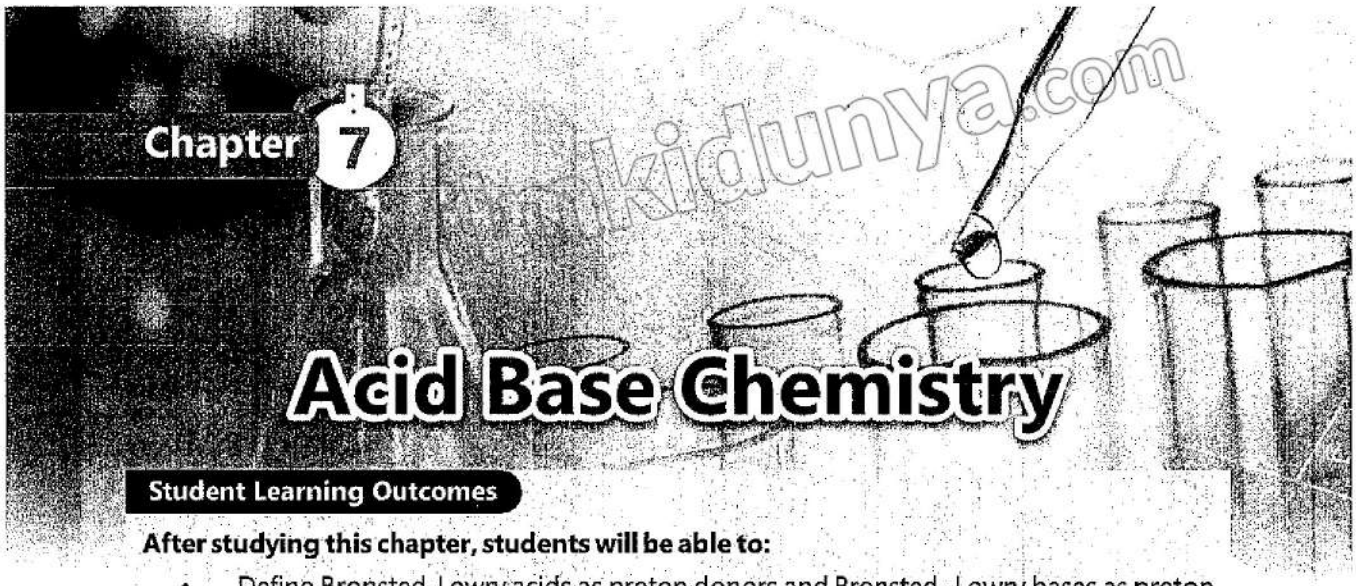

Chapter 7

# Acid Base Chemistry

**Student Learning Outcomes**

**After studying this chapter, students will be able to:**

- Define Bronsted-Lowry acids as proton donors and Bronsted -Lowry bases as proton acceptors
- Recognize that aqueous solutions of acids contain $H^+$ ions and aqueous solutions of alkalis contain $OH^-$ ions
- Define a strong acid and base as an acid or base that completely dissociates in aqueous solution and weak acid and base that partially dissociates in aqueous solution. (Some examples include: Student writing symbol equations to show these for hydrochloric acid, sulphuric acid, nitric acid, and ethanoic acid.)
- Formulate dissociation equations for an acid or base in aqueous solution.
- Recognize that bases are oxides or hydroxides of metals and that alkalis are water-soluble bases
- Describe the characteristic properties of acids in terms of their reactions with metals, bases and carbonates
- Identify the characteristic properties of bases in terms of their reactions with acids and ammonium salts
- Define acid rain.
- Discuss effects of acid rain and relate them with properties of acids.

## 7.1 Acids and Bases

Acids and bases have been known to mankind since centuries. Acids have been known for their sour taste like the taste of lemon and ability to change the colour of litmus paper from blue to red. There are many substances which contain acids and hence taste sour, such as curd, tamarind, lemon and lime, etc.

Common examples of acids include acetic acid, hydrochloric acid, nitric acid, sulphuric acid and tartaric acid. Most of these acids, we come across in everyday life, are available in the form of aqueous solutions as they can be easily dissolved in water.

