MIST | Technology for Advancement
Military Institute of Science and Technology

# Fundamentals of Chemistry

## CHEM 101

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# Solutions, Units and Solubility


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# Lesson Outcome

## Solutions and Units of Concentration

1. Solutions
2. Classifications and Types of Solution
3. Units of Concentration
4. Molarity, Molality, Normality, Mole fraction

# Solutions

**A solution is a homogeneous mixture composed of two or more substances.**

**Is a solution really Homogenous?**

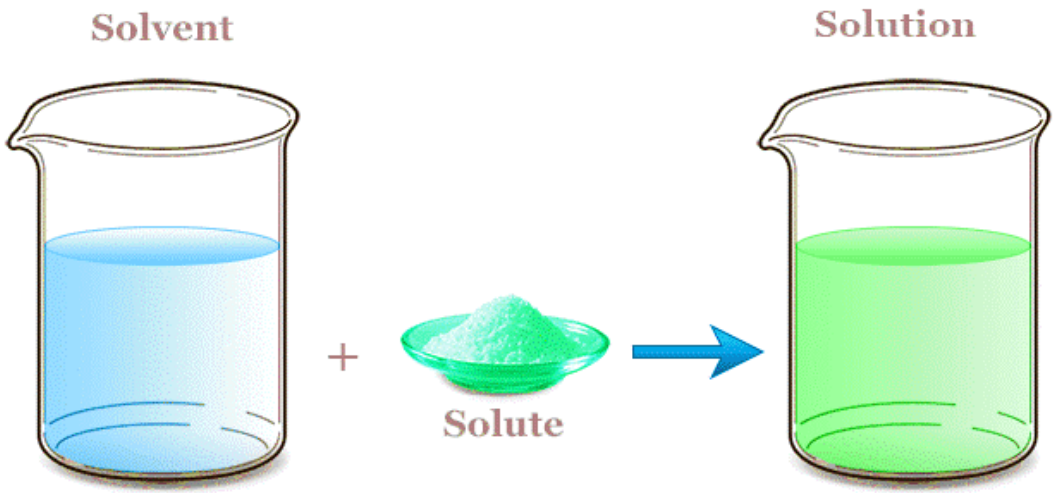
Scale of our observation is crucial

Judge it on molecular level

Microscopic ; Macroscopic

Conc. of solute molecule on **solution bulk** and on **solution surface** is different

The substance present in the largest amount is called the **solvent**




The other substances present in smaller amounts are called **solutes**

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# Solutions

If the **components interact** with each other then it is **not a solution; It becomes a reaction**

## Classifications

**Solutions can be classified in several ways, including:**

- **Based on the state of the solvent and solute: solid, liquid, or gas solutions**
- **Based on the concentration of solute: dilute or concentrated based on the amount of solute present in the solution.**
- **Based on the nature of the solvent and solute: polar or nonpolar based on the polarity of the solvent and solute.**
- **Based on the size of the solute particles: true solutions, colloids, or suspensions based on the size of the solute particles.**

# Types of Solutions: Based on State

| State of Solute | State of Solvent | Example |
|---|---|---|
| **1.** Gas | Gas | Air |
| **2.** Gas | Liquid (Carbonated drinks) | Oxygen in water, $CO_2$ in water |
| **3.** Gas | Solid | Adsorption of $H_2$ by palladium |
| **4.** Liquid | Liquid | Alcohol in water |
| **5.** Liquid | Solid | Mercury in silver |
| **6.** Solid | Liquid | Sugar, Salt |
| **7.** Solid | Solid (Steel) | Metal alloys : Carbon in iron |

