4.4: Patterns of chemical reactions

General types of chemical reactions

There are several ways to classify chemical reactions. The general types of chemical reactions fall in the categories of combination, decomposition, replacement, and combustion reactions, as illustrated in Fig. 4.4.1.

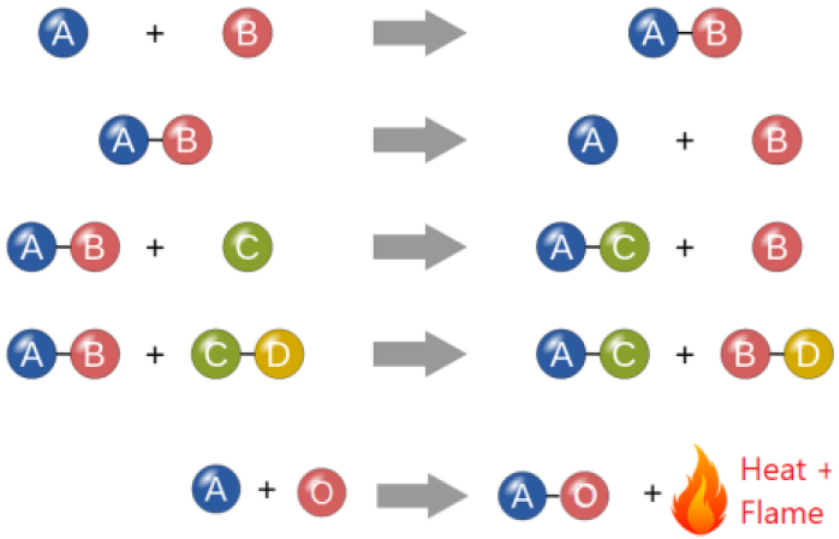

Figure 4.4.1: Illustration of four basic patterns of chemical reactions: combination, decomposition, single & double replacement, and combustion reactions. Source: https://www.hiclipart.com/free-trans...dunqu/download

Combination reactions

A compound is synthesized or formed from two or more substances, e.g.:

$$\mathrm{C + O_2 \longrightarrow CO_2}$$

$$\mathrm{2\,H_2 + O_2 \longrightarrow 2\,H_2O}$$

$$\mathrm{2\,Mg + O_2 \longrightarrow 2\,MgO}$$

$$\mathrm{2\,Na + Cl_2 \longrightarrow 2\,NaCl}$$

$$\mathrm{CaO + CO_2 \longrightarrow CaCO_3}$$

Fig. 4.4.2 shows an example of a hydrogen with oxygen combination reaction that is being developed for use as a fuel in the future.

Figure 4.4.2: Berlin public bus using hydrogen as a fuel in an internal combustion engine (ICE). Hydrogen is stored in ten pressure cylinders of 50 kg of hydrogen at 350 bar. Reaction: \{\ce{2H2 + O2 -> 2H2O}\) + heat. Source: StralsundByzantion / CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0)

Decomposition reactions

The decomposition reactions are the reverse of the combination reaction, i.e., one compound splits apart into two or more substances, usually by heating, e.g.:

$$\mathrm{H_2CO_3 \longrightarrow H_2O + CO_2}$$

$$\mathrm{CaCO_3} \xrightarrow{\Delta} \mathrm{CaO + CO_2}$$

$$\mathrm{2\,KClO_3} \xrightarrow{\Delta} \mathrm{2\,KCl + 3\,O_2}$$

$$\mathrm{2\,H_2O(l)} \xrightarrow{Electrolyisis} \mathrm{2\,H_2(g) + O_2(g)}$$

Fig. 4.4.3 illustrates the last reaction, i.e., decomposition of water through electrolysis.

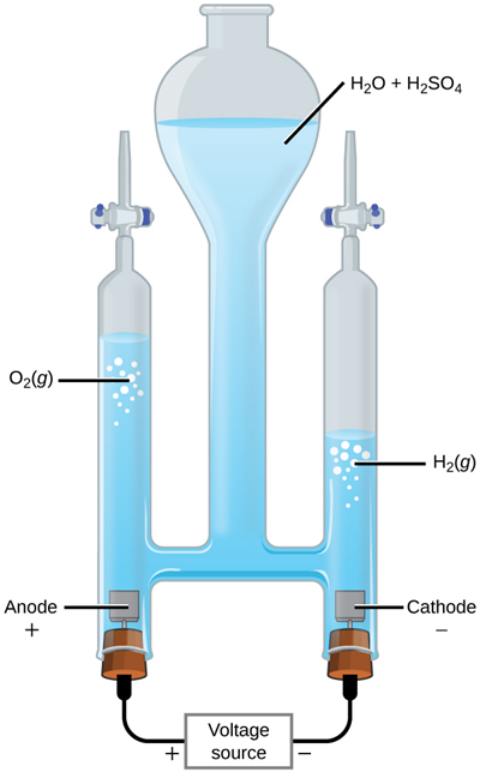

Figure 4.4.3: Decomposition of water through electrolysis $\mathrm{2\,H_2O(l)} \xrightarrow{Electrolyisis} \mathrm{2\,H_2(g) + O_2(g)}$. Source: OpenStax / CC BY (https://creativecommons.org/licenses/by/4.0)

Replacement or substitution reactions

There are two sub-classes of this category of reactions, i.e., single replacement and double replacement reaction.

