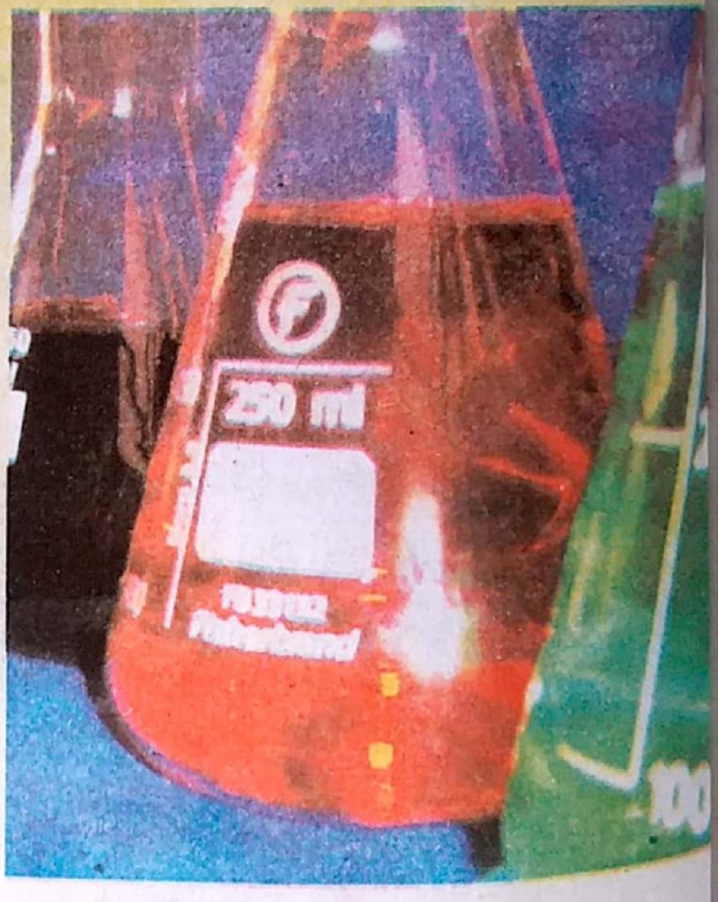
Chapter

10

Acids Bases and Salts

In this chapter you will be able to:

- Define and give examples of Arhenius acids and bases.
- Use the Bronsted-Lowry theory to classify substances as acids or bases, or as proton donors or proton acceptors.
- Classify substances as Lewis acids or bases.
- Write the equation for the self-ionization of water.
- Given the hydrogen ion or hydroxide ion concentration, classify a solution as neutral, acidic or basic.
- Complete and balance a neutralization reaction.



Introduction

The term acid is derived from Latin word acidus, which means sour. Lemon, and oranges are sour in taste because each of them contain an acid known as citric acid. Hydrochloric acid is present in our stomach which helps to digest food. Similarly we use bases and salts in our daily life e.g. washing soda ($Na_2CO_3.10H_2O$) and baking soda ($NaHCO_3$) are used for washing and in bakery respectively.
Similarly Sodium chloride (NaCl) is a salt that we use in our daily diet to taste our food.

10.1 Various Concepts of acids and bases

The Arhenius Concept (1884)
According to this concept all those substances which can give H^+ ion when dissolved in water are called acids e.g.

$$HCl_{(aq)} + H_2O_{(l)} \longrightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

$HC\ell$ is an acid which dissolve in water and give H^+ ion and forms H_3O^+.
Base is a substance which can give hydroxyl ion OH^- when dissolved in water. e.g.

$$NaOH_{(s)} \xrightarrow{H_2O} Na^+_{(aq)} + OH^-_{(aq)}$$

10.1.2 Bronsted and Lowry Concept

According to Bronsted and Lowry concept.
All those substances which donate or tend to donate proton (H^+ ion) are called acids. Whereas those substances which accept or tend to accept proton are known as bases.

$$\underset{\text{acid}}{HCl_{(aq)}} + \underset{\text{base}}{NH_{3(aq)}} \longrightarrow NH^+_{4(aq)} + Cl^-_{(aq)}$$

In this example HCl donates proton and acts as an acid, while NH_3 accepts proton and serves as base.

