

# CHAPTER 10

# SOLUTIONS AND COLLOIDS

## SOLUTIONS

"A heterogeneous mixture of two or more non-reacting substances is called solutions"

## GENERAL PROPERTIES

Four possible types of mixtures may be obtained:

1. A coarse mixture e.g salt and sugar
2. A suspension e.g if finely ground clay is mixed with water
3. A colloidal dispersion e.g gum in water
4. A true solution e.g sugar dissolved in water

## PHASE

Every sample of matter with uniform properties and a fixed composition is called a phase

## SOLUBILITY OF GAS IN LIQUID

- The solubility of gas in liquids depend on pressure
- If the pressure of the system is reduced, the dissolved gas rapidly leaves the solution.
- As these bubbles rises within the solvent their size increases bcz of less pressure. On reaching the liquid's surface, the bubbles burst.
- In closed container, there is equilibrium between the gas above the liquid and gas dissolved in solvent



# PROPERTIES OF SOLUTIONS

1. Particle Size:  $1\text{\AA}$
2. Phase: Homogeneous
3. Charge On Particles: Both positive and negative or may be neutral
4. Visibility Of Particles: Invisible by the naked eye, ordinary microscope as well as electron microscope
5. Dispersion of Light: Cannot scatter light
6. Effect Of Gravity: Particles do not settle under the influence of gravity.

# PROPERTIES OF COLLOIDS

1. Particle Size:  $10\text{\AA}$
2. Phase: Heterogeneous
3. Charge on Particles: Positive or negative
4. Visibility of Particles: Invisible by naked eye and electron microscope but visible in electron microscope
5. Dispersion of Light: Scatter Light

6. Effect of Gravity: Particles do not settle under the influence of gravity.

## PROPERTIES OF SUSPENSIONS

1. Particle Size:  $2000 \text{ \AA}$

2. Phase: Heterogeneous

3. Charge on particles: Positive or negative or may be neutral

4. Visibility of particles: Visible by naked eye and in ordinary microscope

5. Dispersion of light: Scatter Light

6. Effect of Gravity: Particles settle under the influence of gravity

## PHASES / MEDIUM OF COLLOIDS

\* Dispersion Medium: Medium of colloidal solution consisting of a continuous, homogeneous medium is called outer phase or dispersion medium.

\* Dispersed Medium: Medium of colloidal solution consisting of particles of a discontinuous medium is called inner phase or dispersed medium.



## HYDROPHILIC MOLECULES

- If there exist an attractive force between dispersion medium (water as a dispersion medium) and dispersed particles the molecules are called hydrophilic
- The colloids formed by hydrophilic molecules are much stable
- Such colloids if when precipitated can be directly returned into the colloidal form therefore called reversible colloids.

## HYDROPHOBIC MOLECULES

- If there exist repulsive force between dispersion medium (water as dispersion medium) and dispers particles the molecules are called hydrophobic
- The colloids formed by hydrophobic molecules are less stable
- Such colloids if precipitated can not be directly reconverted into colloidal form and hence called irreversible colloids.



# DISSOLUTION PROCESS

- The process of dissolution is explained on the basis of attraction between solute and solvent particles.
- The principle of dissolution is "to overcome the attractive forces in solute and to form new forces between solute and solvent particles". On the basis of this principle polar solute are soluble in polar solvent and non-polar solute are soluble in non-polar solvent.
- A solution forms only when the interactions between solute-solvent molecules are equal to or greater than the interactions between solute-solute and solute-solvent molecules.

Four factors influence the rate at which substances dissolve:

## 1. PARTICLE SIZE

To increase the rate of dissolution, large piece of solid must be grinded into small particles.

## 2. TEMPERATURE

At higher temperature, increased molecular motion increases the interaction of solute and



solvent particles which increase dissolving rate.

### 3. SOLUTION CONCENTRATION

With each addition of solute, the dissolving rate decreases until no more solute is observed to dissolve. At this stage solution is said to be saturated. Any addition of solute to a saturated solution remain un-dissolved and settle to bottom of container.

### 4. STIRRING

Stirring a solution increase the rate at which a solid dissolves decreasing the concentration of solute in the immediate region surrounding the solid solute. Stirring also increase the amount of exposed solute surface to the solvent



# SOLUTIONS OF LIQUIDS IN LIQUIDS

There are three types of liquids in liquids solution:

## 1. COMPLETELY MISCIBLE LIQUIDS

- Mix in all proportions
- Completely homogeneous solutions
- Generally volume decreases on mixing but in some cases it ~~decrease~~ increases.
- Components may be separated by fractional distillation.