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Acids are divided into two types on the basis of their occurrence: natural acids and mineral acids. Acids which are obtained from natural sources are called natural or organic acids. Mineral or man-made acids are prepared from minerals like sodium chloride or sodium nitrate. Common examples of mineral acids are hydrochloric acid, sulphuric acid and nitric acid.

Some common organic acids and their natural sources are given in table (7.1)

**Table (7.1) Some Common Organic Acids and their Sources**

| Organic acid | Natural Source |
|---|---|
| Acetic acid | Vinegar |
| Ascorbic acid | Amla, Guava |
| Citric acid | Lemon, Orange |
| Lactic acid | Sour milk, Curd |
| Formic acid | Ant sting |
| Oxalic acid | Tomato |
| Tartaric acid | Tamarind |

In comparison to acids, alkalis or bases are known for their bitter taste, slippery touch and ability to change the colour of litmus paper from red to blue. An alkali is a base that dissolves in water. Some common examples of alkalis are sodium hydroxide (caustic soda), potassium hydroxide (caustic potash) calcium hydroxide (lime water) and aqueous ammonia ($NH_4OH$). Both sodium hydroxide and potassium hydroxide are extremely corrosive and can burn your skin away.

Metals oxides are also basic in nature because they react with acids to form salt and water. $Na_2O$ is basic oxide because it contains oxide ion, $O^{2-}$, which is a very strong base with a strong tendency to react with water to produce hydroxide ions. $Na_2O_{(s)} + H_2O_{(l)} \longrightarrow 2NaOH_{(aq)}$

Other examples of basic oxides are calcium oxide (CaO), zine Oxide (ZnO) and magnesium oxide (MgO).

Both acids and alkalis are known to cancel the properties of each other when mixed together in equal amounts. The reaction is called neutralization reaction. A salt and water are formed as a result of this reaction.

**Exercise** Name some fruits which contain citric acid.

**Interesting Information!**

Oxalic acid ($H_2C_2O_4$) is the simplest organic diprotic acid. Its commercial uses include bleaching straw and leather and removing rust and ink stains from fabrics.

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**Activity 7.1**

The following compounds are provided in the form of liquid or in the form of their aqueous solutions. Use blue and red litmus paper stripes to show whether these substances are acidic or basic in their aqueous solutions.

| Substance | Acidic | Basic |
|---|---|---|
| Tap water | | |
| Battery water | | |
| Rain water | | |
| Soap solution | | |
| Tooth paste | | |
| Shampoo | | |
| Bleach | | |

**Exercise**

In what ways are mineral acids useful for us?

## 7.2 DIFFERENT CONCEPTS OF ACIDS AND BASES

### Arrhenius Acids and Bases

Although the earlier definitions of acids and bases describe some distinctive features of these substances, yet new and broader definitions were needed to explain their chemical behavior on the molecular level.

Svante Arrhenius, a Swedish Chemist, suggested that acids and bases may be classified in terms of their behavior in water. According to him;

An acid is that substance which dissociates in water to give proton($H^+$) or hydroxonium ion $(H_3O)^+$. Some typical Arrhenius acids are HCl, $HNO_3$, $H_2SO_4$ and HCN.

Svante Arrhenius
(1859-1927)

$$HCl_{(aq)} \xrightarrow{H_2O} H_3O^+_{(aq)} + Cl^-_{(aq)}$$

Similarly, a base is that substance which dissociates in water to give hydroxyl ions $(OH)^-$.

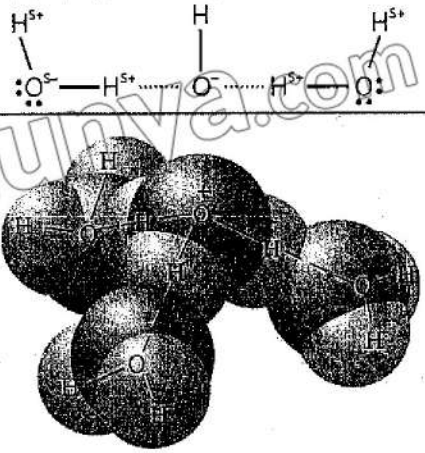
Some typical Arrhenius bases are NaOH, KOH and $Ba(OH)_2$.

