We use a number of materials in our daily life, some of which are sweet, sour, bitter and salty in taste. Now it is very interesting to know that what substances are present in them which make them sour, bitter, sweet or salty? And the answer is

(i) Sour taste of substances is due to acid (latin word acidus which means sour) present in them and are called acidic substances eg. Imli, vinegar etc.
(ii) Bitter taste of substance is due to base present in them and are called basic substances eg. Washing soda, baking soda, etc.
(iii) Sweet taste of substances is due to sugar present in them and are called sugars e.g. cane-sugar, glucose etc.
(iv) Salty taste of substances is due to presence of salts in them and are called salts e.g. sodium chloride, silver nitrate etc.

Let us take examples of some common substances and classify them into acids and bases on the basis of their taste.

Table – 1

Substances	Taste	Nature of substances
Vinegar	Sour	Acidic
Lemon juice	Sour	Acidic
Tamarind (imli) pulp	Sour	Acidic
Apples	Sour	Acidic
Tomatoes	Sour	Acidic
Proteins	Sour	Acidic
Sour milk or curd	Sour	Acidic
Oranges	Sour	Acidic
Washing soda solution	Bitter	Basic
Baking soda solution	Bitter	Basic
Cucumber (kheera) extract	Bitter	Basic
Bitter gourd (karela) extract	Bitter	Basic

Thus, the substances which we use in our daily life can be classified into acids and bases by tasting them. But some chemical substances may be poisonous or dangerous to taste, so it is advised never to taste any chemical substance.

1. INDICATORS

We can distinguish between acids and bases without tasting them by using certain chemicals called **indicators**.

Tests to distinguish between acids and bases: The tests used to distinguish between acids and bases are done with some indicators known as acid base indicators.

Acid – Base Indicators: These are the substances which show one characteristic property (colour, odour etc) in the acidic medium and a different property in the basic medium and thus distinguish between acids and bases. There are two types of acid base indicators depending upon their property.

1.1 INDICATORS SHOWING DIFFERENT COLOURS IN ACIDIC AND BASIC MEDIUM

1.1.1 Litmus solution

Litmus solution is a purple coloured dye. extracted from the lichen plant. It is very interesting to note that litmus solution (purple colour) itself is neither acidic nor basic. To use it as an indicator, it is made acidic or alkaline.

The alkaline form of litmus solution is blue in colour and called blue litmus solution.

The acidic form of litmus solution is red in colour and called red litmus solution.

Blue litmus solution(blue in colour): It is obtained by making the purple litmus extract. alkaline. Thus it is basic in nature and acts as an acid-indicator by giving a characteristic change in its colour in acids.

Red litmus solution(red in colour): It is obtained by making the litmus extract acidic. Thus it is acidic in nature and acts as a base-indicator by giving a characteristic change in its colour in bases.

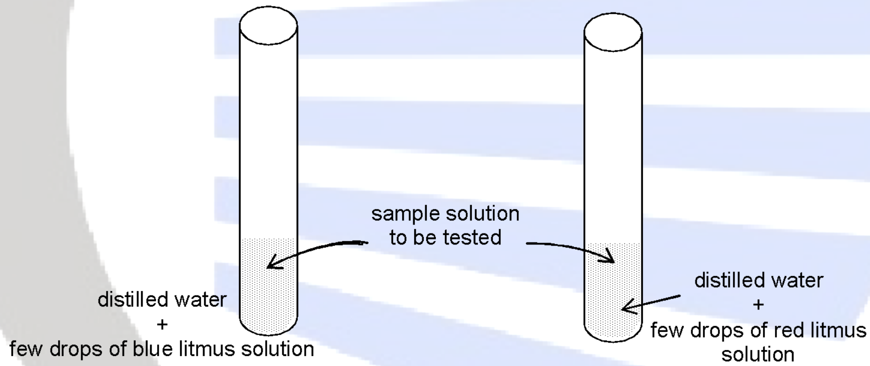
Now questions arise:

(i) How do they (litmus solutions) act as acid –base indicators?

(ii) How do they change their colours in acids and bases?

(iii) How do they test whether the given substance is acidic or basic?

Experiment to test: Take about 2 - 4 ml of distilled water in two test tubes and add 1-2 drops of blue litmus solution in one test tube and red litmus in another test tube. Now add the sample solution of the substance to be tested in both test tubes (fig.)



Litmus test for acid and base

Observation:

(i) Blue litmus solution turns red in acidic medium i.e. blue litmus solution changes into red if the sample solution (to be tested) is acidic.

(ii) Red litmus solution turns blue in basic medium i.e red litmus solution changes into blue if the sample solution (to be tested) is basic.

The above observation can be shown more clearly by taking examples of some commonly used substance as follows

Table 2

Acidic substance turning blue litmus solution into red	Basic substance turning red litmus solution into blue
Vinegar Lemon Juice Tamarind (imli)	Baking soda solution Washing soda solution Bitter gourd (karela) extract

Sour milk or curd Proteins Tomatoes Apples Oranges Juice of unripe mangoes	Cucumber (kheera) extract

It is clear from the above that blue litmus solution acts as acid indicator by giving red colour in acidic medium and red litmus solution acts as base indicator by giving blue colour in basic medium.

Thus litmus solution acts as an acid-base indicator.

1.1.2 Turmeric (haldi)

Turmeric used in kitchen can also be used to test a basic solution i.e. it act as base indicator by giving brown colour in basic medium. In other words yellow colour of haldi turns into brown in basic substances (due to base present in them) and thus distinguishes between acids and bases.

Example: While eating food, if curry falls on the white clothes, a yellow stain is produced in the clothes. When we apply soap solution (basic in nature) on the cloth, the yellow stain becomes brown due to base present in soap solution.

This example shows that turmeric (haldi) act as base indicator by giving brown colour in basic substances.

1.2 SYNTHETIC INDICATORS

The chemical substances which change their colour in acids and bases and thus distinguish between them are called synthetic indicators. Since they distinguish between acids and bases, so they are also called synthetic acid base indicators. The two most common synthetic indicators are

(a) Phenolphthalein and (b) Methyl orange.

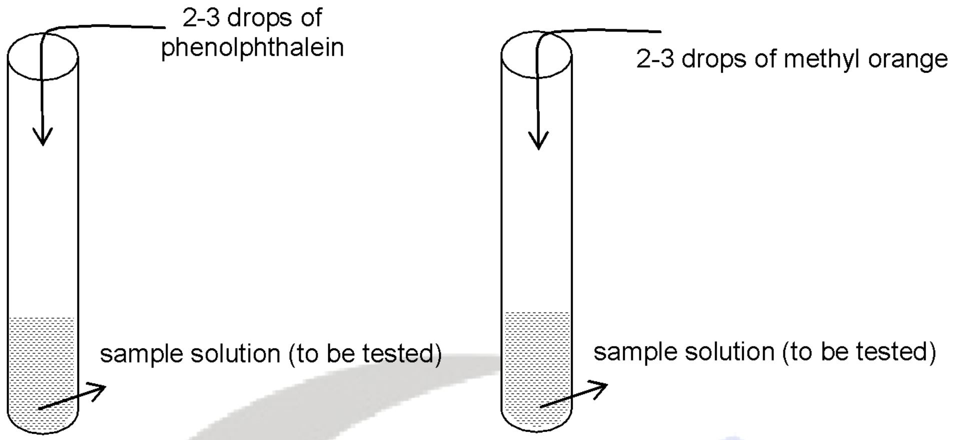
Now questions arise

(i) How do they (synthetic indicators) act as acid-base indicators?

(ii) How do they change their colour in acids and bases?

(iii) How do they test whether the given substance is acidic or basic?

Experiment to test: Take about 2 ml of sample solution (substance to be tested) in a test tube and add 2-3 drops of phenolphthalein or methyl orange (synthetic acid-base indicators) to it as shown in figure.



Test for acid and base using synthetic indicators

Observation:

(a) Colour changes which take place in phenolphthalein are

(i) Phenolphthalein (whose natural colour is colourless) is colourless in acidic medium i.e. it gives no colour, if the sample solution to be tested is acidic.

(ii) Phenolphthalein gives pink colour in basic medium or solution i.e. it turns into pink, if the sample solution to be tested is basic.

(b) Colour changes which take place in methyl orange are

(i) Methyl orange (whose natural colour is orange) gives pink colour in acidic medium or solution i.e. it turns into pink, if the sample solution to be tested is acidic.

(ii) Methyl orange gives yellow colour in basic medium or solution i.e. it turns into yellow, if the sample solution to be tested is basic.

The above observation can be shown clearly by taking examples of some commonly used substances as follows:

Table - 3

Acidic substances turning methyl orange into pink and phenolphthalein remaining colourless	Basic substances turning methyl orange into yellow and phenolphthalein into pink
Vinegar Lemon Juice Tamarind (imli) Sour milk or curd Proteins Tomatoes Oranges Juice of unripe mangoes	Baking soda solution Washing soda solution Bitter gourd (karela) extract Cucumber (kheera) extract

Now, if we see table 2 and table 3 observations, then we conclude that acid – base indicators like (litmus solution i.e. blue litmus solution and red litmus solution), phenolphthalein and methyl orange distinguishes between acids and bases by giving different colours (table 4)

Table – 4

Sample solution	Red litmus solution	Blue litmus solution	Phenolphthalein indicator	Methyl orange indicator
Vinegar	No colour change	Red	Colourless	Pink
Lemon juice	No colour change	Red	Colourless	Pink
Washing soda solution	Blue	No colour change	Pink	Yellow
Baking soda solution	Blue	No colour change	Pink	Yellow

Tamarind (imli)	No colour change	Red	Colourless	Pink
Sour milk or curd	No colour change	Red	Colourless	Pink
Proteins	No colour change	Red	Colourless	Pink
Bitter gourd (karela) extract	Blue	No colour change	Pink	Yellow
Oranges	No colour change	Red	Colourless	Pink
Cucumber (kheera) Extract	Blue	No colour change	Pink	Yellow
Tomatoes	No colour change	Red	Colourless	Pink
Juice of unripe mangoes	No colour change	Red	Colourless	Pink

The above observation can be shown more clearly as follows

Table – 5

Indicator	Colour in acidic solution	Colour in basic solution
Blue litmus solution	Red	No colour change
Red litmus solution	No colour change	Blue
Phenolphthalein	Colourless	Pink
Methyl orange	Pink	Yellow

It is clear from the above table that to test whether a substance is acidic or basic we can use any one of the above indicators. The change in colour with these indicators for the substance taken, show its acidic or basic nature.

In this way acid-base indicators distinguish between acids and bases by showing different colours in acidic and basic medium.

1.3 INDICATORS GIVING DIFFERENT ODOURS IN ACIDIC AND BASIC MEDIUM (Olfactory Indicators)

These are another type of acid-base indicators which distinguish between acids and base by giving different odour or smell in acidic and basic medium i.e. they give one type of odour or smell in acidic medium and a different odour or smell in basic medium and thus distinguish between acids and bases.

These indicators which give different odours or smell in acidic and basic medium are called **olfactory indicators.**

A few of these are given below:

(a) onion odoured cloth strip

(b) vanilla extract
(c) clove oil

1.3.1 Test with onion odoured cloth strip

Take 1-2 ml of dil HCl in a test tube and add 1-2 ml of a basic solution like dil NaOH solution in another test tube. Add a small cloth strip treated with onion extract in each test tube and shake well.

Observation:

(i) acidic solution like dil HCl does not destroy the smell of onion i.e. there is no change in smell of onion in acidic solution or acid.
(ii) basic solution like dil NaOH destroy the smell of onion i.e. odour of onion cannot be detected.

Thus onion odoured cloth strip can be used as a test for acids and bases.

1.3.2 Test with vanilla extract

Take 1-2 ml of acidic solution like dil HCl in one test tube and 1-2 ml of dil NaOH (basic solution) in another test tube. Add a few drops of vanilla extract (having characteristic pleasant smell) in each test tube and shake well.

Observation:

(i) Acidic solution like dil HCl does not destroy the characteristic smell of vanilla extract i.e. there is no change in its smell in acidic solution or acid.
(ii) Basic solution like dilute NaOH destroy the smell of vanilla extract.

Thus vanilla extract can be used to test for acids and bases.

1.3.3 Test with clove oil

Take about 1-2 ml of dil HCl in one test tube and 1-2 ml of dil NaOH in another test tube. Add a few drops of clove oil extract (having a characteristic smell or odour) in each test tube and shake well.

Observation:

(i) Acidic solution like dil HCl does not destroy the characteristic smell or odour of clove oil i.e. there is no change in smell in acidic solution or acid.
(ii) Basic solution like dil NaOH destroy the odour or smell of clove oil i.e. odour of clove oil can not be detected.

Thus clove oil can be used to test for acids and bases.

The above observations can be shown more clearly as follows:

Table - 6

Indicator	Odour or smell in acidic solution	Odour or smell in basic solution
Onion Odoured cloth strip	No change	Can not be detected
Clove oil	No change	Can not be detected
Vanilla extract	No change	Can not be detected

It is clear from the above table that the olfactory indicators like clove oil, vanilla extract, onion odoured cloth strip, etc. distinguish between acids and bases by giving different odours or smell in acidic and basic medium.

2. ACIDS

Those substances which turn blue litmus solution red are called **acids**. The term ‘acid’ has been derived from the Latin word ‘acidus’ which means sour. Acids are sour in taste.

