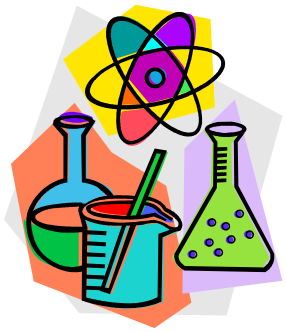


Topic 8: Chemical Reactions

Chemical Equations & Reactions

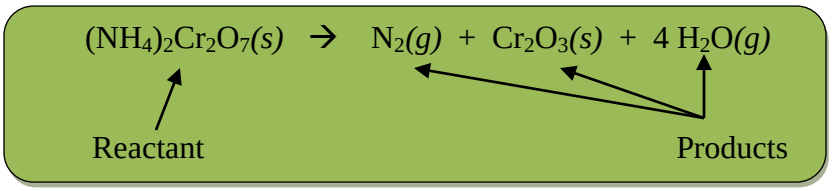
(Chapter 8 in Modern Chemistry)

Describing Chemical Reactions

A **chemical reaction** *is the process by which one or more substances are changed into one or more different substances.* In any chemical reaction, *the original substances are known as the reactants* and *the resulting substances are known as the products*. According to the law of conservation of mass, the total mass of reactants must equal the total mass of products for any given chemical reactions.

Chemical reactions are described by chemical equations. A **chemical equation** *represents, with symbols and formulas, the identities and relative molecular or molar amounts of the reactants and products in a chemical reaction*.

For example, the following chemical equation shows that the reactant ammonium dichromate yields the products nitrogen, chromium(III) oxide, and water.



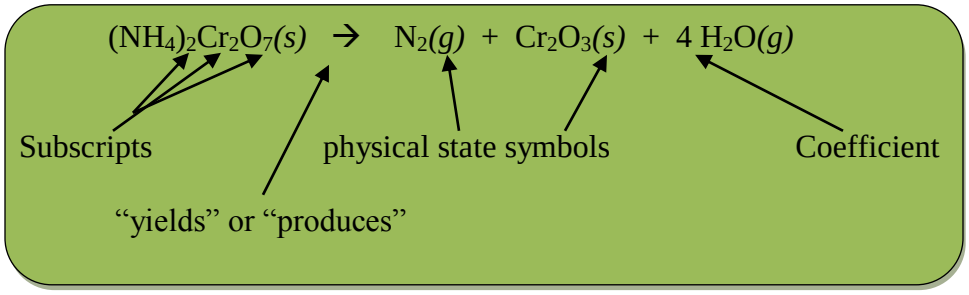
Indications of a Chemical Reaction

Since a chemical reaction produces new substances, the only way to determine if a chemical reaction has actually occurred is by chemical analysis of the product. However, certain easily observed changes usually indicate that a chemical reaction has occurred.

1. *Evolution of energy as heat and light.* A change in matter that releases energy as <u>both</u> heat and light is strong evidence that a chemical reaction has taken place. Some reactions involve only heat or only light. But heat or light by itself is not necessarily a sign of chemical change.
2. *Production of a gas.* The evolution of gas bubbles when two substances are mixed is often evidence of a chemical reaction.
3. *Formation of a precipitate.* Many chemical reactions take place between substances that are dissolved in liquids. If a solid appears after two solutions are mixed, a reaction has likely occurred. *A solid that is produced as a result of a chemical reaction in solution and that separates from the solution is known as a* **precipitate**.
4. *Color change.* A change in color is often an indication of a chemical reaction.

Characteristics of Chemical Equations

A properly written chemical equation can summarize any chemical change. Here is an example equation and a list of requirements that will aid you in writing and reading chemical equations correctly.



1. *The equation must represent know facts.* All reactants and products must be identified.
2. *The equation must contain the correct formulas for the reactants and products.* The symbols and formulas must be correct including elements, diatomic molecules (see Table 1), and ions.
3. *The law of conservation of mass must be satisfied.* Atoms can neither created nor destroyed in ordinary chemical reactions. So there must be the same number of each atom of each element on both side of the equation. To balance numbers of atoms, add coefficients where necessary. A **coefficient** *is a small whole number that appears in front of a formula in a chemical equation*. Placing a coefficient in front of a formula specifies the relative number of moles of the substance; if no coefficient is written the coefficient is understood to be 1.

Learn these!

