6.2: Brønsted–Lowry acids and bases

Some bases do not have hydroxide ions in their formula, yet they act as bases and neutralize acids. For example, ammonia (NH_3) and calcium carbonate ($CaCO_3$) do not contain hydroxide ions, but they neutralize acids. Further, Arrhenius's definition limits the acid-base reactions in the water medium. The acid-base reactions can take place in other mediums also, e.g., HCl –an acid, and NH_3 –a base can react with and neutralize each other in the gas phase also. The Brønsted–Lowry bordered the definition of acids and bases by including the bases mentioned above and also by including acid-base reactions in a non-aqueous medium.

Brønsted–Lowry's definition of acids and bases

Brønsted–Lowry's definition states that:

1. An acid is a proton donor, and
2. A base is a proton acceptor.

or example, HCl is an acid because it donates a proton to the water solvent.

$$\mathrm{HCl(g) + H_2O(l) \rightarrow Cl^{-}(aq) + H_3O^{+}(aq)}$$

Water is a base in the above reaction because it accepts a proton from the acid. In a reaction between HCl and NH_3:

$$\mathrm{HCl(g) + NH_3(\,g) \rightarrow NH_4Cl(s)}$$

HCl is an acid because it donates its proton to NH_3, and the NH_3 is a base because it accepts a proton, as shown in Fig. 6.2.1.

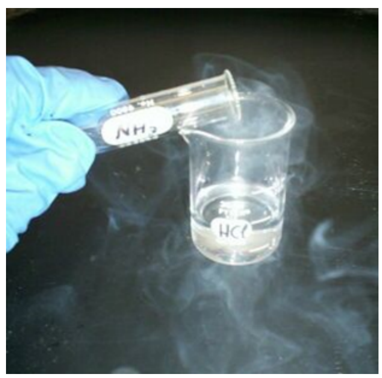

Figure 6.2.1: Proton transfer from HCl to NH_3 is an example of an acid-base reaction. Hydrochloric acid evaporates from liquid HCl in a beaker reacting with ammonia fumes coming from the test tube to produce ammonium chloride (white smoke). Source: Walkerma, Public domain.

Brønsted–Lowry's acids have ionizable protons that they donate to bases. Therefore, Brønsted–Lowry's acid is generally written as HA, where H^+ is the donatable proton, and A^- is the anion of the acid. Examples of acids are HCl, H_2SO_4, HNO_3, and CH_3COOH. Note that acetic acid has only one acidic proton that is attached to the O atom in the carboxylic acid group (–COOH). The rest of the protons attached to carbon atoms are not acidic. All organic acids have a carboxylic acid group (–COOH). Brønsted–Lowry's acid may have net +ve charge, no charge, or net –ve charge on it. For example, H_3O^+, HCl, and HSO_4^- are all acids because they can donate a proton to a base.

Mono-, di- and tri-protic acids

Acids that have only one acidic proton are mono-protic, e.g., **H**Cl, **H**NO_3, CH_3COO**H**, are mono-protic acids where the acid proton is shown in bold font. Some acids have two acidic protons –they are di-protic, e.g., $\mathbf{H_2}SO_4$ and $\mathbf{H_2}CO_3$ are di-protic. The acids with three acidic protons are tri-protic, e.g., $\mathbf{H_3}PO_3$ is a tri-protic acid. For example, phosphoric acid (H_3PO_4) can dissociate and donate three protons, as shown in chemical reactions below:

$$\begin{array}{l} \mathrm{H_3PO_4 + H_2O \rightleftharpoons H_3O^{+} + H_2PO_4{}^{-}} \\ \mathrm{H_2PO_4{}^{-} + H_2O \rightleftharpoons H_3O^{+} + HPO_4{}^{2-}} \\ \mathrm{HPO_4{}^{2-} + H_2O \rightleftharpoons H_3O^{+} + PO_4{}^{3-}} \end{array}$$

The base accepts proton by making a bond with it. The bond is a pair of bonded electrons. Since the proton is a hydrogen atom without an electron, both electrons in the bond come from the base. The base must have a lone pair of electrons on it. The base is usually represented as $:B$ to emphasize a lone pair of electrons on it that is shown as a pair of dots. For example, ammonia, water, and hydroxide ion ($:NH_3$, $H_2\ddot{O}:$, and $:\ddot{O}H^-$) are Brønsted–Lowry's bases, because each of these has an atom with lone pair or lone pairs of electrons on them.

Conjugate acid-base pairs

The acid-base reactions described above are one-way reactions, i.e., reactants go-to products almost 100%. However, the majority of the acid-base reactions are two ways, i.e., reactants form the products and the products react with each other and re-form the reactants. Double arrows between reactants and products represent the two ways reactions. For example, hydrofluoric acid (HF) is a weak electrolyte; it partially dissociates in water to form F^- and H_3O^+, and the products react to re-form the reactants, as shown in Fig. 6.2.2. In the reverse reaction, H_3O^+ is acting as an acid, and F^- is acting as a base. The acid and the base in the products are called conjugate acid and conjugate base, respectively. The acid HF becomes conjugate base F^- after removal of a proton, and the base H_2O becomes conjugate acid H_3O^+ after accepting a proton.

