Pb(C_2H_3O_2)_{2(aq)} + LiCl_{(aq)} \rightarrow$$

First, form the products:

$Pb(C_2H_3O_2)_{2(aq)} + LiCl_{(aq)} \rightarrow$ **$PbCl_2 + LiC_2H_3O_2$**

Then, balance the equation:

$Pb(C_2H_3O_2)_{2(aq)} + \mathbf{2}LiCl_{(aq)} \rightarrow PbCl_2 + \mathbf{2}LiC_2H_3O_2$

Finally, list states of matter:

$Pb(C_2H_3O_2)_{2(aq)} + 2LiCl_{(aq)} \rightarrow PbCl_{2\mathbf{(s)}} + 2LiC_2H_3O_{2\mathbf{(aq)}}$

Practice Problems

2. Predict the products for the following reaction:

$$NH_4Cl_{(aq)} + Ba(NO_3)_{2(aq)} \rightarrow$$

First, form the products:

$NH_4Cl_{(aq)} + Ba(NO_3)_{2(aq)} \rightarrow$ **$NH_4NO_3 + BaCl_2$**

Then, balance the equation:

2$NH_4Cl_{(aq)} + Ba(NO_3)_{2(aq)} \rightarrow$ **2**$NH_4NO_3 + BaCl_2$

Finally, list the states of matter:

$2NH_4Cl_{(aq)} + Ba(NO_3)_{2(aq)} \rightarrow 2NH_4NO_{3\mathbf{(aq)}} + BaCl_{2\mathbf{(aq)}}$

Section 11.3 Assessment

1. What is a net ionic equation?
2. How can you predict the formation of a precipitate in a double displacement reaction?
3. Write the net ionic equation for the following reactions:

d. $Pb(C_2H_3O_2)_{2(aq)} + HCl_{(aq)} \rightarrow PbCl_{2(s)} + HC_2H_3O_{2(aq)}$

$Pb(C_2H_3O_2)_{2(aq)} + 2HCl_{(aq)} \rightarrow PbCl_{2(s)} + 2HC_2H_3O_{2(aq)}$

$\mathbf{Pb^{+2}_{(aq)} + 2Cl^{-}_{(aq)} \rightarrow PbCl_{2(s)}}$

e. $(NH_4)_2S_{(aq)} + Co(NO_3)_{2(aq)} \rightarrow CoS_{(s)} + NH_4NO_{3(aq)}$

$(NH_4)_2S_{(aq)} + Co(NO_3)_{2(aq)} \rightarrow CoS_{(s)} + 2NH_4NO_{3(aq)}$

$\mathbf{Co^{+2}_{(aq)} + S^{-2}_{(aq)} \rightarrow CoS_{(s)}}$

Section 11.3 Assessment

4. Predict the products for the following reactions:

a. $Na_3PO_{4(aq)} + CrCl_{3(aq)} \rightarrow$

$Na_3PO_{4(aq)} + CrCl_{3(aq)} \rightarrow 3NaCl_{(aq)} + CrPO_{4(s)}$

b. $Al_2(SO_4)_{3(aq)} + NH_4OH_{(aq)} \rightarrow$

$Al_2(SO_4)_{3(aq)} + 6NH_4OH_{(aq)} \rightarrow 2Al(OH)_{3(s)} + 3(NH_4)_2SO_{4(aq)}$

THE END!!