Table 1	Elements that normally exist as Diatomic Molecules		
Element	Symbol	Molecular Formula	Physical state at room temperature
Hydrogen	H	H_2	gas
Nitrogen	N	N_2	gas
Oxygen	O	O_2	gas
Fluorine	F	F_2	gas
Chlorine	Cl	Cl_2	gas
Bromine	Br	Br_2	liquid
Iodine	I	I_2	solid

Word and Formula Equations

The first step in writing a chemical equation is to identify the facts to be represented. Information may be given in the form of a word equation or you may need to write a word equation. A **word equation** *is an equation in which the reactants and products in a chemical reaction are represented by words.* A word equation has only qualitative (descriptive) meaning. For example the word equation for the reaction of methane and oxygen is written as follows.

Methane + oxygen → carbon dioxide + water

This equation would read: methane reacts with oxygen to produce carbon dioxide and water. Note that the arrow,→, could also be read as "yields" or "forms".

The next step in writing a correct chemical equation is to replace the names of the reactant and products with appropriate symbols and formulas. You should already know the formulas for most of the compounds that we will use. This **formula equation** *represents the reactants and products of a chemical reaction by their symbols or formulas.*

$CH_4 + O_2 \rightarrow CO_2 + H_2O$ (not balanced)

Additionally, it is appropriate to include the physical state symbols of the substance if known.

$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$ (not balanced)

The *(g)* after each formula indicates that the corresponding substance is in the gaseous state. You could also use *(l)* for liquid, *(s)* for solid, and *(aq)* for aqueous or water solution.

Let's practice writing formula equations from word equations.

Task 8a

Write chemical equation for each of the following sentences. Assume that these reactions take place at room temperature

1. Aluminum reacts with oxygen gas to produce solid aluminum oxide.

2. Phosphoric acid is produced through the reaction between tetraphosphorus decoxide and water.

3. Solid iron(III) oxide reacts with carbon monoxide to produce iron and carbon dioxide.

Formula equations meet two of the three requirements for a correct chemical equation. It represents the facts and shows the correct symbols and formulas for the reactants and products. It does not satisfy the law of conservation of mass. To complete this step, we must balance the equation. To balance an equation there must be the same number of atoms of each element on each side of the arrow. This is usually done by trial and error.

$$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g) \qquad \text{(not balanced)}$$

To balance equation, we use coefficients. Remember coefficients go with the entire compound. 2 CH_4 would mean 2 carbon atoms and 8 hydrogen atoms. 2 Na_2SO_4 would mean 4 sodium atoms, 2 sulfur atoms, and 8 oxygen atoms. 3 $(NH_4)_2CO_3$ would mean 6 nitrogen atoms, 24 hydrogen atoms, 3 carbon atoms, and 9 oxygen atoms.

Task 8b

1. How many atoms of each type are represented in each of the following?
    1. 3 N_2
    2. 2 H_2O
    3. 4 HNO_3
    4. 2 $Ca(OH)_2$
    5. 3 $Ba(ClO_3)_2$
    6. 4 $Mg_3(PO_4)_2$
    7. 6 $Al_2(SeO_4)_3$
    8. 4 C_3H_8

Balancing Equations

General balancing: Notice that you do not need the physical state symbols to balance the equation. They have no effect on the number of atoms so I will ignore them while balancing.

$$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g) \qquad \text{(not balanced)}$$

In this equation, the is 1 C on each side, so the carbons are balanced but there are 4 H's on the reactant side and only 2 H's on the product side. To balance this we will place a coefficient of 2 in front of the H_2O. **Never change subscripts when balancing an equation.**

$$CH_4(g) + O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) \qquad \text{(not balanced)}$$

Now there are 2 O's on the reactant side of the equation but 4 O's on the product side. (Notice that I added the 2 O's from CO_2 to the 2 O's in H_2O.) To balance this we will place a coefficient of 2 in front of the O_2.

$CH_4(g)$ + 2 $O_2(g)$ → $CO_2(g)$ + 2 $H_2O(g)$ (balanced)

You could read this as: 1 mole of methane gas reacts with 2 moles of oxygen gas to produce 1 mole of carbon dioxide gas and 2 moles of water vapor.

It is always a good idea to recheck the equation after you are finished. Sometimes while changing the coefficient for one substance you may change one of the elements that you have already balanced. Also when there is no coefficient, it is understood to be 1.

This is a simple equation. Balancing equations takes practice. The more you practice, the easier balancing will become.