The conjugate acid-base pair

The conjugate acid-base pair is related to the loss and gain of H^+. For example, HF/F^- is a conjugate acid-base pair, and H_3O^+/H_2O is also a conjugate acid-base pair.

In other words, remove the acidic proton from an acid to get its conjugate base and add a proton to a base to get its conjugate acid.

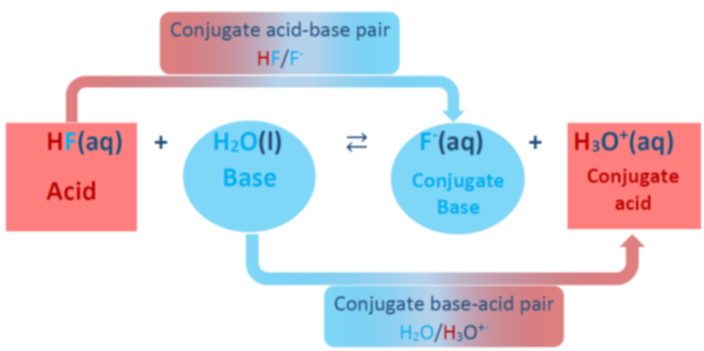

Figure 6.2.2: HF –an acid that loses a proton to form its conjugate base F^-, and water -acts as a base by accepting a proton to form its conjugate acid H_3O^+.

Another example is ammonia NH_3 which dissolves in water and accepts a proton to form its conjugate acid NH_4^+, as shown in Fig. 6.2.3. Water H_2O acts as an acid by donating a proton and forming its conjugate base OH^-. The two conjugate acid-base pairs in this reaction are NH_4^+ /NH_3 and H_2O/OH^- that are related by loss and gain or an H^+.

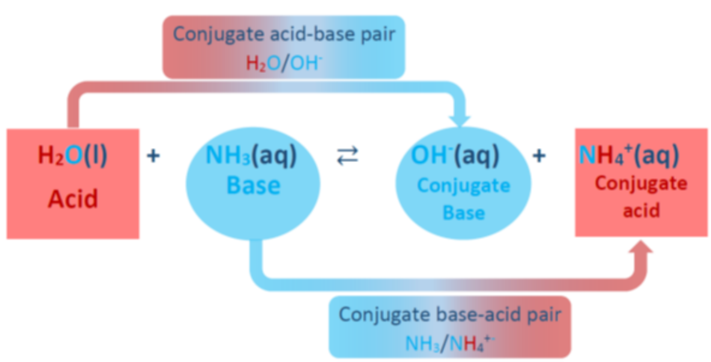

Figure 6.2.3: H_2O –acts as an acid that loses a proton to form its conjugate base OH^-, and NH_3 –a base accepts a proton to form its conjugate acid NH_4^+.

Example 6.2.1

Identify the conjugate acid-base pairs in the following reaction?

$$H_3PO_4(aq) + NH_3(aq) \rightleftarrows H_2PO_4^- + NH_4^+$$

Solution

1. Identify the substance that has donated a proton in the reactants –it is an acid.
2. Remove a proton from the acid to form its conjugate base: $H_3PO_4/H_2PO_4^-$.
3. Identify the substance that has accepted a proton in the reactants –it is a base.
4. Add a proton to the base to form its conjugate acid: NH_3/NH_4^+.

Note

Note that loss of a proton from an acid forms its conjugated base with the charge decreased by one, e.g., $H_3PO_4/H_2PO_4^-$, HSO_4^-/SO_4^{2-}, and NH_4^+/NH_3. Similarly, the gain of a proton by a base forms its conjugate acid with the charge increased by one, e.g., $HPO_4^{2-}/H_2PO_4^-$, HCO_3^-/H_2CO_3, and NH_3/NH_4^+.

Amphoteric substances

Water acts as a base in some reactions, e.g., with HF, and as an acid in some reactions, e.g., with NH_3.

Substances like water that can act as an acid and also as a base are called amphoteric substances.

Other examples of amphoteric substances include HSO_4^-, HCO_3^-, and NH_3, as illustrated in Fig. 6.2.4.

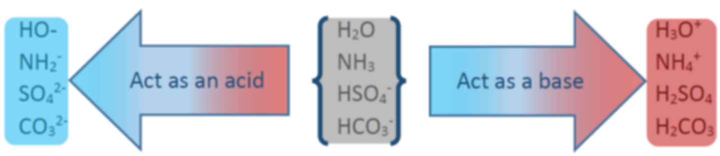

Figure 6.2.4: Examples of amphoteric substances that can act as an acid in some reactions and also as a base in other reactions.