# Chapter - 4 Solutions

## ⇒ Introduction :

A solution is a special type of homogeneous mixture composed of two or more substances. A binary solution is composed of two components, one is solute and the other is solvent. In such a mixture, a solute is a substance dissolved in another substance, known as a solvent. The solution usually has the state of the solvent as usually solvent is the larger fraction of the mixture. Solutions may be of three basic types : solid solutions, liquid solutions and gaseous solutions. The term "aqueous solution" is used when one of the solvents is water. One important parameter of the solution is the concentration, which is a mixture of the amount of solute in a given amount of solution or solvent.

## ⇒ Atomic weight/mass :

The atomic mass of an element may be defined as "the average relative mass of one atom of the element as compared to the mass of an atom of Carbon ($C^{12}$) taken as 12".

Unit : atomic mass unit (amu) or simply 'u'.

Ex :-

| Element | Atomic mass in amu | Gm atom mass |
|---|---|---|
| H | 1.008 ≈ 1 | 1.008 gm |
| N | 14 | 14 gm |
| O | 16 | 16 gm |
| Cl | 35.5 | 35.5 gm |
| Na | 23 | 23 gm |

* Gram atomic mass : It is simply the atomic mass expressed in gm.

Note : When the mass is expressed in amu, it refers to the mass ~~expressed in gm~~ of one atom of the element. But when expressed in gm, it refers to the mass of one mole of atoms ($6.023 \times 10^{23}$ atoms) of the element.

## ⇒ Molecular weight/mass :

The molecular mass of a substance is defined as the average relative mass of one molecule of it as compared to the mass of an atom of Carbon ($C^{12}$) taken as 12.

Unit : amu (atomic mass unit)

It is calculated by adding the atomic weights of the constituent atoms present in one molecule.

* Gream molecular weight : It is simply the molecular weight expressed in gream (gm).

Ex:-

| Compound | Molecular weight | Gm. molecular weight |
|---|---|---|
| NaCl | $23 + 35.5 = 58.5$ amu | 58.5 gm |
| $HNO_3$ | $1 + 14 + 48 = 63$ amu | 63 gm |
| $O_2$ | $2 \times 16 = 32$ amu | 32 gm |
| $Cl_2$ | $2 \times 35.5 = 71$ amu | 71 gm |
| $H_2SO_4$ | $(2\times1) + 32 + (4\times16) = 98$ amu | 98 gm |
| $K_2CO_3$ | $(2\times39) + 12 + (3\times16) = 138$ amu | 138 gm. |

⇒ Equivalent weight :-

The equivalent weight of a substance may be defined as "the number of parts by mass of it, which combines with or displaces directly or indirectly 1.008 parts by mass of hydrogen, 8 parts by mass of oxygen or 35.5 parts by mass of chloreine".

Unit : Equivalent weight has no unit. It is a number only.

* Gream equivalent weight : It is the equivalent weight expressed in gream.

Ex:- ① Equivalent wt. of Ca in $CaCl_2$.

40 parts ← → $2\times35.5$ parts

So $2\times35.5$ parts by mass of chloreine combines with Ca = 40 parts

35.5 parts by mass of Chloreine combines with Ca = $\frac{40}{2}$ = 20 parts

Thus, equivalent weight of "Ca" in $CaCl_2$ is 20.

② Equivalent wt. of $H_2SO_4$ from the following chemical equation,

$$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$$

98 parts      $2\times1.008$ parts

$2\times1.008$ parts of hydrogen are liberated from 98 parts of $H_2SO_4$

1.008 parts of hydrogen will be liberated from $\frac{98}{2} = 49$ parts of $H_2SO_4$.

Hence Equivalent wt. of $H_2SO_4$ is 49.