2.1 PHYSICAL PROPERTIES OF ACIDS

(i) **Sour taste:** Almost all acidic substances have a sour taste.
(ii) **Action on litmus solution:** Acids turn blue litmus solution red.
(iii) **Action on methyl orange:** Acids turn methyl orange pink.
(iv) **Action on phenolphthalein:** Phenolphthalein remains colourless in acid.
(v) **Conduction of electricity:** The aqueous solution of acid conducts electricity.
(vi) **Corrosive nature:** Most acids are corrosive in nature. They produce a burning sensation on the skin and make holes on surfaces on which they fall.

2.2 CHEMICAL PROPERTIES OF ACIDS

2.2.1 Reaction of acids with metals

When acid reacts with a metal, then a salt and hydrogen gas are formed.

i.e. metal + acid → salt + hydrogen gas

Example: Reaction of dil H_2SO_4 with zinc metal.

Experiment: Take about 5 ml of dil H_2SO_4 in a test tube and add a few pieces of zinc granules in it. Pass the gas evolved through soap solution. The soap bubbles filled with gas rise.

Test for gas: Bring a burning candle near the gas filled soap bubble.

Observation: The gas present in soap bubble burns with pop sound which shows the gas evolved during reaction is H_2 (hydrogen) gas (figure).

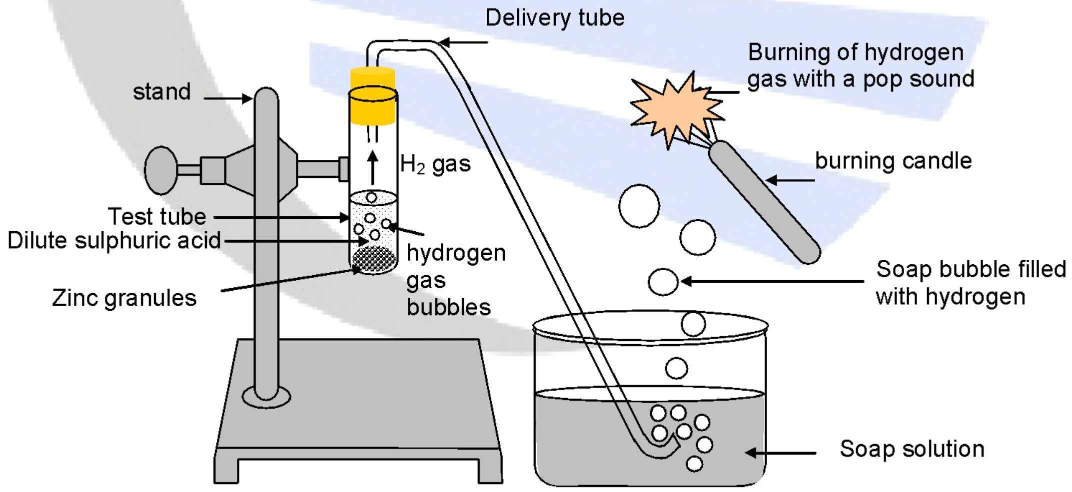


Figure-reaction of Zn granules with dil. H_2SO_4 and test for hydrogen gas by burning

The reaction involved is

$$\underset{\substack{\text{zinc}\\\text{(a metal)}}}{Zn(s)} + \underset{\substack{\text{sulphuric}\\\text{acid (dil)}}}{H_2SO_4\,(aq)} \longrightarrow \underset{\substack{\text{zinc sulphate}\\\text{(a salt)}}}{ZnSO_4\,(aq)} + \underset{\substack{\text{hydrogen}\\\text{gas}}}{H_2\,(\uparrow)}$$

In this reaction more active metal zinc displaces less active hydrogen from H_2SO_4 and this hydrogen is evolved as gas.

Thus it is an example of displacement reaction.

Some more examples of reaction of different metals with a particular acid:

Example 1

$$\underset{\substack{\text{magnesium}\\\text{(a metal)}}}{Mg(s)} + \underset{\substack{\text{hydrochloric acid}\\\text{(dil)}}}{2HCl\,(aq)} \longrightarrow \underset{\substack{\text{magnesium chloride}\\\text{(a salt)}}}{MgCl_2\,(aq)} + \underset{\substack{\text{hydrogen}\\\text{gas}}}{H_2\,(g)}$$

Example 2

$$\underset{\substack{\text{zinc}\\\text{(a metal)}}}{Zn\,(s)} + \underset{\substack{\text{hydrochloric acid}\\\text{(dil)}}}{2HCl(aq)} \longrightarrow \underset{\substack{\text{zinc chloride}\\\text{(a salt)}}}{ZnCl_2\,(aq)} + \underset{\substack{\text{hydrogen}\\\text{gas}}}{H_2(g)}$$

Example 3

$$\underset{\substack{\text{iron}\\\text{(a metal)}}}{Fe(s)} + \underset{\substack{\text{hydrochloric acid}\\\text{(dil)}}}{2HCl(aq)} \longrightarrow \underset{\substack{\text{iron(II) chloride}\\\text{(a salt)}}}{FeCl_2\,(aq)} + \underset{\substack{\text{hydrogen}\\\text{gas}}}{H_2(g)}$$

Example 4

$$\underset{\substack{\text{copper}\\\text{(a metal)}}}{Cu} + \underset{\substack{\text{hydrochloric acid}\\\text{(dil)}}}{2HCl(aq)} \longrightarrow \text{no reaction}$$

It is observed that at room temperature

(i) Mg reacts most vigorously (ii) Zn reacts less vigorously than Mg

(iii) Fe reacts slowly (iv) Cu does not react at all

Conclusion: From above reactions we lead to a conclusion that all metals do not react with same acid with same vigour.

The reason is the different reactivities or activities of metals towards acid.

In the above reactions we observe that metals like Mg, Fe, Zn being more active than hydrogen, displaces hydrogen from acid HCl and release H_2 gas. Thus above reactions are displacement reactions, Cu being less reactive than hydrogen, cannot displace hydrogen from dil HCl. Thus no reaction takes place.

In General

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

2.2.2 Reaction of acid with metal carbonates and metal hydrogen carbonate (or metal bicarbonates)

When an acid reacts with a metal carbonate or metal hydrogen carbonate (metal bicarbonate), then a salt, CO_2 gas and H_2O are formed.

i.e. Metal carbonate + Acid $\longrightarrow$ Salt + CO_2 + H_2O

Metal hydrogen carbonate (or metal bicarbonate) + Acid $\longrightarrow$ Salt + CO_2 + H_2O

Example: Reaction of sodium carbonate (Na_2CO_3) or sodium hydrogen carbonate ($NaHCO_3$) with dil HCl.

Experiment: Take about 0.5g of Na_2CO_3 or $NaHCO_3$ in a test tube and add about 2 ml of dil HCl acid to it. Pass the gas evolved through lime water (taken in another test tube).

Observation: The lime water turns milky, showing that the gas evolved is CO_2 gas.

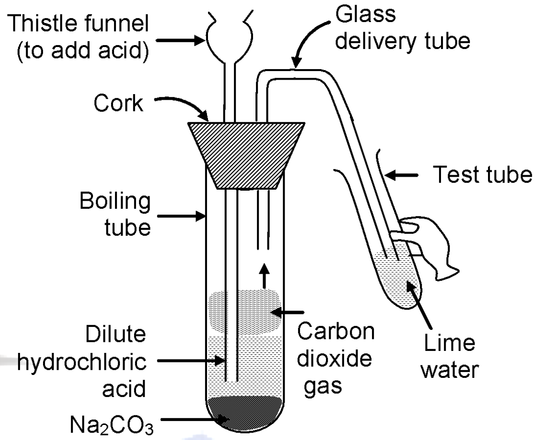


Figure-carbon dioxide gas (formed by the action of dil. HCl and Na_2CO_3 *) being passed through lime water*

The reactions taking place are

$Na_2CO_3(s)$ + $2HCl(aq)$ $\longrightarrow$ $2NaCl(aq)$ + $H_2O(l)$ + $CO_2(g)$

sodium carbonate, hydrochloric acid (dil), sodium chloride (a salt), water, carbondioxide

$Ca(OH_2)$ (aq) + $CO_2(g)$ $\longrightarrow$ $CaCO_3(s)$ + $H_2O(l)$

lime water, carbondioxide, calcium carbonate (white ppt) (milky suspension), water

Some more examples of reaction of metal carbonate and metal bicarbonates with dil acids

MCO_3 + acid $\longrightarrow$ salt + H_2O + $CO_2(g)$

M stands for metal $MHCO_3$ + acid $\longrightarrow$ salt + H_2O + $CO_2(g)$

Example 1

$MgCO_3$ (s) + 2HCl (aq) (dil) $\longrightarrow$ $MgCl_2$ (aq) + H_2O (l) + CO_2

$Mg(HCO_3)_2$ (aq) + 2HCl (aq) (dil) $\longrightarrow$ $MgCl_2$ (aq) + $2H_2O$ (l) + $2CO_2$

Example 2

$CaCO_3$ (s) + H_2SO_4(aq) (dil) $\longrightarrow$ $CaSO_4$(aq) + H_2O (l) + $CO_2(g)$

$Ca(HCO_3)_2$(aq) + H_2SO_4(aq) (dil) $\longrightarrow$ $CaSO_4$(aq) + 2 H_2O (l) + $2CO_2(g)$

Example 3

$ZnCO_3$ (s) + 2HCl (aq) (dil) $\longrightarrow$ $ZnCl_2$(aq) + H_2O (l) + $CO_2(g)$

$Zn(HCO_3)_2$ (aq) + 2HCl(aq) (dil) $\longrightarrow$ $ZnCl_2$(aq) + $2H_2O$ (l) + $2CO_2(g)$

2.2.3 Reaction of acids with bases

When an acid reacts with a base then a salt and water are formed, i.e

Acid + Base $\longrightarrow$ Salt + water

This reaction is called **neutralization reaction**, because when acid and base react with each other, they neutralize each other's effect (i.e base destroys the acidic property of acid and acid destroys the basic property of base).

Example: Reaction of hydrochloric acid (HCl) with sodium hydroxide (NaOH).

Experiment: Take about 10 ml of dil NaOH solution in a conical flask and add 2-3 drops of phenolphthalein indicator to it. The solution will turn pink (showing that it is basic in nature). Now add dil HCl solution from burette into flask slowly till the pink colour in the solution disappears.

Observation: This point (at which pink colour disappear) is called end point.

At end point:

(i) The dil NaOH solution in flask has been completely neutralised by dil HCl solution added from burette, dil NaOH has completely reacted with dil HCl.

(ii) $\underset{\text{(from acid)}}{[H^+]} = \underset{\text{(from base)}}{[OH^-]}$ (in case of NaOH & HCl)

In case of NaOH and HCl, and thus the reaction mixture has become neutral.

The chemical reaction can be written as

$$\underset{\substack{\text{sodium hydroxide}\\\text{(base)}}}{NaOH(aq)} + \underset{\substack{\text{hydrochloric acid}\\\text{(acid)}}}{HCl(aq)} \longrightarrow \underset{\substack{\text{sodium chloride}\\\text{(salt)}}}{NaCl(aq)} + \underset{\text{water}}{H_2O(l)}$$

This reaction of acid and base to form salt and water is called neutralization reaction or neutralization of base by an acid

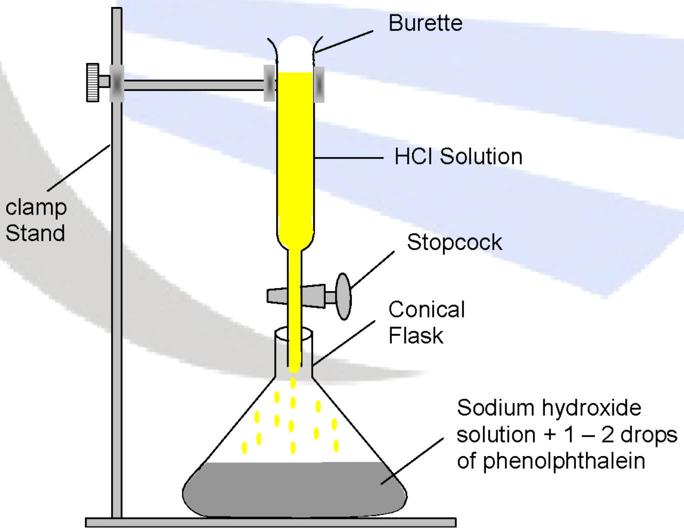


Figure-neutralisation of NaOH solution by HCl solution using phenolphthalein indicator

In the solution, NaOH, HCl and NaCl ionize completely into ions, so the above reaction can be written as:

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

Canceling out the common ions on both sides, we get:

$$\underset{\substack{\text{hydroxide ion}\\\text{(from base)}}}{OH^-} + \underset{\substack{\text{hydrogen ion}\\\text{(from acid)}}}{H^+} \xrightarrow[\text{Reaction}]{\text{neutralisation}} \underset{\text{water}}{H_2O}$$

Hence, neutralization may also be defined as the reaction between H^+ ions given by acid with the OH^- ions given by base to form water

2.2.4 Reaction of acids with metallic oxides

Acid react with metal oxide to form salt and water.

i.e. Metal oxide + Acid → Salt + Water

This reaction is similar to the neutralization reaction between acid and a base to form salt and water. Thus, the reaction between acids and metal oxides is a kind of neutralization reaction and shows that metallic oxides are basic oxides.

Example:

Reaction of copper (II) oxide with dilute hydrochloric acid:

Experiment: Take about 1- 2g of copper (II) oxide (black in colour) in a beaker. Add dil HCl slowly with constant stirring.

Observation: Black CuO dissolves in dil HCl and a bluish green solution is formed due to formation of copper (II) chloride ($CuCl_2$) as salt.

