CHEQ 1094 CLASSIFICATION OF CHEMICAL REACTIONS

There are very many chemical reactions known. Fortunately, there are not that many *types* of reaction. Hence, we can classify chemical reactions according to the type of reaction. There are many classifications possible and one reaction may be classified in more than one way. All classifications are useful because they help in understanding and remembering many of the known reactions and in predicting some new reactions. Many reactions fall into one of the following **five** classes: (1) **Combustion**, (2) **Combination**, (3) **Decomposition**, (4) **Single Replacement**, and (5) **Double Replacement**.

COMBUSTION REACTIONS

Many compounds are flammable; they can burn when reacted with oxygen. The reaction is called combustion; it gives off a lot of heat but heat must be supplied to start the reaction. We will consider only combustion reactions of compounds containing C and H, and those containing C, H and O. The **only** products of complete combustion of such compounds are CO_2 and H_2O. Hence, each molecule of the compound produces a number of CO_2 molecules equal to the number of C atoms per molecule and a number of H_2O molecules equal to *half* the number of H atoms per molecule. The number of O_2 molecules needed per molecule of compound is obtained by balancing the equation.

$$C_6H_{12}(l) + 9O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$$

The physical state of the compound would have to be given; both O_2 and CO_2 exist as gases (except at very low temperatures), and H_2O would exist as a liquid after cooling (it can also be written as a gas).
When the molecule contains oxygen, the number of O atoms in the molecule must be counted when balancing the equation.

$$C_9H_{18}O + 13O_2 \rightarrow 9CO_2 + 9H_2O$$

The equation may have to be multiplied by 2 to make the number of O_2 molecules a whole number.

$$C_8H_{14} + 11\tfrac{1}{2}O_2 \rightarrow 8CO_2 + 7H_2O$$

becomes $$2C_8H_{14} + 23O_2 \rightarrow 16CO_2 + 14H_2O$$

COMBINATION REACTIONS (A + B $\rightarrow$ C)

A combination reaction is one in which <u>two or more</u> reactants form <u>one</u> product. Combination reactions can be assigned to several sub-classes, including the following.

(a) **Metal + non-metal $\rightarrow$ ionic compound**

The combination of a metal and a non-metal produces a binary ionic compound. For the **A** group metals, the charge on the derived cation is known and hence the formula of the ionic product is *predictable*. Some reactions, such as that between Na and Cl_2, are spontaneous while others, such as that between Mg and O_2, require heating.

$$2Na(s) + Cl_2(g) \longrightarrow 2NaCl(s)$$

$$2Mg(s) + O_2(g) \xrightarrow{\Delta} 2MgO(s)$$

(b) **Non-metal + non-metal $\rightarrow$ molecular compound**

The combination of two non-metals produces molecular compounds but the product is *not predictable* in most cases. Thus, the reaction of N_2 with O_2 can form NO, N_2O, NO_2, N_2O_3, N_2O_5 and N_2O_4. Similarly, P can form two different compounds on reaction with Cl_2.

$$P_4(s) + 6Cl_2(g) \longrightarrow 4PCl_3(l)$$

$$P_4(s) + 10Cl_2(g) \longrightarrow 4PCl_5(s)$$

(c) **Metal oxide + water → metal hydroxide**

Some examples are:

$$Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(s)$$

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

(d) **Non-metal oxide + water → oxyacid**

Some examples are:

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(l)$$

$$P_2O_5(s) + 3H_2O(l) \longrightarrow 2H_3PO_4(s)$$

DECOMPOSITION REACTIONS (A → B + C)
Most decomposition reactions are not easily predictable but many carbonates decompose on heating to the oxide and CO_2.

$$MgCO_3(s) \xrightarrow{\Delta} MgO(s) + CO_2(g)$$

Other examples are:

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

$$NH_4NO_2(s) \xrightarrow{\Delta} N_2(g) + 2H_2O(l)$$

SINGLE REPLACEMENT REACTIONS (A + BC → AC + B)
Many single replacement reactions involve the reaction of a metal with H_2O, an acid, or the salt of another metal [(a) to (c), below]. The **Activity Series** (see below) can be used to predict if a reaction occurs.

(a) **Active metal + water → metal hydroxide + H_2**
The first five metals in the activity series (Li to Na) are reactive enough to displace H from H_2O.

$$2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(s) + H_2(g)$$

(b) **Metal + acid → metal salt + H_2**
Metals **above** H in the activity series will displace H from an acid.

$$2Al(s) + 6HCl(aq) \longrightarrow 2AlCl_3(aq) + 3H_2(g)$$

$$Cu(s) + HCl(aq) \longrightarrow \text{NO REACTION}$$

(c) **Metal A + metal B salt → metal B + metal A salt**
A metal will displace a **lower** (in the activity series) metal.

$$Zn(s) + CuSO_4(aq) \longrightarrow Cu(s) + ZnSO_4(aq)$$

$$Ni(s) + MgCl_2(aq) \longrightarrow \text{NO REACTION}$$

(d) **Halogen A + halide B → halogen B + halide A**
A halogen will displace a **less reactive** halogen (lower in the Periodic Table) from its halide salt.