* Relationship between atomic weight, equivalent weight and valency

$$\text{Equivalent weight (E)} = \frac{\text{Atomic weight}}{\text{Valency}}$$

⇒ **Equivalent weights of Acids, Bases and Salts :-**

① **Equivalent weights of Acids :**

The equivalent weight of an acid is numerically equal to the molecular weight of the acid divided by the basicity.

$$E_{Acid} = \frac{\text{Molecular weight}}{\text{Basicity}}$$

Where basicity is the number of replaceable hydrogen atoms present in one molecule of the acid.

| Acid | Formula | Mol. wt. | Basicity | Eq. wt |
|---|---|---|---|---|
| Hydrochloric acid | $HCl$ | 36.5 | 1 | $\frac{36.5}{1} = 36.5$ |
| Sulphuric acid | $H_2SO_4$ | 98 | 2 | $98/2 = 49$. |
| Phosphoric acid | $H_3PO_4$ | 98 | 3 | $98/3 = 32.66$ |
| Formic acid | $HCOOH$ | 46 | 1 | $46/1 = 46$. |
| Acetic acid | $CH_3COOH$ | 60 | 1 | $60/1 = 60$ |
| Oxalic acid | COOH / COOH | 90 | 2 | $90/2 = 45$ |
| Phosphorous acid* | $H_3PO_3$ | 82 | 2 | $82/2 = 41$ |
| Boric acid* | $H_3BO_3$ | 62 | 1 | $62/1 = 62$. |

② **Equivalent weights of Bases :**

The equivalent weight of a base is numerically equal to the molecular weight of the base divided by the acidity.

$$E_{Base} = \frac{\text{Molecular weight}}{\text{Acidity}}$$

where acidity is the no. of replaceable OH groups present in one molecule of base.

| Base | Molecular formula | Mol. wt. | Acidity | Eq. wt |
|---|---|---|---|---|
| Sodium hydroxide | $NaOH$ | 40 | 1 | $40/1 = 40$ |
| Potassium hydroxide | $KOH$ | 56 | 1 | $56/1 = 56$ |
| Calcium hydroxide | $Ca(OH)_2$ | 74 | 2 | $74/2 = 37$ |
| Barium hydroxide | $Ba(OH)_2$ | 171 | 2 | $171/2 = 85.5$ |
| Aluminium hydroxide | $Al(OH)_3$ | 78 | 3 | $78/3 = 26$ |

③ **Equivalent weights of Salts :**

The equivalent weight of a salt is numerically equal to the molecular weight of the salt divided by the total no. of Positive or negative charges.

$$E_{salt} = \frac{\text{Molecular weight}}{\text{Total no. of +ve or -ve charge}}$$

**Note :** Total no. of Positive charge = No. of metal × Valency.

| Salt | Molecular formula | Mol. wt. | Total +ve or -ve Charge | Eq. wt |
|---|---|---|---|---|
| Sodium Chloride | $NaCl$ | 58.5 | $1\times1=1$ | 58.5 |
| Potassium carbonate | $K_2CO_3$ | 138 | $1\times2=2$ | $138/2=69$ |
| Calcium Sulphate | $CaSO_4$ | 136 | $1\times2=2$ | $136/2=68$ |
| Aluminium Sulphate | $Al_2(SO_4)_3$ | 342 | $2\times3=6$ | $342/6=57$ |

→ **Modes of Expressions of Concentration :-**

Concentration of a solution is the measure of the amount of solute present in a given amount of solution or solvent. The concentration of a solution can be expressed in the following ways:

(i) **Molarity (M):** Molarity of a solution may be defined as "the no. of gram mole of the solute present per litre of solution".

**Unit :** gram mole/litre or M.

Mathematically it can be expressed as,

$$M = \frac{w \times 1000}{M_s \times V_{ml}}$$

where, $w$ = weight of solute in gm
$M_s$ = Molecular wt. of solute
$V_{ml}$ = Volume of solution in ml.

* **Molar solution :-**

The solution containing 1 gm mole of the solute per litre of solution is called a "molar solution".

**For Example :** The solution containing 36.5 gm of HCl, 40 gm of NaOH, 58.5 gm of NaCl or 98 gm of $H_2SO_4$ per litre of solution is called molar solution.

**Note:** ① Decimolar solution = $\frac{1}{10}$ M, Semi molar solution = $\frac{1}{2}$ M
Centimolar solution = $1/100$ M.

② The solution whose strength is known is called standard solution.