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

Water has an essential role to play in Arrhenius concept of acids and bases. Whenever an acid or a base dissociates in water, its molecules participate in reaction by surrounding the resultant proton ($H^+$) and hydroxyl ion($OH^-$). Since proton is very small in size and its charge density is very high, it forms a strong bond with the lone pair of water molecule to give hydroxonium ion, $H_3O^+$.

According to some reports upto four water molecules may surround the proton. Similarly, hydroxyl ion are also surrounded by water molecules as shown in the figure (7.1).

Arrhenius also explained the process of neutralization. According to him when a strong acid and a strong base are dissolved in water, they completely dissociate into ions.



Arrangement of water molecules around $H^+$

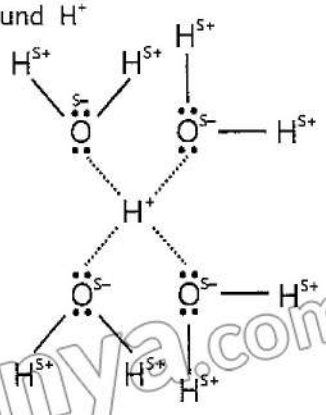


Fig (7.1)

$$HCl_{(aq)} \xrightleftharpoons{H_2O} H_3O^+_{(aq)} + Cl^-_{(aq)}$$

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

**Exercise**

How do chloride ions exist in water?

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The hydroxonium ion and the hydroxyl ion then react to form water with the evolution of heat.

$$H_3O^+_{(aq)} + OH^-_{(aq)} \longrightarrow 2H_2O_{(l)} + \text{Heat}$$

The salt NaCl that is formed with water does not exist as solid crystals. It remains present in the solution as hydrated spectator sodium ions ($Na^+$) and chloride ions ($Cl^-$).

Mineral acids are generally very strong acids. The strength of an acid depends upon the extent to which it is ionized in water. Hydrochloric acid ionizes in water completely giving a large amount of hydronium ions in water.

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

Sulphuric acid being a diprotic acid ionizes in two steps.

$$H_2SO_{4(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + HSO^-_{4\,(aq)}$$

$$HSO^-_{4(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + SO^{2-}_{4\,(aq)}$$

Nitric acid ionizes in single step.

$$HNO_{3(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + NO^-_{3\,(aq)}$$

Contrary to mineral acids, organic acids ionize upto a very limited extent and hence they are weak acids.

Glacial acetic acid has a percent ionization of only 0.132%.

$$CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + CH_3COO^-_{(aq)}$$

It means that out of 100 molecules of acetic acid, only 1.32 molecules dissociate and the rest remain undissociated.

Similarly, the percent ionization of formic acid having cocentration 1.50M is 1.06%. Which means 987 molecules out of 1000 remain undissociated.

$$HCOOH + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + HCOO^-_{(aq)}$$

NaOH and KOH are the examples of strong bases because they also ionize completely in water.

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

$NH_4OH$ and $Al(OH)_3$ are the examples of weak bases because they only partially ionize in water.

$$NH_4OH_{(aq)} \overset{H_2O}{\rightleftharpoons} NH^+_{4\,(aq)} + OH^-_{(aq)}$$

**Exercise**

Why does ammonium hydroxide only partially ionize in water?

**Interesting Information!**

**Stomach Acidity**

Stomach acidity or hyperacidity conditions are a common problem. Most often the problem arises when a person takes fatty and spicy foods which cause more acid to produce in the stomach than required.

Our stomach produces hydrochloric acid to digest the food that we eat. Whenever we eat, cells within the lining of the stomach produce acid. Problem occurs when these cells produce more acid than your stomach needs. When it happens, the person suffers from stomach acidity. The common indication of such a condition is the feeling of burning sensation right below our breast bone. A person may also feel sour taste in mouth and heart burn or pain near the heart area. The uneasy condition may easily be cured by taking weak bases like calcium hydroxide and magnesium hydroxide commonly known as antacids. These antacids remove minor stomach disorders by neutralizing the stomach acid, but the concentration of hydroxyl ions in them is too low to harm the throat or stomach.