Examples:

Water and methanol, benzene and cyclohexane, acetone and water.

## 2. COMPLETELY IMMISCIBLE LIQUIDS

- Incapable of being mixed or blended

Examples:

Water and benzene, Carbon disulphide and water, cyclohexene and water.

## 3. PARTIALLY MISCIBLE LIQUIDS

- Mix upto a limited extent
- On mixing such liquids, two layers are formed. Each layer is a saturated solution of the other liquid. Such solutions are called conjugated solutions



→ The mutual solubilities of these solutions change by temperature changes.

Examples:

1. Phenol-water
2. Aniline - water
3. Aniline - n - hexane
4. Nicotine - water
5. Triethylamine - water

## PHENOL - WATER SYSTEM

Density of water =  $1\text{gcm}^{-3}$

Density of phenol =  $1.07\text{gcm}^{-3}$

\* At  $25^{\circ}\text{C}$

Upper Layer : 5% solution of phenol in water

Lower Layer : 30% water in phenol

The lower layer of greater density due to greater percentage of phenol.

\* At  $65.9^{\circ}\text{C}$  (CRITICAL SOLUTION TEMPERATURE)

→ A homogeneous mixture forms

→ This homogeneous mixture contains 34% phenol and 66% water.

The temperature of  $65.9^{\circ}\text{C}$  at which two conjugate solutions merge into one another, is called critical solution temperature or upper consolute temperature.



# SOLUBILITY

"The weight in grams of a solute necessary to saturate 100 g of a solvent at constant temperature and pressure is called solubility"

OR

"The maximum amount of solute that dissolves in the given quantity of a solvent under given ~~set~~ conditions is called solubility"

It is commonly expressed in number of grams of solute per  $\text{cm}^3$  of solution or in terms of number of moles of solute per  $\text{dm}^3$  of solution.

## FACTORS AFFECTING SOLUBILITY

### 1. NATURE OF SOLUTE AND SOLVENT

- An ionic or polar solute dissolves in polar solvents. while a non-polar solute dissolves in non-polar solvents.
- Generally most of the inorganic substances dissolve in water than in an organic solvent while organic substances dissolve in organic solvent like benzene.

Examples:

At  $20^\circ\text{C}$ , 100g of water dissolve ~~in~~ ~~100~~ 192g  $\text{NH}_4\text{NO}_3$ , 6.5g of mercuric chloride ( $\text{HgCl}_2$ ) and only  $8.4 \times 10^{-4}$ g of  $\text{AgBr}$



## 2. PRESSURE

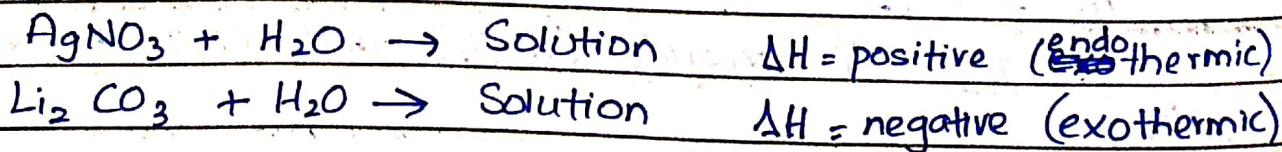
- The effect of pressure on the solubility of solids in liquids is generally quite small. The solubility of gases is affected much by varying the pressure.
- At constant temperature, the solubility of a gas in a liquid is directly proportional to the pressure of gas above the liquid.
- $\text{CO}_2$  is filled in cola drinks at pressure 3-5 atm

## 3. TEMPERATURE

- The solubility of most of the solid and liquid solutes increase with rise in temperature.
- The solubility of  $\text{KNO}_3$  and  $\text{Al}_2(\text{SO}_4)_3$  increases with increase in temperature.
- The solubility of certain solids like  $\text{Ce}_2(\text{SO}_4)_3$ ,  $\text{Li}_2\text{CO}_3$  and  $\text{LiCl}$  decreases with increase in temperature
- Solubility of  $\text{NaCl}$  and  $\text{KBr}$  is almost not affected by increase or decrease in temperature but remains constant.

## SOLUBILITY AND HEAT OF SOLUTION

The change in solubility with temperature is closely related to heat of solution of the substance.