Equations containing polyatomic ions: If you notice that polyatomic ions are in the equation, and they do not split apart. It is sometimes easier to consider them as one entity.

$H_2SO_4(aq)$ + $NaNO_3(aq)$ → $HNO_3(aq)$ + $Na_2SO_4(aq)$ (not balanced)

I would balance this by balancing the hydrogen atoms first. This requires me to put a 2 in front of HNO_3.

$H_2SO_4(aq)$ + $NaNO_3(aq)$ → 2 $HNO_3(aq)$ + $Na_2SO_4(aq)$ (not balanced)

Now I have 2 H's on each side. I also have 1 sulfate ion (SO_4) on each side. Since sulfate stayed together, I do not have to treat the sulfur and oxygen atoms separately. This makes balancing easier since there are oxygen atoms in every substance.

I have 1 Na atom on the reactant side but 2 Na atoms on the product side. I will place a 2 in front of $NaNO_3$. This also gives me 2 nitrate ions (NO_3) on each side.

$H_2SO_4(aq)$ + 2 $NaNO_3(aq)$ → 2 $HNO_3(aq)$ + $Na_2SO_4(aq)$ (balanced)

Equations containing water: Water can be written as H_2O or HOH. Pick whichever is easier for you to balance.

HCl*(aq)* + NaOH*(aq)* → NaCl*(aq)* + HOH*(l)* (balanced)

Here water is written as HOH because it is easier to see what happened and to balance the equation. This equation is already balanced as written. If you are given one of these in homework or on a test, I ask that you write "balanced" or put a "B" beside it. This tells me you knew what you were doing and not just skipping the problem.

Task 8c

Balance the following equations.

1. ____$NaNO_3$ + ____PbO → ____$Pb(NO_3)_2$ + ____Na_2O
2. ____AgI + ____$Fe_2(CO_3)_3$ → ____FeI_3 + ____Ag_2CO_3
3. ____$C_2H_4O_2$ + ____O_2 → ____CO_2 + ____H_2O
4. ____$ZnSO_4$ + ____Li_2CO_3 → ____$ZnCO_3$ + ____Li_2SO_4
5. ____V_2O_5 + ____CaS → ____CaO + ____V_2S_5
6. ____$Mn(NO_2)_2$ + ____$BeCl_2$ → ____$Be(NO_2)_2$ + ____$MnCl_2$
7. ____$AgBr$ + ____$GaPO_4$ → ____Ag_3PO_4 + ____$GaBr_3$
8. ____H_2SO_4 + ____$B(OH)_3$ → ____$B_2(SO_4)_3$ + ____H_2O
9. ____S_8 + ____O_2 → ____SO_2
10. ____Fe + ____$AgNO_3$ → ____$Fe(NO_3)_2$ + ____Ag

Task 8d

1. Write **balanced** equations for the following reactions. Include physical state symbols where indicated.

    a. Solid calcium reacts with solid sulfur to produce solid calcium sulfide.

    b. Hydrogen gas reacts with fluorine gas to produce hydrogen fluoride gas.

    c. Solid aluminum metal reacts with aqueous zinc chloride to produce solid zinc metal and aqueous aluminum chloride.

2. Translate the following chemical equations into sentences:

   a. $CS_2(l) + 3\ O_2(g) \rightarrow CO_2(g) + 2\ SO_2(g)$

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

Additional Symbols Used in Chemical Equations

Symbols Used in Chemical Equations	
$\longrightarrow$	"Yields"; indicates result of reaction
$\rightleftharpoons$	Used in place of a single arrow to indicate a reversible reaction
(s)	Solid state; also used to indicate a precipitate
$\downarrow$	Used only to indicate a precipitate
(l)	Liquid state
(aq)	Aqueous solution; dissolved in water
(g)	Gaseous state
$\uparrow$	Used only to indicate a gaseous product
$\overset{\triangle}{\longrightarrow}$	Reactants are heated
$\overset{\text{heat}}{\longrightarrow}$	Reactants are heated
$\overset{\text{2 atm}}{\longrightarrow}$	Pressure at which reaction is carried out, in this case 2 atm
$\overset{\text{pressure}}{\longrightarrow}$	Indicates that reaction is carried out abouve normal atmospheric pressure
$\overset{\text{O°C}}{\longrightarrow}$	Temperature at which reaction is carried out, in this case 0°C
$\overset{MnO_2}{\longrightarrow}$	Formula of catalyst, used to alter the rate of the reaction

Significance of a Chemical Equation

Now that the equations are balanced, it is useful in doing quantitative chemistry.