## 7.3 Bronsted – Lowry concepts of Acids and Bases

Arrhenius concept of acids and bases is very simple and easily understandable but it has got its limitations. For example, $Na_2CO_3$, $K_2CO_3$ and $NH_3$ do not contain any hydroxyl group which will get ionized by water but all these compounds behave as bases and yield $OH^-$ in water. Arrhenius definitions also require that water must be present as a solvent in order for a compound to behave as an acid or a base. It was realized that a broader definition for acids and bases is needed to cover all the aspects of the concept.

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Johannes N. Bronsted
(1879-1947)


Thomas M. Lowry
(1874-1936)

To remove the limitations of Arrhenius concept, Bronsted and Lowy gave the following definitions of acids and bases:

**An acid is a substance that donates a proton.**

This definition requires that to behave as an acid a compound must have a proton to donate. The condition of the presence of water during this donation was, however, eliminated. All Arrhenius acids are, thus, Bronsted-Lowry acids as well for example, HCl. It dissociates in water to give $H^+$ and $Cl^-$. It also donates $H^+$ to $H_2O$ forming $H_3O^+$.

**A base is a substance that accepts a proton.**

For example, $OH^-$, $CN^-$, $NH_3$ and $Cl^-$ are all bases because they have the ability to accept a proton. Note that except $OH^-$ all other species are not Arrhenius bases. All Arrhenius bases are, however, Bronsted-Lowry bases as well.

All Bronsted-Lowry acids and bases are not Arthenius acids and bases. $NH_4^+$ is not Arrhenius acid and $NH_3$ is not Arrhenius base.

According to Bronsted-Lowry, an acid base reaction is that reaction in which a proton is transferred from a proton donor to its acceptor. This reaction may take place in gas phase or in the presence of any solvent.

Consider the following reaction between hydrogen chloride gas and liquid water.

$$\underset{\text{Acid}}{HCl_{(g)}} + \underset{\text{Base}}{H_2O_{(l)}} \rightleftharpoons H_3O^+_{(aq)} + Cl^-$$

In this reaction, HCl gas acts as an acid because it donates its proton to water which acts as a base.

Similarly when ammonia gas dissolves in water, a proton is transferred from water to ammonia and ammonium ion is formed.

$$\underset{\text{Base}}{NH_{3(g)}} + \underset{\text{Acid}}{H_2O_{(l)}} \rightleftharpoons \underset{\text{Conjugate base}}{OH^-_{(aq)}} + \underset{\text{Conjugate acid}}{NH_4^+{}_{(aq)}}$$

Ammonia is a base while water is an acid in this reaction. Water has the ability to act both as an acid or a base depending upon the other compound with which it reacts.



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Water is therefore called an amphoteric compound which means a compound that can behave both as an acid and a base.

In the reverse reaction, $OH^-$ is a base because it accepts a proton donated by the acid $NH_4^+$. In order to differentiate, $OH^-$ is called the conjugate base while $NH_4^+$ the conjugate acid.

Some other examples of Bronsted-Lowry acids and bases.

$$\underset{\text{Acid}}{HCN_{(aq)}} + \underset{\text{Base}}{H_2O_{(l)}} \rightleftharpoons \underset{\text{Conjugate acid}}{H_3O^+_{(aq)}} + \underset{\text{Conjugate base}}{CN^-_{(aq)}}$$

$$\underset{\text{Acid}}{HI_{(aq)}} + \underset{\text{Base}}{H_2O_{(l)}} \rightleftharpoons \underset{\text{Conjugate acid}}{H_3O^+_{(aq)}} + \underset{\text{Conjugate base}}{I^-_{(aq)}}$$

**Exercise**

Give two examples of Bronsted–Lowry bases which are not bases by Arrhenius definition.

## 7.4 Properties of Acids and Bases

### a. Acids give the following three types of reactions.

1. With alkalis or metal oxides, they form salts and water.

$$2HNO_3(aq) + CaO\ (s) \longrightarrow Ca\ (NO_3)_2(aq) + H_2O\ (l)$$

$$H_2SO_4(aq) + 2KOH\ (aq) \longrightarrow K_2SO_4\ (aq) + 2H_2O\ (l)$$

2. With reactive metals (Mg, Zn) they form salts and evolve hydrogen gas.

$$Mg\ (s) + 2HCl(aq) \longrightarrow MgCl_2\ (aq) + H_2\ (g)$$

$$Zn\ (s) + H_2SO_4\ (aq) \longrightarrow ZnSO_4\ (aq) + H_2\ (g)$$

The unreactive metals Cu, Ag, Au, and Pt do not evolve hydrogen gas with acids.

**Activity 7.2**

Take a few granules of zinc in a clean test tube. Add dilute $H_2SO_4$ in it and heat it gently. Identify the gas evolved in this reaction by taking a burning match stick near the mouth of test tube. Note the observations in your notebook.

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3. They decompose metal carbonates and hydrogen cabonates evolving carbon dioxide gas.

$$CaCO_3\,(s) + 2HCl\,(aq) \longrightarrow CaCl_2\,(aq) + H_2O\,(1) + CO_2\,(g)$$

$$2NaHCO_3\,(s) + H_2SO_4\,(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(1) + 2CO_2\,(g)$$

## b. Properties of Alkalis

As already mentioned alkalis are those bases which are soluble in water. Examples of alkalis are NaOH, KOH etc. $Ca(OH)_2$ is sparingly soluble in water while $Cu(OH)_2$ is insoluble.

Apart from reacting with acids in neutralization reactions, alkalies also react with ammonium salts and liberate ammonia gas

$$NaOH(aq) + HCl(aq) \longrightarrow NaCl\,(aq) + H_2O\,(l)$$

$$Ca(OH)_2 + H_2SO_4(aq) \longrightarrow CaSO_4\,(aq) + 2H_2O\,(l)$$

$$Ca\,(OH)_2\,(aq) + 2NH_4Cl\,(aq) \longrightarrow CaCl_2\,(aq) + 2H_2O\,(1) + 2NH_3\,(g)$$

$$NaOH\,(aq) + NH_4NO_3\,(aq) \longrightarrow NaNO_3\,(aq) + H_2O\,(1) + NH_3\,(g)$$

### Activity 7.3

How to clean a blocked drain?

Blocked drains are one of the most common problems that we face every other day. Different blockages require different chemicals to remove them.

One of the ways to clean the drain is to pour half a cup of sodium bicarbonate solution into the drain followed by half a cup of vineger. Cover the drain and wait for thirty minutes. Pour boiling water down the drain.

Caustic chemical drain cleaners are capable of dissolving grease, hair, food and other common blockages. Pour down the caustic cleaner into your drain. Wait for half an hour and then flush your drain with water.

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## 7.5 Acid Rain and its Effects

When rain water has pH less than 5.6, it is called acid rain. Burning of fossil fuels releases harmful gases in air. These gases, $SO_3$ and $NO_2$ when mixed with moisture present in air form acid droplets. These droplets then fall on the ground as acid rain.

$$2SO_{2(g)} + O_{2(g)} \longrightarrow 2SO_{3(g)}$$

$$SO_{3(g)} + H_2O_{(l)} \longrightarrow H_2SO_{4(aq)}$$

$$2NO_{2(g)} + H_2O_{(l)} \longrightarrow HNO_{3(g)} + HNO_{2(g)}$$

### Effects of Acid Rain

Acid rain causes a number of adverse effects on soil, plants, aquatic life and human-made structures.

Acid rain makes soil more acidic. It dissolves and washes away nutrients present in the soil which are needed by plants. Many plants cannot live or grow in an acidic soil. It can damage vegetation and plants. Acid rain can make water of the water bodies too acidic for aquatic animals to live in. Due to this, many lakes, rivers, ponds and streams no longer have fish. Acid rain and the dry deposition of acidic particles damage buildings, statues, automobiles and other structures made of stone and metal.