→ When heat of solution of solution is positive, the solubility of a substance increases with increase in temp and decrease with decrease in temp

→ If the heat of solution is negative, the solubility of a substance decrease with increase in temp and vice versa.

## SOLVATION

Solvation is the process by which solvent molecules surround and interact with solute ions or molecules. When water is solvent, it is known as hydration.

When ionic compound is dissolved in solvent it splits into ions. Solvent molecules surround these ions by directing their negative poles towards positive ions and +ve poles towards ~~five~~ ions. This interaction is called ion-dipole interaction.

Process of solvation of ionic and molecular substances is similar in the sense that in both cases the process of solvation involves the disruption of solute particles from the crystal lattice. Then these particles are surrounded by solvent molecules. However, the heat of solvation in both cases is much different since ion-dipole interactions are much stronger than dipole-dipole or dispersion forces. Heat of solvation for ionic species is generally larger than those for molecular solvents.



# HEAT OF SOLUTION

Solution making process is accompanied by either absorption or evolution of heat.

Heat of solution measures the net energy flow that occurs as a substance dissolves.

~~The~~ Lattice Energy of Solute: ( $\Delta H_{\text{lattice}}$ )

The energy needed to break solute particles.

HEAT OF HYDRATION ( $\Delta H_{\text{hyd}}$ )

The energy released when solute particles bind to water molecules in the solution is called heat of hydration. It increases with increasing charge of the ions and decrease with increasing size of the ions.

For other solvents this energy is known as heat of solvation.

Heat of Solution

$$\Delta H_{\text{solution}} = \underset{+ve}{\Delta H_{\text{lattice}}} + \underset{-ve}{\Delta H_{\text{hyd}}}$$

ENDOTHERMIC AND EXOTHERMIC

Conventionally heat energy absorbed (endothermic) is shown by a positive sign and heat evolved (exothermic) by a negative sign.

Energy is always evolved when a gas is dissolved in solvent, as only the solute-solvent interactions are operative.



### Exothermic Examples:

$\text{NaOH}$  in water

$\text{CaCl}_2$  in water

$\text{MgSO}_4$  in water

### Endothermic Examples:

$\text{KI}$  in water

$\text{NH}_4\text{NO}_3$  in water

$\text{NaCl}$  in water

$\text{KCl}$  in water

### Cold Packs:

$\text{NH}_4\text{NO}_3$  in water

This can also be used as freezing mixture

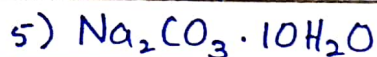
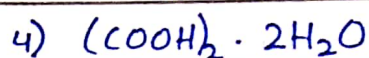
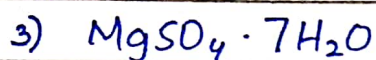
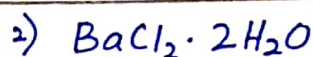
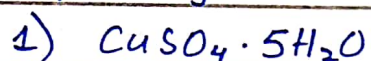
### Hot Packs:

$\text{CaCl}_2$  or  $\text{MgSO}_4$  in water



# WATER OF CRYSTALLIZATION OR WATER OF HYDRATION

The water molecules that combine with compounds as they are crystallized from aqueous solution are called water of crystallization or water of hydration e.g



A definite number of water molecules adhere to the salt depending on its size and chemical nature.

Percentage Of Water In A Hydrate:

$$\% \text{ of } \text{H}_2\text{O} \text{ in hydrate} = \frac{\text{mass of water in hydrate}}{\text{mass of hydrate}} \times 100$$

## NUMERICAL:

250g of  $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$  on heating produced 159.82g  $\text{CuSO}_4$ . Calculate the percent of water in the  $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$ . Also determine the value of  $x$ .

Sol:

$$\text{mass of } \text{CuSO}_4 \cdot x\text{H}_2\text{O} = 250 \text{ g}$$

$$\text{mass of } \text{CuSO}_4 = 159.82 \text{ g}$$

$$\begin{aligned} \text{Mass of water in hydrate} &= 250 - 159.82 \\ &= 90.18 \text{ g} \end{aligned}$$



$$\begin{aligned} \% \text{ of } H_2O \text{ in hydrate} &= \frac{90.18g}{250g} \times 100 \\ &= 36.07\% \end{aligned}$$

$$x = \text{no. of moles of } H_2O = \frac{\text{mass of } H_2O \text{ in hydrate}}{\text{molar mass of } H_2O}$$

$$= \frac{90.18g}{18g/mol}$$

$$x = 5 \text{ mol}$$



# PERCENTAGE COMPOSITION

## 1. W/W %

$$\frac{W}{W} \% = \frac{\text{Weight of solute (in g)}}{\text{Weight of solution (in g)}} \times 100$$