1. *The coefficients of a chemical reaction indicate relative, not absolute amounts of reactants and products.* This is a ratio of the smallest numbers of atoms, molecules, or ions that will satisfy the law of conservation of mass.

$$H_2(g) + Cl_2(g) \rightarrow 2\ HCl(g)$$

This shows that 1 molecule of hydrogen gas reacts with 1 molecule of chlorine gas to produce 2 molecules of hydrogen chloride gas.

It could also represent 20 molecules of hydrogen gas reacts with 20 molecules of chlorine gas to produce 40 molecules of hydrogen chloride gas.

Or in terms of amounts in moles: 1 mole of hydrogen gas reacts with 1 mole of chlorine gas to produce 2 mole of hydrogen chloride gas.

2. *The relative masses of the reactants and products of a chemical reaction can be determined from the reaction's coefficients.* Remember in Topic 7 that you can convert moles to mass in grams by multiplying by the appropriate molar mass.

$$1\ mol\ H_2 \times \frac{2.02\ g\ H_2}{mol\ H_2} = 2.02\ g\ H_2$$

$$1\ mol\ Cl_2 \times \frac{70.90\ g\ Cl_2}{mol\ Cl_2} = 70.90\ g\ Cl_2$$

$$2\ mol\ HCl \times \frac{36.46\ g\ HCl}{mol\ HCl} = 72.92\ g\ HCl$$

The chemical equation shows that the mass of the reactants: 2.02 g H_2 + 70.90 g Cl_2 equals the mass of the product: 72.92 g HCl

3. *The reverse reaction for a chemical equation has the same relative amounts of substances as the forward reaction.* This means that 2 moles of hydrogen chloride gas would decompose to make 1 molecule of hydrogen gas and 1 mole of chlorine gas.

Types of Chemical Reactions

There are thousands of known chemical reactions that occur. Often it is necessary to predict the products formed in one of these reactions. Therefore it is useful to classify reactions according to various similarities and regularities. There are several ways to classify chemical reactions and none are perfect but we will look at five basic types of reactions: synthesis, decomposition, single displacement, double displacement, and combustion. Later we will look at other types.

Remember:
1. Write the symbols.
2. Check for diatomic molecules.
3. Check oxidation numbers.
4. Write physical state symbols if available.
5. Balance.

The order of steps 1-4 can be mixed, but step 5 must be completed last.

Synthesis

In a synthesis reaction, two or more substances combine to form a new compound.

General equation:

$$A + X \rightarrow AX$$

Example:
Magnesium reacts with oxygen

$$Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

Oxides of metals are usually solids while nonmetallic oxides are usually gases.

Oxygen is a diatomic molecule hence the subscript 2

Note that to get the formula for magnesium oxide oxidation numbers were used as in Topic 5. Mg has a 2+ charge and O has a 2- charge. Since they equal zero there are no subscripts.

Special synthesis reactions

1. Metallic oxides react with water to produce metallic hydroxides.

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$$

2. Nonmetallic oxides react with water to produce oxyacids.

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

3. Metallic oxides can react with carbon dioxide to produce metallic carbonates.

$$Na_2O(s) + CO_2(g) \rightarrow Na_2CO_3(s)$$

4. Metallic oxides can react with nonmetallic oxides to produce salts.

$$CaO(s) + SO_2(g) \rightarrow CaSO_3(s)$$

Note that the oxidation number of the metal and the nonmetal will remain the same. This will allow you to determine the number of oxygen atoms in the product.

5. Metallic chlorides react with oxygen to produce metallic chlorates.

$$2\ KCl(s) + 3\ O_2(g) \rightarrow 2\ KClO_3(s)$$

Task 8e

Write the balanced equations for the following synthesis reactions.

1. Lithium metal reacts with oxygen gas

2. Iron metal reacts with oxygen gas to produce an iron(III) compound

3. Calcium reacts with iodine

4. Barium oxide reacts with carbon dioxide

Decomposition

In a decomposition reaction, a single compound undergoes a reaction that produces two or more simpler substances.