The reaction taking place is:

$$\underset{\substack{\text{copper (II) oxide}\\\text{(black)}}}{CuO(s)} + \underset{\text{hydrochloric acid}}{2HCl(aq)} \longrightarrow \underset{\substack{\text{copper (II)chloride}\\\text{(salt)}}}{CuCl_2(aq)} + \underset{\text{water}}{H_2O}$$

2.3 WHAT DO ALL ACIDS HAVE IN COMMON OR CHEMICAL NATURE OF ACIDS

To see what is common in all acids, let us perform the following experiment with different acids:

Experiment to illustrate chemical nature of acids or what do all acids have in common:

Take four test tubes and label them as A, B, C and D. Place them in a test tube stand. Take about 2 ml of each dil HCl, dil H_2SO_4, dil HNO_3 and dil CH_3COOH in test tubes A, B, C and D respectively. Now add few pieces of zinc granules in each test tube.

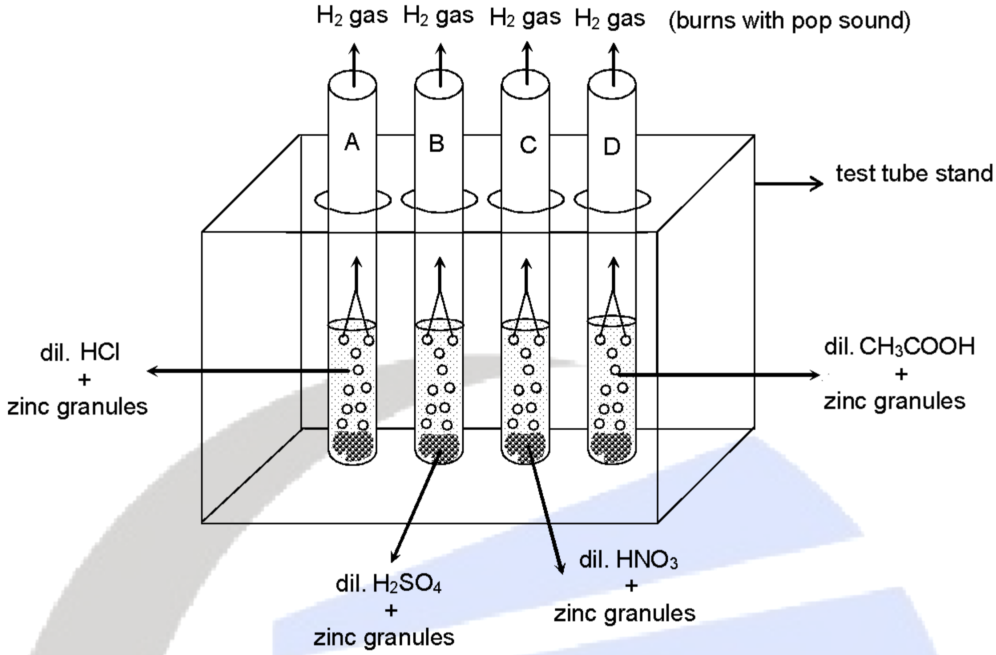


Figure-reaction of Zn metal with different acids

Observation: There is evolution of hydrogen gas (H_2) in each test tube which burns with a pop sound on bringing a burning a candle near the mouth of tubes.

Conclusion: Hydrogen is common in all acids i.e. all acids contain hydrogen which they liberate when they react with active metals.

Thus we can say that acids are the substance which contain hydrogen, which they liberate when they react with active metals.

All acids contain hydrogen but all hydrogen containing compounds are not acids, for example, glucose ($C_6H_{12}O_6$) and alcohol (C_2H_5OH) contain hydrogen but they are not acids.

It can be explained more clearly by following experiment.

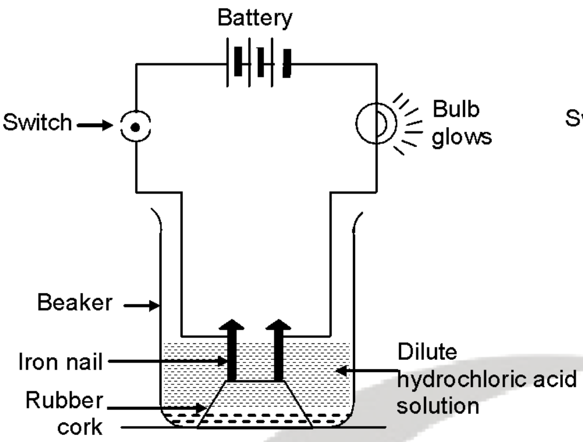
Experiment to show that all compounds containing hydrogen are not acids: The experiment is based on the fact that acids conduct electricity through their aqueous solutions.

(i) Take aqueous solutions of hydrogen containing compounds like hydrochloric acid (HCl), sulphuric acid (H_2SO_4), glucose $(C_6H_{12}O_6)$ and alcohol (C_2H_5OH) in 4 beakers respectively.

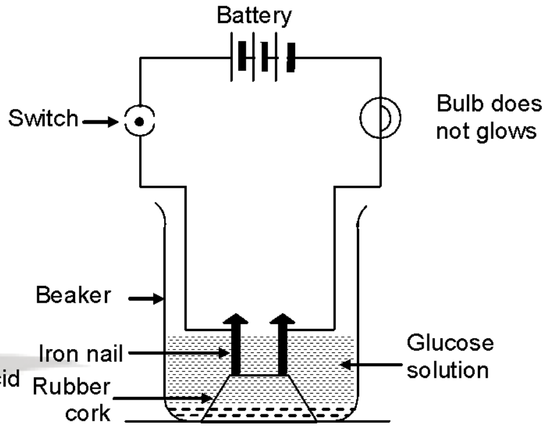
(ii) Fix two iron nails on the rubber cork and place the cork in each beaker

(iii) Connect the nails to the two terminals of a 6 volt battery through a switch and a bulb (fig) in each beaker

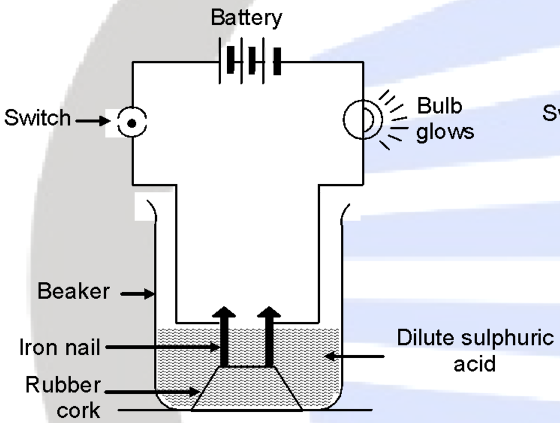
(iv) Switch on the current in each case



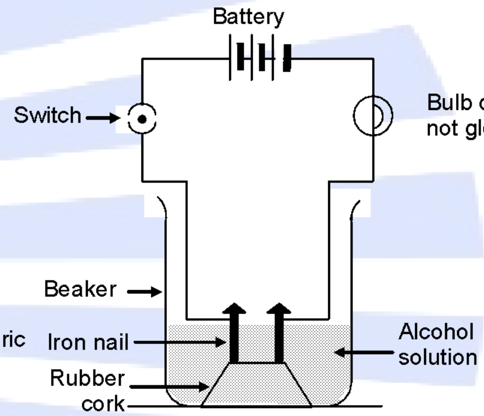
(a) Hydrochloric acid solution in water conducts electricity



(b) Glucose solution in water does not conduct electricity



(c) Sulphuric acid solution in water conducts electricity



(d) Alcohol solution in water does not conduct electricity

Observation:

(i) Bulb starts glowing in arrangements a and c containing aqueous solutions of HCl and H_2SO_4 acids respectively.

It shows aqueous solutions of hydrochloric acid (HCl) and sulphuric acid (H_2SO_4) conduct electricity.

(ii) Aqueous solutions of glucose $(C_6H_{12}O_6)$ and alcohol (C_2H_5OH) do not conduct electricity (i.e. they do not allow electricity to pass through them) as bulb does not glow in arrangements b and d containing aqueous solutions of glucose and alcohol.

Explanation: Conduction of electricity through the aqueous solutions of acids (HCl and H_2SO_4) is due to the ions present in them. For example, aqueous solution of H_2SO_4 contains H^+ and SO_4^{2-} ions. These ions can carry electric current and thus are responsible for conduction of electricity through HCl and H_2SO_4 solutions. On the other hand aqueous solutions of glucose and alcohol (hydrogen containing compounds) do not contain H^+ ions or any other ions. Due to absence of ions, aqueous solutions of glucose and alcohol do not conduct electricity.

Conclusion: From the above experiment, we lead to a conclusion that only those hydrogen containing compounds are acidic which when dissolved in water give H^+ ions in the solution. Thus the definition of acid is modified as:

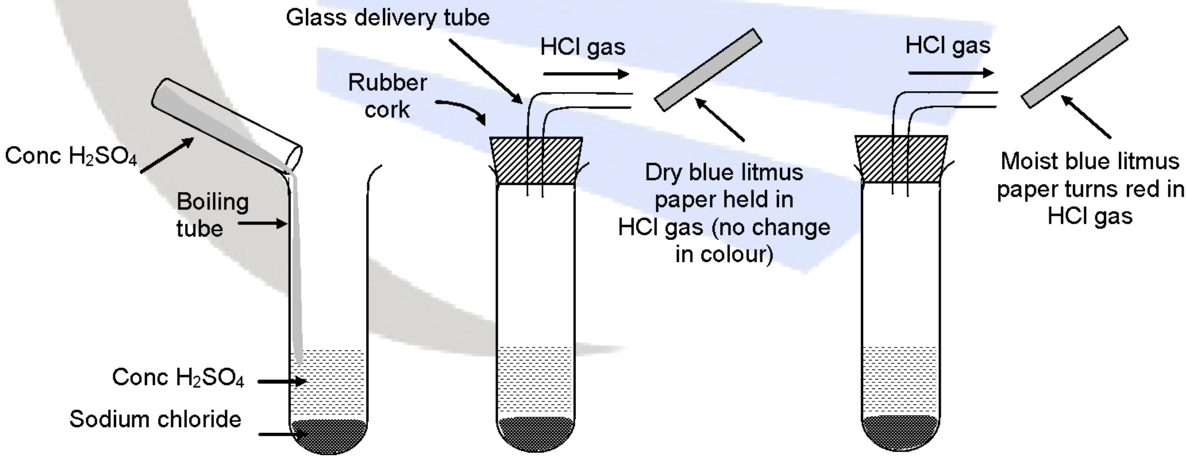
Acids are the substances which contain hydrogen and which when dissolved in water give H^+ ions in the solution. This is called **Arrhenius definition of acids** given by Arrhenius in 1884.

2.4 ROLE OF WATER IN SOLUTION OF AN ACID OR WHAT HAPPENS TO AN ACID IN WATER SOLUTION?

It is observed that acidic behaviour of acids is due to the presence of H^+ ions in them, which they give only in presence of water. So in the absence of water, a substance will not form H^+ ions and hence will not show its acidic behavior. It can be explained more clearly by following experiments:

Experiment: Take about 1–2 g of NaCl in a dry test tube. Add some concentrated H_2SO_4 into the test tube. Following reaction takes place producing hydrogen chloride (HCl) gas

$$\underset{\text{sodium chloride}}{NaCl} + \underset{\substack{\text{sulphuric acid}\\\text{(conc.)}}}{H_2SO_4} \rightarrow \underset{\text{sodium hydrogen sulphate}}{NaHSO_4} + \underset{\text{hydrogen chloride gas}}{HCl}$$



(a) Preparation of HCl gas (b) Testing HCl gas with dry litmus paper (c) Testing HCl gas with moist (wet) litmus paper

Now bring a dry blue litmus paper and a wet (or moist) blue litmus paper near the mouth of test tube (which contains HCl gas)

Observation:

(i) The dry litmus paper does not turn red. It shows that HCl gas does not behave as an acid in absence of water (since there is no water in dry litmus paper).
(ii) The wet (or moist) litmus paper turns red. It shows that HCl gas act as an acid only in presence of water (which is present in moist or wet litmus paper).

Explanation:

(i) When HCl gas come in contact with dry litmus paper, then HCl does not dissociate into ions (i.e H^+ and Cl^- ions) due to absence of water in dry litmus paper.

Since H^+ ions are responsible for acidic behaviour of acids, HCl gas does not show acidic behaviour with dry litmus paper and thus it does not turn the blue litmus red (due to absence of H^+ ion in dry HCl gas).

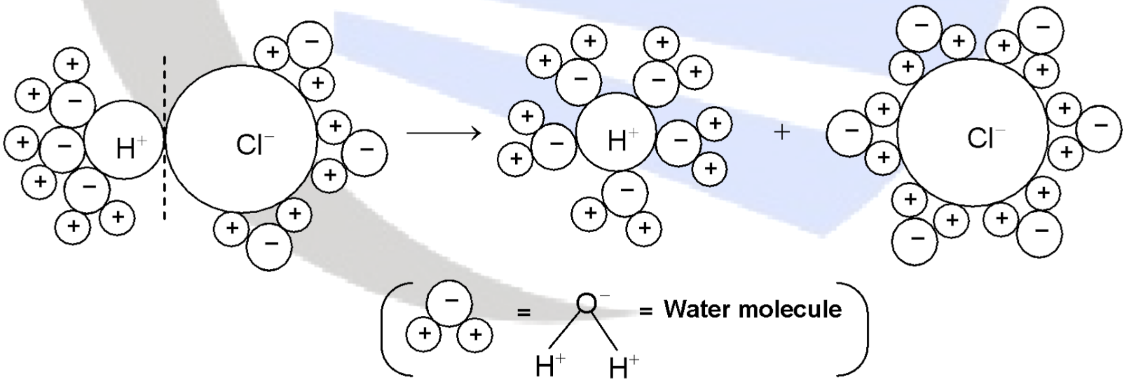
$$\underset{\text{(acts as gas)}}{HCl(g)} \xrightarrow{\text{in absence of water}} \text{Dissociation does not occur.}$$

(ii) When HCl gas comes in contact with wet litmus paper, then HCl dissociates into H^+ and Cl^- ions due to dissociation of HCl in water present in wet litmus paper.