10% solution of glucose means:

10 g of glucose

90 g of water

## 2. W/V %

10% NaOH W/V means

10 g NaOH

100 cm<sup>3</sup> water

## 3. V/W %

10% Alcohol V/W means

10 cm<sup>3</sup> alcohol

100 g solution

## 4. V/V %

10% V/V alcohol in water means:

10 cm<sup>3</sup> alcohol

90 cm<sup>3</sup> water



# MOLARITY

The number of moles of solute per  $\text{dm}^3$  of solution.

$$\text{Molarity} = \frac{\text{Number of moles of solute}}{\text{Volume of solution } (\text{dm}^3)}$$

$$1 \text{ cm}^3 = 10^{-3} \text{ dm}^3$$

# MOLALITY

Number of moles of solute present in 1 kg of solvent.

$$m = \frac{\text{No. of moles of solute}}{\text{No. of kg of solvent}}$$

The molality is independent of temperature whereas molarity depends on temperature. This is because molarity is based on volume of solution. As the temperature increases, the amount of solute remains constant but volume of solution increases slightly, thus molarity decreases slightly.



# MOLE FRACTION

\* Mole Fraction of Solvent

$$X_1 = \frac{n_1}{n_1 + n_2}$$

$n_1$  : no. of moles of solvent

$n_2$  : no. of moles of solute

\* Mole Fraction of Solute

$$X_2 = \frac{n_2}{n_1 + n_2}$$

$$X_1 + X_2 = 1$$

Mole fraction is also independent of temperature.

## \* PARTS PER MILLION

$$\text{ppm} = \frac{\text{wt. or vol. of solute}}{\text{wt. or vol. of solution}} \times 10^6$$

wt : Taken in gram

Volume : Taken in  $\text{cm}^3$



## \* PARTS PER BILLION

$$\text{ppb} = \frac{\text{wt. or vol. of solute}}{\text{wt. or vol. of solution}} \times 10^9$$

## \* PARTS PER TRILLION

$$\text{ppt} = \frac{\text{wt. or vol. of solute}}{\text{wt. or vol. of solution}} \times 10^{12}$$



# RAOULT'S LAW

$$P = P^{\circ} X_1$$

$P$  : Vapour pressure of solution

$P^{\circ}$  : Vapour Pressure of pure solvent

$X_1$  : Mole Fraction of solvent

## \* RELATIVE LOWERING OF VAPOUR PRESSURE

$$\frac{\Delta P}{P^{\circ}} = X_2$$

$X_2$  : mole fraction of solute

## \* LOWERING IN VAPOUR PRESSURE

$$\Delta P = P^{\circ} X_2$$

## \* THEORY

When a non-volatile solute is dissolved in a solvent, the vapour pressure of solution ( $P$ ) is directly proportional to mole fraction of solvent ( $X_1$ )

$$P = P^{\circ} X_1$$

\* The relative lowering of vapour pressure is directly proportional to mole fraction of solute.

$$\frac{P^{\circ} - P}{P^{\circ}} = X_2 \quad \text{or} \quad \frac{\Delta P}{P^{\circ}} = X_2$$

$$(\Delta P = P^{\circ} - P)$$



\* Lowering in Vapour pressure ( $\Delta P$ ) depends on temperature whereas relative lowering in vapour pressure ( $\Delta P/p^0$ ) is independent of temperature.

$$* \Delta P = P^0 X_2$$

\* Lowering of Vapour pressure ( $\Delta P$ ) increase with increase in temperature.

\* Relative Lowering of vapour pressure ( $\Delta P/p^0$ ) of solution depends only on mole fraction of solute and is completely independent of either the nature of solute or solvent. It is also independent of temperature.

## **COLLIGATIVE PROPERTIES OF DILUTE SOLUTION**

A colligative property is one which depends on the number of solute molecules but not on their nature.

The colligative properties of a dilute solution containing a non-volatile and non-electrolyte solute are:

1. Lowering of Vapour Pressure
2. Elevation of Boiling Point
3. Depression of Freezing Point
4. Osmotic Pressure



## ✦ LOWERING OF VAPOUR PRESSURE

$$\frac{\Delta P}{P^0} = \frac{n_2}{n_1 + n_2}$$

$$\frac{\Delta P}{P^0} = \frac{W_2 M_1}{W_1 M_2}$$

## ✦ ELEVATION OF BOILING POINT

### EBULLIOSCOPIC CONSTANT $K_b$

For 1mol of any solute if dissolved in 1kg of pure solvent, the elevation of boiling point is called molal boiling constant or ebullioscopic constant.

### $K_b$ OF WATER

If 1mol of a solute is dissolved in 1kg of pure water the solution now boils at  $100.52^\circ\text{C}$  instead of  $100^\circ\text{C}$ .

The difference  $0.52^\circ\text{C}$  is the ebullioscopic constant  $K_b$  of water

### FACTORS AFFECTING ELEVATION OF BOILING POINT

1. Nature of solvent
2. Concentration of solute



\*  $\Delta T_b = k_b m$  (IN BOOK)

$$\Delta T_b = T_2 - T_1$$

$\Delta T_b$ : elevation of boiling point

$k_b$ : molal boiling constant or ebullioscopic constant

$m$ : molality

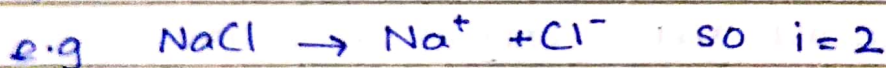
\*  $\Delta T_b = i k_b m$  (FROM ETEA 2018)

$i$  = Vant Hoff Factor

The vant Hoff Factor is a constant associated with the amount of dissociation of solute in the solvent.

→ For substances which donot dissociate in water such as sugar  $i = 1$

→ For solutes that completely dissociate into two ions,  $i = 2$



### \* MOLALITY ( $m$ )

$$m = \frac{1000 W_2}{W_1 M_2}$$



## \* DEPRESSION OF FREEZING POINT

$$\Delta T_f = T_1 - T_2$$

$$\Delta T_f = K_f m$$

$K_f$ : molal freezing point constant or cryoscopic constant

$m$ : molality of solution

$$\Delta T_f = K_f \left( \frac{1000 W_2}{M_2 W_1} \right)$$

## \* OSMOSIS

\* SEMI PERMEABLE MEMBRANES:

(i) For low molecular mass solutes in water:

Copper Ferrocyanide  $Cu_2 [Fe (CN)_6]$

(ii) For high molecular mass solutes in organic solvents:

cellulose or cellulose nitrate

## OSMOSIS DEFINITION

The process by which molecules of a solvent tend to pass through a semi permeable membrane from a less concentrated solution into a more concentrated one.

The solvent molecules move from a dilute solution into



a more concentrated solution (which becomes more dilute)

## \* REVERSE OSMOSIS

A process by which a solvent passes through a porous membrane in the direction opposite to that for natural osmosis when subjected to a hydrostatic pressure greater than the osmotic pressure.

## \* ENDOSMOSIS

The flow of solvent molecules to the solution

## \* EXOSMOSIS

The flow of solvent molecules from solution to pure solvent. Exosmosis is also called reverse osmosis

## \* OSMOTIC PRESSURE

The mechanical pressure which must be applied on a solution to prevent osmosis of the solvent into the solution through a semi permeable membrane is called osmotic pressure of solution

At constant temp, the osmotic pressure is directly proportional to the concentration of solution.

$$\pi = \frac{R C T}{M}$$

$\pi$  : osmotic pressure

R : Ideal gas constant

T : Temperature

M : Molar mass

C : Concentration of solution

# \* SOLUBILITY OF SODIUM SULPHATE

• Temp upto 305.4 K:  
Solubility Increase

• Temp Greater than 305.4 K:  
Solubility Decrease

## REASON:

\* Below 305.4 K  $\rightarrow$   $\text{Na}_2\text{SO}_4$  from decahydrate in water  
( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ )

\* Above 305.4 K  $\rightarrow$  It adopts anhydrous form

\* Maximum solubility  $\rightarrow$  305.4 K - 313K



# CLASSIFICATION OF COLLOIDS

## • ON BASIS OF COMPONENTS

8 Types

1. Foam → Gas In Liquid
2. Solid foam → Gas In Liquid
3. Fog, aerosol → Liquid In Gas
4. Emulsion → Liquid In Liquid
5. Gel → Liquid in solid
6. Smoke → Solid in gas
7. Sol or colloidal solution → Solid in Liquid
8. Solid in solid

