ACIDS, BASES AND SALTS–CLASS 10

The word 'acid' is derived from the Latin acere, meaning sour. Acids are sour. Lemon and other citrus fruits contain citric acid. Mild turns sour due to lactic acid. We know that many nonmetal oxides, e.g., SO_2, SO_3, NO_2, N_2O_5 and CO_2 are acidic oxides and form acids with water. Sulphuric, hydrochloric and nitric acids are generally called mineral acids. They are also the common laboratory acids.

The word 'base' is not related to taste. All bases taste bitter. Most metal oxides and hydroxides, e.g., MgO, CaO and $Mg(OH)_2$ are bases. Ammonia is also a base. The odour of fishes is due to trimethyl amine, an organic base similar to ammonia. Bases which are soluble in water are called alkalis, e.g., NaOH and KOH.

Acids combine with bases to form salts. For example, hydrochloric acid reacts with sodium hydroxide to form sodium chloride the most well known salt.

The classical or molecular theory of acids, bases and salts

Lavoisier studied sulphuric acid and nitric acids and believed that oxygen was an essential constituent of acids. Davy, however, showed that hydrochloric acid does not contain oxygen. Soon, other acids which do not contain oxygen were found, like hydrobromic acid and hydroiodic acid. In 1838, Liebig suggested that all acids contain hydrogen, which may be replaced by metals to form salts. For example, NaCl is the salt formed by the replacement of the hydrogen of hydrochloric acid by sodium.

Acids

An acid is a compound that contains hydrogen atoms(s) which can be wholly or partially replaced by metal atom(s) or positive radical(s).

Examples

1. HCl is an acid as it contains an H atom which can be replaced by Na to give NaCl or by the NH_4^+ radical to give NH_4Cl.
2. H_2SO_4 is an acid as it contains two H atoms which can be wholly or partially replaced to give Na_2SO_4 or $NaHSO_4$ respectively.

Acids can be divided into two types on the basis of their occurrence -

1. Natural acids
2. Mineral acids.

Natural Acid - Acids which are obtained from natural sources are called natural acid or organic acid.

Commonly found organic acids	Their natural sources
Citric acid	Orange, lemon
Tartaric acid	Tamarinds, grapes
Lactic acid	Curd/ sour milk
Oxalic acid	Tomatoes
Acetic acid	Ketchup, vinegar
Formic acid	Ant sting, nettle leaf sting

Mineral Acids - Mineral acids are man-made acids in the lab, such as hydrochloric acid (HCl), sulphuric acid (H_2SO_4), nitric acid (HNO_3), etc.

General Characteristics of acids

All acids have some common characteristics.

1. They have a sour taste.
2. They turn blue litmus red.
3. Their aqueous solutions conduct electricity.
4. Metals react with acids to give hydrogen gas and the corresponding metal salt. Nitric acid, HNO_3 is one acid which does not give hydrogen with any metal except magnesium and manganese.

$$2HCl + Mg \rightarrow MgCl_2 + H_2 \uparrow$$
$$H_2SO_4 + Zn \rightarrow ZnSO_4 + 2H_2 \uparrow$$

5. Acids produce CO_2 gas with carbonates and hydrogen carbonates (also called bicarbonates). CO_2 evolves with effervescence.
$$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2 \uparrow$$
$$NaHCO_3 + H_2SO_4 \rightarrow 4Na_2SO_4 + H_2O + CO_2 \uparrow$$
$$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2 \uparrow$$

6. Metal sulphites give SO_2 gas with effervescence of being treated with acids.
$$Na_2SO_3 + 2HCl \rightarrow 2NaCl + H_2O + SO_2 \uparrow$$
$$Na_2SO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + SO_2 \uparrow$$

7. Metal sulphides give H_2S gas with acids. It may be identified by its smell of rotten eggs.
$$Na_2S + 2HCl \rightarrow 2NaCl + H_2S \uparrow$$
$$Na_2S + H_2SO_4 \rightarrow Na_2SO_4 + H_2S \uparrow$$

8. Acids react with metallic oxides to form salt and water
$$2HNO_3 + ZnO \rightarrow Zn(NO_3)_2 + H_2O$$
$$2HCl + CuO \rightarrow CuCl_2 + H_2O$$

Bases

Bases are compounds t hat react with acids to form salts, usually accompanied by water.
In general, bases are oxides and hydroxides of metals. Ammonia and some related compounds are also bases.

Examples

1. Na_2O is a base as it reacts with acids to form salts and water.
$$Na_2O + 2HCl \rightarrow 2NaCl + H_2O$$
$$Na_2O + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$$
Base Acid Salt Water

2. $Ca(OH)_2$ is a base as it reacts with acids to form salts and water.
$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$$

3. NH_3 is a base as it reacts with acids to give salts.
$$NH_3 + HCl \rightarrow NH_4Cl$$
$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$
Base Acid Salt

Alkalis

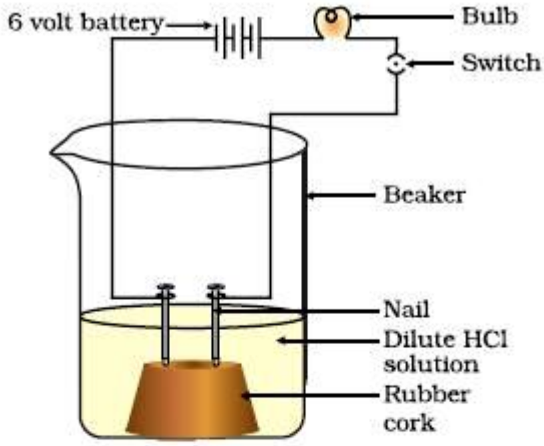
Soluble bases are called alkalis.
NaOH, KOH, $Ba(OH)_2$ and NH_4OH are examples of alkalis. But $Mg(OH)_2$, $Al(OH)_3$, $Fe(OH)_2$, $Fe(OH)_3$, $Cu(OH)_2$, $Zn(OH)_2$ being insoluble bases, are not alkalis.