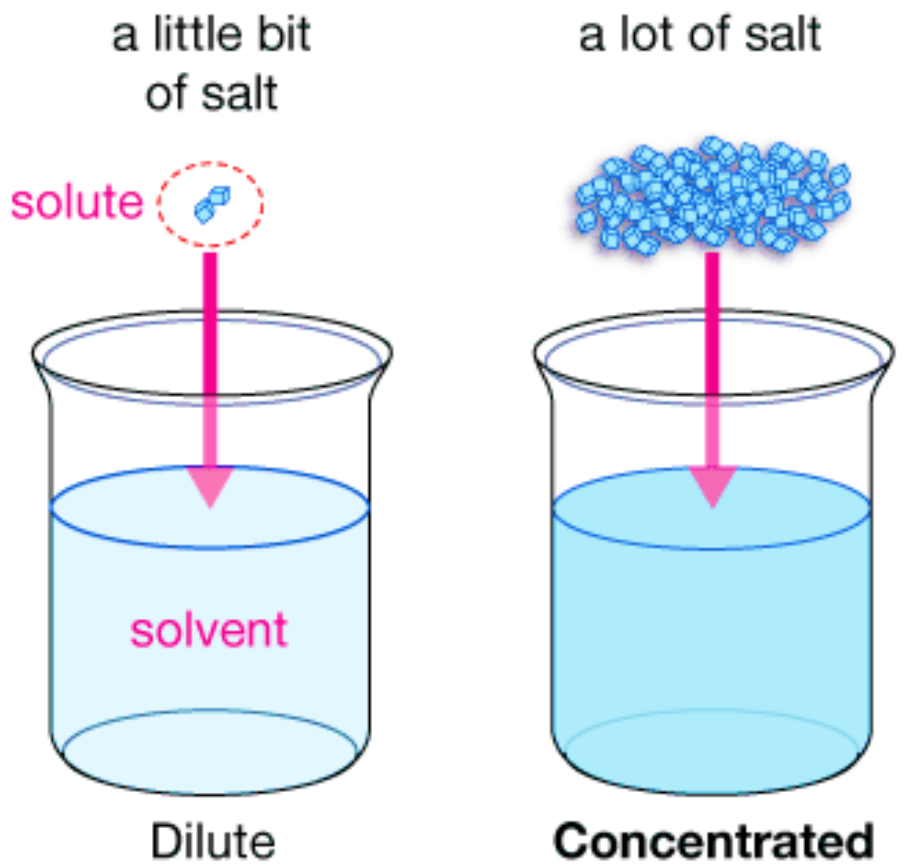
# Solutions: Based on Concentration

## Dilute Solutions

**A teaspoon of sugar dissolved in a cup of water is a dilute solution.**

## Concentrated Solutions

**A cup of sugar dissolved in a cup of water is a concentrated solution.**

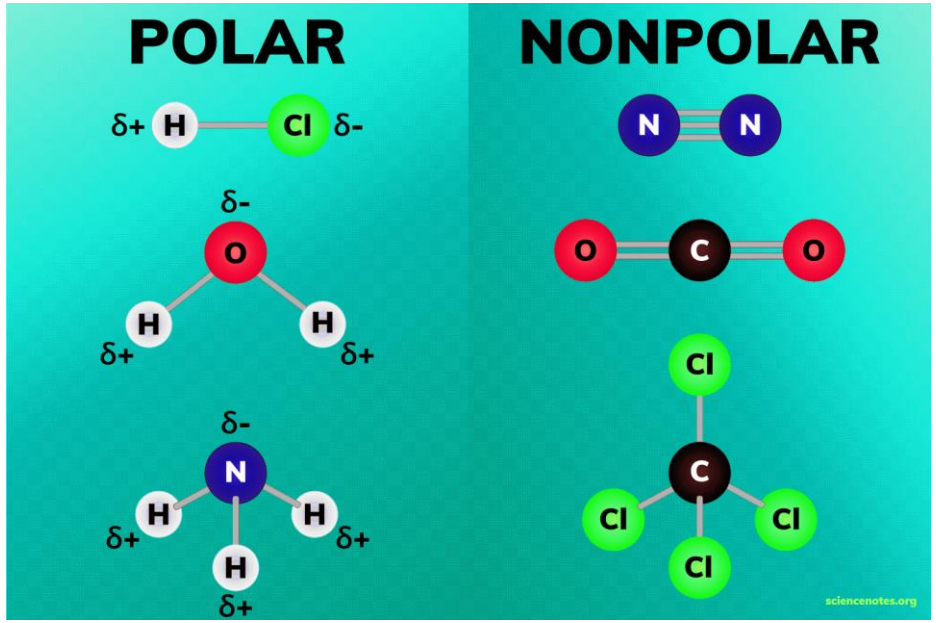


# Solutions: Based on Nature

## Polar Solutions

**The solution in which the solvent and solute molecules have polar bonds and possess a permanent dipole moment.**

**Examples of polar solvents include water, ethanol, and ammonia, ionic compounds, acids, and some organic compounds.**

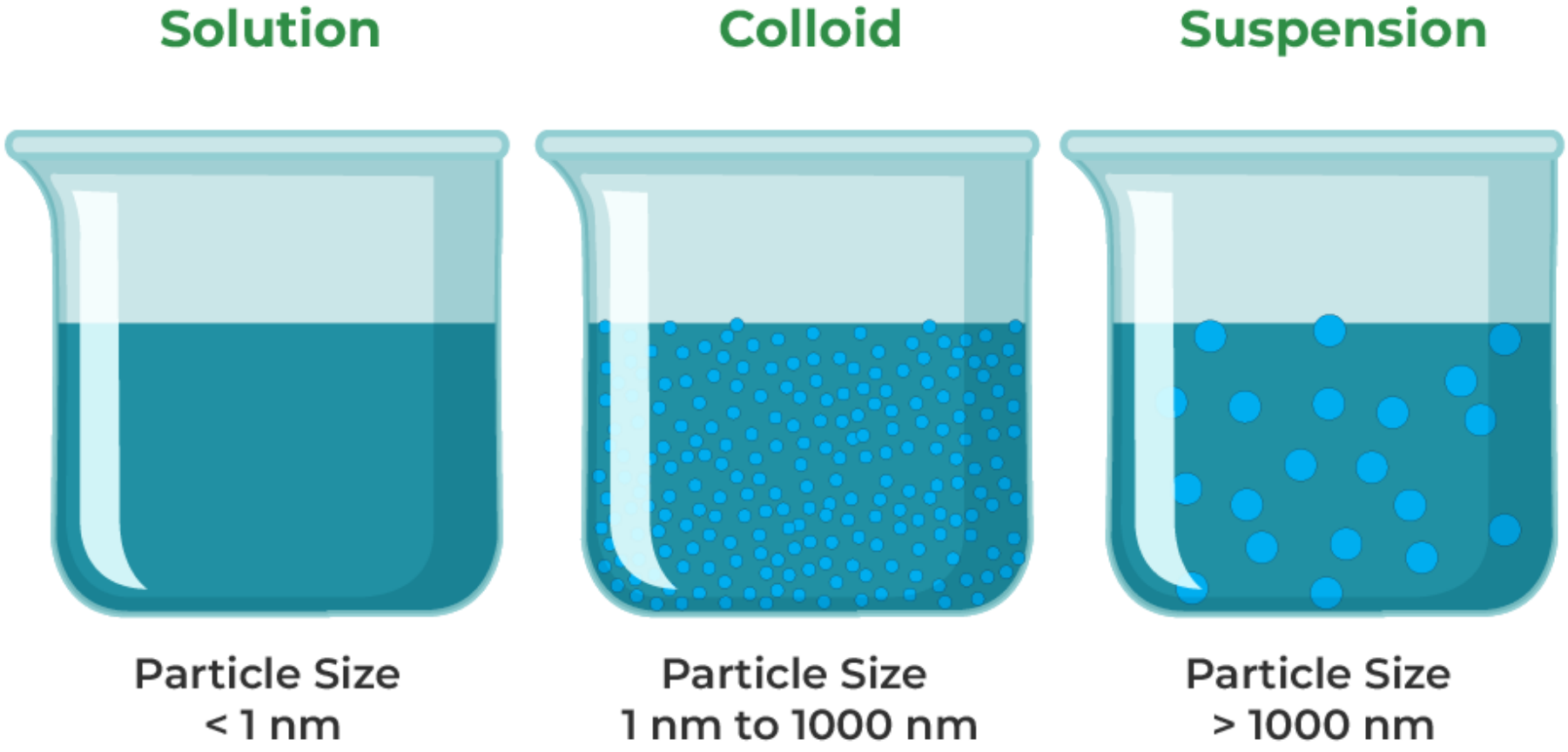



| DEN Range | Bond Type |
|---|---|
| 0.0 – 0.39 | Nonpolar Covalent |
| 0.4 – 0.89 | Moderately Polar Covalent |
| 0.9 – 1.69 | Very Polar Covalent |
| 1.7 or greater | Ionic |

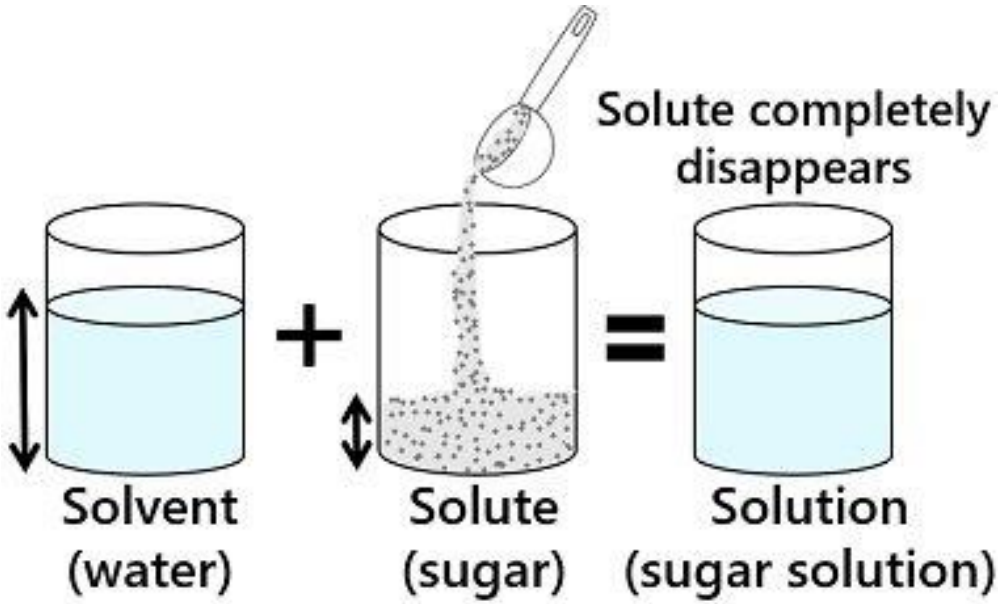
## Non-polar Solutions

**The solution in which the solvent and solute molecules have non-polar bonds and do not possess a permanent dipole moment. Examples of non-polar solvents include hexane, benzene, and carbon tetrachloride.**