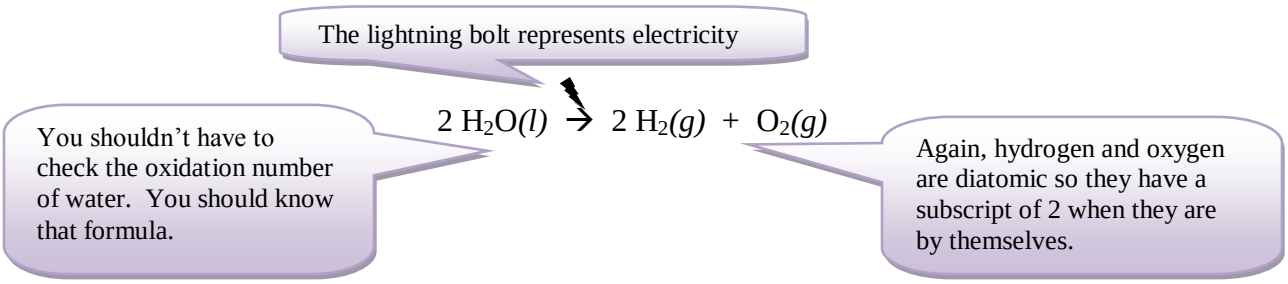
. **General equation:**

$$AX \rightarrow A + X$$

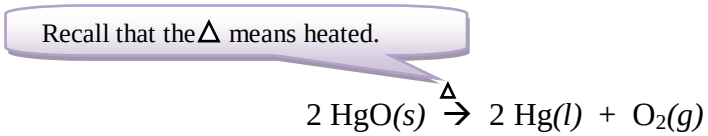
Examples:

Binary Compounds

1. Water decomposes by an electric current
   The decomposition of a substance by an electric current is called **electrolysis**.



2. Mercury(II) oxide decomposes when heated.
   Oxides of less active metals decompose into their elements when heated.



Special decomposition reactions

These reactions are the reverse of the synthesis reactions.

1. Metallic hydroxides decompose to produce metallic oxides and water.

$$NaOH(s) \xrightarrow{\Delta} Na_2O(s) + H_2O(s)$$

2. Oxyacids decompose into nonmetallic oxides and water.

$$H_2SO_4(aq) \xrightarrow{\Delta} SO_3(g) + H_2O(l)$$

3. Metallic carbonates decompose to metallic oxides and carbon dioxide.

$$CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$$

4. Metallic chlorates decompose to metallic chlorides and oxygen.

$$2\ KClO_3(s) \xrightarrow{\Delta} 2\ KCl(s) + 3\ O_2(g)$$

Task 8f

Write the balanced equations for the following decomposition reactions.

1. The decomposition of solid sodium chloride when heated

2. Solid calcium hydroxide decomposes

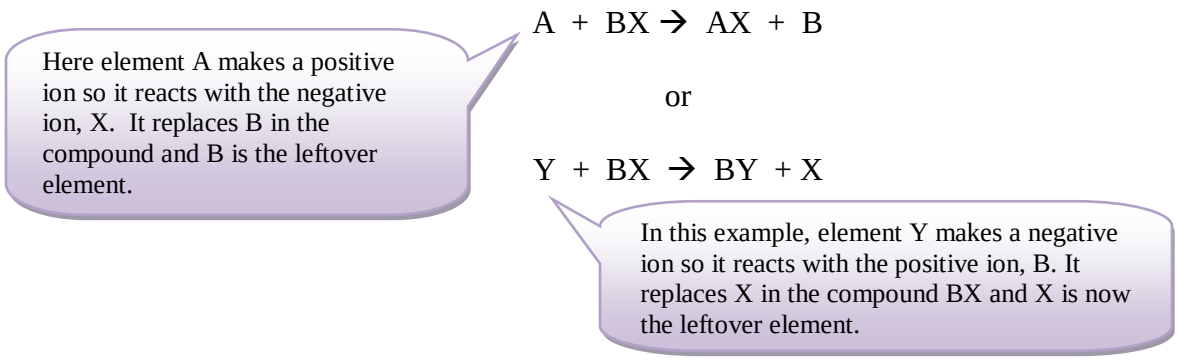
3. Solid silver chloride decomposes

4. Heat is applied to solid magnesium chlorate

Single Displacement

In a single displacement reaction one element replaces a similar element in a compound.

