**9. Chemical Reactions**

**9.1 Types of Chemical Reactions**

Chemists have identified many millions of different chemical compounds that can react in many different ways to form new chemical compounds. One of the popular classification schemes is to breaks them up into few major categories or types based on the simplicity/complexity of reactants/products in chemical reactions. Some of these types have been given more than one name and is could get complicated. You need to recognize the pattern, as you may encounter different names in different places.

**Classification based on the simplicity/complexity of reactants/products**

**1) Combination**: **A + B AB**



**2H2(g) + O2(g)**  **2H2O(g)**



**C(s) + O2(g)**  **CO2(g)**



**CaO(s) + H2O(l)**  **Ca(OH)2(s)**



**Other modifications**: **A synthesis reaction** involves two or more substances combining to make a more complex substance. The reactants may be elements or compounds, and the product will always be a compound. The general formula for **synthesis** (simple to complex): **CO2 + H2O C6H12O6 + O2** (photosynthesis)



**2) Decomposition:** One substance is broken down into two or more, simpler substances.

**AB A + B; E.g. KClO3  KCl + O2**



**C12H22O11(s)**  **12C(s) + 11H2O(g)**



**Pb(OH)2(s)**  **PbO(s) + H2O(g)**



**2Ag2O(s)**  **4Ag(s) + O2(s)**



**3) Displacement:**

**a) Single Displacement:** In this type of reaction, a neutral element metal or nonmetal become an ion as it replaces another ion in a compound.

**M1X + M2 M2X + M1:**



**For metals**

Thereaction follows **Activity series**: Active metal, **M2** (Fe) at beginning of the series replaces the **M1**+ ion, and produces metal **M1**, (Cu)

**Metals**:Li> K>Ca>Na>Mg>Al>Zn>Cr>Fe>Ni>Sn>Pb>H>Cu>Hg>Ag>Pt>Au

**E.g. Fe(s) + Cu(NO3)2(aq) Fe(NO3)2(aq) + Cu(s)**



**Zn(s) + H2SO4(aq)**  **ZnSO4(aq) + H2(g)**



**2Al(s)+ 3CuCl2(aq)**  **2AlCl3(aq) + 3Cu(s)**



**Non-metals: MX1 + X2 MX1 + X2:**



Thereaction follows **Activity series**: Nonmetal, **X2** (Cl2) at beginning of the series replaces the **X1**- ion, and produces nonmetal **X2**, (I2)

**Activity series:** F>Cl>Br>I

**E.g. 2 NaI(aq) + Cl2(g) 2 NaCl(aq) + I2(s)**



**KBr(aq) + Cl2(g)**  **KCl(aq) + Br2(l)**



**b) Double Displacement** (exchange- metathesis) the compounds in this type of reaction exchange partners: **AB + XY AY + XB**



**E.g. Ca(OH)2 + 2 HNO3 Ca(NO3)2(aq) + 2H2O(l)**



**AgNO3(aq) + NaCl(aq) AgCl(s) + NaNO3(aq)**



**ZnBr2(aq) + 2AgNO3(aq) Zn(NO3)2(aq) + 2AgBr(s)**



**H2SO4(aq) + 2NaOH(aq) Na2SO4(aq) + 2H2O(l)**



**Classification of reactions based on types of reactants and products**.

**1) Formation Reactions:** One mole of a compound is formed by elements at 1 atm and 25°C. Notice that some stoichiometric coefficients are fractional to maintain the one mole on the compound on the product side.

**E.g. Na(s) + ½Cl2(g) NaCl(s)**



**C(s) + O2(g) CO2(g)**



**H2(g) + ½ O2(g) H2O(l)**



**2Na(s) + C(s) + O2(g) + ½O2(g) Na2CO3(s)**



**2Na(s) + H2(g) + 2C(s) + O2(g) + ½ O2(g) 2NaHCO3(s)**



**2) Combustion Reactions:** When an organic compound like butane is burned, it reacts with the oxygen in the air to form carbon dioxide and water.Normally organic compound with **O2** produce **H2O** and **CO2**

**E.g.** **2 C4H10(g) + 13O2(g) 8CO2(g) + 10H2O(g)**



**CH4(g) + 2O2(g) CO2(g) + 2H2O(g)**



**2C2H6(g) + 7O2(g) 4CO2(g) + 6H20(g)**



**C3H8(g) + 5O2(g) 3CO2(g) + 4H2O(g)**



**3) Acid/Base (neutralization) Reactions:** When an acid and a base are placed together, they react to neutralize the acid and base properties, producing a salt. The compound formed by the cation of the base and the anion of the acid is called a salt. The combination of hydrochloric acid and sodium hydroxide produces common table salt, NaClAn acid and a base react to form water and salt.

**E.g. HCl(aq) (acid ) + NaOH(aq) (base) NaCl(aq) (salt) + H2O(l)**



**H2SO4(l) (acid ) + Ca(OH)2(*s*) (base) CaSO4(s) (salt) + 2H2O(l)**



**H2SO4 (acid) + KOH (base) K2SO4 (salt) + H2O (water)**



**4) Precipitation Reactions:** Two soluble salt solutions mixed to produce an insoluble salt in the form of a precipitate which settles at the bottom of the reaction vessel. This is normally a double displacement. Precipitation predicted by **solubility rules** often happens with double replacement reactions or metathesis reactions, and one of the most common such reactions is the reaction between silver nitrate and sodium chloride:

**E.g. AgNO3(aq) + NaCl(aq) AgCl(s) insoluble salt + NaNO3(aq)**



**5) Gas formation reaction:** two chemicals react to produce a gas: **CO2, SO2, SO3, H2S, H2, NH3**

**E.g. Ca(CO)3(s) + HCl(aq) CaCl2(aq) + CO2(g) + H2O(l)**



Classify reactions based on **simplicity/complexity of reactants/products**

a) 2Fe(s)+ 2O2(g) 2FeO(s):Combination, Synthesis



c) Ca(OH)2(aq) + H3PO4(aq) Ca3(PO4)2(aq) + H2O(l): Double Displacement



d) 2NaCl(s)  2Na(s) + Cl2(g): Decomposition



e) N2 (g) + 3H2(g) 2NH3(g): Combination, Synthesis



f) Fe(s)  + CuSO4(aq) FeSO4(aq) + Cu(s):  Single Displacement



g) 2P(s)  + 3Cl2(g) 2PCl3(l):  Combination, Synthesis



h) P4O10(s)  + 6H2O(l) 4H3PO4(aq): Combination, Synthesis



i) 3Fe(s)  + 4H2O(l) Fe3O4(s)  + 4H2(g): Single Displacement



j) 2H3PO4(aq) H4P2O7(s) + H2O(l): Decomposition



k) AgNO3(aq) + Cu(s)  CuNO3(aq) + Ag(s):  Single Displacement



Classify reactions based on **type of reactants and products**:

C2H6(g) + O2(g) CO2(g) + H2O(g): Combustion Reactions



Ca(OH)2(aq) + H3PO4(aq) Ca3(PO4)2(aq) + H2O(l): Acid/Base, Double Displacement



2C4H10(g) + 13O2(g) 8CO2(g) + 10H2O(g): Combustion Reactions



Na(s) + ½Cl2(g) NaCl(s):  Combination Synthesis, Formation Reactions



2Na(s)  + H2O(l) 2NaOH(aq) + H2(g): Single Displacement



½N2 (g) + 3/2H2(g) NH3(g): Combination, Synthesis, Formation Reactions



HCl(aq) + FeS(s)  FeCl2(aq) + H2S(g): Double Displacement



P(s)  + 3/2Cl2(g) PCl3(l):  Combination, Synthesis, Formation Reactions



Al2(SO4)3(aq) + 3Ca(OH)2(aq) 2Al(OH)3(s) + 3CaSO4(aq): Double Displacement,Precipitation



CaC2(s)  + 2H2O(l) C2H2(g) + Ca(OH)2(aq): Double Displacement



2As(s) + 6NaOH(aq) 2Na3AsO3(aq) + 3H2 (g): Single Displacement



**9.2 Redox and Nonredox Reactions**

**Oxidation-Reduction Reactions**

Redox reactions primarily involve the transfer of electrons between two chemical species.

All single replacement reaction are redox reactions.

