Acids and Bases

Acids and bases are very important class of chemicals that we come across in our everyday lives that are essential in sustaining biological systems, but we never realize their importance and their chemical actions. They are basis for many household and medicinal products. Commercially, they carry the common names like aspirin (chemical name is acetylsalicylic acid), milk of magnesia (chemical name is magnesium hydroxide), etc. Before, we can discuss any kind of reactions involving acids and bases, we have to know more about them.

General Properties of Acids and Bases

Acids

- Sour taste; vinegar, citrus products
- Water like feeling
- Blue litmus turns red
- Aqueous solutions conduct electricity
- React with certain metals, such as, Mg, to produce hydrogen gas
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$$2HCl(aq) + Mg(s) \longrightarrow MgCl_2(aq) + H_2(g)$$

- React with carbonates, such, calcium carbonate and bicarbonates, such as, sodium bicarbonate, to produce carbon dioxide gas

- $2HCl(aq) + CaCO_3(s) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$
  $HCl(aq) + NaHCO_3(s) \longrightarrow NaCl(aq) + H_2O(l) + CO_2(g)$

Bases

- Bitter taste
- Slippery feeling, e.g. soap
- Red litmus turns blue
- Aqueous solutions conduct electricity

The above given properties of acids and bases are for laymen only. But to do any kind of chemistry involving acids and bases, we need to understand chemical definitions of these. Over the years, various chemists have defined acids and bases in various ways progressively from a simple definition to more sophisticated defintion based on the available knowledge at that time. These definitions are discussed below.

Arrhenius Acids and Bases

The first and the simple definitions of acids and bases were put forward by the Swedish chemist Svante Arrhenius in the late nineteenth century.

Acid is a substance that produces hydrogen ion (H^+) in solution.
Base is a substance that produces hydroxide ion (OH^-) in solution.

In order to produce H^+ in solution, the acid must contain H^+ and in order to produce OH^- in solution, the base must contain OH^-. Based on these definitions, HCl, HNO_3, and H_2SO_4 are classified as acids because they contain H^+, and NaOH, $Ca(OH)_2$, and $Al(OH)_3$ are considered as bases because they contain OH^-.

Bronsted Acids and Bases

Arrhenius definitions of acids and bases are simple and limited; they must contain H^+ and OH^- to label them as acids and bases. However, there are many substances behave like acids and bases but do not contain H^+ and OH^- ions. This prompted Johannes Bronsted (Danish chemist) in 1932 to come with new definitions:

Acid is a substance that donates proton (H^+) in solution.
Base is a substance that accepts proton (H^+) in solution.

Note that the definition of an acid is very similar to that of Arrhenius, but the definition of base defers from Arrhenius.

Hydrochloric acid is a Bronsted acid because it donates proton in water:

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

Since the above reaction exists in water, it is more appropriately represented as

$$HCl(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

Here the hydrated proton H_3O^+ (H^+ +H_2O) is known as **hydronium ion**. This equation shows a reaction in which HCl donates a proton to water and water gains a proton. Therefore, HCl labeled as Bronsted acid and H_2O as Bronsted base.

Conjugate Acid-Base Pairs

The concept of conjugate acid-base pairs is arises as a result of Bronsted definition of acids and bases. The conjugate pair is an *acid and its conjugate base* or *a base and its conjugate acid.* How the conjugate pairs are formed? When acid loses the proton, it becomes conjugate base and when the base gains the proton, it becomes conjugate acid. Consider the following example of ionization of acetic acid:

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^- + H_3O^+$$

acid1 base2 base1 acid2

When $CH_3COOH(aq)$(Bronsted acid) loses H^+, it becomes CH_3COO^- (Bronsted base). Therefore, these two labeled as conjugate acid-base pairs that is indicated by acid1 and base1. Similarly, when $H_2O(l)$ (Bronsted base) accepts H^+, it becomes H_3O^+ (Bronsted acid). Therefore, these two are labeled as acid-base pair that is indicated by acid2 and base2.

According to Bronsted, ammonia (NH_3) can be classified as a base even though it lacks hydroxide ion (OH^-) due to the fact that it accepts proton from the water when it is dissolved in water.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH^+{}_4(aq) + OH^-(aq)$$

base1 acid2 acid1 base2

In this example, $NH^+{}_4$ is the conjugate acid of NH_3 and OH^- is the conjugate base of H_2O.

Remember

Acid become conjugate base upon losing the proton:

acid → conjugate base +H$^+$

Base becomes conjugate acis upon accepting proton:

base + H$^+$ → conjugate acid

Note: Conjugate base has one less proton than its corresponding acid and conjugate acid has one more proton than its corresponding base.

Example

Classify each of these species as a Bronsted acid or base or both.

(a) H_2O
(b) OH^-
(c) HCN
(d) HBr
(e) NH_2^-

Answer

(a) Both; H_2O can loose H^+ to become OH^-. In that case it is a Bronsted acid. It can also gain H^+ to become H_3O^+. In that case it is a Bronsted base.
(b) Bronsted base; OH^- is a negative ion and attracts H^+. Hence it is Bronsted base.

(c) Bronsted acid; it looses H^+ to become CN^-.
(d) Bronsted acid; it looses H^+ to become Br^-.
(e) Bronsted base; it is a negative ion and hence gains H^+ to become NH_3.

Example

Identify the conjugate acid-base pairs in the following reactions.

(a) $NH_3(aq) + HF(l) \rightleftharpoons NH^+{}_4(aq) + F^-(aq)$

(b) $CN^-(aq) + H_2O(l) \rightleftharpoons HCN(aq) + OH^-(aq)$

Answer

(a) HF looses the proton and becomes F^-, and hence these two are conjugate acid-base pair. NH_4^+ is formed when NH_3 gains a proton, and hence these two are conjugate acid-base pair.

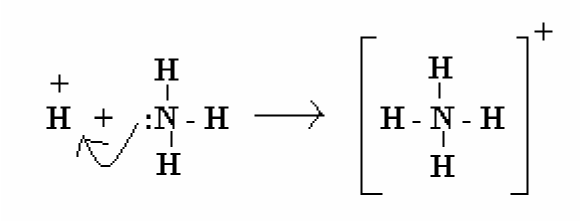
(b) acid-base pair1: HCN and CN^- and acid-base pair2: H_2O and OH^-.

Lewis Definitions of Acids and Bases

A more general theory of acids and bases than previously defined was introduced by the American Chemist G. N. Lewis in 1923. His definitions are given below:

A base *is a substance that can donate a pair of electrons.*
An acid *is a substance that can accept a pair of electrons.*

For example in the formation of NH_4^+, NH_3 acts as a **Lewis base** because it donates a pair of electrons to proton H^+, which acts as a **Lewis acid** by accepting a pair of electrons.



Remember

- **Lewis acid is an electron pair acceptor.**
- **Lewis base is an electron pair donor.**

Example

Identify Lewis acid and base in $F_3B – NH_3$.

Answer

NH_3 is a Lewis base because it has a pair of electrons. BF_3 is a Lewis acid because it accepts the pair of electrons.