Single replacement reactions involve one substance replacing a part of another, e.g.:

$$\mathrm{Zn(s) + CuCl_2(aq) \longrightarrow ZnCl_2(aq) + Cu(s)}$$

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

Fig. 4.4.4 shows an example of a single replacement reaction of magnesium resulting in hydrogen gas formation.

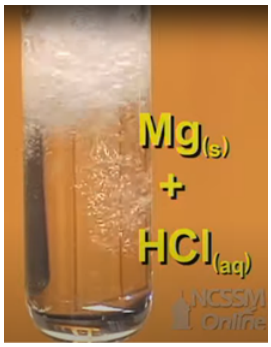

Figure 4.4.4: Single replacement reaction of magnesium with hydrochloric acid producing hydrogen gas: $\mathrm{Mg(s) + 2\,HCl(aq) \longrightarrow MgCl(aq) + H_2(g)\uparrow}$ Source: taken form NCSSM online youtube video, 05/18/20, https://www.youtube.com/watch?v=OBdgeJFzSec

Double replacement reactions or metathesis involve the mutual exchange of partners between two substances, e.g. the following precipitation reactions:

$$\mathrm{NaCl(aq) + AgNO_3(aq) \longrightarrow AgCl(s)\downarrow + NaNO_3(aq)}$$

$$\mathrm{Na_2CO_3(aq) + CaCl_2(aq) \longrightarrow CaCO_3(s)\downarrow + 2\,NaCl(aq)}$$

Combustion reactions

Combustion is a reaction of a substance with oxygen, often with the formation of flame and release of much heat, e.g.:

$$\mathrm{C_8H_{16} + 12\,O_2 \longrightarrow 8\,CO_2 + 8\,H_2O + Heat}$$

$$\mathrm{C + O_2 \longrightarrow CO_2 + Heat}$$

$$\mathrm{2\,H_2 + O_2 \longrightarrow 2\,H_2O + Heat}$$

$$\mathrm{2\,Mg + O_2 \longrightarrow 2\,MgO + Heat}$$

Fig. 4.4.5 shows the above reaction, i.e., combustion of Mg in air.

Figure 4.4.5: An image of Ignited Magnesium burning in the air in normal conditions. Yannickcosta1, CC BY SA3, https://commons.wikimedia.org/wiki/File:Magburn1.jpg

Usually, combustion is considered as the reaction of a substance containing carbon and hydrogen with oxygen resulting in carbon dioxide, water, flame, and heat, e.g., burning methane on a kitchen stove:

$$\mathrm{CH_4 + 3\,O_2 \longrightarrow CO_2 + 2\,H_2O + Heat}$$

Classification of chemical reaction

The chemical reactions are generally classified based on what exchanges during the reaction. These include;

1. the transfer of electrons in oxidation-reduction reactions,
2. transfer of protons in acid-base reactions, and
3. a part of reactants mutually exchanges in precipitation reactions, as described below.

Oxidation-reduction reactions

The oxidation-reduction or **redox** reaction involves the exchange of electrons. For example, reactions between a metal and nonmetal involve the transfer of electrons from the metal to the nonmetal forming an ionic bond, as shown in Fig. 4.4.6.

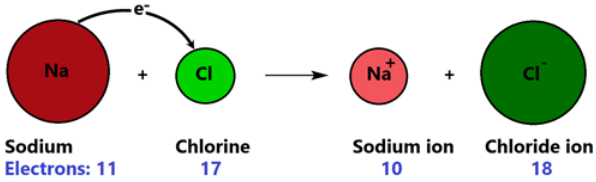

Figure 4.4.6: Illustration of an electron transfer in an oxidation-reduction reaction: $\mathrm{Na} + \mathrm{Cl} \longrightarrow \mathrm{Na}^{+} + \mathrm{Cl}^{-}$

Acid-base reactions

The acid-base reactions involve the transfer of protons from an acid to a base, as shown in Fig. 4.4.7.

Figure 4.4.7: Proton transfer from HCl to $\mathrm{NH_3}$ is an example of an acid-base reaction: $\mathrm{HCl} + \mathrm{NH_3} \longrightarrow \mathrm{NH_4Cl}$. Hydrochloric acid (in beaker) reacts with ammonia fumes to produce ammonium chloride (white smoke). Source: Walkerma, Public domain

Precipitation reactions

These are double displacement reactions in water that results in the precipitation of one of the products, as shown in Fig. 4.4.8.

Figure 4.4.8: Lead (II) iodide precipitates when potassium iodide is mixed with lead (II) nitrate: $\mathrm{Pb(NO_3)_2(aq) + 2\,NaI(aq) \longrightarrow 2\,NaNO_3(aq) + PbI_2(s)\downarrow}$ Source: PRHaney / CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0)

The precipitation reactions and the acid-base reactions are described in the later chapters. The oxidation-reduction reactions are discussed in the following section.