**Single Displacement: AX + Y YX + A:** Thereaction follows **Activity series**:



**Metals**:Li> K>Ca>Na>Mg>Al>Zn>Cr>Fe>Ni>Sn>Pb>H>Cu>Hg>Ag>Pt>Au

**E.g.** Fe + Cu(NO3)2 Fe(NO3)2 + Cu,



**Non-metals:** F>Cl>Br>I

**E.g.** Cl2 + 2 NaI 2 NaCl + I2



**Assign Oxidation Numbers to atoms in a compound or ion.**

* 1. **Elements**: Oxidation number (ON) of atoms in an element is zero (0). E.g. O2
  2. **Monoatomic ions**: ON equal to charge. E.g. Na+, ON = +1; Cl-, ON = -1
  3. **The group number in the periodic table**: could be used for main group elements. Transition metals show variable ONs E.g. Fe shows either +3 or +2.
  4. **Sum of the oxidation numbers**: In an element, compound is equal to zero.
  5. **Sum of the oxidation numbers**: In an a cation/ anion is equal to the ionic charge.
  6. **Almost most of the time**: ON of H =+1, and O=-2

E.g. What is the oxidation number or state of Cl in HClO4?

H → +1, O → -2 neutral compound, thus sum is equal to zero

4O → 4 × -2 = -8; H → 1 × +1 = +1; 0 = +1(H) + y(Cl) + (-8)

y = +7

Oxidation number or state of Cl in HClO4 is +7.

**E.g. What are the oxidation numbers, reducing agent, oxidizing agent, reduction half reaction (RHR) and oxidation half reaction (OHR) for the following reaction?**

|  |  |  |
| --- | --- | --- |
| **Reaction**: | **Zn (s) + 2 HCl (aq) → ZnCl2 (aq) + H2 (g)** | |
| **Oxidation number** | Zn= 0 H = +1 Cl= -1 Zn= +2, Cl= -1 H=0 | |
| **Reducing agent :**  Zn (s)  **Oxidizing agent:**  HCl (aq) | | |
| **Reduction Half Reaction (RHR)** | | 2H+ (aq) + 2e - → H2 (g) |
| **Oxidation Half Reaction (OHR)** | | Zn (s) → Zn2+ (aq) + 2e - |

Chemistry at a Glance: Types of Chemical Reactions  
9.3 Terminology Associated with Redox Processes

**LEO The Lion Goes GER!**

**Oxidation:** The compound have an atom that **loses** an electron is said to be oxidized

**Reduction:** The compound have an atom that **gains** an electron is said to be reduced.

**Oxidation number**: number of lost or gained relative to neutral atom.

**Reducing agent**: the reactant that gives up electrons and increases oxidation number.

**Oxidizing agent:** the reactant that gains electrons and increases oxidation number..

**Oxidation number**: number of lost or gained relative to neutral atom

**9.4 Collision Theory and Chemical Reactions**

The collision theory model of chemical reactions can be used to explain the observed rate laws for both one-step and multi-step reactions. This model assumes that the rate of any step in a reaction depends on the frequency of collisions between the particles involved in that step.

ClNO2(g) + NO(g) NO2(*g*) + ClNO(g)



The kinetic molecular theory assumes that the number of collisions per second in a gas depends on the number (moles) of particles per liter. The rate at which NO2 and ClNO are formed in this reaction should therefore be directly proportional to the concentrations of both ClNO2 and NO shown as [ClNO2] and [NO].

Rate = k[ClNO2][NO]

9.5 Exothermic and Endothermic Reactions  
9.6 Factors That Influence Reaction Rates

Rates of chemical reactions are affected by the following:

a) Temperature

b) Concentration

c) Catalysts

d) Particle size of solid reactants  
9.7 Chemical Equilibrium  
Chemistry at a Glance: Factors That Influence Reaction Rates  
9.8 Equilibrium Constants  
9.9 Altering Equilibrium Conditions: Le Châtelier's Principle  
Chemical Connections: Combustion Reactions, Carbon Dioxide, and Global Warning; "Undesirable" Oxidation-Reduction Processes: Metallic Corrosion; Stratospheric Ozone: An Equilibrium Situation