4.5 Stoichiometry and balancing equations

The *stoichiometry* of a chemical reaction relates to the molar ratio with which the chemicals react and the products are formed, based on the assumption that the reaction goes to completion (i.e. that all the reactants are completely converted to products). Whilst something of a simplification, this assumption allows the calculation of the amounts of reagents needed to carry out chemical processes. Since all chemical reactions proceed on a molecular level the relative amounts of chemicals involved can be calculated from the ratio of the number of molecules of each chemical species involved in the governing chemical equation. So, for example, in Equation 4.7 the stoichiometric ratio of the HCl, NaOH and NaCl is 1:1:1. This means that the corresponding weight ratio, according to Tables 13 and 14, is 36.5:40:58.5. On the other hand, for the precipitation reaction (where formation of a solid is denoted "↓"):

$$AlCl_3 + 3H_2O \Rightarrow Al(OH)_3\downarrow + 3HCl \qquad (4.11)$$

the stoichiometric ratio of hydroxide ions (OH^-) to aluminium ions (Al^{3+}) in aluminium hydroxide is 3:1. This equation implies that dosing of water with aluminium salts has a profound effect on the solution pH because hydrochloric acid is generated by *hydrolysis*.

Example: precipitation of aluminium hydroxide

What mass of hydrochloric acid is generated by 2kg of aluminium chloride and what mass of aluminium hydroxide is precipitated?

From Equation 4.11, 1 mole of $AlCl_3$ generates 3 moles of HCl and 1 mole of $Al(OH)_3$.

From Table 12, the molar weights are:

$AlCl_3$ = 27 + (3 x 35.5) = 133.5 g
HCl = (35.5 + 1) = 36.5 g
$Al(OH)_3$ = 27 + 3 x (16 + 1) = 78 g

So, for the reaction stoichiometry of 3 moles HCl to one mole $AlCl_3$ and $Al(OH)_3$:

133.5 g $AlCl_3$ hydrolyses to produce 78 g $Al(OH)_3$ and 3 x 36.5 = 109.5 g HCl

So, 2 kg $AlCl_3$ produces 2 x 78/133.5 = 1.2 kg $Al(OH)_3$ and 3 x 109.5/133.5 = 1.64 kg HCl

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A fundamental principle of chemistry is that the products and reactants of a chemical equation are in perfect balance: there is no net gain of either material or electrical charge. The balance in charge arises from the *redox* principle, which states that oxidation of one species of a chemical reaction must necessarily give rise to reduction of another. For example, the oxidation of Fe^{2+} can be expressed in many forms - all of which obey the fundamental rule of material and charge balance:

$$Fe^{2+} \Rightarrow Fe^{3+} + 1e^- \qquad (4.12)$$

$$4Fe^{2+} + O_2 + 10H_2O \Rightarrow 4Fe(OH)_3\downarrow + 8H^+ \qquad (4.13)$$

$$2Fe^{2+} + \tfrac{1}{2}O_2 + 4OH^- + H_2O \Rightarrow 2Fe(OH)_3\downarrow \qquad (4.14)$$