Since H^+ ions are responsible for acidic behaviour of acids. HCl gas shows acidic behaviour with wet litmus paper and thus it turns it into red (due to presence of H^+ ions in wet HCl gas) i.e.

$$\underset{\text{(acts as acid)}}{HCl(g)} \xrightarrow{\text{in presence of water}} \underset{\text{(dissociation occurs)}}{H^+(aq) + Cl^-(aq)}$$

Such dissociation of a covalent molecule like HCl into ions in the presence of water is called **ionization**. The ionization of water is shown more clearly as follows:



Dissociation of HCl into H^+ and Cl^- ions in presence of water.

It is clear from the figure that, after dissociation of HCl, a number of water molecules remain attached to H^+ and Cl^-. Hence they are represented as $H^+(aq)$ and $Cl^-(aq)$ (aq indicating water molecules)

Alternatively, H^+ ions combine with water molecule to form an ion called **hydronium ion**.

$$\underset{\text{hydrogen ion}}{H^+} + \underset{\text{water molecule}}{H_2O} \longrightarrow \underset{\text{hydronium ion}}{H_3O^+}$$

Thus H^+ does not exist freely in water, but exist in combination with water molecules. Hence, we represent it as $H^+(aq)$ or H_3O^+.

Conclusion: The properties of an acid is due to $H^+(aq)$ ions or hydronium ions (H_3O^+) which it gives in the aqueous solution.

2.5 CLASSIFICATION OF ACIDS ON THE BASIS OF DEGREE OF IONIZATION OR STRENGTH OF ACIDS ON BASIS OF DEGREE OF IONIZATION

The acids are classified into two categories on the basis of the degree of ionization as follows:

1. Strong acids
2. Weak acids

2.5.1 Strong acid

An acid which is completely ionized in water and thus produces a large amount of $H^+(aq)$ ions is called a strong acid e.g. acids like hydrochloric acid (HCl), nitric acid (HNO_3) and sulphuric acid (H_2SO_4) are completely ionized in water and thus produce large amounts of $H^+(aq)$ ions in the solution. So these are called strong acids. The ionization of these acids are represented as follows:

(i) $$\underset{\text{hydrochloric acid}}{HCl} + water \rightarrow \underset{\text{hydrogen ion}}{H^+(aq)} + \underset{\text{chloride ion}}{Cl^-(aq)}$$

or

$$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

(ii) $$\underset{\text{nitric acid}}{HNO_3} + water \rightarrow \underset{\text{hydrogen ion}}{H^+(aq)} + \underset{\text{nitrate ion}}{NO_3^-(aq)}$$

or

$$HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$$

(iii) $$\underset{\text{sulphuric acid}}{H_2SO_4} + water \rightarrow \underset{\text{hydrogen ion}}{2H^+(aq)} + \underset{\text{sulphate ion}}{SO_4^{2-}(aq)}$$

or

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

Characteristics of strong acids

Due to large amounts of H^+ (aq) ions in the solutions of strong acids,

(i) They react rapidly with other substances (such as metals, metal carbonates and metal hydrogen carbonates or metal bicarbonates).

(ii) They have a high electrical conductivity.

(iii) They are strong electrolytes.

2.5.2 Weak acids

An acid which is partially ionized in water and thus produces small amount of H^+ (aq) ions is called a weak acid. e.g. Acids like acetic acid (CH_3COOH) formic acid $(HCOOH)$, carbonic acid (H_2CO_3) and phosphoric acid (H_3PO_4) etc, are partially ionised in water and thus produce small amounts of H^+ (aq) ions in the solution, so these are called weak acids. The ionization of these acids are represented as follows:

(i) $$\underset{\text{acetic acid}}{CH_3COOH} + \text{water} \rightleftharpoons \underset{\text{acetate ion}}{CH_3COO^-(aq)} + \underset{\text{hydrogen ion}}{H^+(aq)}$$

or

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$$

(ii) $$\underset{\text{carbonic acid}}{H_2CO_3} + \text{water} \rightleftharpoons \underset{\text{hydrogen ion}}{2H^+(aq)} + \underset{\text{carbonate ion}}{CO_3^{2-}(aq)}$$

or

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

(iii) $$\underset{\text{phosphoric acid}}{H_3PO_4} + \text{water} \rightleftharpoons \underset{\text{hydrogen ion}}{3H^+(aq)} + \underset{\text{phosphate ion}}{PO_4^{3-}(aq)}$$

or

$$H_3PO_4(aq) \rightleftharpoons 3H^+(aq) + PO_4^{3-}(aq)$$

(iv) $$\underset{\text{formic acid}}{HCOOH} + \text{water} \rightleftharpoons \underset{\text{formate ion}}{HCOO^-(aq)} + \underset{\text{hydrogen ion}}{H^+(aq)}$$

or

$$HCOOH(aq) \rightleftharpoons HCOO^-(aq) + H^+(aq)$$

Characteristics of weak acids:

Due to small amounts of $H^+(aq)$ ions in the solutions of weak acids,

(i) They react quite slowly with other substances (such as metals, metal carbonates and metal bicarbonates etc).

(ii) They have low electrical conductivity.
(iii) They are weak electrolytes.

Conclusion:

Greater the degree of ionization, greater is the amount of $H^+(aq)$ ions produced in solution and stronger is the acid (or greater is strength of acid).

Smaller the degree of ionization, smaller is the amount of $H^+(aq)$ ions produced in the solution and weaker is the acid (or smaller is the strength of acid).

Thus,

Strength of an acid $\propto$ Degree of ionization ↓ Directly proportional to

2.6 DILUTION OF CONCENTRATED ACIDS–AN EXOTHERMIC REACTION

2.6.1 Concentrated acid

Pure acid is generally known as the concentrated acid.

2.6.2 Dilute acid

A concentrated acid mixed with water is called a dilute acid and this process of mixing of water to a concentrated acid is called dilution.

Experiment to verify that dilution of a concentrated acid is exothermic

Take a small amount of water in a beaker. Note its temperature. Now put a few drops of conc. H_2SO_4 or conc. HNO_3 acid into it and note the temperature of beaker again.

Observation:

There is rise in temperature in each case.

Thus dilution of conc. acid is an exothermic reaction and is accompanied by ionization of acid as follows:

Chemical reactions:

$$\underset{\text{sulphuric acid (conc)}}{H_2SO_4(l)} + \underset{\text{water}}{2H_2O} \rightarrow \underset{\text{hydronium ion}}{2H_3O^+(aq)} + \underset{\text{sulphate ion}}{SO_4^{2-}(aq)} + \underset{\text{released}}{\text{Heat}}$$

$$\underset{\text{nitric acid (conc.)}}{HNO_3(l)} + \underset{\text{water}}{H_2O(l)} \rightarrow \underset{\text{hydronium ion}}{H_3O^+(aq)} + \underset{\text{nitrate ion}}{NO_3^-(aq)} + \underset{\text{released}}{\text{Heat}}$$

Conclusion:

From the above experiment we lead to a conclusion that dilution of concentrated acid in water is an exothermic (or heat releasing) reaction.

2.6.3 How to dilute a concentrated acid?

Since dilution of a concentrated acid is highly exothermic reaction, the heat produced is so large that the solution may splash out or glass beaker may break in which dilution is carried out due to excessive heating. Hence to slow down the exothermic process, dilution of a concentrated acid is always done by adding acid into water and not water into acid as shown in figure.

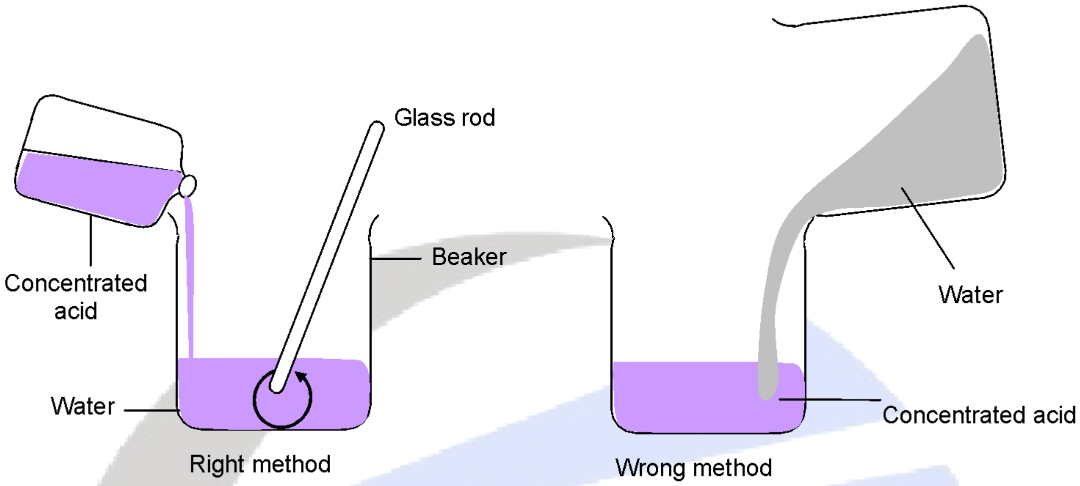


Figure-dilution of a concentrated acid

Conclusion:

We should dilute an acid by mixing acid into water and not water into acid

2.6.4 Effect of dilution on [H^+] of an acid

On dilution, the [H^+] in the solution decreases and the solution become less acidic (or strength of acid decreases). This can be verified by the following experiment

Experiment to verify that strength of an acid decreases on dilution

Take about 5 ml of dilute HCl acid in test tube A. In another test tube B, take 5 ml of more diluted HCl (10 times more dilute than HCl in test tube A). Similarly take about 5 ml of more diluted HCl (10 times more dilute than HCl in test tube B) in test tube C.

Now add few pieces of zinc granules in each of the test tubes.

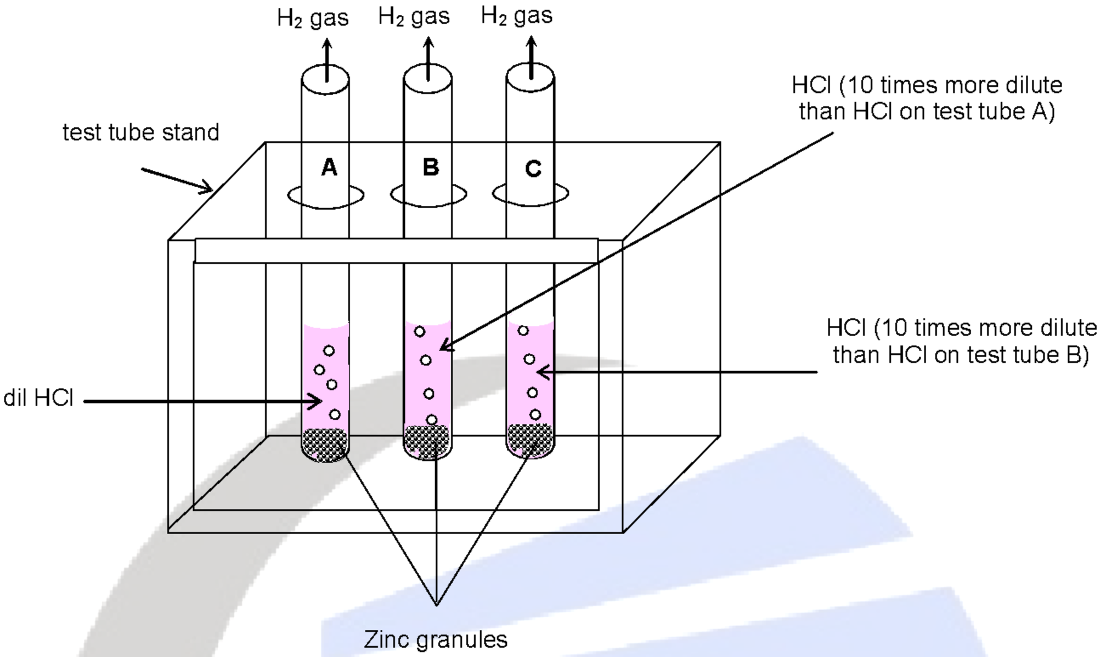


Figure-effect of dilution of an acid

Observation:

There is evolution of hydrogen (H_2) gas in each case. According to the reaction:

$$\underset{\text{zinc}}{Zn} + \underset{\substack{\text{(dil)}\\ \text{hydrochloric acid}}}{2HCl} \rightarrow \underset{\text{zinc chloride}}{ZnCl_2} + \underset{\text{hydrogen}}{H_2(g)}$$

It is observed that the rate of evolution of H_2 gas is fastest in test tube A (having small dilution) and lowest in test tube C (having large dilution) and moderate in test tube B.

Conclusion:

From the above experiment we lead to a conclusion that on dilution, $[H^+]$ in solution decreases. Thus acidic strength of an acid decreases on dilution (since strength of an acid is due to the presence of $[H^+]$ in solution).