# Solutions: Based on Size



# Solutions

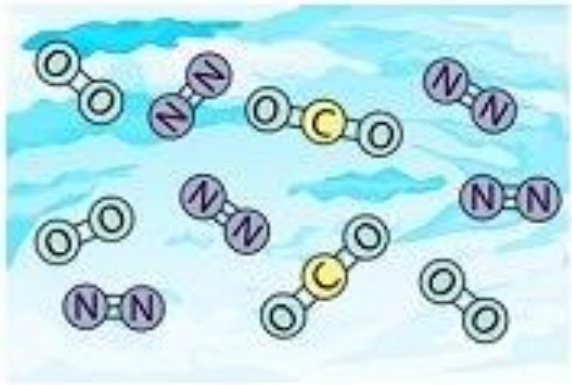



## Common Examples of Solutions



### Honey

It is a mixture of sugars and other carbohydrates



### Air

It is a mixture containing gases nitrogen and oxygen with trace amount of other gases




### Soda water

It is a mixture containing carbon-dioxide and water

# Colloids

## What Is a Colloid?

A colloid is a mixture of microscopic particles that are suspended in another medium.




**Milk**

Protein and fat globules dispersed in liquid



**Smoke**

Solid soot particles dispersed in air



**Gelatin**

Water dispersed in a protein medium

# Types of Colloidal Systems

| Type Name | Dispersed Phase | Dispersion medium | Examples |
|---|---|---|---|
| **Foam** | gas | liquid | whipped cream, shaving cream, soda-water |
| **Solid foam** | gas | solid | froth cork, pumice stone, foam rubber |
| **Aerosol** | liquid | gas | for, mist, clouds |
| **Emulsion** | liquid | liquid | milk, hair cream |
| **Solid emulsion (gel)** | liquid | solid | butter, cheese |
| **Smoke** | solid | gas | dust, soot in air |
| **Sol** | solid | liquid | paint, ink, colloidal gold |
| **Solid sol** | solid | solid | ruby glass (gold dispersed in glass), alloys. |

# Colloids

## LYOPHILIC AND LYOPHOBIC SOLS OR COLLOIDS

**Sols are colloidal systems in which a solid is dispersed in a liquid.**

These can be subdivided into two classes :

(*a*) Lyophilic sols (solvent-loving)

(*b*) Lyophobic sols (solvent-hating)

**Lyophilic sols are those in which the dispersed phase exhibits a definite affinity for the medium or the solvent.**

The examples of lyophilic sols are dispersions of starch, gum, and protein in water.

**Lyophobic sols are those in which the dispersed phase has no attraction for the medium or the solvent.**

The examples of lyophobic sols are dispersion of gold, iron (III) hydroxide and sulphur in water. The affinity or attraction of the sol particles for the medium, in a lyophilic sol, is due to hydrogen bonding with water. If the dispersed phase is a protein (as in egg) hydrogen bonding takes place between water molecules and the amino groups ( –NH–, $–NH_2$) of the protein molecule. In a dispersion of starch in water, hydrogen bonding occurs between water molecules and the – OH groups of the starch molecule. **There are no similar forces of attraction when sulphur or gold is dispersed in water.**

# Colloids

## CHARACTERISTICS OF LYOPHILIC AND LYOPHOBIC SOLS

Some features of lyophilic and lyophobic sols are listed below.

### (1) Ease of preparation

Lyophilic sols can be obtained straightaway by mixing the material (starch, protein) with a suitable solvent. The giant molecules of the material are of colloidal size and these at once pass into the colloidal form on account of interaction with the solvent.

Lyophobic sols are not obtained by simply mixing the solid material with the solvent.

### (2) Charge on particles

Particles of a hydrophilic sol may have little or no charge at all.

Particles of a hydrophobic sol carry positive or negative charge which gives them stability.

### (3) Solvation

Hydrophilic sol particles are generally solvated. That is, they are surrounded by an adsorbed layer of the dispersion medium which does not permit them to come together and coagulate. Hydration of gelatin is an example.

There is no solvation of the hydrophobic sol particles for want of interaction with the medium.

### (4) Viscosity

Lyophilic sols are viscous as the particle size increases due to solvation, and the proportion of free medium decreases. Warm solutions of the dispersed phase on cooling set to a gel *e.g.*, preparation of *table jelly*.

Viscosity of hydrophobic sol is almost the same as of the dispersion medium itself.

# Colloids

### (5) Precipitation

Lyophilic sols are precipitated (or coagulated) only by high concentration of the electrolytes when the sol particles are dissolved.

Lyophobic sols are precipitated even by low concentration of electrolytes, the protective layer being absent.

### (6) Reversibility

The dispersed phase of lyophilic sols when separated by coagulation or by evaporation of the medium, can be reconverted into the colloidal form just on mixing with the dispersion medium. Therefore this type of sols are designated as **Reversible sols.**

On the other hand, the lyophobic sols once precipitated cannot be reformed merely by mixing with dispersion medium. These are, therefore, called **Irreversible sols.**

### (7) Tyndall effect

On account of relatively small particle size, lyophilic sols do not scatter light and show no Tyndall effect. Lyophobic sol particles are large enough to exhibit tyndall effect.

### (8) Migration in electronic field

Lyophilic sol particles (proteins) migrate to anode or cathode, or not at all, when placed in electric field.