## EXAMPLES

1. Foam : Soap lather, beer, foam, whipped cream
2. Solid Foam : Air dispersed in solids such as metals, glass and polystyrene
3. Fog, Aerosol : Clouds, fog, mist, aerosol sprays
4. Emulsion : Homogenized milk,  $H_2O$  in oil or benzene
5. Gel : Sweet, Jellies, Gelatin, ointments, silicagel,  $Fe(OH)_3$  gel
6. Smoke : Coal ~~dis~~ smoke (carbon dispersed),  $NH_4Cl$  fumes,  $I_2$  vapours in air, suspended dust
7. Sol :  $As_2S_3$ , Gold or  $Fe(OH)_3$ , sol solution of high polymers, milk, lassi

8. Solid in solid: coloured glasses, minerals, gems, alloys and mixed crystals

## • ON BASIS OF BEHAVIOUR TOWARDS LIQUIDS

### LYOPHILIC

If force of attraction exist between the particles of dispersed phase and dispersion medium, the sol is called lyophilic. If the dispersion medium is water, then the sol is termed as hydrophilic.

### LYOPHOBIC

The existence of a repulsive force between the dispersed phase and the dispersion medium terms the sol as lyophobic. In case of water it is called hydrophobic.



# PROPERTIES OF COLLOIDS

## 1. OPTICAL PROPERTIES

The scattering is the appearance of light away from the normal optical path due to a contraction between light and particles. If the particles are of colloidal size we see the light scattered in all directions.

→ Blue colour of sky is due to scattering of light by colloidal dust particles in air

→ Sea water looks blue due to scattering effect of light by colloidal impurities in sea water.

## 2. BROWNIAN MOVEMENT

→ The colloidal particles move on zigzag path.

This movement is called Brownian movement

→ The colloidal particles acquire the same kinetic energy as that of the bombarding particles.

→ A zigzag motion of colloidal particles can be observed by an ultra microscope.

## 3. FILTERABILITY

→ Colloidal particles cannot be separated by ordinary filtration. These particles can be moved generally by specially designed filters of extremely fine porosity called ultrafilters.

→ This process of separation of colloidal particles by ultrafilters is called ultrafiltration.



## 4. DIFFUSIBILITY

Little power of diffusion

## 5. COLOUR

- The colour of colloidal solution depends on size and shape of colloidal particles and the wavelength of scattered light
- e.g. silver sols with different particles size show different colours.

## 6. OSMOTIC PRESSURE

- The osmotic pressure of dilute solution is  $\pi = \frac{RTC}{M}$
- Larger the molecules (M - Molecular mass) the smaller will be osmotic pressure.
- The osmotic pressure of colloidal solution is generally small, but can be measured accurately by means of specially designed osmometer.

## 7. EFFECT OF TEMPERATURE CHANGES

- When an egg is boiled or fried, small colloidal particles convert into a lump by coagulation.
- ~~→ The charged colloidal particles attract solvent molecules which form a layer around them.~~
- By heating milk, coagulation of casein in milk occurs. Cooling and even exposing to sunlight may help jellies set.
- It has been observed that a change in temp coagulate colloids.



## 8. STABILITY OF COLLOIDS

- The stability of colloidal system depend on charge, solvation and Brownian motion.
- The charged colloidal particles attract solvent molecules, which form a layer around them. It is this layer which prevents them from aggregation
- The Brownian motion counteracts the force of gravity on the colloidal particles and is partly responsible for stability of the colloidal system.



## ZEOTROPIC MIXTURE

The mixture whose separation is possible by fractional distillation.

It is ideal mixture and obey Raoult's law.

## AZEOTROPIC MIXTURE

Azeotropic mixture or constant boiling point mixture is a mixture of two or more liquids whose proportions cannot be altered or changed by simple distillation.

→ Azeotropic mixture boils at constant temperature

→ Non-ideal mixture

## TYNDALL EFFECT

The tyndall effect is light scattering by particles in a colloid or in a very fine suspension.

\* No. of moles in 1 litre or  $1\text{dm}^3$  of water:

55.5 mol



# IDEAL SOLUTION

1. Volume of solution is equivalent to sum of volumes of all components i.e.  $\Delta V = 0$
2. Enthalpy change is zero i.e.  $\Delta H = 0$
3. Obeys Raoult's law

# NON-IDEAL SOLUTION

1.  $\Delta V \neq 0$
2.  $\Delta H \neq 0$
3. Shows deviation from Raoult's law