Conjugate Acid and Conjugate Base:

When an acid gives proton (H^+) it forms negatively charged species which can accept proton and act as a base and is called conjugate base of the corresponding acid e.g.

$$\underset{\text{acid}}{CH_3COOH} + \underset{\text{base}}{H_2O} \rightleftharpoons \underset{\text{Conjugate base}}{CH_3COO^-} + \underset{\text{Conjugate acid}}{H_3O^+}$$

When acetic acid (CH_3COOH) loses a proton it forms CH_3COO^- ion which can take proton and acts as a base and thus CH_3COO^- is called conjugate base of the acid (CH_3COOH).

When a base takes proton then it forms positively charge species which can act as an acid and is called conjugate acid of the corresponding base. e.g.

$$\underset{\text{base}}{NH_3} + \underset{\text{acid}}{H_2O} \longrightarrow \underset{\text{Conjugate acid}}{NH_4^+} + \underset{\text{Conjugate base}}{OH^-}$$

NH_4^+ is called conjugate acid of NH_3.

Monoprotic Acids

Those acids which can donate only one proton are called mono protic acids e.g.

HCl, HBr, HNO_3 and HCN etc.

Polyprotic Acids

Those acids which can donate two or more than two protons are called polyprotic acids e.g.

H_2SO_4 and H_3PO_4

Amphoteric Substances:

Those substances which can act both as an acid and a base are called amphoteric substances e.g. water.

When water is treated with an acid it acts as a base but when it is treated with a base, it acts as an acid. e.g.

$$\underset{\text{acid}}{HCl} + \underset{\text{base}}{H_2O} \longrightarrow \underset{\text{conj base}}{Cl^-} + \underset{\text{conj acid}}{H_3O^+}$$

$$\underset{\text{base}}{NH_3} + \underset{\text{acid}}{H_2O} \longrightarrow \underset{\text{conj acid}}{NH_4^+} + \underset{\text{conj base}}{OH^-}$$

$$\underset{\text{acid}}{H_2O} + \underset{\text{base}}{H_2O} \longrightarrow \underset{\text{conj base}}{OH^-} + \underset{\text{conj acid}}{H_3O^+}$$

10.1.3 The Lewis Concept

According to Lewis.

Those species (Molecules or ions) which can accept a pair of electrons are called acids.

While those species which can donate a pair of electrons are called bases.

An acid base reaction involves the donation of electrons pair from base to an acid and forming coordinate covalent bond.

Compounds having less than eight electrons in velance shell of central atom and positive ions act as lewis acids.

While compounds having lone pair of electrons in the valance shell or negatively charged ions can donate electron pair and behave as Lewis bases.

For Example:

$$\underset{\text{base}}{\ddot{N}H_3} + \underset{\text{acid}}{BF_3} \longrightarrow \underset{\text{Complex}}{[H_3N \longrightarrow BF_3]}$$

$$\underset{\text{acid}}{H^+} + \underset{\text{base}}{\ddot{N}H_3} \longrightarrow \underset{\text{Ammonium ion}}{[H_3N \longrightarrow H]^+}$$

$$\underset{\text{acid}}{H^+} + \underset{\text{base}}{H_2\ddot{O}:} \longrightarrow \underset{\text{Hydronium ion}}{[H_2\ddot{O} \longrightarrow H]^+}$$

I. STRONG ACIDS:

Acids, which are ionized almost completely in aqueous solution and give higher concentration of H^+ ions, are called strong acids. OR

Acids, which are completely dissociated in aqueous solutions, are called strong acids. HCl, HNO_3, and H_2SO_4 are examples of strong acids.

HCl is a strong acid and when it is dissolved in water, it dissociates completely to give hydrogen ions (H^+) $HCl_{(aq)} \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$

It has been proved that solution of HCl does not have any un-dissociated HCl molecules in it. All the molecules of HCl have been completely dissociated to give H^+ and Cl^- ions.

ii. WEAK ACIDS:

The acids, which partially ionize in aqueous solution and give lower concentration of H^+ ion, are called weak acid. OR

The acids, which do not dissociate completely when added to water, are called weak acids. For example, acetic acid is a weak acid. When it is dissolved in water, only few molecules of it dissociate to give hydrogen ions (H^+) and acetate ions.

$$CH_3COOH_{(aq)} \rightleftharpoons H^+_{(aq)} + CH_3COO^-_{(aq)}$$

Acetic acid dissociates only slightly. Therefore, in the solution apart from H^+ and $CH_3COO^-_{(aq)}$ ion, un-dissociated acetic acid, molecules are also present.