# Colloids

## COMPARISON OF LYOPHILIC AND LYOPHOBIC SOLS

| Lyophilic Sols | Lyophobic Sols |
|---|---|
| 1. Prepared by direct mixing with dispersion medium. | 1. Not prepared by direct mixing with the medium. |
| 2. Little or no charge on particles. | 2. Particles carry positive or negative charge. |
| 3. Particles generally solvated. | 3. No solvation of particles. |
| 4. Viscosity higher than dispersion medium; set to a gel. | 4. Viscosity almost the same as of medium; do not set to a gel. |
| 5. Precipitated by high concentration of electrolytes. | 5. Precipitated by low concentration of electrolytes. |
| 6. Reversible. | 6. Irrerversible. |
| 7. Do not exhibit Tyndall effect. | 7. Exhibit Tyndall effect. |
| 8. Particles migrate to anode or cathode, or not at all. | 8. Particles migrate to either anode or cathode. |

# Colloids

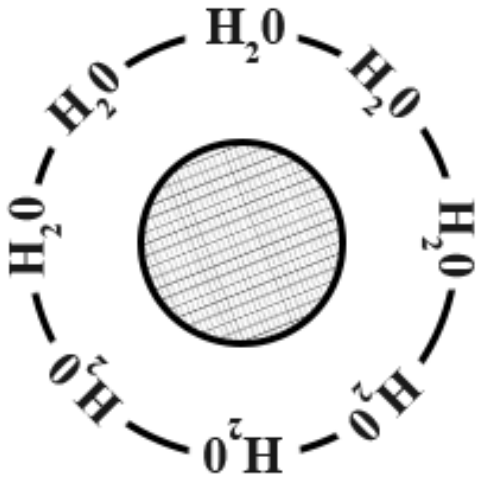
Lyophobic sols can be stabilized by the addition of a **stabilizing agent**, such as a **surfactant or a polymer**, which adsorbs onto the surface of the particles and prevents them from aggregating.

**The stabilizing agent used in lyophobic sols can carry a charge, which can in turn impart a charge on the particles and the resulting colloidal dispersion.**

For example, if a cationic surfactant is used as the stabilizing agent, it will adsorb onto the surface of the negatively charged particles and neutralize their charge, resulting in a positively charged colloidal dispersion. Conversely, if an anionic surfactant is used as the stabilizing agent, it will adsorb onto the surface of the positively charged particles and neutralize their charge, resulting in a negatively charged colloidal dispersion.

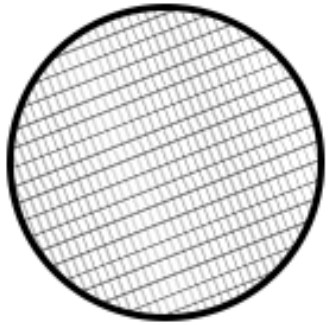
So, **lyophobic sols can carry a charge if a charged stabilizing agent** is used to stabilize the colloidal dispersion.

# Colloids



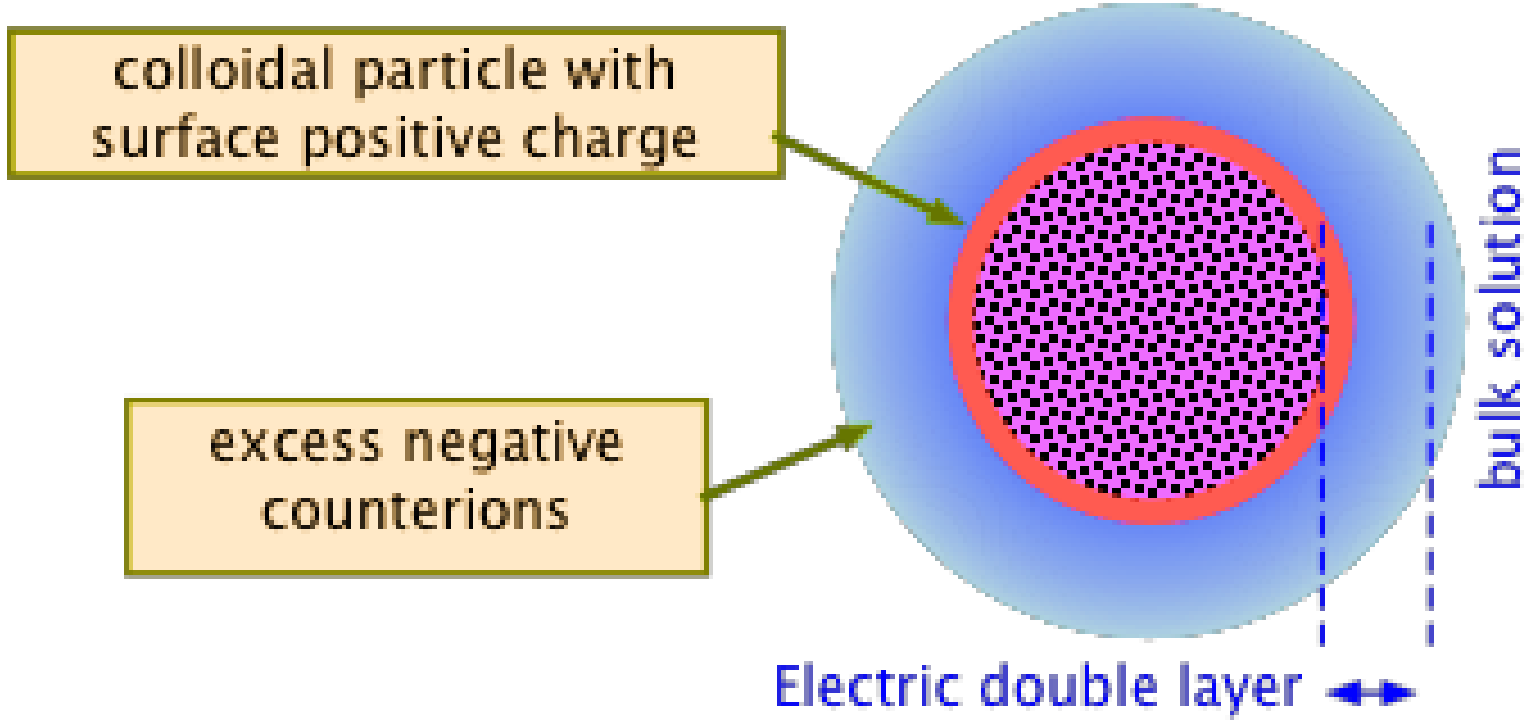

**Lyophilic colloid**

**Gelatin, Starch [Polymer]**



**Lyophobic colloid**

**Gold Sol, Sulphur Sol**



# Suspension

**A suspension is defined as a heterogeneous mixture in which the solid particles are spread throughout the liquid without dissolving in it.**