* Preoblems :-

Q-1 : 0.4 gm of Caustic soda (NaOH) is preesent in 200 ml of its solution. Find out the molarity of the solution.

Solution : Given data,

Weight of solute (w) = 0.4 gm
Volume of solution ($V_{ml}$) = 200 ml
Mol. wt. of solute ($M_s$) = 23 + 16 + 1 = 40 amu

Thus, Molareity (M) = $\frac{w \times 1000}{M_s \times V_{ml}} = \frac{0.4 \times 1000}{40 \times 200} = 0.05\ M$

Hence, the molarity of the solution is 0.05 M.

Q-2 : How many greams of Caustic potash (KOH) are reequired to preepare 1.5 litre of a decimolare solution ?

Solution : Given data,

Weight of solute (w) = ?
Volume of solution ($V_{ml}$) = 1.5 litree = 1500 ml
Mol. wt. of solute ($M_s$) = 39 + 16 + 1 = 56 amu
Molareity of the solution = $\frac{1}{10}$ M = 0.1 M

Thus, $M = \frac{w \times 1000}{M_s \times V_{ml}} \Rightarrow w = \frac{0.1 \times 56 \times 1500}{1000} = 8.4\ gm$.

Hence, 8.4 gm of caustic potash is reequired to preepare 1.5 litre of decimolare solution.

(ii) **Normality (N)** : Normality of a solution is defined as "the no. of gream equivalent of the solute preesent pere litree of solution". It is reepresented by "N".

Unit : gream equivalent/litre or "N".

Mathematically,

$$N = \frac{w \times 1000}{E_s \times V_{ml}}$$

where, w = wt. of solute in gm
$V_{ml}$ = Volume of solution in ml
$E_s$ = Eq. wt. of

* **Noremal solution** : The solution containing 1 gm equivalent of the solute pere litree of solution is called a noremal solution or 1N solution.

For Example : The solution containing 36.5 gm of HCl, 49 gm of $H_2SO_4$ or 40 gm of NaOH pere litre of solution is called a noremal solution.

* Preoblems:

Q-1 :- 5.6 gm of Caustic Potash (KOH) is present in 800 ml of its solution. What is the noremality of the solution?

Solution: Given data,

Wt. of solute, w = 5.6 gm

volume of solution, $V_{ml}$ = 800 ml

Eq. wt. of solute, KOH; $E_s$ = $\frac{\text{Mol. wt}}{\text{Acidity}} = \frac{56}{1} = 56$

$$\therefore \text{Noremality "N"} = \frac{w \times 1000}{E_s \times V_{ml}} = \frac{5.6 \times 1000}{56 \times 800} = 0.125 \text{ N (Ans)}$$

Q-2: 10 ml of $H_2SO_4$ having density 1.2 gm/ml is present in 400 ml of its solution. Calculate the noremality of the solution.

Solution: Given data,

wt. of solute, w = density x volume = 1.2 x 10 = 12 gm

volume of solution, $V_{ml}$ = 400 ml.

Eq. wt. of $H_2SO_4$ = $\frac{\text{Mol. wt.}}{\text{Basicity}} = \frac{98}{2} = 49$

$$\therefore \text{Noremality, N} = \frac{w \times 1000}{E_s \times V_{ml}} = \frac{12 \times 1000}{49 \times 400} = 0.612 \text{ N}$$

Hence, noremality of the solution is 0.612 N.

*(iii) Molality (m): Molality of a solution may be defined as "the no. of gream mole of solute present per 1000 gm (1 kg) of solvent" and it is represented by the symbol "m".

Unit = gream mole / Kg or "m".

Mathematically it can be expressed as,

$$m = \frac{w \times 1000}{M_s \times W}$$

Where, w = wt. of solute in gm

$M_s$ = Mol. wt. of solute

W = wt. of solvent in gm

* Molal solution: The solution containing 1 gm mole of solute per 1000 gm of solvent is called a molal solution.

For Example: 58.5 gm of NaCl, 40 gm of NaOH, 56 gm of KOH or 98 gm of $H_2SO_4$ per 1000 gm of water (solvent) is called molal solution.