General Characteristics of Bases

Bases have the following general properties.
1. Alkali solutions feel slippery.
2. Alkalis turn red litmus blue.
3. Bases in the molten state or in aqueous solutions conduct electricity.
4. Some metals, e.g., Zn, Al and Sn, give hydrogen gas when boiled with alkalis.
$$Zn + 2NaOH \rightarrow Na_2ZnO_2 + H_2 \uparrow$$
$$2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2 \uparrow$$
$$Sn + 2NaOH \rightarrow Na_2SnO_2 + H_2 \uparrow$$
5. On heating, bases decompose into metal oxides and water.
$$Cu(OH)_2 \rightarrow CuO + H_2O$$
$$2Fe(OH)_3 \rightarrow Fe_2O_3 + 3H_2O$$
6. Alkalis give ammonia gas on being heated with ammonium salts.
$$(NH_4)_2SO_4 + 2KOH \rightarrow 2NH_3 + K_2SO_4 + 2H_2O$$
$$NH_4Cl + NaOH \rightarrow 2NH_3 + NaCl + H_2O$$
7. Bases react with acids to form salt and water

$NaOH + HCl \rightarrow NaCl + H_2O$
$KOH + HNO_3 \rightarrow KNO_3 + H_2O$
$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$
$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 + 2H_2O$

Conduction of Electricity in Acids/Bases -
Take solution of hydrochloric acid (HCl).
Fix two nails on a cork, and place the cork in a beaker.
Connect the nails to the two terminals of a 6 volt battery through a bulb and a switch.
Now pour some dilute HCl in the beaker and switch on the current.
What do you observe?



Bulb will start glowing.
It indicates that there is flow of electricity in HCl solution.
When we pour some dilute hydrochloric acid in a beaker, it gets ionized and produces hydrogen ions (H^+) and chloride ions (Cl^-)

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

Hydrogen ions react with water and make hydronium ions.

$H^+ + H_2O \rightleftharpoons H_3O^+$

These chloride and hydronium ions can move in solution to conduct electricity.
You can repeat the same activity with other acids and bases.
Acid and base solution can conduct electricity due to formation of mobile ions. Therefore, acid and base solutions are called electrolytes.

The basicity of an acid

The number of replaceable hydrogen atoms in molecule of an acid is known as the basicity of the acid.
HCl and HNO_3 have a basicity of 1 as each of them contains only one replaceable H atom. Therefore, they are said to be monobasic. H_2SO_4 has a basicity of 2 and is therefore said to be dibasic. H_3SO_4 has a basicity of 2 and is therefore said to be dibasic. H_3PO_4 (basicity = 3) is a tribasic acid.
The types of salts formed by an acid depend upon its basicity. For example, a monobasic acid like HCl will form only one type of salt, such as NaCl or KCl, but a dibasic acid like H_2SO_4 has a basicity of 2 and is therefore said to be dibasic. H_3PO_4 will form two types of salts, e.g., $NaHSO_4$ and Na_2SO_4. We will discuss this little later. However, it is apparent at this stage that the classification of acids according to basicity is useful.

Monobasic acids (basicity = 1)

Examples: HCl, HBr, HI, H_3PO_2, HNO_3, $HClO_3$ (hypochlorous acid), $HClO_4$ (perchloric acid), HCOOH (formic acid), CH_3CHOOH (acetic acid).

Polybasic acids (basicity ≥ 2)

Dibasic acids (basicity = 2)

Examples: H_2SO_4, H_3PO_3, H_2CO_3, $(COOH)_2$ (oxalic acid).

Tribasic acids (basicity = 3)

Example: H_3PO_4

Tetrabasic acids (basicity = 4)

Example: H_4SiO_4 (silicic acid)

Acidity of Bases

The acidity of base is the number of hydroxyl groups which a molecule of it can lose on reaction with an acid to form salt(s).

Thus NaOH or KOH, which loses one hydroxyl groups on reaction with an acid, has an acidity of 1 and is, therefore, called a monoacidic base. $Ca(OH)_2$ is a diacidic base and $Fe(OH)_3$, a triacidic base.
It is useful to classify bases according to acidity – bases of differing acidities from different kinds of salts.

Monoacidic Bases (acidity = 1)

Examples: NaOH, KOH, NH_4OH

Diacidic Bases (acidity = 2)

Examples: $Mg(OH)_2$, $Ca(OH)_2$, $Ba(OH)_2$, $Fe(OH)_2$, $Cu(OH)_2$.$Zn(OH)_2$

Triacidic Bases (acidity = 3)

Examples: $Fe(OH)_3$, $Al(OH)_3$, $Cr(OH)_3$ (the maximum acidity has been found to be 3).
In case the base is an oxide of a metal, you should consider the hydroxide of the same metal in the same valence state for calculating the acidity. For example, Na_2O will have the acidity 1 as its hydroxide is NaOH. Similarly the acidity of CaO, CuO and FeO is 2 as the corresponding hydroxides are $Ca(OH)_2$, $Cu(OH)_2$ and $Fe(OH)_2$. And the acidity of Al_2O_3 and Fe_2O_3 is 3 as the corresponding hydroxides are $Al(OH)_3$ and $Fe(OH)_3$.

The Modern Theories of Acids, Bases and Salts
Arrhenius's Theory

The first major breakthrough in the understanding of the chemical nature of acids, bases and salts came with the ionic theory given by the Swedish chemist Svante Arrhenius. In 1884, Arrhenius proposed that salts dissociate into positive and negative ions in aqueous solutions. In 1887, he extended his theory to include acids and bases.

Acids: Acids are substances which dissociate in aqueous solutions to give the hydrogen ion, H^+.
Thus, HCl, H_2SO_4 are acids because they dissociates in an aqueous solution to give H^+ ions.

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

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{-2}$$

An acid of the general formula HA dissociates s follows.

$$HA \rightarrow H^+ + A^-$$

Strong acids and Weak acids

The dissociation may be complete or partial, giving rise to two categories of acids, – strong and weak.

1. Strong acids: Acids which dissociate practically completely into H^+ ions in aqueous solutions are called strong acids.

For example, mineral acids are strong acids as they dissociate almost completely into H^+ ions in aqueous solutions. Unidirectional arrows are used while representing such dissociations.

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

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{-2}$$

$$HNO_3 \rightarrow H^+ + NO_3^-$$

2 Weak acids: Acids which dissociate only to a small extent into H^+ ions in aqueous solutions are known as weak acids.
Organic acids in general and many inorganic acids, like H_2CO_3, dissociate only partially and to a small extent into H^+ ions. Out of every 100 molecules of the acid taken, 10, 20, or 30 may dissociate into H^+ ions and the rest remains as molecules. Such dissociations are shown using signs of reversibility.

$$HA \rightleftharpoons H^+ + A^-$$

$$CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$$

$$H_2CO_3 \rightleftharpoons 2H^+ + CO_3^{-2}$$

Bases

Bases are substances which dissociate in a aqueous solutions to give hydroxide ions(s), OH^-.

For example, sodium hydroxide, potassium hydroxide and barium hydroxide are bases because they dissociate to give OH^-.

$$NaOH \rightleftharpoons Na^+ + OH^-$$
$$KOH \rightleftharpoons K^+ + OH^-$$
$$Ba(OH)_2 \rightleftharpoons Ba^{+2} + 2OH^-$$

A base of the general formula $M(OH)_n$ dissociates as follows.

$$M(OH)_n \rightleftharpoons M^{+n} + nOH^-$$

The dissociation may again be complete or partial, giving rise to two categories of base – strong and weak.

1. Strong Bases: Bases which dissociate almost completely to give OH^- ions in aqueous solution are called bases.
For example, NaOH, KOH and $Ba(OH)_2$ are strong bases as they are almost completely dissociated.

$$NaOH \rightleftharpoons Na^+ + OH^-$$
$$KOH \rightleftharpoons K^+ + OH^-$$
$$Ba(OH)_2 \rightleftharpoons Ba^{+2} + 2OH^-$$

2. Weak bases: The bases which dissociate only to a small extent to give OH^- ions in aqueous solution are known as weak bases.

Ammonium hydroxide and sparingly soluble metal oxides and hydroxides, e.g. $Zn(OH)_2$, $Al(OH)_3$, etc., are weak bases as they dissociate only to a small extent to give OH^- ions.

$$NH_4OH \rightleftharpoons NH_4^+ + OH^-$$
$$Zn(OH)_2 \rightleftharpoons Zn^{+2} + 2OH^-$$
$$Al(OH)_3 \rightleftharpoons Al^{+3} + 3OH^-$$

It is obvious that the lower the solubility, the weaker is the base.

Strengths of acids and bases

Arrhenius's theory gives us a clue to knowing the relative strengths of acids and bases.

Acids: The greater the extent to which an acid dissociates into H^+ ions in an aqueous solution, the stronger is the acid.

Thus a mineral acid like HCl, HNO_3 or H_2SO_4 is a stronger acid than H_2CO_3 or an organic acid like CH_3CHOOH. This is because a mineral acid dissociate completely into H^+ ions in an aqueous solution whereas H_2CO_3 or CH_3COOH does so only to a small extent.

Bases: The greater the extent to which a base dissociates into OH^- ions in aqueous solution, the stronger is the base.
Thus NaOH is a stronger base than NH_4OH as NaOH dissociates into OH^- ions to a much greater extent than NH_4OH.

Strong acids

Mineral acids like HCl, HNO_3, H_2SO_4 and HI, $HClO_4$.

Weak acids

1. Organic acids, e.g., acetic acid (CH_3COOH), formic acid (HCOOH) and oxalic acid ($C_2H_2O_4$).
2. H_2CO_3 (carbonic acid), H_3PO_4 (phosphoric acid), H_3PO_3 (phosphorus acid).

Strong Bases

1. Alkali metal oxides and hydroxides Na_2O, K_2O, NaOH, KOH.
2. Some alkaline earth metal oxides and hydroxides CaO, BaO, $Ca(OH)_2$, $Ba(OH)_2$.

Weak Bases

1. Some metal oxides and hydroxides MgO, Al_2O_3, FeO, Fe_2O_3, CuO, ZnO, $Mg(OH)_2$, $Al(OH)_3$, $Zn(OH)_2$, $Fe(OH)_2$, $Fe(OH)_3$, $Cu(OH)_2$, $Zn(OH)_2$.

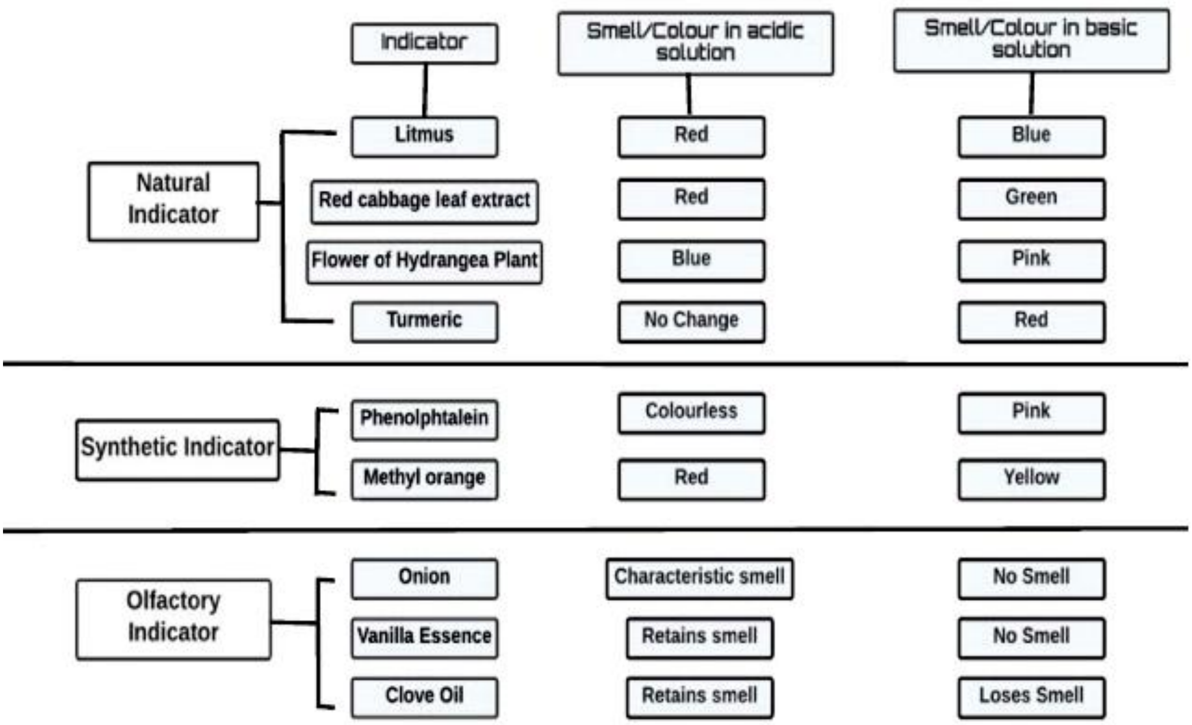
Indicators

Indicators are substances which change their colour/smell in different nature of the solutions.

Types of Indicators

(1) Natural indicators: These are found in certain colouring plants. E.g.: Litmus, red cabbage leaves extract, flowers of hydrangea and turmeric plants.
(2) Synthetic indicators: These are chemical substances. E.g.: methyl orange, phenolphthalein, etc.
(3) Olfactory indicators: These are the substances which give out different odours in different natured solutions.

Colour	Dark Red	Red	Red	Orange Red	Orange	Orange yellow	Greenish yellow	Green	Greenish blue	Blue	Navy blue	Purple	Dark purple	Violet	Violet
pH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14



Salts

Arrhenius proposed that when salts dissolve in water, they dissociate into positive and negative particles called ions. For example, NaCl dissociates into Na^+ and Cl^- ions in an aqueous solution.

$$NaCl \rightarrow Na^+ + Cl^-$$

As we know, salts formed by neutralisation reactions between acids and bases. Every salt has one part derived from a base and the other derived from an acid. When a salt dissociates in water, the part that has come from a base forms a cation (positive ion) and the one derived from an acid forms an anion (negative ion). The charges on the cation and the anion are equal to their respective valencies. You must bear in mind that the total charge on the cation and the anion must balance, i.e., add up to zero. The following examples will make this clear.

Examples:

$BaCl_2 \rightarrow Ba^{+2} + 2Cl^-$ (The charge on one Ba^{++} ions is balanced by the charges on 2 Cl^- ions.)

$Na_2SO_4 \rightarrow 2Na^+ + SO_4^{-2}$ (The charge on one SO_4^{2-} ion is balanced by that on $2Na^+$ ions.)

$$Al_2(SO_4)_3 \rightarrow 2Al^{+3} + 3SO_4^{-2}$$

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

Limitations of Arrhenius Concept

i) It is applicable only to aqueous solutions. For the acidic or basic properties, the presence of water is absolutely necessary. Dry HCl shall not act as an acid.

ii) The concept does not explain acidic or basic properties of acidic and bases in non–aqueous solvents respectively.

iii) It fails to explain the acidic nature of the non–protic compounds such as SO_2, NO_2, CO_2, P_2O_5, etc., which do not have hydrogen for furnishing H^+ ions.

iv) If fails to explain the basic nature of compounds like NH_3, Na_2CO_3, etc., which do not have OH in the molecule to furnish OH^- ions.

v) It fails to explain the acidic nature of certain salts such as $AlCl_3$ in aqueous solution.

Illustration 1: ***Which of the following is an acid?*** ***NH_3, NH_2OH, NH_4OH, HN_3.***

Solution: HN_3 is hydrazoic acid. Where as remaining all are bases.

Illustration 2: ***What is the basicity of the following acids?***
(a)CH_3COOH (b) $H_3 PO_2$ (c)$H_3 PO_3$ (d)$H_3 PO_4$ (e)$H_3 BO_3$

Solution: Basicity is the number of replaceable hydrogen atoms, so in water acids will furnish in the following ions:

(a) $CH_3COOH \rightarrow CH_3COO^- + H^+$ – 1

(b) $H_3PO_2 \rightarrow H_2PO^- + H^+$ – 1

(c) $H_3PO_3 \rightarrow HPO^{-2} + 2H^+$ – 2

(d) $H_3PO_4 \rightarrow PO_4^{-3} + 3H^+$ – 3

(e) $H_3BO_3 + H_2O \rightarrow [B(OH)_4]^- + H^+$ – 1

The Lowry–Bronsted Theory of Acids and Bases

In 1923, within a few months of each other, Johannes Nicolaus Bronsted in Denmark and Thomas Martin Lowry in England independently published more or less same theory about acids and bases.

According to them, an acid is a substance from which a proton can be removed, and a base is a substance that can remove a proton from an acid.

In other words, an acid is a proton donor, and a base is a proton acceptor.

However, the truth is slightly different from what 'donor' and 'acceptor' imply. An acid does not 'give' or 'donate' a proton; the proton is snatched by a base from the acid. The base is a molecule (or an ion) with an intrinsic tendency to collect protons. As soon as the base approaches the acid, it tries to rip the proton off the acid molecule and add it to itself.

A strong acid loses its proton to a base more easily than does a weak acid. Similarly a strong base takes away a proton from an acid more easily than does a weak base.

It is, thus, clear that an acid can show its character only in the presence of a base and vice versa. The neutralization reaction between an acid (HA) and a base (B) involves only the transfer of a proton (H^+) from the acid to the base, resulting in the formation of a new acid (BH^+) and a new base (A^-).

$$B + HA \rightarrow BH^+ + A^-$$

HA is the acid because it can lose its proton to the base B. Similarly, BH^+ can lose protons to A^-, and so BH^+ is the acid and A^-, the base. Thus, there are two bases (B and A^-) and two acids (BH^+ and HA) in the system. The base B and acid BH^+, which differ from each other only by a proton (H^+), are said to form a conjugate pair. BH^+ is the conjugate acid of the base B. Similarly, A^- (the base) and HA (the acid) also form a conjugate pair.

Thus, the conjugate acids and bases can be derived by using the following rule.

The conjugate base of an acid = Remove H^+ from the acid, and the conjugate acid of a base = Add H^+ to the base. For example,

(i) The conjugate base of the acid HCl is Cl^- ion, and

(ii) The conjugate acid of the base NH_3 is the NH_4^+ ion.

$$B + HA \rightarrow BH^+ + A^-$$

For example,

$$NH_3 + HCl \rightarrow NH_4^+ + Cl^-$$

List of some common conjugate Acid–Base pairs:

Acid = Base + H^+	Base = Acid – H^+
$HClO_4$ (perchloric acid)	ClO_4^- (perchlorate ion)
HI (hydroiodic acid)	I^- (iodide ion)
HBr (hydrobromic acid)	Br^- (bromide ion)
HCl (hydrochloric acid)	Cl^- (chloric ion)
H_2SO_4 (sulphuric acid)	HSO_4^- (hydrogensulphate ion)
HNO_3 (nitric acid)	NO_3^- (nitrate ion)
H_3O^+ (hydronium ion)	H_2O (water)
HSO_4^- (hydrogensulphate ion)	SO_4^{-2} (sulphate ion)
HF (hydrofluoric acid)	F^- (fluoride ion)
HNO_2 (nitrous acid)	NO_2^- (nitrite ion)
HCOOH (formic acid)	$HCOO^-$ (formate ion)
CH_3COOH (acetic acid)	CH_3COO^- (acetate ion)
NH_4^+ (ammonium ion)	NH_3 (ammonia)
H_2O (water)	OH^- (hydroxide ion)
NH_3 (ammonia)	NH_2^- (amide ion)

Limitations

A substance is termed as an acid or base if it reacts with some other substance, i.e., if it donates proton to other substance, it is an acid and if it accepts proton from other substance, it is a base.

LEWIS CONCEPT

G. N. Lewis (in 1923) proposed a more general theory of acids and bases. This is accepted most widely because of its simplicity. Acidic or basic–behaviour is explained in terms of the electrons.
According to the theory **an acid** is defined as "'A substance that can accept an electron pair to form a co–ordinate covalent bond''.
Example: H^+; BF_3; $SnCl_4$ etc.
A **base** is defined as ''A substance that can donate a lone pair of electrons to form a coordinate covalent bond''.
Example: H_2O and NH_3
In simple an electron pair acceptor is an acid while electron pair donor is a base.

Types of Lewis acids: The Lewis acids can be divided into the following 5 types.

1. All cations: Ex: Ag^+, CO^{+3}, Cu^{+2}, Fe^{+3} etc.
2. Compounds whose central atom has an incomplete octet and possessing an empty orbital. Ex: BF_3, BCl_3. $AlCl_3$, $FeCl_3$
3. Compounds in which the central atom has available d – orbitals and may expand its octet. Ex: SiF_4; $SnCl_4$; SF_4; TeF_4;
4. Molecules having multiple bonds between atoms of dissimilar electro negativities Ex: CO_2, SO_2, SO_3, NO_2.
5. Elements with an electron sextet Ex: S, O, Se, Te

Types of Lewis bases: The Lewis bases are divided into 3 types

1. All anions: Ex: Cl^-, OH^-, CN^-, NH_2^-, F^-, SCN^- (thiocyanate ion)
2. Molecules with one or two lone pairs on the central atom.

Ex: H_2O, NH_3, ROH, RNH_2, ROR, C_5H_5N (pyridine);

3. Molecules with multiple bonds.

Ex: CO; NO; $HC \equiv CH$; $H_2C = CH_2$

Limitations of Lewis theory:

1. One of the serious defects in the theory is that it cannot explain the strength of acids and bases.
2. Acids like HCl; H_2SO_4 react with bases such as NaOH or KOH but do not form coordinate covalent bond.

3. Generally acid–base interactions i.e., neutralization reactions are instantaneous reactions but some Lewis acid – base reactions go on very slowly.

Ionic product of water (K_w): Pure water is a poor conductor of electricity. But conductivity and other measurements support that water ionizes to very small extent producing H^+ and OH^- ion. The ionization equilibrium is represented as

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

This shows that water has the dual nature of proton donor and proton acceptor abilities. (Refer to the theories of acids and bases.) Then the equilibrium constant, K, given by

$$K = \frac{[H_3O^+][OH^-]}{[H_2O]^2} \text{ i.e., } K[H_2O]^2 = [H_3O^+][OH^-]$$

Where, the square brackets represent the concentration of the species. Since ionization of H_2O is negligible, $[H_2O]$ can be taken as constant. Therefore $K[H_2O]^2$ = constant, $K_w = [H_3O^+][OH^-]$. The constant K_w is known as ionic product of water at a given temperature. $[H_3O^+][OH^-]$ is simply written as $[H^+][OH^-]$.

''The ionic product of water, K_w, at a given temperature, is defined as the product of the concentration of H^+ and OH^- ions in water or in aqueous solutions''.

At 25°C (room temperature) K_w is $1.0 \times 10^{-14} \frac{\text{moles}^2}{\text{lit.}^2}$. As the temperature increases the ionization of water increases and hence K_w value increase. i.e., $[H^+]$ increase or the pH of the solution decreases. The following table gives the various values at different temperatures.

Water is a neutral liquid (does not change the colour either of blue or of red litmus).

Therefore $[H^+][OH^-]$

$\therefore K_w = [H^+][OH^-] = [H^+]^2$ or $[OH^-]^2 = 1.0 \times 10^{-14}\ M^2$

$$\therefore [H^+] = [OH^-] = \sqrt{1 \times 10^{-14} \frac{\text{moles}^2}{\text{lit}^2}} = 1.0 \times 10^{-7} \frac{\text{moles}}{\text{lit.}}.$$

From the ionic product value of water, knowing either $[H^+]$ or $[OH^-]$ the other can be calculated.

Temperature (in °C)	Ionic product of water (K_w) (in moles²/lit²)
0	0.114×10^{-14}
25	1.008×10^{-14}
50	5.600×10^{-14}
100	51.30×10^{-14}

As interesting feature of K_w is that remains constant even after addition of an acid or a base. Suppose we add HCl to water, the concentration of H^- is increased. Then the equilibrium shifts backward.

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

Thus the concentration of OH^- decreases such that the product of H^+ and OH^- ions remains constant. Similarly when NaOH is added to water the concentration of OH^- ions increases. This again results in the equilibrium shifting backwards. In this process the concentration of H^+ ions decreases such that the product of H^+ ions will be decreased such that the product of H^+ and OH^- ions is again equal to the ionic product of water.

For example at 25° C, K_w is 1.0×10^{-14}. By adding HCl, let us say the concentration of H^+ ions is increased to 10^{-5} from 10^{-7}, then the concentration of OH^- ions will be decreased to 10^{-9} from 10^{-7}, on the other hand let us say by adding NaOH the concentration of OH^- ions is increased to 10^{-14}, then the concentration of H^+ ions will be decreased to 10^{-10}. Note that the product of the concentrations of the two ions is always equal to 10^{-14}.

The solutions of various substances can be divided into neutral, acid or basic solution, depending on the relative amounts of H^+ or OH^- ions.

In neutral solutions $[H^+] = [OH^-]$

In acidic solutions $[H^+] > [OH^-]$

In basic solutions $[H^+] < [OH^-]$

In aqueous solutions of the substances the pH ranges from 1 to 14 and (also sometimes referred to as (0–14).

a. If $[H^+] = [OH^-] = 1 \times 10^{-7}$ M, neutral solution are indicated

b. If $[H^+] > [OH^-]$ i.e., $[H^+] > 10^{-7}$ M or $[OH^-] < 10^{-7}$ M. then the solution is acidic.

c. If $[H^+] < [OH^-]$ i.e., $[H^+] < 10^{-7}$ M or $[OH^-] > 10^{-7}$ M. then the solution is basic.

Thus the nature of a solution (neutral, acidic or basic) is expressed in terms of H^+ ion concentration in it. But in aqueous solution generally it is expressed in terms of pH.

The pH Scale

The Danish biochemist Sorensen proposed a scale – the pH scale – to measure the acidic or basic character of a solution. The term pH was derived from the French puissance de hydrogen or pouvoir hydrogene, which means 'concentration of hydrogen'.

The pH scale is a very convenient scale to express the acidity or alkalinity of a dilute acid or alkaline (basic) solution. It is defined as follows.

The pH of a solution is the logarithm of the inverse of the molar concentration of hydrogen ions $[H_3O^+]$ in the solution. It can also be expressed as the negative logarithm of the molar concentration of hydrogen ions in the solution. Expressing this mathematically,

$$pH = \log_{10} \frac{1}{[H^+]} = -\log_{10}[H^+].$$

The scale ranges from 0 to 14.

Remember that for pure water at 25°C

$$K_w = [H^+]\,[OH^-] = 1 \times 10^{-14}$$

As the concentration of H^+ and OH^- are equal in pure water,

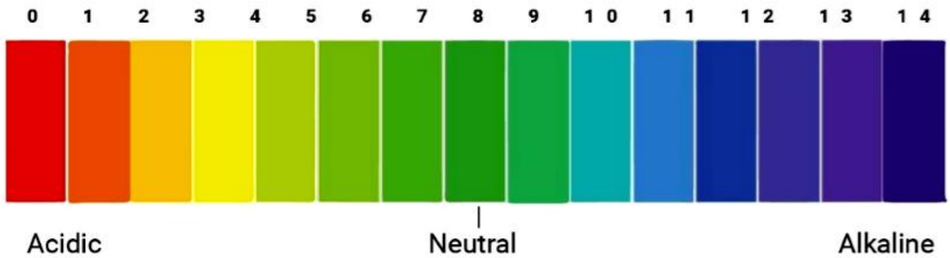
$$[H^+] = [OH^-] = 10^{-7}$$

Hence the pH of pure water is given by

$$pH = \log_{10} \frac{1}{[H^+]} = \log_{10} \frac{1}{10^{-7}} = \log_{10} 10^7 = 7.$$

Thus, the pH of pure water or a neutral solution = 7.

1. If pH is equal to 7, means the solution is neutral.
2. If pH is greater than 7 means alkaline solution.
3. If pH is less than 7 means the solution is acidic.



Representative pH values

Substance	pH
Hydrochloric Acid, 10M	-1.0
Battery acid	0.5
Gastric acid	1.5 - 2.0
Lemon juice	2.4
Cola	2.5
Vinegar	2.9
Orange or apple juice	3.5
Beer	4.5
Acid Rain	<5.0
Coffee	5.0
Tea or healthy skin	5.5
Milk	6.5
Pure Water	7.0
Healthy human saliva	6.5 - 7.4
Blood	7.34 - 7.45
Seawater	7.7 - 8.3
Hand soap	9.0 - 10.0
Household ammonia	11.5
Bleach	12.5
Household lye	13.5
Caustic Soda	13.9

Importance of pH

Human body works at a pH of about 7.4. Stomach has a pH of about 2 due to presence of hydrochloric acid in it. It is needed for the activation of pepsin protein required for protein digestion.

When we eat food containing sugar, then the bacteria present in our mouth break down the sugar to form acids. This acid lowers the pH in the mouth. Tooth decay starts when the pH of acid formed in the mouth falls below 5.5. This is because then the acid becomes strong enough to attack the enamel of our teeth and corrode it. This sets in tooth decay. The best way to prevent tooth decay is to clean the mouth thoroughly after eating food.

Many animals and plants protect themselves from enemies by injecting painful and irritating acids and bases into their skin. When honey bee stings a person, it injects an acidic liquid into the skin. Rubbing with mild base like baking soda solution on the stung area of the skin gives relief.

When a wasp stings, it injects an alkaline liquid into the skin. Then rubbing with a mild acid like vinegar on the stung area of the skin gives relief.

Soil pH and plant growth: Most of the plants grow best when the pH of the soil is close to 7. If the soil is too acidic or basic, the plants grow badly or do not grow at all. The soil pH is also affected by the use of chemical fertilisers in the field. Chemicals can be added to soil to adjust its pH and make it suitable for growing plants. If the soil is too acidic then it is treated with materials like quicklime or slaked lime. If the soil is too alkaline then alkalinity can be reduced by adding decaying organic matter.

Let us now calculate the pH of 1 M HCl and 1 M NaOH solutions.

1 M HCl solution As HCl is a strong acid, it will dissociate practically completely into H^+ (or H_3O) ions and the $[H^+]$ will also be 1M.

So, $pH = \log_{10}\frac{1}{[H^+]}\ \log_{10}\frac{1}{1} = 0.$

1 M NaOH solution As NaOH is a strong base, it will dissociate in an aqueous solution almost completely into OH^- ions. So, NaOH will give rise to 1 M $[OH^-]$ too. We know that

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

$\therefore\quad [H^+] = \frac{10^{-14}}{[OH^-]} = \frac{10^{-14}}{1} = 10^{-14}.$

So, $pH = \log_{10}\frac{1}{[H^+]} = \log 10\ \frac{1}{10^{-14}} = \log 10\ 10^{-14} = 14.$

Illustration 3: ***What is the sum of pH & pOH for a solution?***

Solution: pH + pOH = 14.

Illustration 4: ***10^{-2} M HCl is diluted 100 times. Its pH is***

Solution: $[H^+] = \frac{10^{-2}}{10^2} = 10^{-4}$

pH of 10^{-4} M HCl is 4

Now it will be clear that

- The pH of a neutral solution is 7.
- The pH of an solution is less than 7 and the pH decreases as the acidic character increases, and
- The pH of a basic solution is more than 7 and the pH increases as the basic character increases.

Note that the pH scale is logarithmic and if the pH values of two solutions differ by 1, the solution of lower pH has 10 times as many hydrogen ions per unit volume as the one of higher pH. A solution of pH = 1 is, therefore, 10 times more acidic than pH = 2 and pH = 10 is ten times more basic than pH = 9.

Illustration 5: ***What will be Hydrogen ion concentration of 0.001 N NaOH solution?***

Solution: $[H^+][OH^-] = 10^{-14}.$

$[H^+]\ [10^{-3}] = 10^{-14}.$

$[H^+] = \frac{10^{-14}}{10^{-3}} = 10^{-11}.$

Illustration 6: ***What is the pH values of 0.1 M and 0.01 M HCl solution?***

Solution: HCl is a strong acid and so it will dissociate in an aqueous solution practically completely into H^+ ions.

0.1 M HCl

$[H^+] = 0.1 = 10^{-1}$

So, $pH = \log_{10}\frac{1}{[H^+]} = \log 10\ \frac{1}{10^{-1}} = \log_{10}10^1 = 1.$

0.01 M HCl

$[H^+] = 0.01 = 10^{-2}$

So, $pH = \log_{10}\frac{1}{10^{-2}} = \log_{10}10^2 = 2.$

Illustration 7: ***What is the pH of a solution having a $[H^+] = 2.512 \times 10^{-6}$ M?***

Solution: $\log [H^+] = \log_{10} (2.512 \times 10^{-6})$

$= \log 10^{-6} + \log 2.512$

$\Rightarrow -6 + 0.4 = -5.6$

$-\log [H^+] = 5.6 \Rightarrow pH = 5.6$

Illustration 8: ***What is the pH of 0.01 M HCl?***

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

0.01 0.01

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

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

Illustration 9: ***What is the pH of 0.01 M NaOH?***

Solution: $NaOH \longrightarrow Na^+ + OH^-$

0.01 0.01

$[OH^-] = 10^{-2}$

$[H^+] = \frac{10^{-14}}{10^{-2}} = 10^{-12}$

$pH = -\log [10^{-12}] = 12$

Illustration 10: ***What is the pH of 10^{-8} M HCl?***

Solution: 10^{-8} M HCl is very dilute solution

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

10^{-8} 10^{-8}

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

10^{-7} 10^{-7}

So the H^+ ion con is the sum of HCl and H_2O.

$[H^+] = 10^{-8} + 10^{-7} = 0.1 \times 10^{-7} + 1 \times 10^{-7}$

$= 1.1 \times 10^{-7}$

$pH = -\log[1.1 \times 10^{-7}] = -0.04 + 7 = 6.96$

Illustration 11: ***What is the pH of 10^{-8} M NaOH?***

Solution: $pOH = 6.96$

$pH = 14 - 6.96 = 7.04.$

Illustration 12: ***What is the pH of 10^{-5} M NaCl?***

Solution: NaCl is neutral hence its pH is always 7.

The pH values of some common substances

Substance	pH
Gastric juices	1.0 – 3.0
Soft drinks	2.0 – 4.0
Lemon juice	2.2 – 2.4
Vinegar	2.4 – 3.4
Tomato juice	4.0 – 4.4
Human urine	4.8 – 8.4

Substance	pH
Cow milk	6.3 – 6.6
Saliva	6.5 – 7.5
Pure water	7.0
Blood	7.3 – 7.5
Egg white	7.6 – 8.0
Milk of magnesia	10.5

SALTS

Salts are compounds which are formed on the partial or complete replacement of the hydrogen of an acid by metal atom(s) or positive radial(s).

For example, NaCl, NH_4Cl, Na_2SO_4 and $(NH_4)_2SO_4$ are salts as they as formed on the complete replacement of the hydrogen from HCl or H_2SO_4. Similarly, $NaHSO_4$ is also a salt as it is formed on the partial replacement of the hydrogen of H_2SO_4. There replacements usually occur through a process called neutralization.

Neutralisation

When acid and alkali solutions are mixed in the correct proportions, the solution is neither alkaline nor acidic. Such a solution is said to be neutral (in Latin, neuter means neither). When the Neutral solution is evaporated it leaves a residue. This residue is the salt formed by the reaction between the acid and the alkali. For example, when HCl and NaOH are mixed in a 1 : 1 mole (or molecular) ratio, the resulting solution is neutral and on evaporation leaves a residue of NaCl. The energy released in this reaction is 13.6 Kcal/mol.

$$HCl + NaOH \rightarrow NaCl + H_2O \ + \ 13.6 \text{ K.cal./mol}$$

Mixing solutions of $Ba(OH)_2$ and HCl in the mole ratio 1 : 2 results in the formation of $BaCl_2$, which can be recovered from the neutral solution as a residue by evaporating the water.

$$Ba(OH)_2 + 2HCl \rightarrow BaCl_2 + 2H_2O$$

Insoluble bases, like $Cu(OH)_2$ and $Fe(OH)_3$ react with acids to form salts which pass into solution. The salt can be removed from the solution by evaporating the water

$$H_2SO_4 + Cu(OH)_2 \rightarrow CuSO_4 + 2H_2O$$

$$3HCl + Fe(OH)_3 \rightarrow FeCl_3 + 3H_2O$$

Classification of Salts

From what we have discussed, it is clear that the salts formed from different kinds of acids and bases can also be classified as follows.

Normal Salts

Salts formed by the complete replacement of the hydrogen atoms of an acid by metal atom(s) or positive radical(s) are called normal salts.

Some examples of normal salts and the acids from which they are divided are given below.

Acids	**Normal salts**
HCl	NaCl, NH_4Cl
H_2SO_4	Na_2SO_4, $(NH_4)_2SO_4$
H_3PO_4	K_3PO_4, $(NH_4)_3\ PO_4$

Acid salts

Salts formed by the replacement of the hydrogen atoms of a polybasic acid by metal atom(s) or positive radical(s) are known as acid salts.

Examples:

Acids	**Acid salts**
H_2SO_4	$NaHSO_4$, NH_4HSO_4
H_2CO_3	$KHCO_3$, $Ca(HCO_3)_2$, NH_4HCO_3
H_3PO_4	NaH_2PO_4, $(NH_4)_3\ PO_4$ (sodium dihydrogenphosphate)
	$(NH_4)H_2PO_4$ (ammonium dihydrogenphosphate)
	Na_2HPO_4 (disodium hydrogenphosphate)

Basic salts

Salts formed by the partial replacement of hydroxyl groups or the incomplete neutralization of a base are called basic salts.

When a base containing more than one hydroxyl group reacts with acid, a salt containing one or more hydroxyl groups may be formed. For example,

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

Pb(OH)Cl is a basic salt (basic lead chloride) as the base has not been completely neutralized. Basic salts are generally represented as compounds of normal salts and bases, for example, basic lead chloride is represented as $Pb(OH)_2.PbCl_2$ rather than Pb(OH)Cl. Some other basic salts are basic lead nitrate, $Pb(NO_3)_2.Pb(OH)_2$,basic lead carbonate, $PbCO_3 . Pb(OH)_2$, basic copper carbonate, $Cu(OH)_2 . CuCO_3$, basic zinc carbonate, $2ZnCO_3 .3Zn(OH)_2 . H_2O$, and basic magnesium carbonate, $MgCO_3. Mg(OH)_2 . 3H_2O$.

