1.3.1 Chemical Reactions

Consider for a moment the number of possible chemical reactions. Because there are millions of chemical compounds, it is logical to expect that there are millions of possible chemical reactions. It would be very difficult to memorize the equations for all the different chemical reactions that occur so chemists have grouped them according to the similarities in the way they react. It is not quite as simple as this though because some chemical reactions can belong to more than one type.

One method divides them into five main types.

1. synthesis (or combination)
2. decomposition
3. single-displacement (or single replacement)
4. double displacement (or double replacement)
5. combustion

In IB Chemistry you need to be able to write balanced chemical equations for reactions and be able to deduce the products formed in reactions when the reactants and products are given.

1. Synthesis reactions
When reactants combine to form one product.

For example:

Potassium + Chlorine → Potassium Chloride
\[ K(s) + Cl_2(g) \rightarrow 2 \text{KCl(s)} \]

Carbon + Hydrogen gas + Oxygen → ethanol
\[ 2C(s) + 3 \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) \rightarrow \text{C}_2\text{H}_5\text{OH}(l) \]

Nitrogen + Hydrogen → ammonia
\[ N_2(s) + 3 \text{H}_2(g) \rightarrow \text{NH}_3(g) \]
2. **Decomposition reactions**
When one reactant breaks down into two or more products or two of more moles of a substance. It is hard to predict the products of decomposition reactions.

For example:

\[
\text{Calcium carbonate} \rightarrow \text{Potassium Oxide} + \text{Carbon dioxide} \\
\text{CaCO}_3(s) \rightarrow \text{CaO(s)} + \text{CO}_2(g)
\]

\[
\text{Hydrogen peroxide} \rightarrow \text{Water} + \text{Oxygen} \\
\text{H}_2\text{O}_2(\text{l}) \rightarrow \text{H}_2\text{O(l)} + \frac{1}{2} \text{O}_2(\text{g})
\]

3. **Single Replacement / displacement reactions**
Occur between an element and a compound. The element replaces or is displaced by an element in the compound.

For example:

\[
\text{Magnesium} + \text{Zinc nitrate} \rightarrow \text{Magnesium nitrate} + \text{Zinc} \\
\text{Mg(s)} + \text{Zn(NO}_3)_2(\text{aq}) \rightarrow \text{Mg(NO}_3)_2(\text{aq}) + \text{Zn(s)}
\]

The element magnesium, Mg is replaced (displaced) by the element zinc, Zn in the compound zinc nitrate.

\[
\text{Chlorine} + \text{Sodium bromide} \rightarrow \text{bromine} + \text{Sodium chloride} \\
\text{Cl}_2(\text{g}) + 2 \text{NaBr (aq)} \rightarrow \text{Br}_2(\text{aq}) + 2 \text{NaCl(aq)}
\]

In this reaction the element chlorine is replaced by the bromine in the sodium bromide.
4. **Double Replacement / displacement reactions**

Occur between two compounds. The two positive metal ions in each reactant swap places (displace one another).

For example:

$\text{Potassium Carbonate} + \text{Barium Chloride} \rightarrow \text{Potassium Chloride} + \text{Barium Carbonate}$

$\text{K}_2\text{CO}_3(\text{aq}) + \text{BaCl}_2(\text{aq}) \rightarrow 2 \text{KCl}(\text{aq}) + \text{BaCO}_3(\text{g})$

**ions**

$K^+, CO_3^{2-} \quad Ba^{2+}, Cl^- \quad K^+, Cl^- \quad Ba^{2+}, CO_3^{2-}$

$\text{Sodium sulfide} + \text{Magnesium nitrate} \rightarrow \text{Sodium nitrate} + \text{Magnesium sulfide}$

$\text{Na}_2\text{S}(\text{aq}) + \text{Mg(NO}_3\text{)}_2(\text{aq}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{MgS(s)}$

**ions**

$Na^+, S^{2-} \quad Mg^{2+}, NO_3^- \quad Na^+, NO_3^- \quad Mg^{2+}, S^{2-}$

In these reactions the two positive metal ions swap places with one another to form two new compounds. In most double displacement reactions the reactants are aqueous solutions. One of the products formed is a solid and another is in solution. The solid product formed from a reaction between two aqueous solutions react is called a **precipitate**.

5. **Combustion reactions**

Reactions where the reactant reacts with oxygen. Commonly referred to as burning.

For example:

If an element combusts the element and oxygen combine to form one product like in a synthesis reaction.

$\text{Magnesium} + \text{Oxygen} \rightarrow \text{Magnesium oxide}$

$\text{Mg(s)} + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{MgO(s)}$

If a molecule combusts in excess oxygen the products are carbon dioxide and water. If oxygen is limiting then carbon monoxide and water are the products.
methane + Excess Oxygen $\rightarrow$ Carbon dioxide + water
\[ \text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g}) \]

methane + Limited Oxygen $\rightarrow$ Carbon monoxide + water
\[ \text{CH}_4(\text{g}) + 1 \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{CO}(\text{g}) + 2 \text{H}_2\text{O}(\text{g}) \]

**Reactions of Acids**

Acids are involved in many of the different types of chemical reactions we use in Chemistry. Most are single and double displacement reactions.

1. \[ \text{acid} \quad + \quad \text{metal} \quad \rightarrow \quad \text{salt} \quad + \quad \text{hydrogen gas} \]

\[ 2\text{HCl} \quad + \quad \text{Zn} \quad \rightarrow \quad \text{ZnCl}_2 \quad + \quad \text{H}_2 \]

2. \[ \text{acid} \quad + \quad \text{Carbonate compound or hydrogen carbonate} \quad \rightarrow \quad \text{salt} \quad + \quad \text{water} \quad + \quad \text{carbon dioxide gas} \]

\[ 2\text{HCl}_{(\text{aq})} \quad + \quad \text{CaCO}_3(s) \quad \rightarrow \quad \text{CaCl}_2(\text{aq}) \quad + \quad \text{H}_2\text{O}(l) \quad + \quad \text{CO}_2(g) \]
\[ \text{HCl}_{(\text{aq})} \quad + \quad \text{NaHCO}_3(s) \quad \rightarrow \quad \text{NaCl}_{(\text{aq})} \quad + \quad \text{H}_2\text{O}(l) \quad + \quad \text{CO}_2(g) \]

3. \[ \text{acid} \quad + \quad \text{metal oxide} \quad \rightarrow \quad \text{salt} \quad + \quad \text{water} \]
or metal hydroxide

\[ 2\text{HCl} + \text{CaO} \rightarrow \text{CaCl}_2 + \text{H}_2\text{O} \]

\[ 2\text{HCl} + \text{Ca(OH)}_2 \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O} \]

4. **Acid** + **Base** → **Salt** + **water**

\[
\text{HCl(aq)} + \text{NaOH (aq)} \rightarrow \text{NaCl (aq)} + \text{H}_2\text{O(l)}
\]

The reactions between acids and bases are also called **neutralization reactions**.

**Exercises**
Write balanced chemical equations (including states) for the following reactions. Identify the type/s of reaction. You may need to look back at your earlier notes.

1. nitric acid reacting with aqueous ammonium carbonate

2. zinc reacting with sulfuric acid

3. potassium hydroxide solution reacting with hydrochloric acid

4. Solid sodium oxide reacting with water to form sodium hydroxide

5. Hydrogen reacting with bromine to form hydrogen bromide

6. Sulfur trioxide reacting with water to form sulphuric acid

7. Magnesium reacting with a copper sulphate solution
8. sulfur dioxide reacting with oxygen

9. Iron(III)oxide reacting with aluminum

10. nitrogen reacting with hydrogen

11. dinitrogen tetroxide gas forming nitrogen dioxide gas

12. copper reacting with zinc oxide

13. ethane reacting with oxygen

14. formation of methanol from its elements

15. hydrogen peroxide forming oxygen gas and water

16. calcium chloride solution reacting with magnesium nitrate solution

17. Solid aluminum oxide reacting with aqueous hydrochloric acid

18. Sodium metal reacting with chlorine gas

19. Solid aluminum oxide reacting with carbon

20. Hydrogen reacting with oxygen

21. Lithium reacting with water