Other examples of weak acids are H_2CO_3 and H_3PO_4.

iii. STRONG BASES:

The bases, which are almost completely ionized in aqueous solution and give higher concentration of OH^- ion, are called strong bases.

For example NaOH is a strong base, which dissociates completely in water as follow.

$$NaOH_{(aq)} \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$$

All the NaOH molecules dissolved in water break up to give Na^+ and OH^- ions. KOH is also an example of a strong base.

iv. WEAK BASES:

The bases, which are partially ionized in aqueous solution and give lower

concentration of OH^- ion, are called weak bases OR
The bases, which do not dissociate completely in water, are called weak bases. For Example NH_4OH is a weak base. It partially dessociate into its ions.

$$NH_4OH_{(aq)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

Society, Technology and Science

Acids and bases are very important in our daily life. Sulfuric acid and hydrochloric acid as well as other acids have many industrial applications. HCl is present in our stomach, which helps in digestion of food. Carbonic acid (H_2CO_3) is a weak acid that is present in a soda water.
Bases also have important role in our daily life. For example NaOH is used to make soaps and as drain opener. Sometime we take bases as antacid such as $Mg(OH)_2$ to neutralize excess of stomach acid which causes heart burn. Slaked lime $Ca(OH)_2$ is used for white washing purposes.

10.2 pH Scale (Hydrogen ion Concentration):

The acidity or basicity of an aqueous solution depends upon the relative numbers of hydronium ions (H_3O^+) and hydroxide ions (OH^-) present in it. Pure water contains equal number of hydronium and hydroxide ions. In water the product of hydronium ions concentration and hydroxide ions concentration is always 1×10^{-14} at 25°C and is called water dissociation constant "k_w".

$$2H_2O \rightleftharpoons H_3O^+ + OH^-$$

$$K_w = [H_3O]^+ [OH]^-$$

$$K_w = 10^{-14}$$

It has been so obtained because at room temp (25°C) water molecules are much stable and only one molecule of H_2O out of 10^7 molecules dissociates into H^+ and OH^- ions i.e

$$H_2O \rightleftharpoons H^+ + OH^- \text{ .... } 1$$

So, Concentration of H^+ ions $= \frac{1}{10^7} = 10^{-7}$ mol.dm^{-3}

Concentration of OH^- ions $= \frac{1}{10^7} = 10^{-7}$ mol.dm^{-3}

k_c for equation 1 is

$$k_c = \frac{[H^+][OH^-]}{[H_2O]}$$

Concentration of water is constant, so

$$k_c\,[H_2O] = [H^+][OH^-]$$

$$k_c\,[H_2O] = k_w$$

$$K_w = 10^{-7} \times 10^{-7} = 10^{-14}$$

Society, Technology and Science

Gastric juice is a digestive fluid, formed in the stomach. It has a pH of 1 to 2 and is composed of hydrochloric acid (HCl) (around 0.5%, or 5000 parts per million), and large quantities of potassium chloride (KCl) and sodium chloride (NaCl). The acid plays a key role in digestion of proteins, by activating digestive enzymes, and making ingested proteins unravel so that digestive enzymes can breakdown the long chains of amino acids.

Gastric juice is produced by cells lining the stomach, which are coupled to systems to increase acid production when needed.

pH and pOH Scales:

Sorenson in 1909 proposed a scale for the measurement of strength of acids and bases called P^H and P^{OH} scale . Here P stands for "potenz" (The potential to be) and H^+ stands for Hydrogen and OH^- stands for hydroxyl ion. The P^H Scale measures how acidic or basic a solution is? It ranges from 0 to 14.

pH	
The logarithm of the reciprocal of moler hydrogen ions concentration is known the P^H	The logarithm of the reciprocal of moler OH^- ions concentration is known the P^{OH} .
$P^H = \log \frac{1}{[H^+]}$ $P^H = \log 1 - \log[H^+]$ As $\log 1 = 0$ $P^H = -\log[H^+]$	$P^{OH} = \log \frac{1}{[OH^-]}$ $P^{OH} = \log 1 - \log[OH^-]$ As $\log 1 = 0$ $P^{OH} = -\log[OH^-]$
The negative logarithm of moler hydrogen ions concentration is called P^H.	The negative logarithm of moler OH^- ions concentration is called P^{OH} .
P denotes negative log. $-\log = P$	

As we have

$$Kw = [H^+][OH^-] = 10^{-14}$$

Take negative logarithm of above equation.

$$-\log kw = -\log[H^+][OH^-] = -\log 10^{-14}$$

$$[-\log[H^+]] + [-\log[OH^-]] = -(-14)\log 10$$

As $\log 10 = 1$

$$P^H + P^{OH} = 14.$$

The sum of pH and pOH for a neutral substance is 14. i.e. pH $=7$ and pOH $=7$.

For a neutral solution pH is equal to 7 and pOH is equal to 7. Each pH whole number value below 7 is ten times more acidic than the next higher value. For example a pH of 3 is ten times more acidic than pH of 4 and 100 times more acidic than pH of 5. The same holds true for pH values above 7 each of which is ten times more alkaline (basic) than the next lower whole number value i.e. a pH of 9 is ten times more alkaline than pH of 8.

Example: Calculate the pH and pOH of 0.001M solution of nitric acid=?

Solution:

$$\underset{0.001}{HNO_3} \longrightarrow \underset{0.001}{H^+} + \underset{0.001}{NO^{-3}}$$

Hydrogen ions concentration $=\left[H^+\right]=0.001=\frac{1}{1000}=10^{-3}$

$$\text{pH}=-\log\left[H^+\right]$$

$$-\log 10^{-3}=-(-3)\log 10$$

$$\text{pH}=3$$

As

$$\text{pH} + \text{pOH} = 14$$

So

$$\text{pOH} = 14 - \text{pH}$$

$$\text{pOH} = 14-3=11$$

Example: Calculate the P^H and P^{OH} of 0.01 M Solution of HCl.

Solution:

$$\underset{0.01}{HCl} \longrightarrow \underset{0.01}{H^+} + \underset{0.01}{Cl^-}$$

Hydrogen ions concentration = $\left[H^+\right]=0.01=\frac{1}{100}=10^{-2}$.

$$pH = -\log[H^+]$$
$$= -\log(10^{-2})$$
$$-(-2)\log 10 = 2$$

$pH + pOH = 14$

$pOH = 14 - pH$

$pOH = 14 - 2 = 12$

A scale known as the pH scale has been devised to express the acidic and basic strength of solution in terms of the pH value.

Concentration of H^+ ions	pH	pOH
1 $\frac{1}{10} = 10^{-1}$ $\frac{1}{100} = 10^{-2}$ $\frac{1}{1000} = 10^{-3}$	0 1 2 3	14 13 12 11 Strong acids
10^{-4} 10^{-5} 10^{-6}	4 5 6	10 9 8 Weak acids
10^{-7}	7	$7 \rightarrow$ Neutral
10^{-8} 10^{-9} 10^{-10} 10^{-11}	8 9 10 11	6 5 4 3 Weak Bases
10^{-12} 10^{-13} 10^{-14}	12 13 14	2 1 0 – Strong bases

10.3 Salts

A Compound formed due to neutralization reactions of an acid and base is called salt. A salt consists of positive ion from the base and negative ion from the acid. For example sodium chloride ($NaCl$) is composed of sodium (metal) positive ion (Na^+) and chloride (non–metal) ion Cl^-.

Some metal positive ions ($Na^+, K^+, Ag^+, Mg^{++}, Ca^{++}$)

some negative ions ($C\ell^-, Br^-, SO_4^{-2}, PO_4^{-3}$).

Sodium chloride $NaC\ell$, silver bromide ($AgBr$), potassium sulphate (K_2SO_4) and ferric phosphate ($FePO_4$) etc. are examples of salts.

10.3.1 Preparation of Salts

Salts can be formed in different ways. It can be formed by the neutralization of acids with bases e.g.

$$\underset{\text{acid}}{HCl} + \underset{\text{base}}{NaOH} \longrightarrow \underset{\text{salt}}{NaCl} + \underset{\text{water}}{H_2O}$$

In certain salts there are poly atomic positive ions and poly atomic negative ions e.g. Ammonium sulphate $(NH_4)_2SO_4$ and Ammonium nitrate (NH_4NO_3).

Generally salts are ionic compounds. Soluble salts are called electrolytes. In molten state or in solution state, electrolytes are good conductors of electricity.

10.3.2 Types of Salts

i. Neutral Salts:

The salts formed when the hydrogen ion of an acid are completely replaced by metal ions or a group of atom, behaving like metal ions. Sodium chloride is formed from sodium hydroxide and hydrochloric acid,

$$\underset{\text{Strong acid}}{HCl} + \underset{\text{Strong base}}{NaOH} \rightarrow \underset{\text{salt}}{NaCl} + \underset{\text{water}}{H_2O}$$

For example NaCl is the neutralization product of HCl and NaOH.

Similarly,potassium sulphate, sodium sulphate, sodium carbonate, ammonium sulphate, sodium phosphate etc. are other examples of normal salts.

ii. Acidic Salts:

Salts formed when hydrogen ions of an acid are partially replaced by metal ions or group of atoms behaving like metal ions are called acidic salts.

For example $KHSO_4$, $NaHCO_3$, $(NH_4)\,H_2\,PO_4$, etc are acidic salts. These salts can further react with bases forming neutral salts.

$$H_2SO_4 + KOH \longrightarrow KHSO_4 + H_2O$$

Acidic salts are formed by Polybasic acid only.

iii. Basic Salts:

Salts formed when OH^- ion of a base are partially neutralized by an acids are called basic salts.

For example,

$$Pb(OH)Cl, Cu(OH)Cl$$

$$Pb(OH)_2 + HCl \longrightarrow Pb(OH)Cl + H_2O$$

Basic salts are produced by Poly acid bases.

10.3.3 Uses of Salts

Salts have many different uses, ranging from household to big industries. Many salts, like sodium chloride, are necessary for life itself. Calcium phosphate is the main ingredient of our bones. Some salts, like calcium sulphate dihydrates ($CaSO_4 . 2H_2O$) are used in building materials. Some of the most common salts and their uses are given below.

1. **Sodium carbonate ($Na_2\,CO_3$):** It is also called as soda ash or washing soda. It is used as a cleaning agent in laundries and as water softner. It is also used as raw material in glass manufacturing. It also finds applications in paper industry, petroleum refining industry and leather industry.

2. **Sodium hydrogen Carbonate (sodium bicarbonate) $NaHCO_3$:** It is also called baking soda because it is used for baking cake and other confectionaries. It is used in medicine as antacid and also in tooth paste etc.

3. **Copper sulphate ($CuSO_4 . 5H_2O$) (blue vitriol):** It is used for copper plating in electroplating process. It is also used to kill algae in water reservoirs and in agriculture spray.

4. **Magnesium sulphate ($MgSO_4.7H_2O$) Epsom salt:** It is used as antacid and laxative in medicine. It is also used in dye industries.

5. **Alum or potash alum $K_2SO_4\ Al_2(SO_4)_3.24H_2O$:** It is used for water purification to remove suspended impurities from water by a process called as flocculation. It is widely used in textile industry since it causes dyes to adhere to the fabric. In the field of medicine, it is used as blood coagulant in small injuries.

10.4 Neutralization

When acids react with bases, salt and water is formed, the process is called neutralization reaction.

For example, when HCl reacts with NaOH, NaCl and water are formed.

$$\underset{\text{Acid}}{HCl_{(aq)}} + \underset{\text{Base}}{NaOH_{(aq)}} \rightarrow \underset{\text{salt}}{NaCl_{(aq)}} + \underset{\text{water}}{H_2O_{(l)}}$$

To understand the process of neutralization the acid, base and salt should be written in their ionic form.

$$H^+_{(aq)} + Cl^-_{(aq)} + Na^+_{(aq)} + OH^-_{(aq)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)} + H_2O_{(l)}$$

In solution, HCl exists as H^+(or H_3O^+) and Cl^-, and NaOH exists as Na^+ and OH^-. In neutralization H^+ reacts with OH^- to form water, leaving Na^+ and Cl^- ions which are present on both sides as they have not reacted. They are called spectator ions. Only H^+ and OH^- combine to form H_2O.

Thus the net reaction is the chemical combination of OH^- ion and H^+ ion to form water molecule. The net reaction of neutralization is as under.

$$H^+ + OH^- \rightarrow H_2O$$

10.5 Common ion Effect:

The process in which the solubility of already present electrolyte in solution is decreased by adding another electrolyte having the common ion is called common ion effect.
In this process the solubility of less soluble electrolyte is decreased by adding more soluble electrolyte in the solution where both gives common ion for example:
When we add $KC\ell$ into solution of less soluble salt $KC\ell O_3$, then due to common ion effect. The solubility of $KC\ell O_3$ decreases. So $KC\ell O_3$ separates out of solution as crystals.

$$KClO_3 \rightleftharpoons K^+ + ClO_3^-$$

$$KCl \longrightarrow K^+ + Cl^-$$

2. When $HC\ell$ is added to solution of H_2S, they produce H^+ as common ion.

$$H_2S \rightleftharpoons 2H^+ + S^{-2}$$

$$HCl \longrightarrow H^+ + Cl^-$$

Because H_2S is a weak acid and HCl is a stronger acid, therefore ionization of H_2S is suppressed. Thus less S^{-2} ions are produced.

3. When we add $NH_4C\ell$ to solution of NH_4OH, the $\overset{+}{N}H_4$ ion is common.

$$NH_4Cl \rightleftharpoons NH_4^+ + Cl^-$$

$$NH_4OH \rightleftharpoons NH_4^+ + OH^-$$

Due to common ion effect the ionization of NH_4OH is suppressed and less OH^- ions are produced.

KEY POINTS

- According to Arhenius those substances which can give H^+ ion in water are called acids, while those which can give OH^- ion in water are called bases.
- According to Lowry and Bronted those substances which donate or tend to donate proton are called acids, while those which accept or tend to accept proton are called bases.
- According to Lewis those species which can accept a pair of electron are called acids, while those which can donate a pair of electron are called bases.
- A specie and which can act as a base as well as acid is called amphoteric substance
- P^H and P^{OH} scales are used for the measurement of strength of acid and bases.
- P^H of neutral solution is 7
- P^H of acidic solution is less than 7
- P^H of basic solution is more than 7
- When an acid neutralizes a base salt is formed
- Salts are of three types i.e neutral, acidic and basic.

EXERCISE

Q.1 Select the suitable option.

i. According to Bronsted, Acids are:
   a. Proton donor b. Proton accepter
   c. Electron donor d. Electron accepter

ii. NH_3 is ______________.
   a. Acid b. Base
   c. Salt d. Buffer Solution

iii. Neutral solution has a P^H value :
   a. 3 b. 5
   c. 7 d. 14

iv. Lower the PH value __________ will be an acid.
   a. Weaker b. Stronger
   c. Neutral d. Alkaline

v. Salts are ______________ compounds.
   a. Acidic b. Basic
   c. Neutral d. Neutral

vi. Those bases which give hydroxyl ion in water are called.
   a. Acids b. Alkalies
   c. Salts d. Neutral substances

vii. $KHSO_4$ is a __________ salt.
   a. Basic b. Acidic
   c. Neutral d. Neutral

Q.2 Write short answers to the following questions:

i. What are double salts?
ii. What are amphoteric substances
iii. Differentiate between lone pair and bond pair of electrons
iv. What will be the pH and POH of 0.001M NaOH solution?
v. Calculate the pH and POH of 0.05M HCl Solution?

Q.3 Write long answers to the following questions:

i. What are salts and explain their different types.
ii. Write a detailed note on P^H.
iii. Define common ion effect. Explain with example how it effects the chemical reactions.
iv. Write different concepts of acids.
v. Define Lewis acids and bases, giving examples.