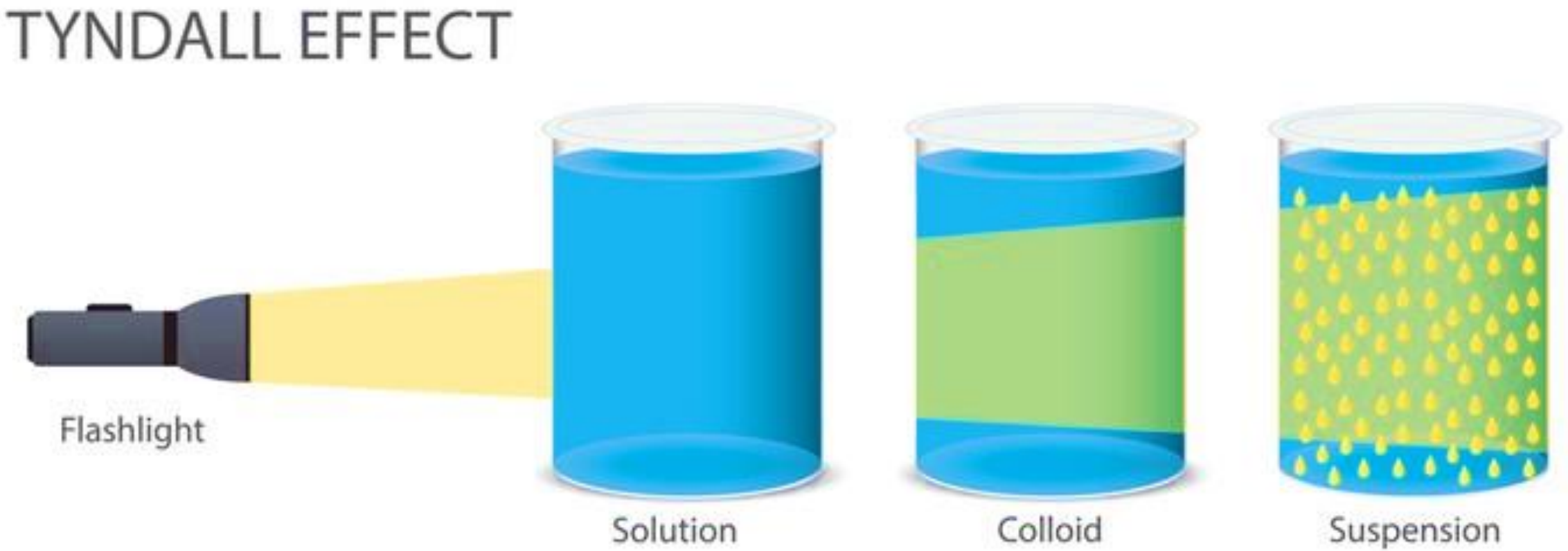
## Examples of Suspension



# Solution Vs Suspension Vs Colloid

| Solution | Colloid | Suspension |
|---|---|---|
| homogeneous | visually homogeneous, microscopically heterogeneous | heterogeneous |
| particle size 0.01–1 nm atoms, ions, molecules | particle size 1–1000 nm molecules or aggregates | particle size >1000 nm large particles or aggregates |
| do no separate on standing | do not separate on standing | particles settle out |
| cannot be separated by filtration | cannot be separated by filtration | can be separated by filtration |
| does not scatter light | Tyndall effect or opaque | Tyndall effect or opaque |

# Optical Property




**How can you differentiate between a true solution and colloidal solution?**

# Solutions




They are usually prepared by heating a saturated solution and then slowly cooling down.

# Units of Concentration

**The concentration of a solution is the amount of solute present in a given amount of solvent or solution.**

## Molarity

The number of moles of solute dissolved in one liter (1000 mL) of solution.

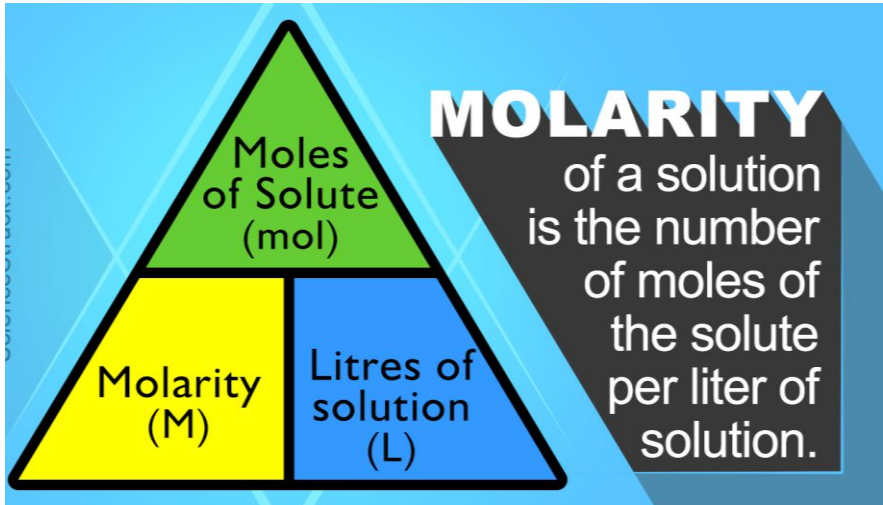
$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Volume in litres}}$$

Unit = mol/L or M

**Vol. of solution depends on temp.**

⬇

**Molarity: Temp. Dependent**



# Numericals

- What is the molarity of a solution that contains 0.25 moles of NaCl in 500 milliliters of solution?
- How much sodium chloride (NaCl) is required to prepare 500 milliliters of a 0.1 M solution of NaCl?
- A solution of hydrochloric acid (HCl) has a molarity of 0.5 M. What volume of this solution is required to react completely with 25 mL of 0.1 M sodium hydroxide (NaOH)?

# Units of Concentration

## Normality

Normality of a solution (symbol $N$) is defined *as number of equivalents of solute per litre of the solution* :

$$\text{Normality } (N) = \frac{\text{Equivalents of solute}}{\text{Volume of solution in litres}}$$

Thus, if 40 g of NaOH (eq. wt. = 40) be dissolved in one litre of solution, normality of the solution is one and the solution is called $1N$ (one-normal). A solution containing 4.0 g of NaOH is 1/10 $N$ or 0.1 $N$ or decinormal.

**Normality = Molarity x Number of equivalents per mole**

depends on the chemical species and the type of reaction being considered.

- Calculate the normality of a 0.2 M solution of sulfuric acid ($H_2SO_4$).
- Calculate the volume of 0.1 N hydrochloric acid (HCl) required to neutralize 25 mL of a 0.05 N sodium hydroxide (NaOH) solution.

# Units of Concentration

**For acids** $E = \dfrac{\text{Molecular weight}}{\text{protocity or basicity of acid}}$

For example, for $H_3PO_4$, $E = \dfrac{M}{3}$

For $H_2SO_4$, $E = \dfrac{M}{2}$ (Also for $H_2C_2O_4 \cdot 2H_2O$)

**For bases** $E = \dfrac{\text{Molecular weight}}{\text{Acidity or number of } OH^- \text{ ions}}$

For example, for $Ca(OH)_2$, $E = \dfrac{M}{2}$

For $Al(OH)_3$, $E = \dfrac{M}{3}$

**For ions** $E = \dfrac{\text{Molecular weight}}{\text{Charge on ion}}$

For example, for $SO_4^{2-}$, $E = \dfrac{M}{2}$

For $PO_4^{3-}$, $E = \dfrac{M}{3}$

# Units of Concentration

## Molality

Molality of a solution (symbol *m*) is defined as **the number of moles of solute per kilogram of solvent :**

