In 1923, chemists Johannes Nicolaus Brønsted and Thomas Martin Lowry independently developed definitions of acids and bases based on the compounds' abilities to either donate or accept protons (\(H^+\) ions). In this theory, acids are defined as proton donors; whereas bases are defined as proton acceptors. A compound that acts as both a Brønsted-Lowry acid and base together is called amphoteric.

The Brønsted-Lowry Theory of Acids and Bases

Brønsted-Lowry theory of acid and bases took the Arrhenius definition one step further, as a substance no longer needed to be composed of hydrogen (\(H^+\)) or hydroxide (\(OH^-\)) ions in order to be classified as an acid or base. For example, consider the following chemical equation:

\[
\text{HCl (aq) + NH}_3 \rightleftharpoons \text{NH}_4^+ \text{(aq) + Cl}^- \text{(aq)}
\]

Here, hydrochloric acid (HCl) "donates" a proton (\(H^+\)) to ammonia (NH\(_3\)) which "accepts" it, forming a positively charged ammonium ion (\(NH_4^+\)) and a negatively charged chloride ion (\(Cl^-\)). Therefore, HCl is a Brønsted-Lowry acid (donates a proton) while the ammonia is a Brønsted-Lowry base (accepts a proton). Also, \(Cl^-\) is called the conjugate base of the acid HCl and \(NH_4^+\) is called the conjugate acid of the base NH\(_3\).

- A Brønsted-Lowry acid is a proton (hydrogen ion) donor.
- A Brønsted-Lowry base is a proton (hydrogen ion) acceptor.

In this theory, an acid is a substance that can release a proton (like in the Arrhenius theory) and a base is a substance that can accept a proton. A basic salt, such as \(Na^+\)F\(^-\), generates OH\(^-\) ions in water by taking protons from water itself (to make HF):

\[
\text{F}^-_{(aq)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{HF}_{(aq)} + \text{OH}^-_{(aq)}
\]

When a Brønsted acid dissociates, it increases the concentration of hydrogen ions in the solution, \([H^+])\); conversely, Brønsted bases dissociate by taking a proton from the solvent (water) to generate \([OH^-]\).

- **Acid dissociation**

\[
\text{HA}_{(aq)} \rightleftharpoons \text{A}^-_{(aq)} + \text{H}^+_{(aq)}
\]

- **Acid Ionization Constant:**

\[
K_a = \frac{[A^-][H^+]}{[HA]}
\]

- **Base dissociation:**

\[
\text{B}_{(aq)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{HB}^+_{(aq)} + \text{OH}^-_{(aq)}
\]

- **Base Ionization Constant**

\[
K_b = \frac{[HB^+][OH^-]}{[B]}\]
The determination of a substance as a Brønsted-Lowery acid or base can only be done by observing the reaction. In the case of the HOH it is a base in the first case and an acid in the second case.

To determine whether a substance is an acid or a base, count the hydrogens on each substance before and after the reaction. If the number of hydrogens has decreased that substance is the acid (donates hydrogen ions). If the number of hydrogens has increased that substance is the base (accepts hydrogen ions). These definitions are normally applied to the reactants on the left. If the reaction is viewed in reverse a new acid and base can be identified. The substances on the right side of the equation are called conjugate acid and conjugate base compared to those on the left. Also note that the original acid turns in the conjugate base after the reaction is over.

Note

Acids are Proton Donors and Bases are Proton Acceptors

For a reaction to be in equilibrium a transfer of electrons needs to occur. The acid will give an electron away and the base will receive the electron. Acids and Bases that work together in this fashion are called a conjugate pair made up of conjugate acids and conjugate bases.

\[ HA + Z \rightleftharpoons A^- + HZ^+ \]

A stands for an Acidic compound and Z stands for a Basic compound

- A Donates H to form HZ^+.
- Z Accepts H from A which forms HZ^+
- A^- becomes conjugate base of HA and in the reverse reaction it accepts a H from HZ to recreate HA in order to remain in equilibrium
- HZ^+ becomes a conjugate acid of Z and in the reverse reaction it donates a H to A^- recreating Z in order to remain in equilibrium
Questions

1. Why is \( \text{HA} \) an Acid?
2. Why is \( \text{Z}^- \) a Base?
3. How can \( \text{A}^- \) be a base when HA was and Acid?
4. How can \( \text{HZ}^+ \) be an acid when Z used to be a Base?
5. Now that we understand the concept, let's look at an example with actual compounds! \( \text{HCl + H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^- \)
   • HCL is the acid because it is donating a proton to \( \text{H}_2\text{O} \)
   • \( \text{H}_2\text{O} \) is the base because \( \text{H}_2\text{O} \) is accepting a proton from HCL
   • \( \text{H}_3\text{O}^+ \) is the conjugate acid because it is donating an acid to CL turn into it's conjugate acid \( \text{H}_2\text{O} \)
   • \( \text{Cl}^- \) is the conjugate base because it accepts an H from \( \text{H}_3\text{O} \) to return to it's conjugate acid HCl

How can \( \text{H}_2\text{O} \) be a base? I thought it was neutral?

Answers

1. It has a proton that can be transferred
2. It receives a proton from HA
3. \( \text{A}^- \) is a conjugate base because it is in need of a H in order to remain in equilibrium and return to HA
4. \( \text{HZ}^+ \) is a conjugate acid because it needs to donate or give away its proton in order to return to it's previous state of Z
5. In the Brønsted-Lowry Theory what makes a compound an element or a base is whether or not it donates or accepts protons. If the \( \text{H}_2\text{O} \) was in a different problem and was instead donating an H rather than accepting an H it would be an acid!

Contributors

• Sarah Rundle (UCD), Charles Ophardt, Professor Emeritus, Elmhurst College; Virtual Chembook