* Preoblems:

Q-1 :- 5.85 gm of NaCl (common salt/table salt) is present in 200 gm of water. Calculate the molality of solution.

Solution: Given data,

wt. of solute, $w = 5.85$ gm

wt. of solvent, $W = 200$ gm

Mol. wt. of solute, $M_s = 23 + 35.5 = 58.5$ amu

Thus molality, $m = \frac{w \times 1000}{M_s \times W} = \frac{5.85 \times 1000}{58.5 \times 200} = 0.5\,m$

Hence, molality of the solution is 0.5 m.

Q-2: 5.6 gm of KOH is present in 300 gm of its solution in water. Calculate the molality of the solution.

Solution: Given data,

wt. of solute, $w = 5.6$ gm

wt. of solution $= 300$ gm

$\therefore$ wt. of solvent, $W$ = wt. of solution − wt. of solute

$= 300 - 5.6 = 294.4$ gm

Mol. wt. of solute, $M_s = 39 + 16 + 1 = 56$ amu

Thus, molality, $m = \frac{w \times 1000}{M_s \times W} = \frac{5.6 \times 1000}{56 \times 294.4} = 0.339\,m$

Hence, molality of the solution is 0.339 m.

⇒ pH of Solutions:

pH of a solution is defined as the negative logarithm of the hydrogen ion concentration in moles per litre or molarity.

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

pH is normally used to know whether a solution is acidic, alkaline or neutral in nature.

(i) If pH < 7; the solution is acidic

(ii) If pH > 7; the solution is Basic / Alkaline.

(iii) If pH = 7; the solution is neutral.

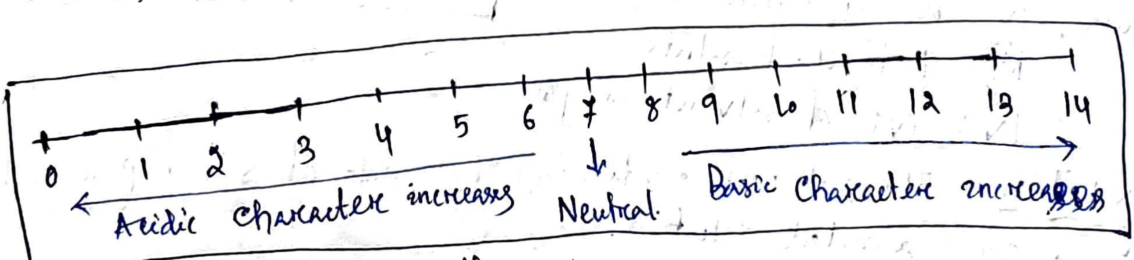


fig: pH Scale

Note: Pure water has a pH value of "7" at 25°c and is neutral. The pH value of water decreases with the increase in temperature.

## Some important Formulae :

(i) $pH = -\log[H^+]$

(ii) $pOH = -\log[OH^-]$

(iii) $pH + pOH = 14$

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

(v) $[H^+] = 10^{-pH}$

(vi) $[OH^-] = 10^{-pOH}$

### * Problems :

1. Find out the pH values of the following solutions.
   (i) 0.01 M HCl solution (ii) 0.001 M $HNO_3$ solution
   (iii) 0.01 M NaOH solution (iv) 0.01 M $H_2SO_4$ solution.

**Solutions :** i.

$$HCl \longrightarrow H^+ + Cl^\ominus$$
0.01 M    0.01 M

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

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

ii.
$$HNO_3 \longrightarrow H^+ + NO_3^-$$
0.001 M    0.001 M

$[HNO_3] = [H^+] = 0.001M = 10^{-3} M$

$\therefore pH = -\log[H^+] = -\log(10^{-3}) = -(-3\log 10) = 3.$

iii.
$$NaOH \longrightarrow Na^+ + OH^-$$
0.01 M    0.01 M

$[NaOH] = [OH^-] = 0.01M = 10^{-2} M$

$pOH = -\log[OH^-] = -\log(10^{-2}) = -(-2\log 10) = 2$

$pH + pOH = 14$ ; $pH = 14 - pOH \Rightarrow pH = 14 - 2 = 12$

$\therefore pH = 12$

iv.
$$H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$$
0.01 M    $(2 \times 0.01)$ M