Important Note: Acidic strength of an acid is affected by two factors:

(i) Degree of ionization of an acid:

i.e strength of an acid $\propto$ degree of ionization

Greater the degree of ionization, greater will be $[H^+]$ in the solution and thus greater will be the strength of an acid (or stronger will be an acid). Similarly, smaller the degree of ionization smaller will be $[H^+]$ in solution and thus smaller will be the strength of an acid (or weaker will be the acid).

(ii) Dilution of an acid:

i.e strength of an acid $\propto \frac{1}{\text{dilution of an acid}}$, greater the dilution of an acid, lesser will be $[H^+]$ in the solution and thus lesser will be the strength of an acid (or weaker will be the acid)

Similarly smaller the dilution of an acid, greater will be $[H^+]$ in solution and thus greater will be the strength of an acid (or stronger will be the acid).

2.6.5 More about acids

(i) Some naturally occurring acids: A few naturally occurring sources of acids and the acids present in them are given in table below:

S. No.	Natural source	Acid Present
1.	Oranges, lemons	Citric acid
2.	Apples	Malic acid
3.	Tomatoes	Oxalic acid
4.	Tamarind (Imli)	Tartaric acid
5.	Sour milk or curd	Lactic acid
6.	Vinegar	Acetic acid
7.	Proteins	Amino acids

(ii) Handling acidic food stuff in the household : In traditional kitchens, copper and brass vessels are used even today. Hence, if curd or other sour substances which are acidic in nature are kept in these vessels, they react to form toxic compounds(since acids react with metals) and make the food stuff unfit for consumption.

Therefore, to protect them from such a reaction, these vessels have to be coated with a thin layer of tin(kalai) from time to time.

2.6.6 Usefulness of certain acids

(i) Hydrochloric acid (HCl) produced in the stomach kill the harmful bacteria that may enter into the stomach along with the food we eat.

(ii) Vinegar (acetic acid) is used in the pickling of food as a method of preservation of food.

3. BASES

Those substances which change red litmus solution blue are called bases. They are bitter in taste.

3.1 PHYSICAL PROPERTIES OF BASES

(i) Bitter taste: Almost all basic substances have a bitter taste.
(ii) Action on litmus solution: Bases turn red litmus solution into blue.
(iii) Action on methyl orange: Bases turn methyl orange into yellow.
(iv) Action on phenolphthalein: Bases turn phenolphthalein into pink.
(v) Conduction of electricity: Like acid, the aqueous solution of a base also conducts the electricity.

3.2 CHEMICAL PROPERTIES OF BASES

3.2.1 Reaction of bases with metals

When a base reacts with a metal then a metal salt and H_2 (g) are formed

i.e. Metal + Base → Salt + H_2 gas

Example:

Reaction of Sodium hydroxide (NaOH) with zinc metal (Zn)

Experiment: Take 2-3 pieces of zinc granules in a test tube and add about 2-3 ml of conc. NaOH solution in to it and warm the contents.

Observation: There is evolution of H_2 gas which burns with a pop sound (on bringing a burning candle near the mouth of tube).

The reaction involved is:

$$\underset{\text{zinc (a metal)}}{Zn(s)} + \underset{\text{sodium hydroxide (conc.)}}{2NaOH} \rightarrow \underset{\text{sodium zincate (a salt)}}{Na_2ZnO_2} + \underset{\text{hydrogen gas}}{H_2(g)}$$

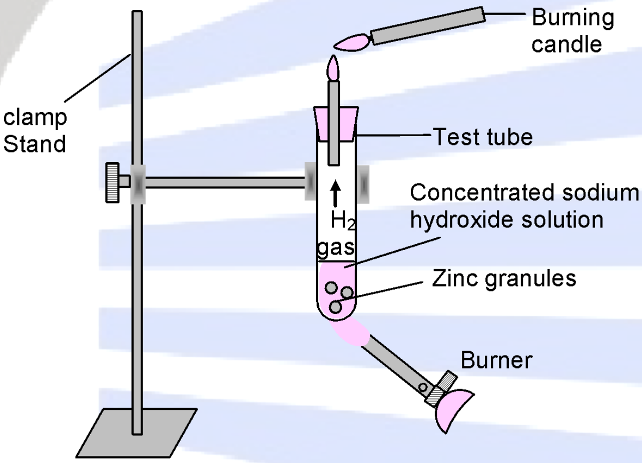


Figure-study of the reaction of sodium hydroxide with Zn metal

3.2.2 Reaction of Bases with Acids

When a base reacts with an acid then salt and water are formed

i.e. Base + Acid ⟶ Salt + Water

This reaction is called neutralization reaction, because when base and acid react with each other, they neutralize each others effect (i.e. acid destroys the basic property of a base and a base destroys the acidic property of an acid)

Example:

(i)

$$\underset{\text{sodium hydroxide (base)}}{NaOH(aq)} + \underset{\text{hydrochloric acid (acid)}}{HCl(aq)} \longrightarrow \underset{\text{sodium chloride (salt)}}{NaCl(aq)} + \underset{\text{water}}{H_2O(l)}$$

(ii)

$$2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

sodium hydroxide (base) | sulphuric acid (acid) | sodium sulphate (salt) | water

These reactions of bases and acids to form salt and water are called neutralization reactions or neutralization of acids and bases. (As discussed in detail in neutralization reaction of acids and bases in the topic on Acids)

Conclusion: Reaction of a base with an acid is a neutralization of an acid by base i.e. in the reaction of base with acid, base neutralize or destroy the acidic properties of an acid.

3.2.3 Reaction of base with non-metal oxide

Bases react with non-metal oxide to form salt and water

i.e. Non metal oxide + Base $\longrightarrow$ Salt + water

This reaction is similar to the neutralization reaction between acid and base to form salt and water. Thus, the reaction between bases and metal oxides is a kind of neutralization reaction and shows that non-metal oxides are acidic oxides.

Example:

Reaction of calcium hydroxide (lime water) with carbon dioxide.

Calcium hydroxide (lime water) is a base and carbon dioxide (CO_2) is a non-metal oxide, so when they react with each other, salt and water are produced according to the reaction:

$$\underset{\substack{\text{calcium hydroxide}\\\text{(lime water)}\\\text{(base)}}}{Ca(OH)_2(aq)} + \underset{\substack{\text{carbondioxide}\\\text{(non-metal oxide)}}}{CO_2(g)} \longrightarrow \underset{\substack{\text{calcium}\\\text{carbonate}\\\text{(salt)}}}{CaCO_3(g)} + \underset{\text{water}}{H_2O(l)}$$

Thus, it is an example of neutralization reaction (reaction of acid and base to form salt and water). It shows that non-metal oxides are acidic in nature.

Conclusion:

Reaction of bases with non-metal oxides are neutralization reactions which show the acidic nature of non-metals.

3.3 CHEMICAL NATURE OF BASES

Like acids, bases also possess some general characteristic properties which show that chemically bases must have something in common.

It is found that when bases are dissolved in water, they produce OH^- ions (hydroxide ions) in the solution according to the reactions:

(i) $$\underset{\substack{\text{sodium hydroxide}\\\text{(base)}}}{NaOH} + \text{water} \longrightarrow \underset{\text{sodium ions}}{Na^+(aq)} + \underset{\text{hydroxide ion}}{OH^-(aq)}$$

or

$$NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$$

(ii) $$KOH + \text{water} \longrightarrow K^+(aq) + OH^-(aq)$$

potassium hydroxide (base) — potassium ion — hydroxide ion

or

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

(iii) $$NH_4OH + water \longrightarrow NH_4^{+}(aq) + OH^{-}(aq)$$

ammonium hydroxide (base) — ammonium ion — hydroxide ion

or

$$NH_4OH(aq) \longrightarrow NH_4^{+}(aq) + OH^{-}(aq)$$

Thus, bases when dissolved in water produce OH^{-} ions in the solution. Such dissociation of bases into ions in presence of water is called **ionization**. These OH^{-} ions are responsible for the basic properties of the bases which they give only when dissolved in water. Hence a base can be defined as:

A base is a substance which when dissolved in water gives hydroxide $[OH^{-}]$ ions in the solution. This is called **Arrhenius definition of bases** which was put by Arrhenius in 1884.

Conclusion:

The properties of base are due to $OH^{-}(aq)$ ions which it gives in the aqueous solution (or with water).

or

Basic properties of bases are due to presence of $OH^{-}(aq)$ ions which they produce only in presence of water.

or

In absence of water, a substance will not form $OH^{-}(aq)$ ions and hence will not show its basic behaviour.

or

Necessary and sufficient condition for a substance or compound to be a base is that it should give $OH^{-}(aq)$ ions in presence of water (or when dissolved in water).

Note:

(i) In solution, like H^+ ions are represented by $H^+(aq)$, the OH^- ions are also represented by $OH^-(aq)$.

(ii) All bases contain $-OH$ group, but all $-OH$ group containing compound are not bases. For example C_2H_5OH (ethyl alcohol) contains $-OH$ group, but since, it does not ionize in water to give OH^- ions it is not a base.

(iii) Greater the amount of OH^- ions in the solution, stronger is the base.

3.4 CLASSIFICATION OF BASES ON THE BASIS OF DEGREE OF IONIZATION

The bases are classified into two categories on the basis of degree of ionization as follows:

(i) Strong bases

(ii) Weak bases

3.4.1 Strong Bases

A base which is completely ionized in water and thus produces a large amount of OH^- (aq) ions in the solution is called a strong base e.g. bases like sodium hydroxide $(NaOH)$, potassium hydroxide (KOH) are completely ionized in water and thus produce large amounts of $OH^-(aq)$ ions in the solution. So these are called strong bases.

The ionization of these bases is represented as follows:

(i) $\underset{\text{sodium hydroxide}}{NaOH} + \text{water} \longrightarrow \underset{\text{sodium ion}}{Na^+(aq)} + \underset{\text{hydroxide ion}}{OH^-(aq)}$

or

$$NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$$

(ii) $\underset{\text{potassium hydroxide}}{KOH} + \text{water} \longrightarrow \underset{\text{potassium ion}}{K^+(aq)} + \underset{\text{hydroxide ion}}{OH^-(aq)}$

or

$$KOH(aq) \longrightarrow K^+(aq) + OH^-(aq)$$

3.4.2 Weak bases

A base which is partially ionized in water and thus produces a small amount of $OH^-(aq)$ ions in the solution is called a weak base, e.g. bases like ammonium hydroxide (NH_4OH),

calcium hydroxide $Ca(OH)_2$, magnesium hydroxide $Mg(OH)_2$ are weak bases as they ionize partially in water to produce small amounts of $OH^-(aq)$ ions in the solution.
The ionization of these bases is represented as follows:

(i) NH_4OH (Ammonium hydroxide) + water $\rightleftharpoons$ $NH_4^+(aq)$ (Ammonium ion) + $OH^-(aq)$ (hydroxide ion)

or

$$NH_4OH(aq) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

(ii) $Ca(OH)_2$ (calcium hydroxide (lime water)) + water $\rightleftharpoons$ $Ca^{2+}(aq)$ (calcium ion) + $2OH^-(aq)$ (hydroxide ion)

or

$$Ca(OH)_2(aq) \rightleftharpoons Ca^{2+}(aq) + 2OH^-(aq)$$

(iii) $Mg(OH)_2$ (magnesium hydroxide) + water $\rightleftharpoons$ $Mg^{2+}(aq)$ (magnesium ion) + $2OH^-(aq)$ (hydroxide ion)

or

$$Mg(OH)_2(aq) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq)$$

Conclusion:

Greater the degree of ionization, greater is the amount of $OH^-(aq)$ ions produced in the solution and thus stronger is the base (or greater is the strength of base).

Smaller the degree of ionization, smaller is the amount of $OH^-(aq)$ ions produced in the solution and thus weaker is the base (or smaller is the strength of base). Thus,

Strength of base $\propto$ Degree of ionization.

3.5 DILUTION OF BASE: AN EXOTHERMIC REACTION

Like acids, dilution of bases with water or mixing of bases with water is an exothermic process e.g. if we dissolve bases like NaOH, KOH in water, the solution is found to be hotter. This shows that dissolution of bases in water is an exothermic process.

3.6 EFFECT OF DILUTION ON STRENGTH OF A BASE

Like acids, on dilution of base with water, $[OH^-]$ in the solution decrease and thus, solution becomes less basic (or strength of base decrease)
Important Note: Basic strength of a base is affected by two factors:

(i) Degree of ionization of a base i.e. strength of base ∝ degree of ionization. Greater the degree of ionization, greater will be $[OH^-]$ in the solution and thus greater will be the strength of a base (or stronger will be a base).

Similarly, smaller the degree of ionization, smaller will be $[OH^-]$ in the solution and thus, smaller will be the strength of the base (or weaker will be the base).

(ii) Dilution of a base: Strength of a base $\propto \frac{1}{\text{dilution of a base}}$ greater the dilution of a base, lesser will be $[OH^-]$ in the solution and thus, lesser will be the strength of the base (or weaker will be the base).

Similarly, smaller the dilution of a base, greater will $[OH^-]$ in the solution and thus, greater will be the strength of the base (or stronger will be the base).

4. STRENGTH OF ACID AND BASE SOLUTION: pH SCALE

Strength of an acid or base can be measured on pH scale.

pH scale: A scale of numbers from 0 to 14 on which the strength of an acid or base is measured is known as pH scale.

pH is defined as negative logarithm of $[H^+]$ or $[H_3O^+]$

i.e. $pH = -\log[H^+]$ or $pH = -\log[H_3O^+]$

e.g. if $[H^+] = 10^{-1}\text{mol L}^{-1}$, then $pH = -\log(10^{-1}) = \log 10 = 1$

if $[H^+] = 10^{-2}\text{mol L}^{-1}$, then $pH = -\log(10^{-2}) = 2\log 10 = 2$

It is clear from the above expression that pH of a solution is the magnitude of the negative power to which 10 must be raised to express the $[H^+]$ of the solution in mol L^{-1}.

In other words, pH stands for power of hydrogen ions (p stands for power and H stands for hydrogen)

e.g.

If $[H^+] = 10^{-1}\text{mol L}^{-1}$, then pH = 1

If $[H^+] = 10^{-2}\text{mol L}^{-1}$, then pH = 2

If $[H^+] = 10^{-6}\text{mol L}^{-1}$, then pH = 6 and so on

and If $[OH^-] = 10^{-6}\text{mol L}^{-1}$, then $[H^+] = 10^{-8}\text{mol L}^{-1}$ and pH = 8

[$\because$ $[H^+][OH^-] = 10^{-14}\text{mol L}^{-1}$ at 298K $\Rightarrow 10^{-6} \times 10^{-8} = 10^{-14}\text{ mol L}^{-1}$]

similarly if $[OH^-]=10^{-14}\,mol\ L^{-1}$ then $[H^+]=10^{\circ}$ $\because$ $[H^+]\,[OH^-]=10^{-14}$

so that $\left[10^0 \times 10^{-14} = 10^{-14}\right]$

and pH = 0

if $[OH^-]=10^0 mol L^{-1}, [H^+]=10^{-14}$ [so that $10^{-14}\times 10^0 = 10^{-14}$] and pH = 14 and so on

pH values for acidic or basic or neutral solution in terms of $[H^+]$ can be expressed as follows:

4.1 FOR A NEUTRAL SOLUTION (OR WATER)

$[H^+]=[OH^-]=10^{-7} mol L^{-1}$

⇒ its pH = 7 (magnitude of negative power to which 10 must be raised to express $[H^+]$)

4.2 FOR AN ACIDIC SOLUTION

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

or $[H^+]>10^{-7} mol\ L^{-1}$ (i.e. $10^{-6}, 10^{-5}$ etc.)

⇒ its pH < 7 (i.e. 6, 5, 4, ….0)

4.3 FOR A BASIC SOLUTION

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

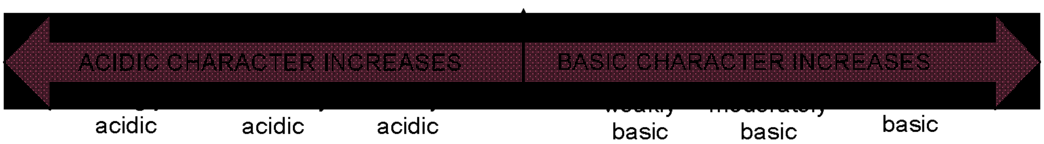
or $[OH^-]>10^{-7} mol\ L^{-1}$ (i.e. $10^{-6}, 10^{-5}$, etc.)

or $[H^+]<10^{-7}$ mol L^{-1} (i.e. $10^{-8}, 10^{-9}$ etc so that $[H^+][OH^-]=10^{-14}$)

⇒ its pH > 7 (i.e. 8, 9, 10, ….14)

Hence, acidic or basic strength or neutral nature of solution may be expressed on the pH scale from 0 to 14 as follows:

H^+	10^{0}	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}
$[OH^-]$	10^{-14}	10^{-13}	10^{-12}	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	10^{0}
	10^{-14}	10^{-13}	10^{-12}	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	10^{0}
pH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14



Conclusion: From the above figure, we lead to a conclusion that
(i) for a neutral solution, pH = 7
(ii) for a basic solution, pH > 7
(iii) for an acidic solution, pH < 7

4.4 MEASUREMENT OF STRENGTH OF ACIDIC AND BASIC SOLUTIONS

To measure the exact strength of the solution of an acid or a base, we determine the pH of the solution by using two methods given below:

4.4.1 Using universal indicator

A universal indicator is a mixture of a number of indicators (or dyes) which show different colours at different values.

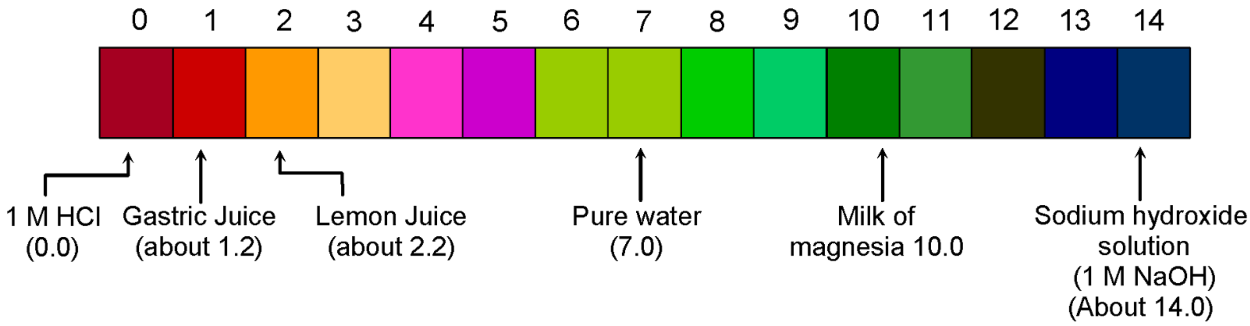
To measure the pH value of any solution, paper strip coated with universal indicator (known as pH paper) is dipped into the given solution and its colour is noted. Thus pH value of the solution can be found out (as the universal indicator shows different colours at different pH values).

Experiment:

Take pH paper (paper coated with universal indicator) and add 2-3 drops of sample solution of various substances like saliva (before and after meal), lemon juice, coffee, tomato juice, 1 M NaOH, and 1 M HCl etc. Observe the change in colour and note the approximate pH value and nature of substance in observation table as shown below:

S. No.	Sample solution	Colour of pH paper	Approx. pH value	Nature of substance
1.	Saliva (before meals)	Greenish blue	7.4	Weakly basic
2.	Saliva (after meals)	Orange yellow	5.8	Weakly acidic
3.	Lemon juice	Red	2.2	Strongly acidic
4.	Coffee	Orange yellow	5.0	Weakly acidic
5.	Tomato juice	Orange	4.1	Moderately acidic
6.	Gastric juice	Red	1.2	Strongly acidic
7.	Tooth paste	Greenish blue	8.0	Weakly basic
8.	Eggs	Greenish blue	7.8	Weakly basic
9.	Blood	Greenish blue	7.4	Weakly basic
10.	Pure water	Greenish	7.0	Neutral
11.	Vinegar	Orange	4.0	Moderately acidic
12.	Soft drinks	Greenish yellow	6.0	Weakly acidic
13.	Milk of magnesia	Navy blue	10.0	Moderately basic
14.	Washing soda	Blue	9.0	Moderately basic
15.	IM NaOH	Violet	14.0	Strongly basic
16.	IM HCl	Dark red	0.0	Strongly acidic

The above observation can be shown more clearly on the following chart (which shows different colours at different pH values with particular, pH paper for some common substances.)



Conclusion:

(i) The solution with pH = 0-3 are strongly acidic, with pH = 3-5 are moderately acidic while with pH = 5–7 are weakly acidic.

(ii) The solution with pH = 7-9 are weakly basic, with pH = 9-12 are moderately basic, while with pH = 12-14 are strongly basic.

The pH paper gives only the approximate value of pH of the solution.

4.4.2 By using pH metre

Since pH paper gives approximate value of pH of the solution, thus to measure the accurate value of pH of the solution, we use an instrument called pH meter.

Now a days, pH of solutions is measured accurately with the help of pH meter

4.5 ROLE OF pH IN EVERYDAY LIFE

The pH plays an important role in many activities of our daily life. Let us discuss in detail

4.5.1 pH in our digestive system

Our stomach produces hydrochloric acid (of pH ≈ 1.2) which helps in digesting food without harming the stomach.

However when we take too much of spicy food, the amount of hydrochloric acid produced increases beyond the required limit and thus causes sharp pain and irritation in the stomach due to indigestion of food. The problem is called **acidity**.

In order to cure indigestion and get rid of pain, we take bases called 'antacids' (antacid means anti-acid). Antacids being basic in nature react with excess acid in the stomach and neutralize it and thus gives relief to the person concerned.

The two common antacids used for curing indigestion due to acidity are magnesium hydroxide (milk of magnesia) and sodium hydrogen carbonate or sodium bicarbonate (baking soda).

4.5.2 pH change as the cause of tooth decay

When we eat food containing sugar, then the bacteria present in our mouth break down the sugar to form acids (such as lactic acid). This acid lowers the pH in the mouth (making it more acidic).

Tooth decay starts when pH of acid formed in the month falls below 5.56.

This is because when the acid becomes strong enough to attack the enamel of our teeth and corrode it. This sets in tooth decay. Though tooth enamel is made of calcium phosphate (which is hardest material in our body), but it starts getting corroded when the pH in mouth is lower than 5.5.

Prevention of tooth decay

(i) The best way to prevent tooth decay is to clean the mouth thoroughly after eating food (by rinsing it with lots of clean water).

(ii) Many toothpastes contain bases to neutralize the mouth acid (The pH of toothpaste being about 8.0). So using toothpastes (which are generally basic) for cleaning the teeth can neutralize the excess acid in mouth and prevent tooth decay.

4.5.3 Self defense by animals and plants through chemical warfare

We feel pain and irritation, when we are stung by an honeybee or yellow ant due to acid (formic acid i.e. methanoic acid) injected into our skin by bee or the ant.

To get relief, we apply the solution of mild base like baking soda, to neutralize the ant's sting.

Similarly we feel pain and irritation, when we are stung by the nettle plants (having leaves with sting) due to formic acid injected by these leaves into our skin.

To get relief we rub the injected area with the leaf of the dock plant (which provides the base) neutralize the acidic sting of nettle plant.

5. SALTS

Salts are the ionic compounds consisting of two parts, one carrying a positive charge (called positive ion or cation) and the other part carrying a negative charge (called a negative ion or anion).

For example $\overset{+}{Na}Cl^{-}$ is a salt having Na^{+} as cation and Cl^{-} as anion.

5.1 FORMATION OF SALTS

The most common method of formation of salts is by the neutralization of acids and bases (i.e. reaction between an acid and a base)

e.g.

(i)
$$\underset{\text{(base)}}{\underset{\text{sod. hydroxide}}{NaOH}} + \underset{\text{(acid)}}{\underset{\text{hydrochloric acid}}{HCl}} \xrightarrow[\text{reaction}]{\text{neutralization}} \underset{\text{(a salt)}}{\underset{\text{sodium chloride}}{NaCl}} + \underset{\text{water}}{H_2O}$$

(ii) $MgO + H_2SO_4 \xrightarrow[\text{reaction}]{\text{neutralization}} MgSO_4 + H_2O$

magnesium oxide (base) — sulphuric acid (acid) — magnesium sulphate (salt) — water

(iii) $NH_4OH + HCl \xrightarrow[\text{reaction}]{\text{neutralization}} NH_4Cl + H_2O$

ammonium hydroxide (base) — hydrochloric acid (acid) — ammonium. chloride (salt) — water

It is clear from the above reactions that positive part of the salt comes from the base (called **basic radical**) and the negative part of the salt comes from the acid (called **acidic radical**) e.g.

Na^+Cl^- salt, Na^+ (comes from NaOH) is called the basic radical and Cl^- (comes from HCl) is called the acidic radical.

5.2 FAMILY OF SALTS

The salts having same positive ions (or same negative ions) are said to belong to a family of salts.

e.g. NaCl and Na_2SO_4 belong to the family of sodium salts(because they both contain same positive ions as Na^+).

Similarly NaCl & HCl belong to the family of chloride salts (because they both contain same negative ions as Cl^-).

Some of the important families of salts are:

Family	Common positive or negative ions involved	Example
Sodium salts	Sodium ions	NaCl, $NaNO_3$, Na_2SO_4, Na_2CO_3 etc.
Potassium salts	Potassium ions	KCl, KNO_3, K_2SO_4, KBr, K_2CO_3 etc.
Ammonium salts	Ammonium ions	NH_4Cl, NH_4NO_3, $(NH_4)_2SO_4$, NH_4Br etc.
Magnesium salts	Magnesium ions	$MgCl_2$, $MgSO_4$, $MgCO_3$ etc.
Calcium salts	Calcium ions	$CaCl_2$, $(CH_3COO)_2Ca$ etc.
Copper salts	Copper ions	$CuSO_4$, $CuCO_3$, $CuCl_2$
Chloride salts	Chloride ions	NaCl, KCl, $MgCl_2$, $ZnCl_2$, $CaCl_2$ etc.
Sulphate salts	Sulphate ions	Na_2SO_4, $MgSO_4$, $CuSO_4$, $CaSO_4$ etc.

carbonate salts	Carbonate ions	$CuCO_3, MgCO_3, K_2CO_3, Na_2CO_3$ etc.
Nitrate salts	Nitrate ions	$KNO_3, NaNO_3, NH_4NO_3$ etc.

5.3 HYDROLYSIS OF SALTS AND pH OF THEIR SALT SOLUTIONS

Salts formed by the reactions between acid & bases undergo ionization in water. The cations/anions formed by ionization of salts interact with water to form corresponding acids/ bases depending upon the nature of salt.

The process of interaction between water and cations/anions or both of salts is called salts hydrolysis.

5.3.1. Salts of strong acid and strong bases

Example:

$NaCl, KCl, Na_2SO_4, K_2SO_4$

$$NaCl(s) + H_2O \rightarrow NaCl(aq) \rightarrow Na^+(aq) + Cl^-(aq)$$

Note: Neither of the two ions of salts $(Na^+ \text{ or } Cl^-)$ undergoes salt hydrolysis. So the resulting solution is neutral with pH = 7.

> <u>Misconception:</u>
>
> $NaCl + H_2O \longrightarrow NaOH + HCl$ (wrong)
>
> The above reaction is not spontaneous i.e. it will not occur in forward direction. The opposite reaction is spontaneous.
>
> $NaOH + HCl \longrightarrow NaCl + H_2O$ (right)

5.3.2. Salts of strong acids and weak bases

Example:

$NH_4Cl, CuSO_4$

The aqueous solutions of these salts are acidic in nature with $pH < 7$

Example

Hydrolysis of NH_4Cl

$$NH_4Cl(s) + H_2O \longrightarrow NH_4Cl(aq) \longrightarrow NH_4^+(aq) + Cl^-(aq)$$

$$NH_4^+ + H_2O \rightleftharpoons NH_4OH + H^+$$

The solution is acidic due to the H^+ ion produced by the hydrolysis of NH_4^+

Note: Hydrolysis of Cl^- do not takes place.

Misconception:

$NH_4Cl + H_2O \longrightarrow NH_4OH + HCl$ (wrong)

The above reaction is not spontaneous i.e. it will not occur in forward direction. The opposite reaction is spontaneous.

$NH_4OH + HCl \longrightarrow NH_4Cl + H_2O$ (right)

5.3.3. Salt of weak acid and strong base

Example:

Na_2CO_3, CH_3COONa

The aqueous solution of these salts are basic in nature with pH > 7.

Example

Hydrolysis of CH_3COONa

$$CH_3COONa(s) + H_2O \longrightarrow CH_3COONa(aq) \longrightarrow CH_3COO^-(aq) + Na^+(aq)$$

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

The solution is basic due to hydrolysis of $CH_3COO^-(aq)$

Note: Hydrolysis of Na^+ do not takes place.

Misconception:

$CH_3COONa + H_2O \longrightarrow CH_3COOH + NaOH$ (wrong)

The above reaction is not spontaneous i.e. it will not occur in forward direction. The opposite reaction is spontaneous.

$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$ (right)

5.3.4. Salt of weak acid & weak base

Example:

CH_3COONH_4

The aqueous solutions of these salts are almost neutral with pH nearly 7.

Example

Hydrolysis of CH_3COONH_4

$$CH_3COONH_4 + H_2O \longrightarrow CH_3COONH_4(aq) \longrightarrow CH_3COO^- + NH_4^+$$

$$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$$

$$NH_4^+ + H_2O \rightleftharpoons NH_4OH + H^+$$

The solution is almost neutral in nature with pH ≈ 7 due to hydrolysis of both CH_3COO^- and NH_4^+ which produces OH^- and H^+ respectively.

Conclusion:

Salts of strong acid and a strong base are neutral with pH = 7.
Salts of strong acid and a weak base are acidic with pH < 7.
Salts of strong base and weak acid are basic with pH > 7. and
Salts of weak acid and a weak base are almost neutral with pH ≈ 7.

5.4 COMMON SALT (SODIUM CHLORIDE, NaCl)

Chemically, common salt is sodium chloride with formula NaCl. It is also called "table salt" as it is used as an important food material. The table salt used as food material is not pure NaCl, but it contains small amounts of KI and thus table salt sold in market is labelled as "iodized salt". The presence of iodide is essential to protect us from thyroid disorders (disorder of the throat).

5.4.1 Occurrence and extraction of common salt

The common salt occurs naturally in sea water, inland lakes and as rock salt. The extraction of common salt from these sources are given below:

(i) Common salt from sea water

Sea water contains many dissolved salts in it. The major salt present in sea water is common salt (or NaCl). The common salt is obtained from sea water by the process of **evaporation** which is done as follows:

Sea water is trapped in large shallow pools and allowed to stand there. The sun's heat evaporates the water slowly and common salt is left behind. This salt contain impurities of $MgCl_2$, $MgSO_4$ etc and thus purified by removing these impurities by suitable method before it is sold in the market.

(ii) Common salt from inland lakes

Large quantities of salt are obtained by natural evaporation of water of inland lakes e.g. Sambhar lake in Rajasthan (India), Great salt lake (Utah, USA) and Lake Elton (Russia).

(iii) Common salt from underground deposits

The large crystals of common salt found in underground ellipsoids are called "Rock salt". It is usually brown due to presence of impurities in it. Rock salt is mined from underground deposits just like coal.

Common salt is an important starting material for the production of a number of other chemicals such as

1. Sodium hydroxide (caustic soda).
2. Calcium oxychloride (bleaching powder).
3. Sodium carbonate (washing soda).
4. Sodium hydrogen carbonate (baking soda) and many others.

Let us describe the preparation, properties and uses of these chemicals obtained from common salt as starting material.

5.4.2 Sodium hydroxide NaOH (caustic soda)

Sodium hydroxide is commonly known as caustic soda having chemical formula NaOH. It is a strong base.

(i) Manufacture of sodium hydroxide (NaOH)

Sodium hydroxide is manufactured by the electrolysis of a concentrated aqueous solution of sodium chloride (called brine) i.e., when the electricity is passed through a concentrated aqueous solution of sodium chloride (called brine), it decomposes to form sodium hydroxide, chlorine and hydrogen.

$$\underset{\substack{\text{sodium chloride}\\\text{(brine)}}}{2NaCl(aq)} + \underset{\text{water}}{2H_2O(l)} \xrightarrow{\text{Electrolysis}} \underset{\substack{\text{sodium hydroxide}\\\text{(caustic soda)}}}{2NaOH(aq)} + \underset{\text{chlorine}}{Cl_2(g)} + \underset{\text{hydrogen}}{H_2(g)}$$

This process is called **chlor-alkali** because of products formed: chlor for chlorine and alkali for sodium hydroxide.

During electrolysis, Cl_2 gas is produced at the anode (positive electrode), H_2 gas is produced at the cathode (negative electrode) and NaOH solution is produced near the cathode. These products i.e. $NaOH, Cl_2(g)$ & $H_2(g)$ obtained by chlor-alkali process have a large number of uses described below one by one.

(ii) Uses of sodium hydroxide (NaOH)

Sodium hydroxide (NaOH) is used

(a) For making soaps and detergents.
(b) For making artificial textile fibres.
(c) For making paper.
(d) In de-greasing metals.
(e) As reagent in laboratory.
(f) In absorbing poisonous gases.
(g) In petroleum industry.

(iii) Uses of chlorine (Cl_2)

Chlorine is used

(a) As disinfectant and germicide for sterilization of drinking water and water in swimming pools.
(b) In manufacture of chlorofluorocarbons $(CFC's)$ used as refrigerants.
(c) In manufacture of PVC (polyvinyl chloride) used for making shoe soles.
(d) In bleaching of wood pulp and cotton fibres.
(e) In manufacture of pesticides.

(iv) Uses of hydrogen (H_2)

(i) To make ammonia for fertilizers.

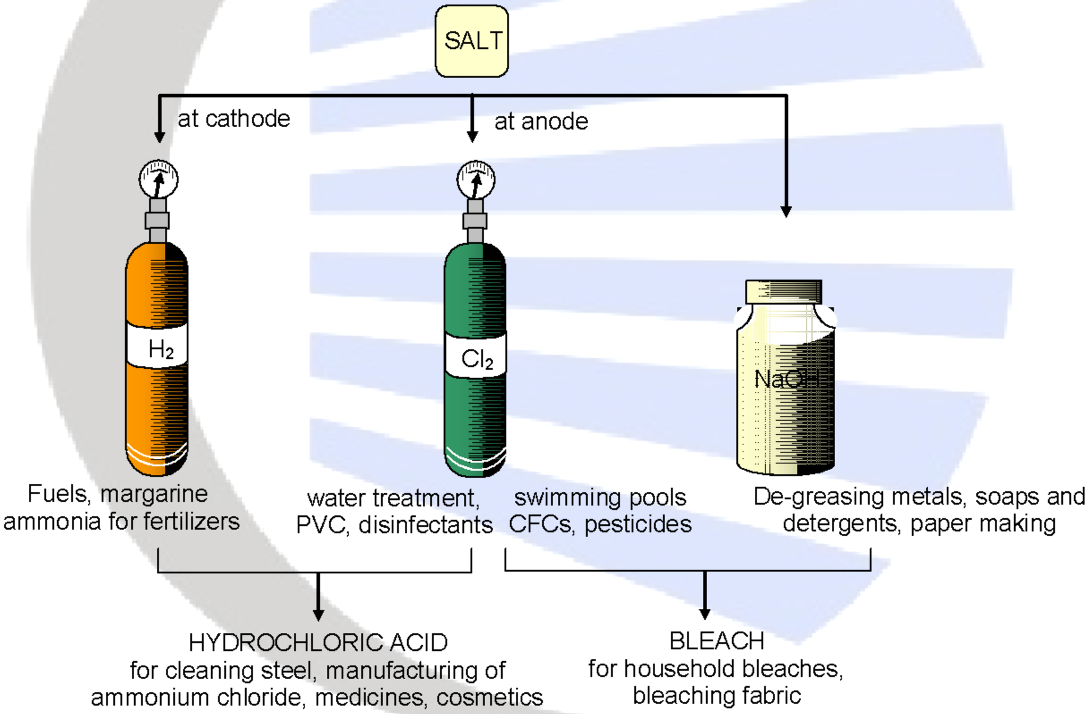
(ii) In metallurgy to reduce heavy metal oxide to metals.
(iii) In hydrogenation of vegetable oils to form solid fats.
(iv) Liquid hydrogen is used as a fuel for rockets.

Hydrogen and chlorine (two products of chlor-alkali process), combine to produce another important chemical called hydrochloric acid (HCl).

So we will now give some of the uses of HCl.

(v) Uses of hydrochloric acid (HCl)

(i) For cleaning steel.
(ii) In the preparation of ammonium chloride.
(iii) In medicines and cosmetics.
(iv) In making plastics like PVC.
(v) As a reagent in the laboratory.
(vi) In making aqua regia (after mixing with HNO_3) for dissolving gold and platinum. The uses of NaOH, Cl_2, H_2 and HCl can be shown more clearly in the figure.



5.4.3 Bleaching powder (calcium oxychloride $CaOCl_2$)

Bleaching powder is chemically calcium oxychloride with the formula $CaOCl_2$.

(i) Manufacture of bleaching powder

The bleaching powder is manufactured by the action of chlorine gas (produced as a by product during manufacture of caustic soda) on dry slaked lime $Ca(OH)_2$. The reactions involved are

$$2NaCl(aq) + 2H_2O(l) \xrightarrow{\text{electrolysis}} 2NaOH(aq) + Cl_2(aq) + H_2$$

$$\underset{\text{Slaked lime}}{Ca(OH)_2} + \underset{\text{chlorine}}{Cl_2} \longrightarrow \underset{\text{bleaching powder}}{CaOCl_2} + \underset{\text{water}}{H_2O}$$

(ii) Uses of bleaching powder

Bleaching powder is used

(a) In textile industry for bleaching cotton and linen.

(b) In paper industry for bleaching wood pulp.

(c) In laundry for bleaching washed clothes.

(d) Making wood unshrinkable.

(e) For disinfecting drinking water to make it free from germs.

(f) As an oxidizing agent in many chemical industries because in the presence of insufficient acid, it gives nascent oxygen.

$$\underset{\text{bleaching powder}}{2CaOCl_2} + \underset{\text{sulphuric acid}}{H_2SO_4} \longrightarrow \underset{\text{calcium sulphate}}{CaSO_4} + \underset{\text{calcium chloride}}{CaCl_2} + \underset{\text{hypochlorous acid}}{2HClO}$$

$$HClO \longrightarrow HCl + \underset{\text{nascent oxygen}}{(O)}$$

(g) In manufacture of chloroform $(CHCl_3)$.

5.4.4 Baking soda, (Sodium hydrogen carbonate $NaHCO_3$)

Baking soda, is chemically sodium hydrogen carbonate with chemical formula $NaHCO_3$.

(i) Manufacture of baking soda

(a) On large scale: Baking soda is produced on a large scale by reacting a cold and concentrated solution of sodium chloride (called brine) with ammonia and carbon dioxide.

$$\underset{\text{sodium chloride}}{NaCl} + \underset{\text{water}}{H_2O} + \underset{\text{ammonia}}{NH_3} + \underset{\text{carbon dioxide}}{CO_2} \longrightarrow \underset{\text{Baking soda}}{NaHCO_3} + \underset{\text{ammonium chloride}}{NH_4Cl}$$

This process is called **solvay process.**

(b) On small scale: On a small scale baking soda can be prepared in the laboratory by passing CO_2 gas through aqueous sodium carbonate solution.

$$\underset{\text{sodium carbonate}}{Na_2CO_3} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2} \longrightarrow \underset{\text{baking soda}}{2NaHCO_3}$$

OR

$$Na_2CO_3(aq) + CO_2 \longrightarrow 2NaHCO_3$$

(ii) Properties of Baking soda

(a) Colour and state

It is a white crystalline solid.

(b) Alkaline nature

It is mild, non-corrosive base. The alkaline nature of baking soda is due to salt hydrolysis.

$$\underset{\substack{\text{baking soda}\\\text{(sodium hydrogen carbonate)}}}{NaHCO_3} + \underset{\text{water}}{H_2O} \xrightarrow{\text{hydrolysis}} \underset{\text{strong base}}{Na^+(aq)} + \underset{\text{weak acid}}{HCO_3^-(aq)}$$

$$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$$

Thus, salt solution is basic due to hydrolysis of HCO_3^- ions

(c) Action of heat

When solid baking soda (or its solution) is heated it decomposes to give sodium carbonate with the evolution of CO_2 gas.

$$\underset{\text{baking soda}}{2NaHCO_3} \xrightarrow{\text{Heat}} \underset{\text{soda carbonate}}{Na_2CO_3} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide gas}}{CO_2}$$

The above reaction takes places when baking soda is heated during the cooking of food. Since baking soda gives CO_2 on heating, it is used as a constituent of baking powder.

(iii) Uses of baking soda ($NaHCO_3$)

(a) As an antacid in medicine

Baking soda is used as an antacid in medicine to remove acidity of the stomach because of its alkaline or basic nature.

Being alkaline baking soda neutralises the excess acid present in the stomach and relieves indigestion.

(b) In making baking powder

Baking soda is used in making baking powder (used in making cakes, bread etc) as follows:

Baking powder is a mixture of baking soda and an acid like tartaric acid or citric acid. When baking powder mixes with water (present in dough made for baking cake or bread) the baking soda reacts with tartaric acid to evolve CO_2 gas.

$$\underset{\text{baking soda}}{NaHCO_3(aq)} + \underset{\text{(from tartaric acid)}}{H^+(aq)} \longrightarrow \underset{\text{(sodium ion)}}{Na^+(aq)} + CO_2(g) + H_2O$$

The CO_2 gas thus produced gets trapped in the wet dough and bubbles out slowly making the cake (or bread) to rise and becomes soft and strong. If however baking powder is not added in the preparation of cake (or bread), then the cake (or bread) obtained will be hard and quite small in size.

(c) In fire extinguisher

The baking soda is used in soda acid fire extinguishers as follows:

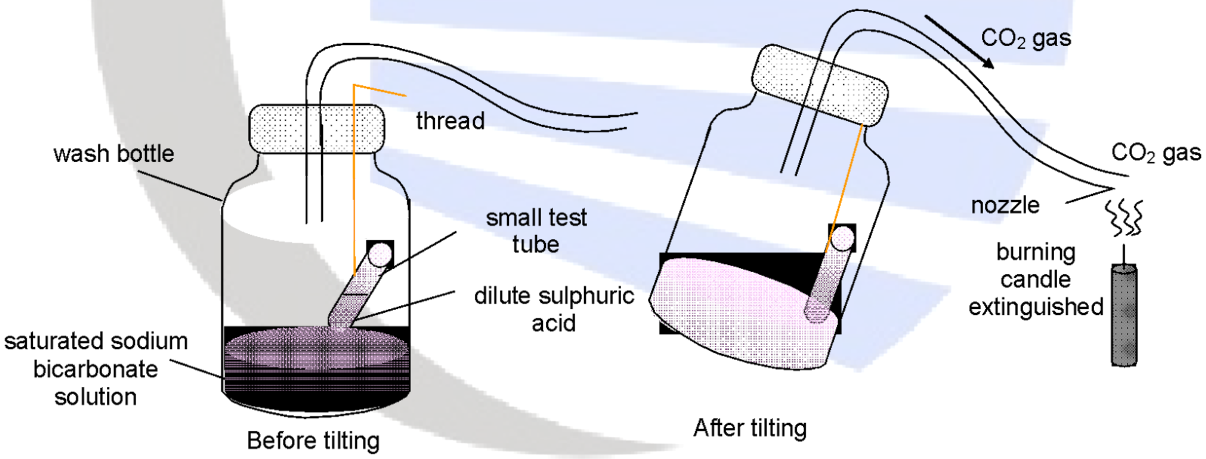
Soda acid fire extinguisher contain a solution of baking soda and Conc. H_2SO_4 in separate container inside them. When the knob of fire extinguisher is pressed then H_2SO_4 acid mixes with baking soda solution to produces CO_2 gas. The pressure of CO_2 gas forces a stream of liquid to fall on burning substance. The CO_2 gas (coming out along with liquid) surrounds the fire. As a result supply of air is cutoff, (because CO_2 gas is heavier than air) and the fire extinguished.

Preparation of soda acid fire extinguisher

Take about 20 ml of a saturated solution of baking soda in a wash bottle. Take about 5 ml dilute H_2SO_4 acid in a small test tube and tie a thread on its neck and then suspend it in wash bottle. Now tilt the wash bottle so that acid in tube mixes into the baking soda solution. Immediately the reaction starts and CO_2 gas starts coming out of the nozzle of the wash bottle with brisk effervescence.

$$2NaHCO_3(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$$

Direct the nozzle towards burning candle. It is immediately extinguished because CO_2 gas being heavier than air surrounds the fire and cuts off supply of air.



Making a soda-acid fire extinguisher

5.4.5 Washing soda (sodium carbonate, $Na_2CO_3 \cdot 10H_2O$)

Washing soda is chemically sodium carbonate decahydrate with formula $Na_2CO_3.10H_2O$ i.e. one mole of Na_2CO_3 contains 10 moles of water of crystallization.

(i) Manufacture of washing soda

Washing soda is manufactured from sodium chloride (or common salt) in the following three steps:

Manufacture of sodium hydrogen carbonate (baking soda) by solvay process: A cold and concentrated solution of sodium chloride (brine) is reacted with ammonia and CO_2 to obtain sodium hydrogen carbonate

$$\underset{\text{sodium chloride}}{NaCl} + \underset{\text{water}}{H_2O} + \underset{\text{ammonia}}{NH_3} + \underset{\text{carbondioxide}}{CO_2} \longrightarrow \underset{\text{sodium bicarbonate}}{NaHCO_3} + \underset{\text{ammonium chloride}}{NH_4Cl}$$

Thermal decomposition of sodium hydrogen carbonate (or baking soda): on heating sodium hydrogen carbonate decomposes to form sodium carbonate.

$$\underset{\text{sod. hydrogen carbonate}}{2NaHCO_3} \xrightarrow{\text{heat}} \underset{\text{sod. carbonate (Anhydrous)}}{Na_2CO_3(s)} + \underset{\text{carbon dioxide}}{CO_2(l)} + \underset{\text{water}}{H_2O(g)}$$

Re-crystallization of sodium carbonate (or soda ash)

Anhydrous sodium carbonate (or soda ash) obtained in step 2 is dissolved in water and subjected to re-crystallization. As a result, crystal of washing soda (sodium carbonate decahydrate) is obtained.

$$\underset{\text{soda ash}}{Na_2CO_3(s)} + \underset{\text{water}}{10H_2O(l)} \longrightarrow \underset{\text{washing soda}}{Na_2CO_3.10H_2O(s)}$$

(ii) Properties of Washing Soda

(a) Colour and state: It is a transparent crystalline solid (when freshly prepared) containing 10 molecules of water of crystallisation.

(b) Action of air: On exposure to air, washing soda crystals lose 9 molecules of water of crystallisation to form a monohydrate which is a white powder

$$Na_2CO_3.10H_2O(s) \xrightarrow{\text{Exposed to air}} Na_2CO_3.H_2O + 9H_2O$$

(transparent crystals)

This process is called **efflorescence**

(c) Action of heat: On heating, washing soda loses all the molecule of water and becomes anhydrous.

$$\underset{\text{washing soda}}{Na_2CO_3.10H_2O} \xrightarrow{\text{Heat}} \underset{\text{Anhydrous sodium carbonate (soda ash)}}{Na_2CO_3} + \underset{\text{water}}{10H_2O}$$

(iii) Uses of washing soda (sodium carbonate)

Washing soda is used

(a) In laundry for cleaning of clothes.
(b) For removing permanent hardness of water.
(c) In manufacture of glass, soap, paper, borax caustic soda etc.
(d) In textile and petroleum refining.

(e) As cleaning agent for domestic purposes.
(f) As laboratory reagent.

5.5 ARE THE CRYSTALLINE SALTS REALLY DRY

The crystalline salts or crystals of salts appear to be dry but actually they are not. They contain water of crystallization. It can be explained as follows:

Water of crystallization: The fixed number of water molecules present in one formula unit of salt is called water of crystallization.

For example

(i) Sodium carbonate crystals (washing soda crystals) contains 10 molecules of water of crystallization in one formula unit and hence written as $Na_2CO_3.10H_2O$.

(ii) Calcium sulphate crystals (gypsum crystals) contain 2 molecules of water of crystallization in one formula unit and hence written as $CaSO_4.2H_2O$.

(iii) Copper sulphate crystals contain 5 molecules of water of crystallization in one formula unit and hence written as $CaSO_4.5H_2O$.

It is clear from the above examples that water of crystallization is not free water, so it does not wet the salts. Thus the crystalline salts which seem to be dry contain water of crystallization. It can be explained more clearly by following experiment.

Experiment to test the presence of water of crystallization in a crystalline salt.

Take a few crystals of copper sulphate $(CuSO_4.5H_2O)$ in a dry test tube. Copper sulphate crystals are blue in colour. Heat the test tube.

Observation:

(i) Blue copper sulphate crystals turn white.
(ii) Water vapours appear on the upper parts inside the test tube.

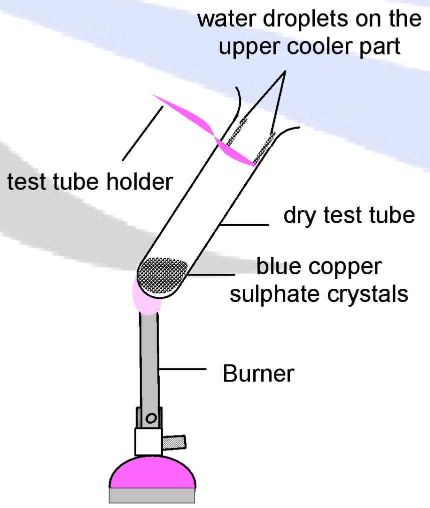


Figure-experiment to test the presence of water of crystallisation in copper sulphate crystals

Explanation: The blue copper sulphate crystals $(CuSO_4.5H_2O)$ on heating give out water vapour which condensed on the upper parts of the test tube and the salt left behind was anhydrous copper sulphate $(CuSO_4)$ which was white in colour.

$$\underset{\substack{\text{Copper sulphate}\\ \text{crystals}\\ \text{(blue, hydrated)}}}{CuSO_4.5H_2O} \xrightarrow{\text{heat}} \underset{\substack{\text{copper sulphate}\\ \text{(white, anhydrous)}}}{CuSO_4} + 5H_2O$$

Conclusion:
Crystalline salt contain water of crystallization which are lost on heating.

5.5.1 Types of salts on the basis of water of crystallization

Salts are classified into two types on the basis of water of crystallization

(i) Anhydrous salts which contain no water of crystallization e.g. $NaCl, CuSO_4$.

(ii) Hydrated salts

The salts which contain a fixed number of water molecules of crystalisation. A few examples of these salts are

(a) Copper sulphate $(CuSO_4.5H_2O)$.

(b) Washing soda $(Na_2CO_3.10H_2O)$.

(c) Gypsum $(CaSO_4.2H_2O)$.

(d) Plaster of paris $(CaSO_4 \cdot \frac{1}{2}H_2O)$.

Out of these plaster of paris is very useful salt which is discussed below:

5.5.2 Plaster of Paris $(CaSO_4 \cdot \frac{1}{2}H_2O)$ or P.O.P.

Chemically, plaster of Paris is calcium sulphate hemihydrate with formula $CaSO_4 \cdot \frac{1}{2}H_2O$.

It is obtained from gypsum which is mainly found in Paris.

(i) **Manufacture:** Plaster of Paris is obtained by heating gypsum $(CaSO_4.2H_2O)$ at 373 K in a kiln.

$$\underset{\text{gypsum}}{CaSO_4.2H_2O} \xrightarrow{373K} \underset{\text{plaster of paris}}{CaSO_4 \cdot \frac{1}{2}H_2O} + \underset{\text{water}}{\frac{3}{2}H_2O}$$

(ii) **Properties of plaster of Paris (POP)**

(a) Colour and state: It is a white powder.

(b) Reaction with water: (setting of plaster of Paris (or POP).

When POP is mixed with water and left for half an hour to one hour, it sets to a hard mass due to rehydration of POP to gypsum.

$$\underset{\text{P.O.P.}}{CaSO_4.\frac{1}{2}H_2O} + \underset{\text{water}}{\frac{3}{2}H_2O} \longrightarrow \underset{\text{gypsum}}{CaSO_4.2H_2O}$$

(c) Effect of heat: When POP is heated at 473K, it forms anhydrous calcium sulphate $(CaSO_4)$ which is known as dead burnt plaster. It has no setting property as it takes up water very slowly.

$$\underset{\text{(P.O.P.)}}{CaSO_4.\frac{1}{2}H_2O} \xrightarrow{473\text{ K}} \underset{\text{dead burnt plaster}}{CaSO_4} + \frac{1}{2}H_2O$$

(iii) Use of plaster of Paris (POP)

(a) For setting fractured bones in right position and in making casts in dentistry.
(b) In making blackboard chalks.
(c) For making smooth surface and ornate designs on walls and ceilings.
(d) In laboratories for sealing air gaps in apparatus so as to make it airtight.
(e) In making toys and decorative materials.