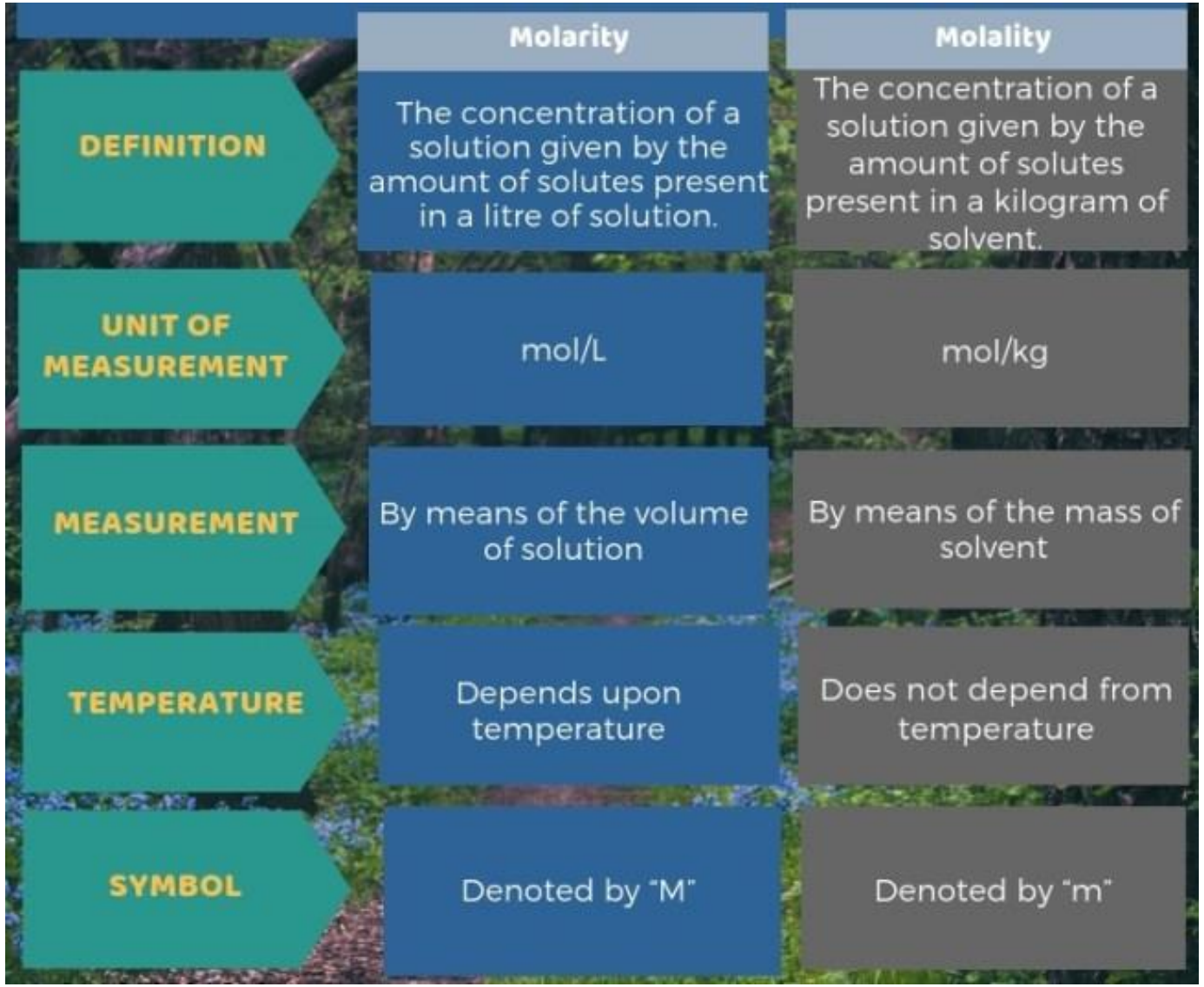
$$\text{Molality } (m) = \frac{\text{Moles of solute}}{\text{Mass of solvent in kilograms}}$$

A solution obtained by dissolving one mole of the solute in 1000 g of solvent is called **one molal** or **1*m* solution.**

Notice the difference between molality and molarity. **Molality is defined in terms of mass of solvent while molarity is defined in terms of volume of solution.**

**Temperature independent** as it is a measure of the number of moles of solute **per kilogram of solvent**. The mass of the solvent remains constant, regardless of the temperature. Therefore, the molality of a solution does not change with temperature, as long as the mass of the solvent remains the same.

# Molarity Vs Molality



# Units of Concentration

## Mole Fraction

A simple solution is made of two substances : one is the solute and the other solvent. Mole fraction, $X$, of solute is defined as **the ratio of the number of moles of solute and the total number of moles of solute and solvent.** Thus,

$$X_{\text{solute}} = \frac{\text{Moles of solute}}{\text{Moles of solute} + \text{Moles of solvent}}$$

If $n$ represents moles of solute and $N$ number of moles of solvent,

$$X_{\text{solute}} = \frac{n}{n + N}$$

Notice that mole fraction of solvent would be

$$X_{\text{solvent}} = \frac{N}{n + N}$$

Mole fraction is unitless and

$$X_{\text{solute}} + X_{\text{solvent}} = 1$$

# Units of Concentration

## Percent by Weight

It is the **weight of the solute as a per cent of the total weight of the solution.** That is,

$$\% \text{ by weight of solute} = \frac{\text{Wt. of solute}}{\text{Wt. of solution}} \times 100$$

**SOLVED PROBLEM.** What is the per cent by weight of NaCl if 1.75 g of NaCl is dissolved in 5.85 g of water.

**SOLUTION**

$$\text{Wt. of solute (NaCl)} = 1.75\text{ g}$$
$$\text{Wt. of solvent } (H_2O) = 5.85\text{ g}$$
$$\therefore \quad \text{Wt. of solution} = 1.75 + 5.85 = 7.60\text{ g}$$