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

Hence, $pH = -\log[H^+] = -\log(2\times10^{-2}) = 1.699.$

→ Importance of pH in ~~Ind~~ Industries :

1. In Sugar Industry :-

The pH value of the sugar cane juice should be nearly "7" i.e. it should be neutral. If the pH value of sugar cane juice becomes less than "7", the sucrose in the juice is hydrolysed into glucose and fructose. On the other hand, if it exceeds "7", undesireable acids and coloured substances are produced.

2. In Paper Industries :-

Paper is used in a broad array of products essential for everyday life; from newspapers, books, magazines, printing, writing papers to cardboard boxes, bags, paper napkins, sanitary tissues etc. We are daily surrounded by paper products.

The most important use of paper is writing. The quality of paper used for printing or writing should be good and it depends on many parameters. One of the parameters is Cobb, which needs to be controlled. Cobb control is nothing but the control of quality and binding of pulp in such a fashion that whatever is written by any source such as ink, etc. on paper, it should not spread as well as leave its impression on back side of paper. Cobb variation is minimized by maintaining pH of the pulp in the range of pH; 5-6. Before processing, the raw pulp has pH in the range of 7-8. This should be controlled and brought down to acidic range i.e., pH of 5 to 6.

Cobb control is done by addition of Alum (which is in the range of pH; 2-3) and rosin to pulp. When alum and rosin are mixed with pulp after a certain distance pH of the mixture is measured and if it is not in the desired range, the transmitter will control the Alum dosing via controller so that pH of the pulp is maintained. Rosin on the other side has no such controlled action. It will be getting dosed to the pulp continuously in a specific quantity. It is the Alum whose dosing is controlled depending upon pH variations.

## 3. In Textile Industreies :-

In all textile processes in which aqueous solutions are used, balancing the pH of the solution is primary. pH Control is critical for a no. of reasons. The effectiveness of oxidising and reducing agents is pH dependent. The amount of chemicals required for a given process is directly related to the pH. The solubility of substances, such as dyes and impurities vary with pH. The corrosive and scaling potential of processing solutions is also heavily influenced by pH. All these issues affect quality and costs.

Along with surface tension, pH plays an important role in the wetting and saturating processes. for example, caustic solutions cause interfibrillar swelling in cotton cellulose and cannot be squeezed out as easily as water, which can reduce quality in subsequent processing.

The scouring of wool is a good example of a process where maintaining the pH value permits a better solubilization of certain impurities. for example, a pH of 10 is considered optimum for the removal of wool wax.

In the instance of vat dyeing, pH controls the solubilization of the dyes. Initially, the quantity of caustic soda present must be adequate to ensure the solubility of the leuco form. Once the dye has been exhausted, the pH is adjusted such that the dye returns to its insoluble form and is mechanically trapped in the fibre.

Between the colour kitchen and processing, controlling the pH improves the lab-to-bulk reproducibility of colour. Monitoring and controlling pH ensures consistency of colour from batch to batch, as well.

To effectively bleach cellulose (e.g. cotton) with a minimum amount of damage, the bleaching solution must be alkaline. This keeps the hypochlorite stable and also prevents the presence of reducing groups that cause an apparently well-bleached cloth to yellow with age. Additionally, an acidic solution will form toxic and corrosive chlorine gas. Bleaching liquor is therefore usually maintained at a pH of 9. The permanence of the white obtained is thereby increased, and the bleaching is safe. Due to environmental concerns in recent times, $H_2O_2$ bleaching has became more prevalent. Its reaction products, $O_2$ and $H_2O$, are relatively harmless. However, $H_2O_2$ is a weak acid. Thus, its conjugate base ; $HO_2^-$, is used to perform the actual bleaching. To ensure an adequate concentration of $HO_2^-$, the solution pH must be tightly controlled. NaOH is used to maintain the pH at a very alkaline level of 12 - 12.5.