4 Theories of Acids and Bases

Content

4.1 Arrhenius, Brønsted-Lowry and Lewis theories of acids and bases

Learning Outcomes

Candidates should be able to:

(a) show understanding of, and apply the Arrhenius theory of acids and bases

(b) show understanding of, and apply the Brønsted-Lowry theory of acids and bases, including the concept of conjugate acids and conjugate bases

(c) show understanding of, and apply the Lewis theory of acids and bases (including non-aqueous system, e.g. reaction between BF_3 and NH_3)

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4.1 Arrhenius, Brønsted-Lowry and Lewis theories of acids and bases

Define

Acid

An **acid** is a species which donates proton (H^+) to a base.

Base

A **base** is a species which accepts proton (H^+) from an acid.

Degree of dissociation

The **degree of dissociation**, α , is defined as the fraction of molecules that dissociate into ions.

pH

The **pH** of a solution is defined as the negative of the logarithm to base 10 of the hydrogen ion concentration in mol dm^{-3}.

- The *pH* of an acid can be found by using the formula

  $pH = -\log_{10} [H^+]$

- The *pH* of an acid depends on the concentration as well as the degree of dissociation.
- Its value changes with concentration. Therefore, a more reliable method for the determination of the pH of a solution is to use its *dissociation constant*, as the value is constant at all dilutions and varies only with temperature.
- Universal indicators or a pH meter can be used to determine the *pH* of a solution.
- The colour of the universal indicator changes from red at pH 0 to green at pH 7 to purple at pH 14.
- The *pOH* of a base can be found by using the formula

  $pOH = -\log_{10} [OH^-]$

  At 25°C, pOH + pH = 14.

Example

❶ The pH of 0.02 M nitrous acid is 2.45.

$pH = -\log_{10} [H^+]$
$2.45 = -\log_{10} [H^+]$

$[H^+] = 3.55 \times 10^{-3}$ mol dm^{-3}

Understand

Arrhenius Theory

The **Arrhenius theory** states that an acid is a substance which dissociates to produce protons while a base produces hydroxide ions when dissolved in water.

- Acids are substances which produce hydrogen ions in solution.
- Bases are substances which produce hydroxide ions in solution.
- The acid and base react to form water:

  $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

- However, it cannot account for compounds which have basic properties though they do not contain the OH group in their molecules. An example of this would be ammonia.

Example

① Hydrochloric acid reacts with sodium hydroxide solution to form a salt and water.

$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

This is a neutralization reaction – H^+ and OH^- ions react to form water.

Hydrochloric acid is also neutralized by ammonia solution.

$HCl(aq) + NH_3(aq) \rightarrow NH_4Cl(aq)$

In both cases, a salt is obtained. However, there is no OH^- ion in the reaction with ammonia, which cannot be explained by Arrhenius theory.

The OH^- ions in fact come from the reaction between ammonia and water:

$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

Brønsted-Lowry Theory

The **Brønsted-Lowry theory** states that an *acid* is a proton (H^+) donor, and a *base* is a proton acceptor.

[***Examined in*** 2016p1.35, 2016p1.33]

- Every acid will have a *conjugate base*, which is defined as the particle left when the acid has donated its proton.

- Every base will have a *conjugate acid*, which is defined as the particle formed when the base has accepted the proton.

[***Examined in*** 2017p1.6]

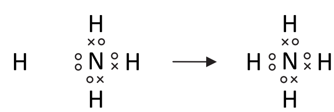
- The acid and base, which differ by a proton, then form a conjugate pair.

  $$\text{Acid} \rightleftharpoons \text{Base} + H^+$$

- The Brønsted-Lowry theory is in harmony with Arrhenius theory, and is also able to account for compounds which have basic properties though they do not contain the OH group in their molecules.

Example

① According to Brønsted-Lowry theory, ammonia is a base because it accepts a proton (H^+). The hydrogen becomes attached to the lone pair on the nitrogen of the ammonia via a *dative covalent bond*.



② In the reaction between hydrazine and sulfuric acid:

$N_2H_4 + H_2SO_4$	$\rightarrow$ $N_2H_6^{2+}$	$+$	SO_4^{2-}
Base Acid	Conjugate acid		Conjugate base

[***Examined in*** 2017p3.2a]

Lewis Theory

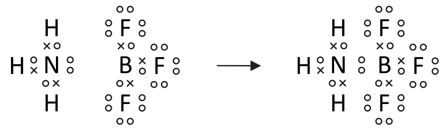
The **Lewis theory** states that an acid accepts electron pairs while a base donates electron pairs.

[***Examined in*** 2017p1.6]

- This explains the reaction between ammonia and boron trifluoride, a proton and a hydroxide ion, and the formation of complex ions by transition metals.

- In the reaction between boron trifluoride (BF_3) and ammonia (NH_3), the base is the electron pair donor (NH_3) and the acid is the electron pair acceptor (BF_3).

- There are 6 electrons around B. Therefore B can accept 2 more electrons to form a stable octet structure. The nitrogen atom has a lone pair of electrons to share with boron and thus forms a *dative covalent bond*.



- Although the term "donor" was used, the electron pair does <u>not</u> actually leave the NH_3 molecule. It <u>changes</u> from a non-bonding pair to a bonding pair of electrons.

- BF_3 is a *Lewis acid* as it has <u>no</u> H to donate. Compounds of Group III elements are Lewis acids, e.g. BF_3 and $AlCl_3$, which have only <u>6</u> electrons in their bonding orbitals to accept an electron pair from the Lewis base (the electron pair donor).

Notes: