CHAPTER

10 Acid, Bases And Salts

Animation 10.1: Insol Base Preparation
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Animation 10.2: Chemanim
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Students Learning Outcomes

Students will be able to:

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

Introduction:

Acids, bases and salts are three distinct classes in which almost all the organic and inorganic compounds are classified. A famous Muslim Chemist Jabir Bin Hayan prepared nitric acid (HNO_3), hydrochloric acid (HCl) and sulphuric acid (H_2SO_4). In 1787, Lavoisier named binary compounds of oxygen such as CO_2 and SO_2 as acids which on dissolution in water gave acidic solutions. Later on in 1815, Sir Humphrey Davy discovered that there are certain acids which are without oxygen, e.g., HCl. Davy proved the presence of hydrogen as the main constituent of all acids. It was also discovered that all water soluble metallic oxides turn red litmus blue, which is a characteristics of bases. The word acid is derived from the Latin word 'Acidus' meaning sour. The first acid known to man was acetic acid, i.e., in the form of vinegar.

We all have a little concentration of hydrochloric acid in our stomach, which helps to break down the food. Sometimes, the amount of stomach acid becomes too much, which causes 'acidity'. This uncomfortable feeling is easily treated by taking an alkaline medicine. The alkali neutralizes the acid, producing a harmless chemical called a salt.

10.1 CONCEPTS OF ACIDS AND BASES

Table 1.2 Acids and bases are recognized by their characteristic properties, such as:

Acids	Bases
1. Acids have sour taste. For example, unripe citrus fruits or lemon juice.	1. Bases have bitter taste and feel slippery, for example, soap is slippery to touch.
2. They turn blue litmus red.	2. They turn red litmus blue.
3. They are corrosive in concentrated form.	3. They are non-corrosive except concentrated forms of NaOH and KOH.
4. Their aqueous solutions conduct electric current	4. Their aqueous solutions conduct electric current.

10.1.1 Arrhenius Concept of Acids and Bases

According to Arrhenius concept (1787):

Acid is a substance which dissociates in aqueous solution to give hydrogen ions. In general, the ionization of acids take place as follows.

$$HA_{(aq)} \overset{water}{\rightleftharpoons} H^+_{(aq)} + A^-_{(aq)}$$

For example, substances such as HC1, HNO_3 , CH_3 COOH, HCN, etc., are acids because they ionize in aqueous solutions to provide H^+ ions.

$$HCl_{(aq)} \overset{water}{\rightleftharpoons} H^+_{(aq)} + Cl^-_{(aq)}$$

$$HNO_{3(aq)} \overset{water}{\rightleftharpoons} H^+_{(aq)} + NO^-_{3(aq)}$$

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

On the other hand, *base is a substance which dissociates in aqueous solution to give hydroxide ions*

The general ionization of bases take place as follows;

$$BOH_{(aq)} \underset{}{\overset{water}{\rightleftharpoons}} B^{+}_{(aq)} + OH^{-}_{(aq)}$$

The substances such as NaOH, KOH, NH_4OH, $Ca(OH)_2$ etc. are bases because these compounds ionize in aqueous solutions to provide OH^- ions

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

Thus, according to Arrhenius Concept:

Acids give H^+ ions in water, bases give OH ions in water.

Examples of some important acids and bases are given in Table 10.1.

Table 10.2 Acids and Bases

Acids	Bases
Hydrochloric acid, HCl	Sodium hydroxide, NaOH
Nitric acid, HNO_3	Potassium hydroxide, KOH
Sulphuric acid, H_2SO_4	Calcium hydroxide, $Ca(OH)_2$
Phosphoric acid, H_3PO_4	Aluminium hydroxide, $Al(OH)_3$

Limitations of Arrhenius Concept

1. This concept is applicable only in aqueous medium and does not explain nature of acids and bases in non-aqueous medium.
2. According to this concept, acids and bases are only those compounds which contain hydrogen (H^+) and hydroxide (OH^-) ions, respectively. It can't explain the nature of compounds like CO_2, NH_3, etc. which are acid and base, respectively.

Although this concept has limited scope yet, it led to the development of more general theories of acid-base behaviour.

10.1.2 Bronsted-Lowrv Concept

In 1923, the Danish chemist Bronsted and the English chemist Lowry independently presented their theories of acids and bases on the basis of proton-transfer. According to this concept:

An acid is a substance (molecule or ion) that can donate a proton (H^+) to another substance.

A base is a substance that can accept a proton (H^+)from another substance.

For example, HCl acts as an acid while NH_3 acts as a base:

$$HCl_{(aq)} + NH_{3(aq)} \rightleftharpoons NH_4^+{}_{(aq)} + Cl^-{}_{(aq)}$$

Similarly, when HC1 dissolves in water; HC1 acts as an acid and H_2O as a base.

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

It is a reversible reaction. In the forward reaction, HCl is an acid as it donates a proton, whereas H_2O is a base as it accepts a proton. In the reverse reaction, Cl^- ion is a base as it accepts a proton from acid H_3O^+ ion. Cl^- ion is called a conjugate base of acid HCl and H_3O^+ion is called a conjugate acid of base H_2O. It means every acid produces a conjugate base and every base produces a conjugate acid such that there is conjugate acid-base pair. Conjugate means joined together as a pair.

A conjugate acid is a specie formed by accepting a proton by a base.

A conjugate base is a specie formed by donating a proton by an acid.

Thus, conjugate acid-base pair differs from one another only by a single proton.

Similarly

$$\underset{\text{Acid}}{CH_3COOH_{(aq)}} + \underset{\text{Base}}{H_2O_{(aq)}} \rightleftharpoons \underset{\text{Conjugate base}}{CH_3COO^-{}_{(aq)}} + \underset{\text{Conjugate acid}}{H_3O^+{}_{(aq)}}$$

According to Bronsted-Lowry concept, an acid and a base always work together to transfer a proton. That means, a substance can act as an acid (proton donor) only when another substance simultaneously behaves as a base (proton acceptor). Hence, a substance can act as an acid as well as a base, depending upon the nature of the other substance. For example, H_2O acts as a base when it reacts with HCl as stated above and as an acid when it reacts with ammonia such as:

$$H_2O_{(l)} + NH_{3(aq)} \rightleftharpoons NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

Such a substance that can behave as an acid, as well as, a base is called amphoteric.

It has been observed that there are certain substances which behave as acids though they do not have the ability to donate a proton, e.g.,SO_3 . Similarly, CaO behaves as a base but it cannot accept a proton. These observations prove the limitations of Bronsted-Lowry concept of acids and bases.

All Arrhenius acids are Bronsted-Lowry acids, but except OH other Bronsted-Lowry bases are not Arrhenius bases

Table 10.3 Conjugate acid-base pairs of common species

Acid		Base		Conjugate acid		Conjugate base
$HNO_{3(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+_{(aq)}$	+	$NO_3^-{}_{(aq)}$
$H_2SO_{4(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+_{(aq)}$	+	$HSO_4^-{}_{(aq)}$
$HCN_{(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+_{(aq)}$	+	$CN^-_{(aq)}$
$CH_3COOH_{(aq)}$	+	$H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+_{(aq)}$	+	$CH_3COO^-_{(aq)}$
$H_2O_{(l)}$	+	$NH_{3(aq)}$	$\rightleftharpoons$	$NH_4^+{}_{(aq)}$	+	$OH^-_{(aq)}$
$H_2O_{(l)}$	+	$CO_3^{2-}{}_{(aq)}$	$\rightleftharpoons$	$HCO_3^-{}_{(aq)}$	+	$OH^-_{(aq)}$
$HCl_{(l)}$	+	$HCO_3^-{}_{(aq)}$	$\rightleftharpoons$	$H_2CO_{3(aq)}$	+	$Cl^-_{(aq)}$

Problem 10.1

(a) What are conjugate bases of each of the following?

HS^-, H_3O^+, $H_2PO_4^-$, HSO_4^-, HF, CH_3COOH, $[Al(H_2O)_6)]^{3+}$

(b) Give the conjugate acids of the following:

OH^-, HCO_3^-, HPO_4^{2-}, CH_3NH_2, CO_3^{2-}, CH_3COOH

(c) Which of the following behave both as Bronsted acids and Bronsted bases?

H_2O, HCO_3^-, H_2SO_4, H_3PO_4, HS^-

Solution

(a)	Conjugate base	(b)	Conjugate acid
HS^-	: S^{2-}	OH^-	: H_2O
H_3O^+	: H_2O	HCO_3^-	: H_2CO_3
H_2PO_{4-}	: HPO_4^{2-}	HPO_4^{2-}	: $H_2PO_4^-{}_{4\,(aq)}$
HSO_4^-	: SO_4^{2-}	CH_3N_2	: $CH_3NH_3^+$
HF	: F^-		
CH_3COOH	: CH_3COO^-	CO_3^{2-}	CHO_3^-
$[Al(H_2O)_6]^{3+}$	: $[A1\ (H_2O)_5OH]^{2+}$	CH_3COOH	: $H_3COOH_2^+$

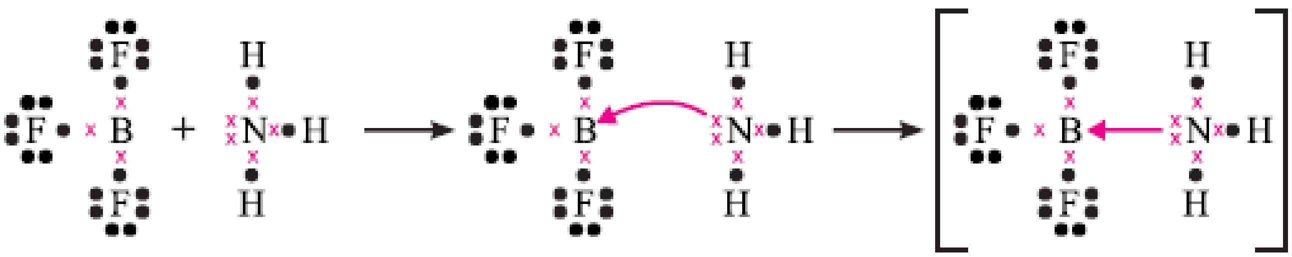
(c) Bronsted acids, as well as, bases are: H_2O, HCO_3^-, HS^-

10.1.3 Lewis Concept of Acids and Bases

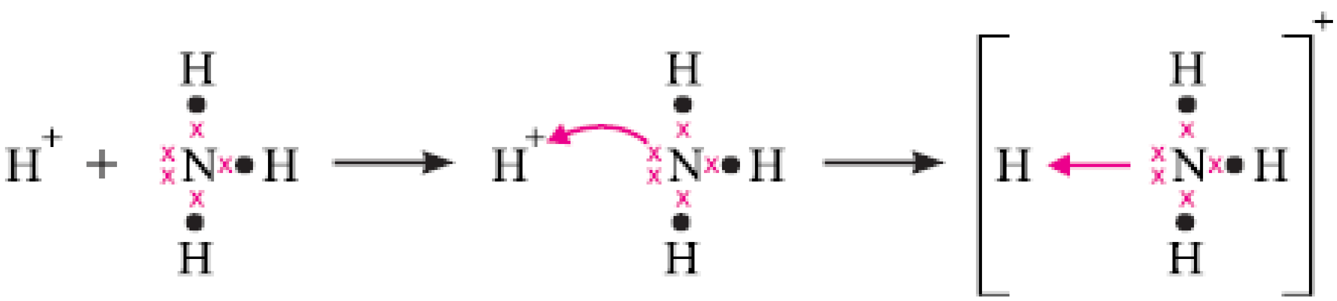
The Arrhenius and Bronsted-Lowry concepts of acids and bases are limited to substances which contain protons. G.N. Lewis (1923) proposed a more general and broader concept of acids and bases. According to this concept:

An acid *is a substance (molecule or ion) which can accept a pair of electrons, while a base is a substance (molecule or ion) which can donate a pair of electrons.*

For example, a reaction between ammonia and boron trifluoride takes place by forming a coordinate covalent bond between ammonia and boron trifluoride by donating an electron pair of ammonia and accepting that electron pair by boron trifluoride.



The cations (proton itself or metal ions) act as Lewis acids. For example, a reaction between $\overset{+}{H}$ and NH_3 , where $\overset{+}{H}$ acts as an acid and ammonia as a base.



The product of any Lewis acid-base reaction is a single specie, called an **adduct.** So, a neutralization reaction according to Lewis concept is donation and acceptance of an electron pair to form a coordinate covalent bond in an adduct.

Acids are electron pair *acceptors* while bases are electron pair donors. Thus, it is evident that any substance which has an unshared pair of electrons can act as a **Lewis base** while a substance which has an empty orbital that can accommodate a pair of electrons acts as **Lewis acid**. Examples of Lewis acids and bases are given below:

Lewis acids. According to Lewis concept, the following species can act as Lewis acids:

(i) *Molecules in which the central atom has incomplete octet*. For example, in BF_3 , $AlCl_3$, $FeCl_3$, the central atoms have only six electrons around them, therefore, these can accept an electron pair.

(ii) *Simple cations can act as Lewis acids*. All cations act as Lewis acids since they are deficient in electrons. However, cations such as Na^+, K^+, Ca^{2+} ions, etc., have a very little tendency to accept electrons. While the cations like H^+, Ag^+ ions, etc., have a greater electron accepting tendency therefore, act as Lewis acids.

Lewis bases. According to Lewis concept, the following species can act as Lewis bases:

(i) Neutral species having at least one lone pair of electrons. For example, ammonia, amines, alcohols etc. act as Lewis bases because they contain a lone pair of electrons:

$$\ddot{N}H_3,\quad R—\ddot{N}H_2,\qquad R—\ddot{\underset{..}{O}}—H$$

(ii) Negatively charged species or anions. For example, chloride, cyanide, hydroxide ions, etc., act as Lewis bases:

$$CN^-,\ Cl^-,\ OH^-,\ \text{etc.}$$

Summary of the Concepts.

Concept	Acid	Base	Product
Arrhenius	give H^+	gives OH^-	salt + H_2O
Bronsted-Lowry	donate H^+	accepts H^+	conjugate acid base pair
Lewis	electron pair acceptor	electron pair donor	adduct


Do you know

It may be noted that all **Bronsted bases are also Lewis bases but all Bronsted acids are not Lewis acids***. According to Bronsted concept, a base is a substance which can accept a proton, while according to Lewis concept, a base is a substance which can donate a pair of electrons. Lewis bases generally contain one or more lone pair of electrons and therefore, they can also accept a proton (Bronsted base). Thus, all Lewis bases are also Bronsted bases. On the other hand, Bronsted acids are those which can give a proton. For example, HCl, H_2SO_4 are not capable of accepting a pair of electrons. Hence, all Bronsted acids are not Lewis acids.*

Test yourself 10.1

1. What is the difference between Arrhenius base and Bronsted-Lowry base?
2. What do you mean by neutralization reaction according to Arrhenius acid-base concept?
3. Prove that water is an amphoteric specie.
4. How can you justify that NH_3 is Bronsted-Lowry base but not Arrhenius base?
5. State and explain the neutralization reaction according to Lewis concept.
6. Define and give the characteristics of a Lewis acid.
7. Why BF_3 behaves as a Lewis acid?
8. Water is an amphoteric specie according to Bronsted- Lowry concept. What is its nature according to Lewis concept?

10.1.4 General Properties of Acids

Physical Properties

Physical properties of acids have been described in the beginning of the chapter.

Chemical Properties

(i) Reaction with Metals

Acids react explosively with metals like sodium, potassium and calcium. However, dilute acids (HCl, H_2SO_4) react moderately with reactive metals like: Mg, Zn, Fe and Al to form their respective salts with the evolution of hydrogen gas.

$$Zn_{(s)} + H_2SO_{4(aq)} \longrightarrow ZnSO_{4(aq)} + H_{2(g)} \uparrow$$

$$2Al_{(s)} + 6HCl_{(aq)} \longrightarrow 2AlCl_{3(aq)} + 3H_{2(g)} \uparrow$$

(ii) Reaction with Carbonates and Bicarbonates

Acids react with carbonates and bicarbonates to form corresponding salts with the evolution of carbon dioxide gas.

$$CaCO_{3(aq)} + 2HCl_{(aq)} \longrightarrow CaCl_{2(aq)} + CO_{2(g)} \uparrow + H_2O_{(l)}$$

$$2NaHCO_{3(aq)} + H_2SO_{4(aq)} \longrightarrow Na_2SO_{4(aq)} + 2CO_{2(g)} \uparrow + 2H_2O_{(l)}$$

(iii) Reaction with Bases

Acids react with bases (oxides and hydroxides of metal and ammonium hydroxide) to form salts and water. This process is called neutralization.

$$NaOH_{(aq)} + HCl_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$$CuO_{(s)} + H_2SO_{4(aq)} \longrightarrow CuSO_{4(aq)} + H_2O_{(l)}$$

(iv) Reaction with Sulphites and Bisulphites

Acids react with sulphites and bisulphites to form salts with the liberation of sulphur dioxide gas.

$$CaSO_{3(aq)} + 2HCl_{(aq)} \longrightarrow CaCl_{2(aq)} + SO_{2(g)}\uparrow + H_2O_{(l)}$$

$$NaHSO_{3(aq)} + HCl_{(aq)} \longrightarrow NaCl_{(aq)} + SO_{2(g)}\uparrow + H_2O_{(l)}$$

(v) Reaction with Sulphides

Acids react with metal sulphides to liberate hydrogen sulphide gas.

$$FeS_{(s)} + H_2SO_{4(aq)} \longrightarrow FeSO_{4(aq)} + H_2S_{(g)}\uparrow$$

Following acids are called mineral acids.
Hydrochloric acid (HCl)
Sulphuric acid (H_2SO_4)
Nitric acid (HNO_3)

Uses of Acids

1. **Sulphuric acid** is used to manufacture fertilizers, ammonium sulphate, calcium superphosphate, explosives, paints, dyes, drugs. It is also used as an electrolyte in lead storage batteries.
2. **Nitric acid** is used in manufacturing of fertilizer (ammonium nitrate), explosives, paints, drugs and etching designs on copper plates.
3. **Hydrochloric** acid is used for cleaning metals, tanning and in printing industries.

4 **Benzoic acid** is used for food preservation.

5 **Acetic acid** is used for flavouring food and food preservation. It is also used to cure the sting of wasps.

Do you know

Naturally Occurring Acids		
	Acid	**Source**
i	Citric acid	Citrus fruits i.e., lemon, oranges
ii	Lactic acid	sour milk
iii	Formic acid	Stings of bees and ants
iv	Butyric acid	Rancid butter
v	Tartaric acid	Tamarind, grapes, apples
vi	Malic acid	Apples
vii	Uric acid	Urine
viii	Stearic acid	Fats

10.1.5 General Properties of Bases

Physical Properties

The physical properties of bases have been described in the beginning of the chapter.

Chemical Properties

(i) Reaction with Acids

Bases react with acid to form salt and water. It is a neutralization reaction.

$$2KOH_{(aq)} + H_2SO_{4(aq)} \longrightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$$

(ii) Reaction with Ammonium Salts

Alkalis react with ammonium salts to liberate ammonia gas:

$$NH_4Cl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + NH_{3(g)}\uparrow + H_2O_{(l)}$$

$$(NH_4)_2SO_{4(aq)} + Ca(OH)_{2(aq)} \longrightarrow CaSO_{4(aq)} + 2NH_{3(g)}\uparrow + 2H_2O_{(l)}$$

Animation 10.3: Acidbase reaction
Source & Credit: lem.ch

(iii) Precipitation of Hydroxides

Alkalis precipitate insoluble hydroxides when added to solutions of salts of heavy metals such as copper, iron, zinc, lead and calcium.

$$CuSO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow \underset{\text{Blue ppt.}}{Cu(OH)_{2(s)}} + Na_2SO_{4(aq)}$$

$$ZnCl_{2(aq)} + 2NaOH_{(aq)} \longrightarrow \underset{\text{White ppt.}}{Zn(OH)_{2(s)}} + 2NaCl_{(aq)}$$

$$FeCl_{3(aq)} + 3NaOH_{(aq)} \longrightarrow \underset{\text{Brown ppt.}}{Fe(OH)_{3\,(s)}} + 3NaCl_{(aq)}$$

$$Pb(NO_3)_{2(aq)} + 2NaOH_{(aq)} \longrightarrow \underset{\text{White ppt.}}{Pb(OH)_{2(s)}} + 2NaNO_{3(aq)}$$

$$CaCl_{2(aq)} + 2NaOH_{(aq)} \longrightarrow \underset{\text{White ppt.}}{Ca(OH)_{2(s)}} + 2NaCl_{(aq)}$$

$$FeSO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow \underset{\text{Dirty Green ppt.}}{Fe(OH)_{2\,(s)}} + Na_2SO_{4(aq)}$$

Uses of Bases

1. **Sodium hydroxide** is used for manufacturing of soap.
2. **Calcium hydroxide** is used for manufacturing of bleaching powder, softening of hard water and neutralizing acidic soil and lakes due to acid rain.
3. **Potassium hydroxide** is used in alkaline batteries.
4. **Magnesium hydroxide** is used as a base to neutralize acidity in the stomach. It is also used for the treatment of bee's stings.
5. **Aluminium hydroxide** is used as foaming agent in fire extinguishers.
6. **Ammonium hydroxide** is used to remove grease stains from clothes.

Test yourself 10.2

1. When acids react with carbonates and bicarbonates, which gas evolves ?
2. Which types of salts produce SO_2 gas on reacting with acids?
3. Give the uses of sulphuric acid.
4. Name the gas liberated when alkalies react with ammonium salts.
5. Write down the colours of the precipitates formed by reaction of aqueous caustic soda with solutions of: copper, zinc and ferric salts.
6. Name an alkali used in alkaline batteries.

Stomach acidity

Stomach secretes chemicals in a regular way to digest food. These chemicals mainly consist of hydrochloric acid along with other salts. Although, hydrochloric acid is highly corrosive, but stomach is protected from its effects because it is lined with cells that produce a base. The base neutralizes stomach acid. The important function of this acid is to break down chemical bonds of foods in the digestion process. Thus, big molecules of food are converted into small ones. It also kills the harmful bacteria of certain foods and drinks.

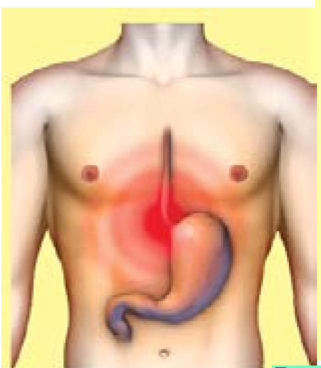
However, sometimes stomach produces too much acid. It causes stomach acidity also called hyperacidity. Symptoms of this disease are feeling burning sensation throughout the gastro intestinal track. These feelings sometimes extend towards the chest, that is called heart burning.

The best prevention from hyperacidity is:

i) Avoiding over-eating and staying away from fatty acids and spicy foods.

ii) Simple and regular eating, remaining in an upright position for about 45 minutes after taking a meal.

iii) Keeping the head elevated while sleeping.



Process of Etching in Art and Industry:

The process of etching on glass is carried out by using a wax stencil. Stencil is placed on areas of glass or mirror that are to be saved from acid. The glass or mirror is dipped into hydrofluoric acid. The acid dissolves the exposed part of the glass thus etching it. This process has been very dangerous because the acid would damage the skin and tissue of artist's body. Although, it is dangerous to deal with acid, yet etching done with acid is very attractive as compared to using other chemicals.

10.2 pH SCALE

Concentration of hydrogen ion $[H^+]$ in pure water is the basis for the pH scale. Water is a weak electrolyte because it ionizes very slightly into ions in a process called auto-ionization or self-ionization;

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

The equilibrium expression of this reaction may be written as

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

As concentration of water (H_2O) is almost constant. The above equation may be written as

$$K_c [H_2O] = [H^+][OH^-]$$

A new equilibrium constant known as ionic product constant of water 'K_w' is used instead of product of equilibrium constant and $[H_2O]$. Therefore,

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25°C$$

As we know, one molecule of water produces one H^+ ion and one OH^-ion on dissociation so

$$[H^+] = [OH^-] \quad \text{Or} \quad [H^+]^2 = 1.0 \times 10^{-14}$$

$$[H^+] = \sqrt{1.0 \times 10^{-14}}$$

$$[H^+] = 1.0 \times 10^{-7}\,M \text{ at } 25°C$$

As it is difficult to deal with such small figures having negative exponents, so it is convenient to convert these figures into a positive figure using a numerical system. It is taking the common (base-10) logarithm of the figure and multiplying it with -1. 'p' before a symbol means' negative logarithm of the symbol. So 'p' before H means negative logarithm of $[H^+]$. Therefore, pH is the negative logarithm of molar concentration of the hydrogen ions. That is,

$$pH = -\log [H^+]$$

With reference to this equation, a scale develops according to the molar concentration of H^+ ions that is called pH scale. It ranges from 0 to 14. According to this scale, pH of water is calculated as:

$$pH = -\log [H^+]$$

$$pH = -\log (1.0 \times 10^{-7}) = 7$$

Similarly

$$pOH = -\log [OH^-]$$

$$pOH = -\log (1.0 \times 10^{-7}) = 7$$

pH value normally varies from 0 to 14. Therefore:

$$pH + pOH = 14$$

So, the sum of the pH and pOH of the solution is always 14 at 25 °C. Such as;

Highly acidic Slightly acidic neutral Slightly basic Highly basic

pH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
pOH	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

A solution of a compound of pH 7 or pOH 7 is considered a neutral solution. Solutions of pH less than 7 are acidic and more than 7 are basic as are also shown in figure 10.1.

More Basic

	$[H_3O+]$	pH	$[OH^-]$	pOH
BASIC	$1x10^{-14}$	14.0	$1x10^{-0}$	0.0
	$1x10^{-13}$	13.0	$1x10^{-1}$	1.0
	$1x10^{-12}$	12.0	$1x10^{-2}$	2.0
	$1x10^{-11}$	11.0	$1x10^{-3}$	3.0
	$1x10^{-10}$	10.0	$1x10^{-4}$	4.0
	$1x10^{-9}$	9.0	$1x10^{-5}$	5.0
	$1x10^{-8}$	8.0	$1x10^{-6}$	6.0
NATURAL	$1x10^{-7}$	7.0	$1x10^{-7}$	7.0
ACIDIC	$1x10^{-6}$	6.0	$1x10^{-8}$	8.0
	$1x10^{-5}$	5.0	$1x10^{-9}$	9.0
	$1x10^{-4}$	4.0	$1x10^{-10}$	10.0
	$1x10^{-3}$	3.0	$1x10^{-11}$	11.0
	$1x10^{-2}$	2.0	$1x10^{-12}$	12.0
	$1x10^{-1}$	1.0	$1x10^{-13}$	13.0
	$1x10^{-0}$	0.0	$1x10^{-14}$	14.0

More acidic

Fig. 10.1 pH scale showing relation among $[H^+]$ and pH & pOH sacle showing relation among $[OH^-]$ and pOH

Since the pH scale is logarithmic, a solution of pH 1 has 10 times higher concentration of $[H^+]$ than that of a solution of pH 2; 100 times than that of a solution of pH 3 and so on. Hence, low pH value means strong acid while high pH value means a strong base and vice versa.

Conclusion

(i) pH of a neutral solution is always 7.
(ii) Acidic solutions have pH less than 7.
(iii) Basic solutions have pH value greater than 7.
(iv) pH and pOH values range from 0 to 14.

Uses of pH

(i) It is used to determine acidic or basic nature of a solution.
(ii) It is used to produce medicines, culture at a microbiological particular concentration of H^+ ion.
(iii) It is used to prepare solutions of required concentrations necessary for certain biological reactions.

10.2.1 Indicators

Indicators are the organic compounds. They have different colours in acidic and alkaline solutions. Litmus is a common indicator. It is red in acidic solutions and blue in alkaline solutions.

Each indicator has a specific colour in acidic medium which changes at a specific pH to another colour in basic medium. For example, phenolphthalein is colourless in strongly acidic solution and red in strongly alkaline solution. It changes colour at a pH of about 9. This means phenolphthalein is colourless in a solution with pH less than 9. If the pH is above 9, phenolphthalein is red as is shown in figure 10.2 .

figure 10.2.

Fig. 10.2. Colours of indicators at different pH solutions

A few commonly used indicators in titrations are given in Table 10.3

Table 10.4 Few important indicators

Indicator	Colour in strongly acidic solution	pH a which colour changes	Colour in strongly alkaline solution
Methyl orange	red	4	Yellow
Litmus	red	7	blue
Phenolphthalein	colourless	9	red

Measuring pH of a Solution

(i) Universal Indicator

Some indicators are used as mixtures. The mixture indicator gives different colours at different pH values. Hence, it is used to measure the pH of a solution. Such a mixed indicator is called Universal Indicator or simply pH indicator. The pH of solution can be measured by dipping a piece of Universal Indicator paper in the solution. The pH is then found by comparing the colour obtained with a colour chart as shown in figure 10.3.

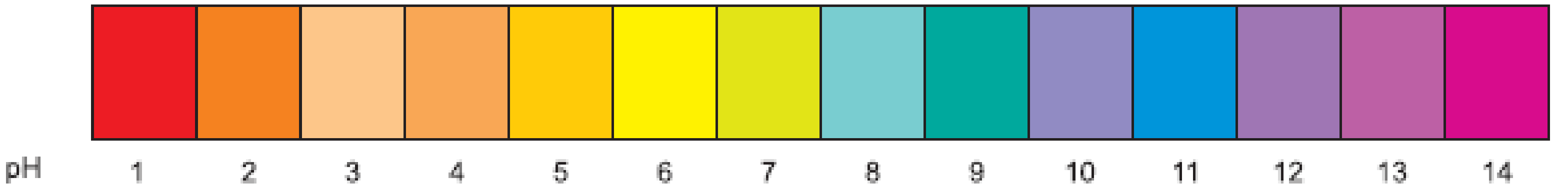
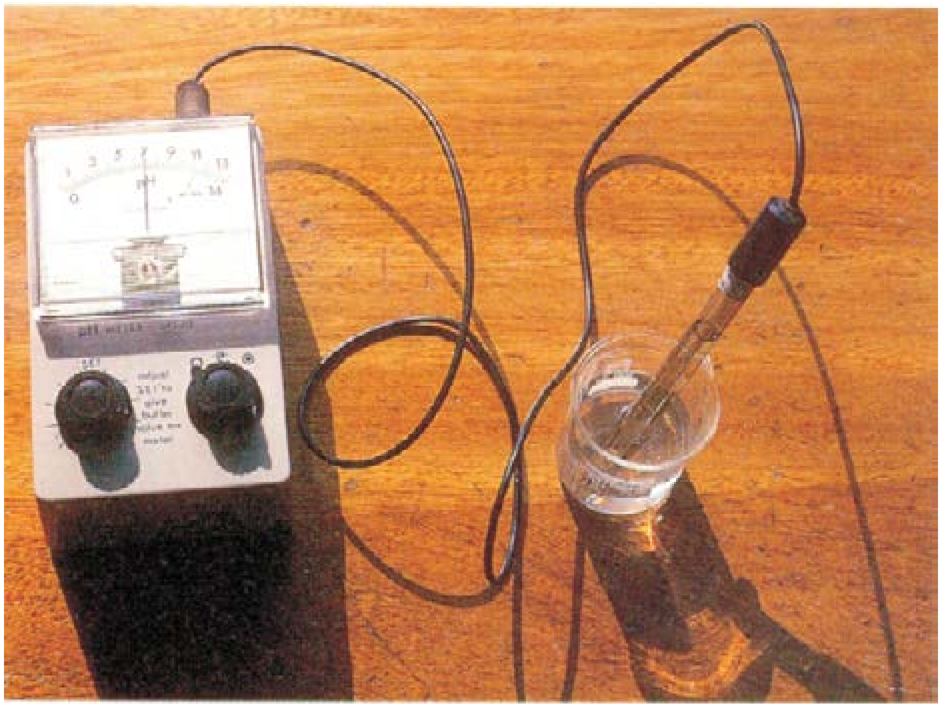


Fig. 10.3. Colours of universal indicator

(ii) The pH Meter

The pH of a solution can be measured with a pH meter. It consists of a pH electrode connected to a meter. The electrode is dipped into the solution and the meter shows the pH either on a scale or digitally. It is much more reliable and accurate method of measuring pH than Universal Indicator paper, though the latter is often more convenient.



Problem 10.2

A solution of hydrochloric acid is 0.01M. What is its pH value?

Solution: Hydrochloric acid is a strong acid so it ionizes completely.

That is: $HCl_{(aq)} \longrightarrow H^+_{(aq)} + Cl^-_{(aq)}$

So, its solution also contains 0.01M H ions, i.e., 10^{-2}M.

$$pH = -\log [H^+]$$

By putting the values of H^+ ions in the above equation:

$$pH = -\log 10^{-2}$$
$$pH = 2$$

Problem 10.3

Find out the pH and pOH of 0.001M solution of KOH?

Solution: Potassium hydroxide solution is a strong base. It ionizes completely such that one mole of KOH gives one mole of OH^- ions.

$$KOH_{(aq)} \longrightarrow K^+_{(aq)} + OH^-_{(aq)}$$

Therefore, 0.001M solution of KOH produces 0.001M OH^- ions.

$$[OH^-] = 0.001\ M \quad \text{or} \quad 10^{-3}\ M$$

$$pOH = -\log 10^{-3} = 3$$

$$pH = 14 - 3 = 11$$

Problem 10.4

Find the pH of 0.01M sulphuric acid?

Solution: Sulphuric acid is a strong dibasic acid. It ionizes completely and its one mole produces 2 moles of hydrogen ions as presented in equation.

$$H_2SO_{4(aq)} \longrightarrow 2H^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

Therefore, 0.01M sulphuric acid will produce 2 x 0.01M hydrogen ions. Hence, hydrogen ions concentration is

$$[H^+] = 2 \times 10^{-2}\ M$$

$$pH = -\log(2 \times 10^{-2}) \qquad = -(\log 2 + \log 10^{-2})$$

$$pH = -\log 2 - \log 10^{-2} \qquad \text{as } -\log 10^{-2} = 2$$

$$pH = 2 - \log 2 \qquad pH = 2 - 0.3 = 1.7$$

Test yourself 10.3

1. *Why pure water is not a strong electrolyte?*
2. *HCl and H_2SO_4 are strong acids. While their solutions are equimolar, they have different pH value as calculated in problem 10.2 and 10.4. Why they have different pH values?*
3. *Why ionic-product constant of water is temperature dependent?*
4. *Differentiate between 'p' and pH.*

Areas of work for analytical chemists.

Analytical chemist examine substances qualitatively and quantitatively. They identify substances and evaluate their properties.

They have a wide area for working ranging from basic research in laboratories to analytical research in industries. They work in almost all industries including manufacturing, pharmaceuticals, healthcare, forensics and public protection - where they test air, water, industrial waste, drugs and food to make sure they are safe. They ensure the quality of the products in industry.

10.3 SALTS

Salts *are ionic compounds generally formed by the neutralization of an acid with a base.*

Salts are made up of positive ions (cations) and negative ions (anions). A cation is metallic ion derived from a base, therefore, it is called basic radical. While anion is derived from an acid, therefore, it is called acid radical.
A salt gets its name from the names of the metal and the acid as shown in Table 10.4.

Table 10.4 Acids and their Salts

Metal	Acid	Salt name
Sodium (Na)	Hydrochloric acid (HCl)	Sodium chloride (NaCl)
Potassium (K)	Nitric acid (HNO_3)	Potassium nitrate (KNO_3)
Zinic (Zn)	Sulphuric acid (H_2SO_4)	Zinc sulphate ($ZnSO_4$)
Calcium (Ca)	Phosphoric acid (H_3PO_4)	Calcium phosphate $Ca_3(PO_4)_2$
Silver (Ag)	Acetic acid (CH_3COOH)	Silver acetate (CH_3COOAg)

Characteristic properties of salts

(i) Salts are ionic compounds found in crystalline form.
(ii) They have high melting and boiling points.
(iii) Most of the salts contain water of crystallization which is responsible for the shape of the crystals. Number of molecules of water are specific for each salt and they are written with the chemical formula of a salt.For example, Copper sulphate $CuSO_4 .5H_2O$; Calcium sulphate $CaSO_4.2H_2O$
(iv) Salts are neutral compounds. Although, they do not have equal number of positive and negative ions, but have equal number of positive and negative charges.

10.3.1 Preparation

Salts may be water soluble or insoluble. The methods used for the preparation of salts are based on their solubility in water.
Salts may be water soluble or insoluble. The methods used for the preparation of salts are based on their solubility in water.

General Methods for the Preparation of Salts

There are five general methods for the preparation of salts. Four methods make soluble salts but one prepares insoluble salts.

(i) Preparation of soluble salts

Soluble salts are often prepared in water. Therefore, they are recovered by evaporation or crystallization.

Animation 10.4: mrtremblaycambridge
Source & Credit: mrtremblaycambridge

(a) By the reaction of an acid and a metal:
(Direct Displacement method)

This is direct displacement method in which hydrogen ion of acid is replaced by a reactive metal. Such as calcium, magnesium, zinc and iron, e.g.

$$\text{Acid} + \text{Metal} \longrightarrow \text{Salt} + \text{Hydrogen gas}$$

$$2HCl_{(aq)} + Mg_{(s)} \longrightarrow MgCl_{2(aq)} + H_{2(g)}$$

(b) By the reaction of an acid and a base:
(Neutralization method)

It is a neutralization reaction in which acid and base react to produce a salt and water.

Animation 10.5: Titolazione
Source & Credit: wikipedia

$$\text{Acid} + \text{Base} \longrightarrow \text{Salt} + \text{Water}$$

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

(c) By the reaction of an acid and metallic oxide:

Mostly the insoluble metallic oxides react with dilute acids to form salt and water

$$\text{Acid} + \text{Metallic oxide} \longrightarrow \text{Salt} + \text{Water}$$

$$H_2SO_{4(aq)} + CuO_{(s)} \longrightarrow CuSO_{4(aq)} + H_2O_{(aq)}$$

(d) By the reaction of an acid and a carbonate:

Dilute acids react with metallic carbonates to produce salts, water and carbon dioxide gas.

$$2HNO_{3(aq)} + Na_2CO_{3(aq)} \longrightarrow NaNO_{3(aq)} + H_2O_{(l)} + CO_{2(g)}$$

(ii) Preparation of insoluble salts

In this method, usually solutions of soluble salts are mixed. During the reaction exchange of ionic radicals (i.e., metallic radicals exchange with acidic radicals) takes place to produce two new salts. One of the salts is insoluble and the other is soluble. The insoluble salt precipitates (solidify in solution).

$$AgNO_{3(aq)} + NaCl_{(aq)} \longrightarrow AgCl_{(s)} + NaNO_{3(aq)}$$

$$Na_2CO_{3(aq)} + CuSO_{4(aq)} \longrightarrow CuCO_{3(s)} + Na_2SO_{4(aq)}$$

1. How are the salts named?
2. Name the salts which are formed when Zn metal reacts with following acids.
   a. nitric acid b. phosphoric acid c. acetic acid
3. How will you justify salts are neutral compounds?
4. How many water of crystallizations are present in $CuSO_4 . 5H_2O$ and $CaSO_4 .2H_2O$?
5. Name the type of reaction that takes place between an acid and a metal. Which gas would evolve in the reaction? Explain with an example.

10.3.2 Types of Salts

Following are the main classes of salts.

(i) Normal salts (ii) Acidic salts
(iii) Basic salt (iv) Double salts
(v) Mixed salts (vi) Complex salts

(i) Normal or Neutral Salts

A salt formed by the total replacement of ionizable H^+ ions of an acid by a positive metal ion or NH^+_4 ions is called normal or neutral salt. These salts are neutral to litmus, that is,

$$HCl_{(aq)} + KOH_{(aq)} \longrightarrow KCl_{(aq)} + H_2O_{(l)}$$

$$H_2SO_{4(aq)} + ZnO_{(s)} \longrightarrow ZnSO_{4(aq)} + H_2O_{(l)}$$

$$H_3PO_{4(aq)} + 3NaOH_{(aq)} \longrightarrow Na_3PO_{4(aq)} + 3H_2O_{(l)}$$

$$HNO_{3(aq)} + NH_4OH_{(aq)} \longrightarrow NH_4NO_{3(aq)} + H_2O_{(l)}$$

(ii) Acidic Salts

These salts are formed by partial replacement of a replaceable H^+ ions of an acid by a positive metal ion.

$$H_2SO_{4(aq)} + KOH_{(aq)} \longrightarrow KHSO_{4(aq)} + H_2O_{(l)}$$

$$H_3PO_{4(aq)} + NaOH_{(aq)} \longrightarrow NaH_2PO_{4(aq)} + H_2O_{(l)}$$

These salts turn blue litmus red.
Acidic salts react with bases to form normal salts.

$$KHSO_{4(aq)} + KOH_{(aq)} \longrightarrow K_2SO_{4(aq)} + H_2O_{(l)}$$

$$NaH_2PO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow Na_3PO_{4(aq)} + 2H_2O_{(l)}$$

(iii) Basic Salts

Basic salts are formed by the incomplete neutralization of a polyhydroxy base by an acid.

$$Al\,(OH)_{3(s)} + HCl_{(aq)} \longrightarrow Al\,(OH)_2\,Cl_{(aq)} + H_2O_{(l)}$$

$$Pb\,(OH)_{2(s)} + CH_3COOH_{(aq)} \longrightarrow Pb\,(OH)\,CH_3COO_{(aq)} + H_2O_{(l)}$$

$$Zn\,(OH)_{2(s)} + HNO_{3(aq)} \longrightarrow Zn\,(OH)\,NO_{3(aq)} + H_2O_{(l)}$$

These salts further react with acids to form normal salts.

$$Al(OH)_2Cl_{(aq)} + HCl_{(aq)} \longrightarrow Al(OH)Cl_{2(aq)} + H_2O_{(l)}$$

$$Al(OH)Cl_{2(aq)} + HCl_{(aq)} \longrightarrow AlCl_{3(aq)} + H_2O_{(l)}$$

$$Pb(OH)CH_3COO + CH_3COOH_{(aq)} \longrightarrow Pb(CH_3COO)_{2(aq)} + H_2O_{(l)}$$

$$Zn(OH)NO_{3(aq)} + HNO_{3(aq)} \longrightarrow Zn(NO_3)_{2(aq)} + H_2O_{(l)}$$

(iv) Double Salts

Double salts are formed by two normal salts when they are crystallized from a mixture of equimolar saturated solutions. The individual salt components retain their properties. The anions and cations give their respective tests. Mohr's salt $FeSO_4$ $(NH_4)_2SO_4\,6H_2O$; Potash alum $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$; Ferric alum $K_2SO_4 \cdot Fe_2(SO_4)_3 \cdot 24H_2O$, are examples of double salts.

(v) Mixed Salts

Mixed salts contain more than one basic or acid radicals. Bleaching powder Ca(OCl) CI, is an example of mixed salts.

(vi) Complex Salts

Complex salts on dissociation provides a simple cation and a complex anion or vice versa. Only the simple ions yields the characteristics test for cation or anion. For example:

Potassium ferrocyanide $K_4[Fe(CN)_6)$ gives on ionization, a simple cation K^+ and complex anion $[Fe(CN)_6]^{-4}$.

10.3.3 Uses of Salts

Salts have vast applications in industries and in our daily life. Some common salts and their uses are given in Table 10.5;

Table 10.5 Uses of Salts

Name of salts	Common and Industrial Uses
Sodium chloride (NaCl)	It is commonly used as a table salt and for cooking purposes, it is also used for de-icing roads in winter and for the manufacture of sodium metal, caustic soda, washing soda.
Sodium carbonate Na_2CO_2) Soda ash	It is used for the manufacture of glass, detergents, pulp and paper and other chemicals.
Sodium carbonate Na_2CO_3, $10H_2O$) Washing soda	It is used as cleaning agent for domestic and commercial purposes, for softening of water, in manufacture of chemicals like caustic soda (NaOH), borax, glass, soap and paper.
Sodium sulphate (Na_2SO_4)	It is used for the manufacture of glass, paper and detergents.
Sodium silicate (Na_2SiO_3)	It is used for the manufacture of detergents, cleaning agents and adhesives.
sodium chlorate ($NaClO_3$)	It is used for manufacture of explosives, plastics and other chemicals.
Sodium tetraborate ($Na_2B_4O_{7.}$ $10H_2O$)	It is used for manufacture of heat resistance glass (pyrex), glazes and enamels, in leather industry for soaking and cleaning hides.
Calcium chloride ($CaCl_2$)	It is used for de-icing roads in winter, as a drying agent of chemical reagents and as freezing agent.
Calcium oxide (CaO) Quick lime	It is used as drying agent for gases and alcohol and in steel making, water treatment and other chemicals like slaked lime, bleaching powder, calcium carbide. For purification of sugar, a mixture of CaO and NaOH called soda lime is used to remove carbon dioxide and water vapours from air.
Calcium sulphate ($CaSO_4$. $2H_2O$)	Gypsum is used as fertilizer, to prepare plaster of Paris which is used for making statues, casts, etc.
Potassium Nitrate (KNO_3)	It is used as fertilizer and for the manufacture of flint glass.

Neutralization Reaction

A reaction between an acid and a base is called a neutralization reaction. It produces a salt and water. A few balanced chemical reactions are given here:

$$\text{Acid} + \text{Base} \longrightarrow \text{Salt} + \text{Water}$$

$$HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

$$H_2SO_{4(aq)} + 2NaOH_{(aq)} \longrightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$$

$$CH_3COOH_{(aq)} + NaOH_{(aq)} \longrightarrow CH_3COONa_{(aq)} + H_2O_{(l)}$$

Interesting Information

Your tears, perspiration and blood taste salty not because of you eat common salt every day rather your body contains other salts that give salty taste to your tears, perspiration and blood.

Test yourself 10.5

1. *Name the types of salts.*
2. *H_3PO_4 is a weak acid but its salt (Na_3PO_4) with strong base NaOH is neutral. Explain it.*
3. *How does the basic salts turns into normal salts? Explain with an example.*
4. *What are complex salts?*
5. *Na_2SO_4 is a neutral salt. What are its uses?*

SOCIETY TECHNOLOGY SCIENCE

Preservatives in food

Chemicals used to prevent food spoilage are called preservatives. Food spoiling may be due to microbial actions or chemical reactions. So preservatives serve as either anti-microbial or antioxidants or both.

Manufacturers add preservatives mostly to prevent spoiling during transportation and storage of foods for a period of time.

Natural food preservatives are salts, sugar, alcohol, vinegar, etc. They efficiently control the growth of bacteria in food. They are used to preserve meat, fish, etc.

Acid Rain

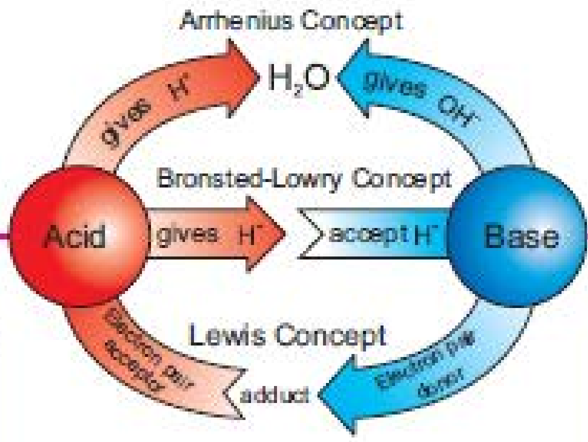
Acid rain is formed by dissolving acidic air pollutants like oxides of sulphur and nitrogen by rain water. As a result pH of the rain water decreases, i.e., it becomes acidic. When this acid rain falls down, it damages animals, plants, buildings, water bodies and even soil.

Key Points

- Strong acids or bases ionize completely in water while weak acids and bases ionize partially.
- According to Arrhenius concept, acids produce H^+ ions in aqueous solution while bases produce OH^- ions in aqueous solution.
- According to Bronsted-Lowry concept, acid are proton donor and bases are proton acceptor, so this concept is applicable to non-aqueous solutions.
- A substance that can behave as an acid as well as base depending upon the nature of other substances is called amphoteric.
- According to Lewis concept; acids are electron pair acceptors and bases are electron pair donors.
- The product of any Lewis acid base reaction is a single specie called adduct.
- "p" scale is the conversion of very small figures into positive figures by taking the common logarithm of the small figure and multiplying it with-1.
- pH scale is the negative logarithm of concentration of hydrogen ions.
- A substance having pH less than 7 is acidic while a substance having pH more than 7 is basic. A substance of pH 7 is called neutral.
- Salts are ionic compounds made up of metallic cation and non-metallic anion.
- Different methods for the preparation of soluble and insoluble salts have been discussed.
- Normal salts are made up of cations of strong bases and anions of strong acids.
- Acidic salts are made up of cations of weak bases and anions of strong acids.

CONCEPT DIAGRAM

Three Concepts of Acids and Bases



Acid reacts with:
- metals
- carbonates and bicarbonates
- bases
- sulphites and bisuphites
- suphides

Base reacts with:
- acids
- ammonium salts
- precipitates as hydroxides

pH & pOH determine nature of compounds, such as acidic, basic or neutral

SALTS Formation

Soluble salts are prepared by a reaction of
- an acid with metals
- an acid with a bases
- an acid with metallic oxides
- an acid with carbonates

Insoluble salts are prepared by mixing solutions of soluble salts

Types of salts:
- Normal salts
- Acidic salts
- Basic salts
- Double salts
- Mixed salts
- Complex salts

Short Questions

1. Name three common household substances having
   a. pH value greater than 7
   b. pH value less than 7
   c. pH value equal to 7
2. Define a base and explain that all alkalies are bases, but all bases are not alkalies.
3. Define Bronsted-Lowry base and explain with an example that water is a Bronsted-Lowry base.
4. How can you justify that Bronsted-Lowry concept of acid and base is applicable to non-aqueous solutions?
5. Which kind of bond is formed between Lewis acid and a base?
6. Why H^+ ion acts as a Lewis acid?
7. Name two acids used in the manufacture of fertilizers.
8. Define pH. What is the pH of pure water?
9. How many times a solution of pH 1 will be stronger than that of a solution having pH 2?
10. Define the followings:
    i. Normal salt ii. Basic salt
11. Na_2SO_4 is a neutral salt while $NaHSO_4$ an acid salt. Justify.
12. Give a few characteristic properties of salts.
13. How are the soluble salts recovered from water?
14. How are the insoluble salts prepared?
15. Why is a salt is neutral, explain with an example?
16. Name an acid used in the preservation of food.
17. Name the acids present in:
    i. Vinegar ii. Ant sting
    iii. Citrus fruit iv. Sour milk
18. How can you justify that $Pb(OH)NO_3$ is a basic salt?
19. You are in a need of an acidic salt. How can you prepare it?
20. Which salt is used to prepare plaster of Paris?

Extensive Questions:

1. Define an acid and a base according to Bronsted-Lowry concept and justify with examples that water is an amphoteric compound.
2. Explain the Lewis concept of acids and bases.
3. What is auto-ionization of water? How is it used to establish the pH of water?
4. Define a salt and give the characteristic properties of salts.
5. Explain with examples how are soluble salts prepared?
6. Give the characteristics of an acidic salt.
7. Give four uses of calcium oxide.
8. You are having a strong acid (HNO_3) and strong base (NaOH) on mixing
   i. What type of salt you will have?
   ii. What type of reaction will it be?
   iii. Will it be soluble or insoluble salt?
   iv. If it is soluble, how will it be recovered?
9. Explain why:
   i. HC1 forms only one series of salts.
   ii. H_2SO_4 forms two series of salts.
   iii. H_3PO_4 form three series of salts.

Give necessary equations.

10. Classify the following salts as soluble or insoluble salts:

i. Sodium chloride	ii. Silver nitrate
iii. Lead chloride	iv. Copper sulphate
v. Barium sulphate	vi. Ammonium chloride
vii. Sodium carbonate	viii. Calcium carbonate
ix. Ferric chloride	x. Magnesium sulphate

11. Complete and balance the following equations:
   i. Aluminium + Hydrochloride acid $\longrightarrow$
   ii. Copper oxide + Sulphuric acid $\longrightarrow$
   iii. Iron sulphide + Sulphuric acid $\longrightarrow$
   iv. Ammonium chloride + Sodium hydroxide $\longrightarrow$
   v. Ferric chloride + Sodium hydroxide $\longrightarrow$

Numericals

1. Calculate the pH and pOH of 0.2 M H_2SO_4?
2. Calculate the pH of 0.1 M KOH?
3. Calculate the pOH of 0.004 M HNO_3?
4. Complete the following Table.

Solution	$[H^+]$	[OH]	[pH]	[pOH]
(i) 0.15 M HI				
(ii) 0.040 M KOH				
(iii) 0.020 M $Ba(OH)_2$				
(iv) 0.00030 M $HClO_4$				
(v) 0.55 M NaOH				
(iv) 0.055 M HCl				
(vii) 0.055 M $Ca(OH)_2$				