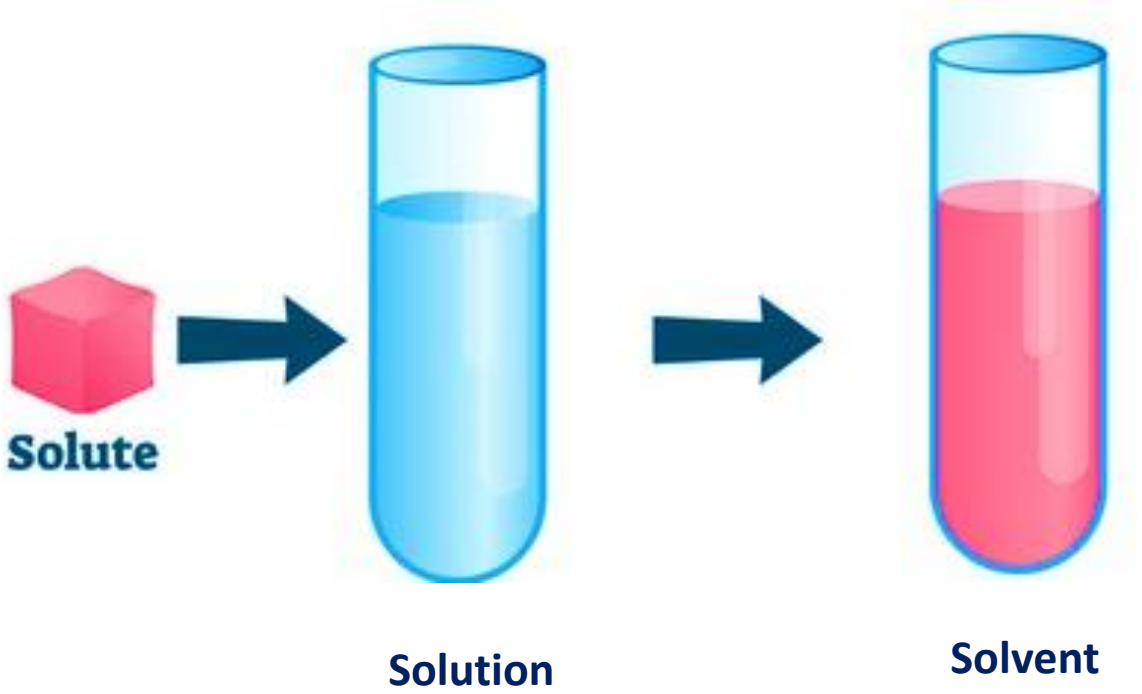
Hence concentration of NaCl % by weight

$$= \frac{1.75}{7.60} \times 100$$
$$= \mathbf{23.0}$$

# Solubility

**Property of a substance that describes its ability to dissolve in a particular solvent.**

More specifically, it is the maximum amount of solute that can be dissolved in a given amount of solvent under specific conditions such as **temperature**, **pressure**, and the **nature** of the solute and solvent.



# Effects of Temp. on Solubility

**The solubility of most solid solutes in liquid solvents increases with increasing temperature while the solubility of gas solutes in liquid solvents decreases with increasing temperature**

For **solid solutes**, the **increase in temperature** provides more energy to the solvent molecules, which causes them to move more quickly and collide with the solute particles with greater force. This results in more solute particles being pulled into the solvent and dissolved, which leads to an **increase in the solubility** of the substance.

For **gas solutes**, with **increasing temperature solubility decreases.** At higher temperatures, gas molecules have more energy, which causes them to move more quickly and escape from the liquid more easily. This results in a decrease in the solubility of the gas in the liquid solvent.

# Effects of Temp. on Solubility

A curve drawn between solubility and temperature is termed **Solubility Curve**. It shows the effect of temperature on the solubility of a substance.

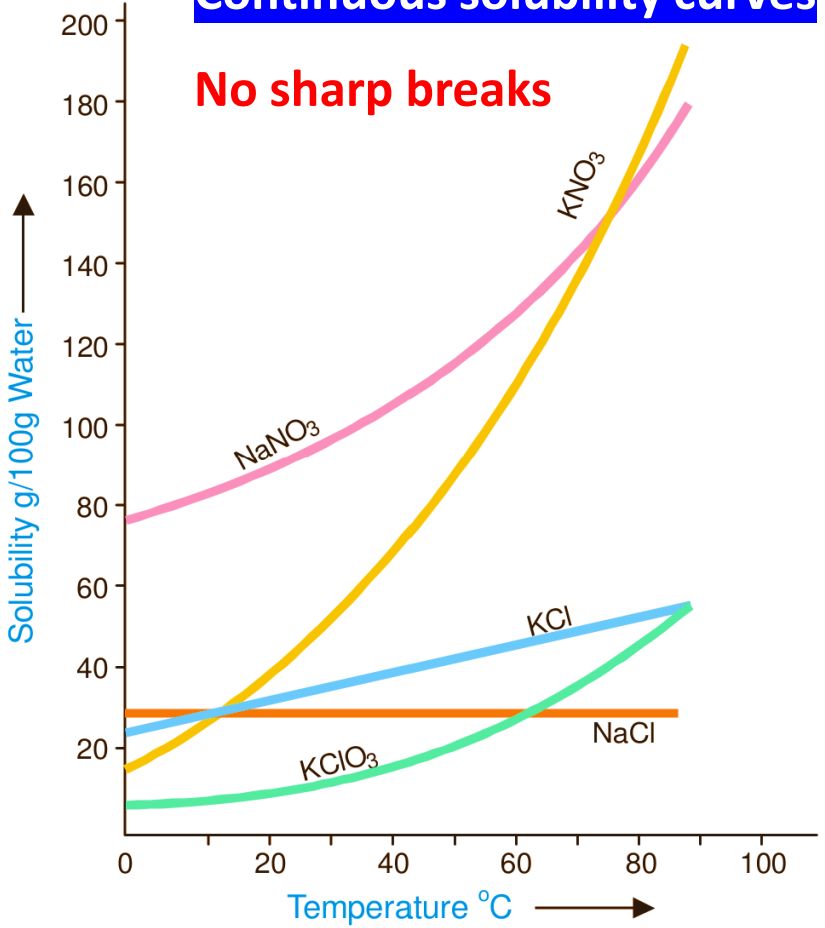
The solubility curves of substances like **calcium acetate** and **calcium chromate** show decrease in solubility with increase of temperature

while there are others like those of **sodium nitrate** and **lead nitrate** which show a considerable increase of solubility with temperature.

The solubility curve of **sodium chloride** shows very little rise with increase of temperature.