. **General equation:**



Examples:

Aluminum metal reacts with a solution of lead(II)nitrate.

$$2\ Al(s)\ +\ 3\ Pb(NO_3)_2(aq)\ \rightarrow\ 3\ Pb(s)\ +\ 2\ Al(NO_3)_3(aq)$$

Chlorine gas reacts with potassium bromide.

$$Cl_2(g)\ +\ 2\ KBr(aq)\ \rightarrow\ 2\ KCl(aq)\ +\ Br_2(l)$$

An **activity series** *is a list of elements organized according to the ease with which the elements undergo certain chemical reaction.* When working with single displacement reactions, it is important for you to check the activity. An activity series is located on the next page.

Activity Series of Metals

Li Rb K Ba Sr Ca Na	React with cold H2O and acids, replacing hydrogen. React with oxygen, forming oxides.
Mg Al Mn Zn Cr Fe Cd	React with steam (but not with cold water) and acids, replacing hydrogen. React with oxygen, forming oxides
Co Ni Sn Pb	Do not react with water. React with acids, replacing hydrogen. React with oxygen, forming oxides
H_2 Sb Bi Cu Hg	React with oxygen, forming oxides.
Ag Pt Au	Fairly unreactive, forming oxides only indirectly.

Activity Series of Halogen Nonmetals

F_2
Cl_2
Br_2
I_2

Elements that are higher on the activity series will replace those that are below it. For example:

Will aluminum react with zinc chloride? Aluminum is higher on the activity series than zinc so yes it will react.

$$2\ Al(s)\ +\ 3\ ZnCl_2(aq)\ \rightarrow\ 3\ Zn(s)\ +\ 2\ AlCl_3(aq)$$

Will cobalt react with sodium chloride? Cobalt is lower on the chart than sodium, therefore there is no reaction.

$$Co(s)\ +\ 2\ NaCl(aq)\ \rightarrow\ NR$$

"NR" stands for no reaction

You can also use the activity series for halogens by using the right side of the activity series. For example:

Will chlorine reacts with sodium fluoride? No, chlorine is lower on the activity series than fluorine.

$$Cl_2(g) + NaF(aq) \rightarrow NR$$

Task 8g

Write the balanced equations for the following single displacement reactions (Assume all of these reactions react).

1. Zinc metal reacts with a lead(II) nitrate solution

2. Aluminum combines with a mercury(II) acetate solution

3. Aluminum reacts with a nickel(II) sulfate solution

4. Sodium metal reacts with water at room temperature

Based on the activity series, predict whether each of the following reactions will occur. Write an appropriate equation for each.

1. Nickel reacts with water

2. Bromine reacts with potassium iodide

3. Gold reacts with hydrochloric acid

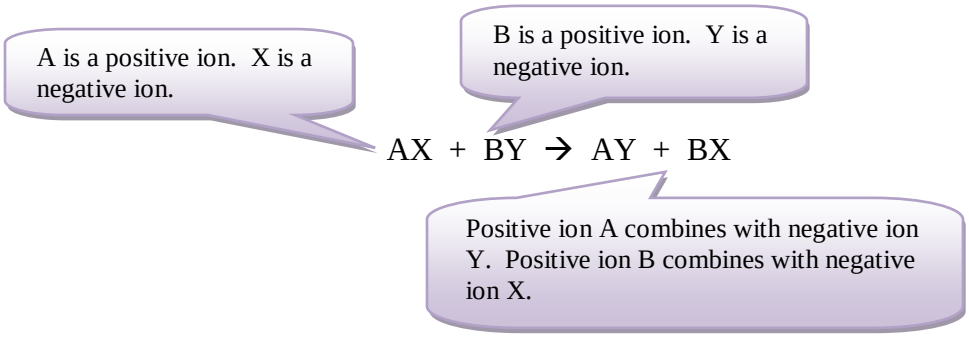
4. Cadmium reacts with hydrochloric acid

5. Magnesium reacts with cobalt(II) nitrate

Double Displacement

In double displacement reactions, the ions of two compounds exchange places in an aqueous solution to form two new compounds.

General equation:



Notice that the ions just switched partners. A combined with Y. B combined with X.

Examples:

An aluminum chloride reacts with a solution of lead(II)nitrate.

$$2\ AlCl_3(aq) + 3\ Pb(NO_3)_2(aq) \rightarrow 3\ PbCl_2(s) + 2\ Al(NO_3)_3(aq)$$

Later in this topic you will learn how to determine the physical state symbols of reactions similar to this one.

Task 8h

Write the balanced equations for the following double displacement reactions.

1. A silver nitrate solution reacts with a solution of sodium chloride

2. Solutions of magnesium nitrate and potassium hydroxide combine

3. Hydrochloric acid reacts with sodium hydroxide in water

4. Copper(I) chloride reacts with barium fluoride

Combustion

In a combustion reaction, a substance combines with oxygen, releasing a large amount of energy in the form of light and heat. If the substance is a hydrocarbon, carbon dioxide and water will be produced in addition to energy.

General equation:

Element + $O_2(g)$ → Oxide of element

The physical state symbol of water depends on the temperature.

Hydrocarbon + $O_2(g)$ → $CO_2(g)$ + $H_2O(l \text{ or } g)$

This part of the equation is always the same except for balancing.

Examples:

Carbon monoxide reacts with oxygen

$$2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g)$$

The combustion of propane

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

Remember, as long as the combustion is of a hydrocarbon, it will always be O_2 → CO_2 + H_2O. Only the balancing will change.

Task 8i

Write the balanced equations for the following combustion reactions.

1. The combustion of ethane

2. The combustion of pentane

3. The reaction of strontium metal and oxygen

Task 8j

1. Classify each of the following reactions as a synthesis, decomposition, single displacement, double displacement, or combustion reaction.

   a. $N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$

   b. $2\ Li(s) + 2\ H_2O(l) \rightarrow 2\ LiOH(aq) + H_2(g)$

   c. $2\ NaNO_3(s) \rightarrow 2\ NaNO_2(s) + O_2(g)$

   d. $2\ C_6H_{14}(l) + 19\ O_2(g) \rightarrow 12\ CO_2(g) + 14\ H_2O(l)$

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

2. Predict the products of the following reactions:

   a. Silver reacts with copper(II) sulfate

   b. Sodium iodide reacts with calcium chloride

   c. Oxygen reacts with hydrogen

   d. Nitric acid reacts with manganese(II) hydroxide

   e. Silver nitrite reacts with barium sulfate

   f. Hydrocyanic acid reacts with copper(II) sulfate

   g. Water reacts with silver iodide

h. Nitric acid reacts with iron(III) hydroxide

i. Lithium bromide reacts with cobalt(II) sulfite

j. Lithium nitrate reacts with silver

k. Nitrogen gas reacts with oxygen gas

l. Carbonic acid decomposes

m. Aluminum chloride reacts with cesium

n. Aluminum nitrate reacts with gallium

o. Sulfuric acid reacts with ammonium hydroxide

p. Acetic acid reacts with oxygen gas

q. Butane burns in the presence of oxygen

r. Potassium chloride reacts with magnesium hydroxide

s. Zinc reacts with gold(II) nitrate

Ions in Aqueous Solutions
(Chapter 13 in Modern Chemistry)

Dissociation

When a compound that is made of ions dissolves in water, the ions separate from one another. This *separation of ions that occurs when an ionic compound dissolves is called* **dissociation**. For example, dissociation of sodium chloride and calcium chloride in water can be represented by the following equations.

$$NaCl(s) \xrightarrow{H2O} Na^{+}(aq) + Cl^{-}(aq)$$
1mole → 1mole + 1mole

2 moles of ions

$$CaCl_2(s) \xrightarrow{H2O} Ca^{2+}(aq) + 2\,Cl^{-}(aq)$$

3 moles of ions

Task 8k

1. Write the equation for the dissolution of aluminum sulfate in water.

2. How many moles of aluminum ions and sulfate ions are produced by dissolving 1 mole of aluminum sulfate?

3. What is the total number of moles of ions produced by dissolving 1 mole of aluminum sulfate?

Precipitation Reactions

Although no ionic compound is completely insoluble, compounds of very low solubility can be considered insoluble for most practical purposes. There are some general rules to help predict whether an ionic compound made of certain ions is soluble. It is important that you learn these.