Solubility of Common Salts

Soluble Salts	Insoluble Salts
All Sodium All Potassium All Ammonium All Nitrates S.P.A.N	
All Chlorides (as well as other Halides - Bromides & Iodides)	Lead (II) Chloride Silver Chloride
All Sulphates	Barium Sulphate Calcium Sulphate (sparingly soluble) Lead (II) Sulphate
Sodium Carbonate Potassium Carbonate Ammonium Carbonate S.P.A	All Carbonates
Group I Metal Phosphates e.g. Na_3PO_4 Ammonium Phosphate $(NH_4)_3PO_4$	All Phosphates
Sodium Hydroxide Potassium Hydroxide Calcium Hydroxide (sparingly soluble) Magnesium Hydroxide (very sparingly soluble) S.P.C.M	All Hydroxides

Some Important Chemical Compounds and their uses

Salt	Preparation	Uses
Common Salt (NaCl) **(Sodium Chloride)**	1. $NaOH + HCl \rightarrow NaCl + H_2O$ 2. From sea water by evaporation 3. From underground deposit {Large crystals of common salt found in underground deposit which is brown due to presence of impurities in it. It is mined from underground deposit like coal.}	1. Raw material for making large number of useful chemicals in industry. E.g.: NaOH (Caustic soda), Na_2CO_3 (Washing soda), $NaHCO_3$ (Baking soda). 2. Preservative in pickle and curing meat and fish. 3. To melt ice and clear roads in winters in cold countries. 4. Used in manufacturing of soap.
Caustic Soda (NaOH) **(Sodium Hydroxide)**	Passing electricity through concentrated solution of NaCl (called '**brine**') $2NaCl + 2H_2O \rightarrow 2NaOH + Cl_2 + H_2$ At anode (+ve electrode): Cl_2 is produced At cathode (–ve electrode): H_2 is produced It is called chlor–alkali process because products formed are chlorine (Chlor) and NaOH (alkali).	**Uses of H_2** 1. Hydrogenation of oil to get vegetable ghee (margarine) 2. To make ammonia for fertilizers 3. In fuel for rockets. **Uses of Cl_2** 1. In water treatment 2. To clean water in swimming pools 3. To make plastic, E.g. PVC 4. To make CFCs, chloroform, dyes etc. **Uses of NaOH** 1. Used in making soap and detergent. 2. Used in manufacturing of paper 3. De–greasing metals 4. Refining oil 5. Making dyes and bleaches **Uses of HCl** 1. Cleaning steel 2. Preparation of chloride, e.g. NH_4Cl 3. In making medicines and cosmetics

		4. In making plastics, PVC etc.
Baking Soda ($NaHCO_3$) (Sodium Hydrogencarbonate)	$NaCl + NH_3 + H_2O + CO_2 \rightarrow NaHCO_3 + NH_4Cl$ **Properties** Action of Heat: $2NaHCO_3 \xrightarrow{\Delta} Na_2CO_3 + H_2O + CO_2$	1. Used as antacid in medicine to remove acidity in the stomach 2. Used in making baking powder (Basic soda + tartaric acid) $NaHCO_3 + H^+ \rightarrow Na^+ + CO_2 + H_2O$ Sodium bicarbonate - from mild acid gives sodium salt of acid, CO_2 and H_2O. The CO_2 produced during the process gets trapped in wet dough and bubbles out slowly to make cake 'rise' so that it becomes soft and spongy. Tartaric acid neutralizes the alkalinity (Na_2CO_3), and therefore it has pleasant taste. 3. Used in soda–acid fire extinguisher
Washing Soda ($Na_2CO_3.10H_2O$) (Sodium Carbonate)	$Na_2CO_3 + 10H_2O \rightarrow Na_2CO_3.10H_2O$ Preparation of **Na_2CO_3** 1. $NaCl + NH_3 + H_2O + CO_2 \rightarrow NaHCO_3 + NH_4Cl$ 2. $2NaHCO_3 \xrightarrow{\Delta} Na_2CO_3 + H_2O + CO_2$	1. Used in glass, soap and paper industries 2. Used in manufacturing of sodium compounds such as Borax 3. Cleaning agent for domestic purpose 4. Remove permanent hardness of water
Bleaching Powder ($CaOCl_2$) Calcium Oxychloride	$Ca(OH)_2 + Cl_2 \xrightarrow{\Delta} CaOCl_2 + H_2O$ $Ca(OH)_2$ is 'Slaked Lime' and $CaOCl_2$ is Calcium oxychloride (bleaching powder) Properties $CaOCl_2 + H_2SO_4 \rightarrow CaSO_4 + Cl_2 + H_2O$ The Cl_2 produced by action of dilute acid acts as bleaching agent.	1. For bleaching cotton and linen in textile industry, for bleaching wood pulp in paper factories, for bleaching washed clothes in laundry 2. Oxidizing agent in chemical industries 3. Disinfecting drinking water
Plaster of Paris (P.O.P) ($CaSO_4.1/2\ H_2O$) (Calcium Sulphate Hemihydrate)	$CaSO_4.2H_2O \xrightarrow{\Delta} CaSO_4.\frac{1}{2}H_2O + \frac{3}{2}H_2O$ * Heating of gypsum should not be done above $100^\circ C$ as above that temperature, water of crystallization will eliminate and anhydrous $CaSO_4$ will be obtained. This anhydrous $CaSO_4$ is known as **Dead Burnt Plaster**. * $CaSO_4.\frac{1}{2}H_2O$ means that two molecules of $CaSO_4$ share one molecule of water. Properties Has remarkable property of setting into a hard mass on wetting with water, as gypsum is formed. $CaSO_4.\frac{1}{2}H_2O + \frac{3}{2}H_2O \rightarrow CaSO_4.2H_2O$ (Gypsum sets as hard mass) Hence, POP should be stored in moisture-proof container as moisture can cause slow setting of POP by hydrating it.	1. Used in hospital for setting fractured bones in the right position to ensure correct healing. 2. Making toys, decorative materials, cheap ornaments, and casts of statues. 3. Used as fire–proofing material 4. Used in chemistry labs for setting air gaps in apparatus. 5. Making smooth surfaces, such as For making ornamental designs on ceilings of houses and other buildings