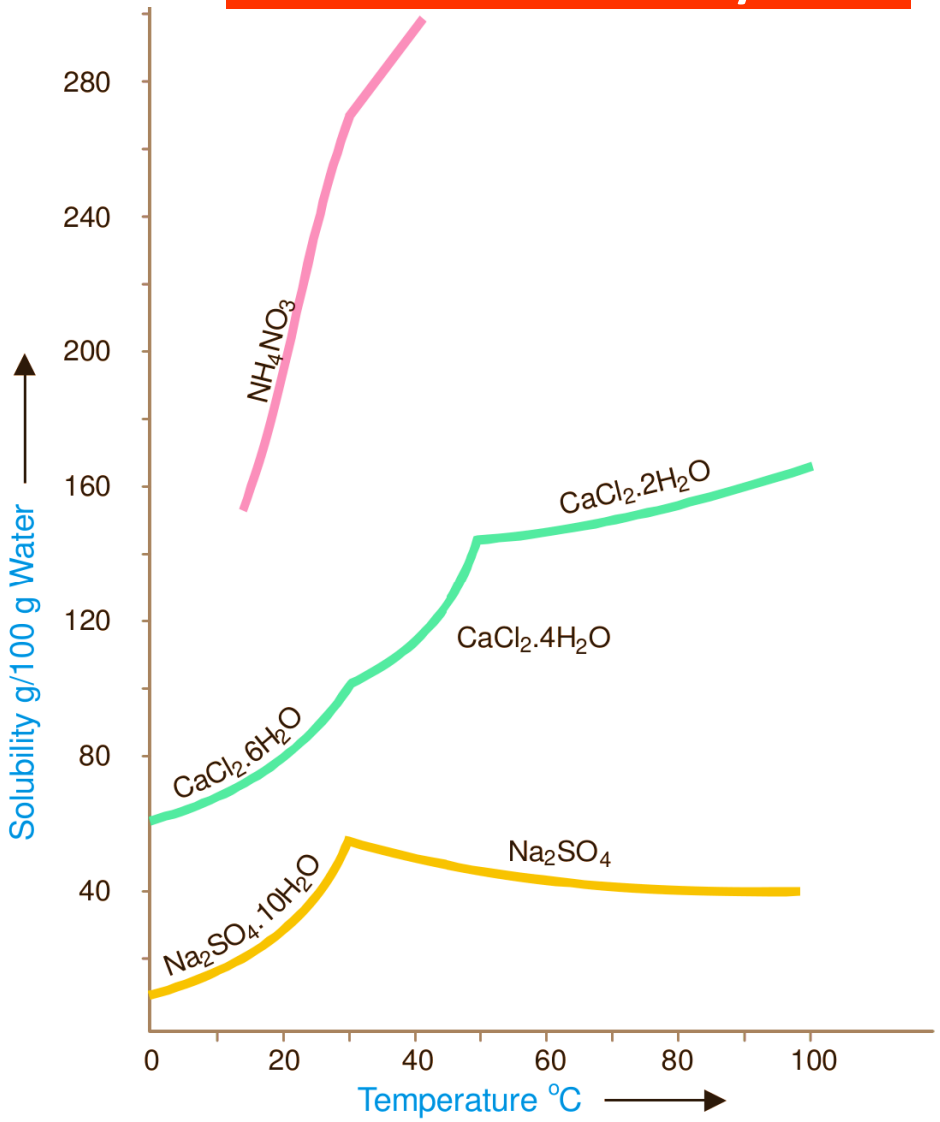
**Continuous solubility curves**

**No sharp breaks**



# SOLUBILITY CURVES

**Discontinuous solubility curves**




Sometimes the solubility curves exhibit sudden changes of direction and these curves are, therefore, called **Discontinuous solubility curves**.

In fact, at the break a new solid phase appears and another solubility curve of that new phase begins. The break in a solubility curve thus shows a point where the two different curves meet each other.

The popular examples of substances which show discontinuous solubility curves are **sodium sulphate, calcium chloride, ammonium nitrate**, etc.

# Effects of Pressure on Solubility

## HENRY'S LAW

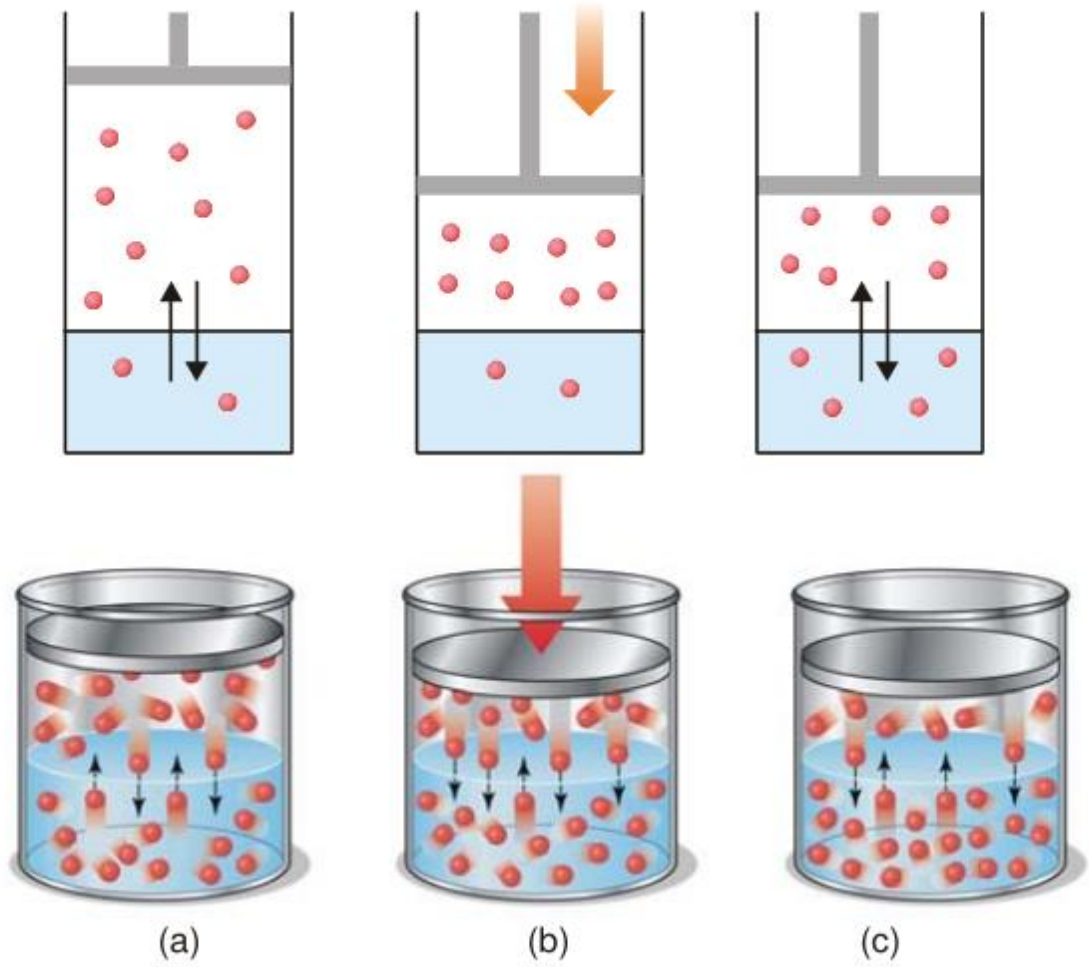
The solubility of a gas in a solvent depends on the pressure and the temperature. When a gas is enclosed over its saturated solution, the following equilibrium exists.

$$\text{gas} \rightleftharpoons \text{gas in solution}$$

If pressure is increased on the system, the equilibrium will move in the direction which will reduce the pressure (Le Chatelier Principle). The pressure can be reduced by more gas dissolving in solvent. Thus solubility or concentration of a gas in a given solvent is increased with increase of pressure.

# Effects of Pressure on Solubility

**A kinetic molecular explanation of the effect of pressure on gas-solution system**




(*a*) Equilibrium exists between the gas molecules and those in solution; (*b*) When pressure is applied, gas volume decreases and concentration in gas phase increases; (*c*) More gas molecules pass into solution to reestablish equilibrium whereby the pressure above the gas is decreased.

# Effects of Pressure on Solubility

**The concentration of a gas dissolved in a solvent is directly proportional to the pressure of a gas at constant temperature**

Mathematically, Henry's Law may be expressed as

$$C \propto P$$

or

$$C = k\,P$$

where P = pressure of the gas; C = concentration of the gas in solution; and $k$ = proportionality constant known as **Henry's Law Constant.** The value of $k$ depends on the nature of the gas and solvent, and the units of P and C used.

## Limitations of Henry's Law

It applies closely to gases with nearly ideal behaviour.

(1) at moderate temperature and pressure.

(2) if the solubility of the gas in the solvent is low.

(3) the gas does not react with the solvent to form a new species. Thus ammonia (or HCl) which react with water do not obey Henry's Law.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$