$Cl_2(aq) + 2NaI(aq) \longrightarrow I_2(aq) + 2NaCl(aq)$

$Br_2(aq) + NaCl(aq) \longrightarrow$ NO REACTION

DOUBLE REPLACEMENT REACTIONS (AB + CD → AD + CB)
When two ionic compounds are mixed in aqueous solution, a reaction occurs if there is (a) an insoluble product, or (b) a molecular product. In other cases, there is simply the same mixture of ions and no change has occurred. Ionic and net ionic equations (see below) help to show this. The **Solubility Rules** (see below) are used to predict if any of the "products" is insoluble.

(a) **Insoluble product (Precipitation reaction)**
The solid that appears when an insoluble product is formed from mixing two aqueous solutions of ionic compounds is called a **precipitate** and hence such reactions are also called **precipitation reactions**.

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

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

Net ionic eq: $Cl^-(aq) + Ag^+(aq) \rightarrow AgCl(s)$

$NaCl(aq) + KNO_3(aq) \rightarrow$ NO REACTION; $NaNO_3$ and KCl are both **soluble**

The ionic equation (below) shows that no change, and hence no reaction, occurs.

$Na^+(aq) + Cl^-(aq) + K^+(aq) + NO_3^-(aq) \rightarrow Na^+(aq) + NO_3^-(aq) + K^+(aq) + Cl^-(aq)$

(b) **Molecular product (Acid-Base reaction)**
The most common type of double replacement reaction in which a molecular compound is formed is the reaction of an acid with a base forming an ionic salt and the molecular compound water.

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

Ionic eq: $Na^+(aq) + OH^-(aq) + H^+(aq) + Cl^-(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l)$

Net ionic eq: $OH^-(aq) + H^+(aq) \rightarrow H_2O(l)$

The reaction of an acid with a carbonate or a hydrogen carbonate is also an acid-base reaction. In these cases, CO_2, as well as water, is formed. The H_2CO_3, which is expected from the double replacement, decomposes to CO_2 and H_2O.

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

REDOX REACTIONS (Oxidation-reduction reactions)
A redox reaction is one in which there is a transfer of electrons from one reactant to another. Many of the reactions discussed above are redox reactions. When ionic compounds are involved, it is easy to see the electron transfer. Many reactions of molecular compounds are also redox reactions but it is more difficult to see this and hence such redox reactions are outside the scope of this course.

(a) **Metal + non-metal → ionic compound**
In the reaction $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$, Na changes from a neutral atom to Na^+ by transferring an electron to Cl which becomes Cl^-.

(b) **Metal + acid → metal salt + H_2**
In the reaction $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$, Zn changes from a neutral atom to Zn^{2+} by transferring two electrons to two H^+ ions which become two H atoms and then couple to form a H_2 molecule.

(c) **Metal A + metal B salt → metal B + metal A salt**
In the reaction $Zn(s) + CuSO_4(aq) \rightarrow Cu(s) + ZnSO_4(aq)$, Zn changes from a neutral atom to Zn^{2+} by transferring two electrons to Cu^{2+} which then becomes a neutral Cu atom.

(d) **Halogen A + halide B → halogen B + halide A**
In the reaction $Cl_2(aq) + 2NaI(aq) \rightarrow I_2(aq) + 2NaCl(aq)$, the two I^- ions change to two I atoms (which couple to form the I_2 molecule) by transferring two electrons to the two Cl atoms (in the Cl_2 molecule) which then become two Cl^- ions.

Note that there is no electron transfer in the double replacement reactions; in precipitation reactions, two ions form an insoluble ionic compound, and in acid-base reactions, a H^+ ion joins with a OH^- ion to form a molecular compound, water.

ACTIVITY SERIES OF THE METALS

Li K Ba Ca Na Mg Al Zn Fe Cd Ni Sn Pb (H) Cu Hg Ag Au
Most reactive → Least reactive

SOLUBILITY RULES

ION	RULES
Group IA NH_4^+	1. All ionic compounds in which the cation is a Group IA element or NH_4^+ are *soluble*.
NO_3^-	2. All nitrates are *soluble*.
Cl^-, Br^-, I^-	3. All chlorides, bromides and iodides are *soluble*, except those of Ag^+ and Pb^{2+}.
SO_4^{2-}	4. All sulphates are *soluble* except for $CaSO_4$, $SrSO_4$, $BaSO_4$, $PbSO_4$ and $AgSO_4$.
S^{2-}	5. All sulphides are *insoluble* except those of the Group IA or IIA elements or NH_4^+.
	6. All other compounds are *insoluble*.