### Key Points

1. Acids are those compounds which have a sour taste and which turn blue litmus red. They also give hydroxonium ions when dissolved in water.
2. Bases or alkalis are those compounds which are bitter in taste, have a slippery touch and which change red litmus blue. They also form hydroxide ions when dissolved in water.
3. In a neutralization reaction, an aqueous solution of an acid reacts with an aqueous solution of a base to give salt and water.
4. According to Arrhenius definitions, acids give protons in water and bases give hydroxide ions in water.
5. Bronsted – Lowry define acid as a proton donor and base as proton acceptor.
6. Generally acids dissolve metals with the evolution of hydrogen gas. They also decompose carbonates and hydrogen carbonates.
7. Generally alkalis or bases react with ammonium salts to evolve ammonia gas.

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## Exercise

**1. Tick (✓) the correct answer.**

(i) Which acid is not used as a food or mixed with food?

(a) Tartaric acid (b) Ascorbic acid
(c) Citric acid (d) Formic acid

(ii) While baking, which gas is responsible for raising the bread and making it soft?

(a) Oxygen (b) Carbon dioxide
(c) Nitrogen (d) Carbon monoxide

(iii) Predict the main characteristics of the reactions of metals with acids.

(a) Metals are dissolved
(b) Metals are converted into salts
(c) Hydrogen gas is evolved
(d) All the above mentioned characteristics are true

(iv) How many hydroxide ions, calcium hydroxide will release in water?

(a) 1 (b) 2 (c) Zero (d) 3

(v) In a neutralization reaction between KOH and $H_3PO_4$, how many molecules of KOH will react with one molecule of $H_3PO_4$?

(a) 2 (b) 1 (c) 3 (d) 4

(vi) Which acid is used in the preparation of soap?

(a) Tartaric acid (b) Citric acid
(c) Stearic acid (d) Oxalic acid

(vii) Which compound is formed when $SO_2$ is dissolved in water?

(a) $SO_3$ (b) $H_2SO_3$ (c) $H_2SO_4$ (d) $H_2S_2O_7$

(viii) Which of the following contains oxalic acid?

(a) Tomato (b) Orange (c) Tamarind (d) Sour milk

(ix) Which compound in the following reaction is behaving as a conjugate base?

$$CH_3COOH_{(aq)} + H_2O_{(l)} \longrightarrow CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$$

(a) $CH_3COOH$ (b) $H_2O$ (c) $CH_3COO^-$ (d) $H_3O^+$

(x) When a chemical reaction is carried out with a substance Z; a gas is produced which turns red litmus paper blue. What is the reaction?

(a) Reaction of an acid with a metal carbonate
(b) Reaction of an acid with ammonium salt
(c) Reaction of an alkali with a metal carbonate
(d) Reaction of an alkali with ammonium salt

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## 2. Questions for Short Answers

i. Choose Arrhenius Acids among the following compounds.
HF, $\overset{+}{N}H_4$, $H_2SO_3$, $SO_3$, $H_2S$, $H_2O$

ii. How does calcium metal react with dilute $H_2SO_4$?

iii. Which salt is formed when HCl reacts with $BaCO_3$?

iv. How will you justify that $HSO^-_4$ is a Bronsted – Lowry acid?

v. What chemical name will you give to soap as a compound?

## 3. Constructed Response Questions

i. Why is HCl not edible although it is present in the stomach and responsible for digestion of food?

ii. In the presence of a drop of an acid, water is known to ionize as follows:

$$H_2O_{(l)} \rightleftharpoons H^+ + OH^-$$

In your opinion, which name will be suitable for water: an acid, a base or both?

iii. Why does $Na_2CO_3$ behave like a base in water?

iv. Is $NaHCO_3$ a base or an acid?

v. What is the difference between a strong acid and a concentrated acid?

## 4. Descriptive Questions

i. Explain Arrhenius concept of acids and bases.

ii. Compare Arrhenius and Bronsted – Lowry concepts of acids and bases.

iii. How does sulphuric acid react with the following compounds?
$NH_4Cl$, $NH_4NO_3$, $MgO$, $MgCO_3$

iv. What happens when a base reacts with a non-metallic oxide. What do you infer about the nature of non-metallic oxide?

v. State the reason of showing acidic character by both dry HCl gas and HCl solution in water.

vi. Differentiate between an acid and its conjugate base.

## 5. Investigative Questions

i. Acids play significant roles within human body. Comment on this statement.

ii. What is observed when $CO_2$ is passed through lime water (i) for a short duration (ii) for a long duration?

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