SOLUBLE COMPOUNDS	INSOLUBLE COMPOUNDS
Group 1 and ammonium	Hydroxides (EXCEPT Group 1 and Ammonium. Hydroxides of Ca^{2+}, Sr^{2+}, and Ba^{2+} are slightly soluble)
Nitrates, Hydrogen carbonates, Chlorates, Perchlorates, and Acetates	
Chlorides, Bromides, and Iodides (EXCEPT those of Pb^{2+}, Ag^{+}, and Hg_2^{2+})	Carbonates, Phosphates, Chromates, Silicates and Sulfides (EXCEPT Group 1 and Ammonium. Sulfides of Group 2 are soluble)
Sulfates (EXCEPT Ca^{2+}, Sr^{2+}, Ba^{2+}, Ag^{+}, Pb^{2+}, and Hg_2^{2+})	

This information is useful in predicting what happen if solutions of two different soluble compounds are mixed. If the mixing results in a combination of ions that forms an insoluble compound, a double-displacement reaction and precipitation will occur. Precipitation occurs when the attraction between the ions is greater than the attraction between the ions and surrounding water molecules. A **precipitate** *is a solid that is produced as a result of a chemical reaction in aqueous solution.*

EXAMPLE: Will a precipitate form when solutions of ammonium sulfide and cadmium nitrate are combined?

Using the solubility rules:

Ammonium sulfide is soluble.
Cadmium nitrate is soluble.
Ammonium nitrate is soluble.
Cadmium sulfide is <u>insoluble</u>. Therefore cadmium sulfide **will** precipitate (ppt).

Net ionic equations

Reactions in aqueous solutions are usually represented as net ionic equations rather than formula equations. A **net ionic equation** *includes only those compounds and ions that undergo a chemical change in a reaction in an aqueous solution*.

To write a net ionic equation:

1. Write a chemical equation.
2. Write an overall ionic equation.
3. Remove ions that are spectator ions.
4. Write the net ionic equation.
5. Balance elements and charges.

Using the example from the previous page:

Solutions of ammonium sulfide and cadmium nitrate are mixed.

1. Write a chemical equation. Use solubility rules to determine physical state.

$$(NH_4)_2S(aq) + Cd(NO_3)_2(aq) \rightarrow NH_4NO_3(aq) + CdS(s)$$

2. Write an overall ionic equation. Ionic compounds that are soluble are written as ions. (Strong acids and bases are also written in ionic form.)

$$NH_4^+(aq) + S^{2-}(aq) + Cd^{2+}(aq) + NO_3^-(aq) \rightarrow NH_4^+(aq) + NO_3^-(aq) + CdS(s)$$

Notice that I do not include the number of ions here. I usually wait until I balance at the end.

3. Remove ions that are spectator ions. *Ions that do not take part in a chemical reaction and are forum in solution both before and after the reaction are* **spectator ions**. Their formulas and charges must match exactly.

$$\cancel{NH_4^+(aq)} + S^{2-}(aq) + Cd^{2+}(aq) + \cancel{NO_3^-(aq)} \rightarrow \cancel{NH_4^+(aq)} + \cancel{NO_3^-(aq)} + CdS(s)$$

NH_4^+ and NO_3^- are spectator ions

4. Write the net ionic equation.

$$S^{2-}(aq) + Cd^{2+}(aq) \rightarrow CdS(s)$$

5. Balance elements and charges. In this case, the elements and charges are already balanced. So the final answer is:

$$S^{2-}(aq) + Cd^{2+}(aq) \rightarrow CdS(s)$$

This looks like a long process, but if you remember the solubility rules, you should be able to do most of these steps in your head.

Not all reactions occur. Sometimes everything is soluble. This means that the ions are just hanging out in solution. A reaction isn't occurring.

For example:

Solutions of potassium nitrate and magnesium sulfate.

$$KNO_3(aq) + MgSO_4(aq) \rightarrow K_2SO_4(aq) + Mg(NO_3)_2(aq)$$

$$K^+(aq) + NO_3^-(aq) + Mg^{2+}(aq) + SO_4^{2-}(aq) \rightarrow K^+(aq) + SO_4^{2-}(aq) + Mg^{2+}(aq) + NO_3^-(aq)$$

Everything cancels here so there is no reaction!

Task 8I

1. Predict whether each of the following compounds is considered soluble or insoluble.

    a. KCl
    b. $NaNO_3$
    c. AgCl
    d. $BaSO_4$
    e. $Ca_3(PO_4)_2$
    f. $Pb(ClO_3)_2$
    g. $(NH_4)_2S$
    h. $PbCl_2$
    i. FeS
    j. $Al_2(SO_4)_3$

2. In the following combinations, determine if a precipitate will occur. If so write a net ionic equation. Identify the spectator ions.

    a. Solutions of potassium sulfate and barium nitrate are combined.

    b. Solutions of barium chloride and sodium sulfate are combined.

    c. Solutions of cesium bromide and lithium iodide are combined.

    d. Aqueous mercury(II) chloride is combined with aqueous potassium sulfide.