COLLOIDS SOLUTION AND CLASSIFICATION OF COLLOIDS

Colloidal Solution

They are considered a heterogeneous system comprising the following three essential components:

1. A Dispersed phase: Also known as the discontinuous or inner phase, this phase consists of discrete particles significantly larger than ordinary molecules. In this phase, small particles of solute are diffused in the solvent.
2. A Dispersion medium or continuous phase or the outer phase: This medium is where the dispersed phase is present. It consists of continuously interlinked molecules.
3. A Stabilizing agent: This substance tends to keep the colloidal particles apart. Some colloids act as self-stabilizers.

   The formula for the colloidal system is: Dispersed phase + Dispersion medium = Dispersion system (Colloidal solution)

   Each of the two phases constituting a colloidal system may be a gas, a liquid, or a solid. For example, in milk, fat globules are dispersed in water, with fat globules forming the dispersed phase and water serving as the dispersion medium.

Types of Colloidal Solutions

1. Sol

If there is a dispersion of a solid in a liquid, solid, or gaseous medium, the resulting solution is called a sol.

2. Colloidal Solution

When there is a dispersion of a solid (dispersed phase) in a liquid (dispersion medium), the resulting solution is called a colloidal solution.

3. Solid Aerosol

The dispersion of a solid (dispersed phase) in a gas (dispersion medium).

4. Liquid Aerosol

If the dispersed phase is a liquid and the dispersion medium is a gas, the resulting sol is called a liquid aerosol.

5. Emulsion

When a liquid is dispersed in another liquid, the resulting system is called an emulsion.

6. Gel

If a colloidal system becomes fairly rigid, it is termed as a gel.

Classification of Colloids

There are a number of bases for the classification of colloids.

1. Based on the characteristics of the dispersed phase and the dispersion medium, colloidal solutions are categorized into the following eight types:

S. No.	Dispersed phase	Dispersion medium	Name	Examples
1	Solid	Solid	Solid sol	Colored, glass, gems, alloys

2	Solid	Liquid	Sol	Paints, ink, white of egg mud
3	Solid	Gas	Aero sol	Smoke dust
4	Liquid	Solid	Gel	Curds pudding chasse jelly
5	Liquid	Liquid	Emulsion	Milk, cream, butter, oil in water,
6	Liquid	Gas	Liquid Aerosol	Clouds mist fog water in air
7	Gas	Solid	Solid Form	Cake, bread lava, stone
8	Gas	Liquid	Form	Soap, lather, whipped, cream

Since the two gases are completely miscible with each other, they always form a true solution.

2. Depending upon the appearance of colloids:
   Based on this classification, colloids are generally categorized into two main groups:
   a. Sol:
      - A colloidal solution that exhibits fluid characteristics is referred to as a sol.
      - Sols are named based on the dispersion medium. For instance, when water is the dispersion medium, they are termed hydrosols; when alcohol is the dispersion medium, they are referred to as alcohols, and so forth.

   b. Gels:
      - A colloid that has a solid-like structure is known as a gel.
      - The degree of rigidity in a gel varies depending on the substance.

3. Depending upon the interaction of the two phases.
   As per the classifications proposed by Perrin and Freundlich, colloids can be categorized into lyophobic and lyophilic types.
   a. Lyophobic or hydrophobic: Colloids are classified as lyophobic when the dispersed phase exhibits a lower affinity for the dispersion medium. In the case of water being the dispersion medium, they are specifically referred to as hydrophobic colloids. Examples of substances falling into this category include metals with particles larger than colloidal particles, or NaCl with particles smaller than colloidal size. Such substances face challenges in transitioning to a colloidal state.
   b. Lyophilic or hydrophilic: Colloids are labeled as lyophilic when the dispersed phase demonstrates a higher affinity for the dispersion medium, and when water is the dispersion medium, they are termed hydrophilic colloids. Also known as natural colloids, substances like proteins, starch, and rubber are encompassed within this category.

4. Depending upon the electrical charge on the dispersed phase:
   On this classification basis, colloids can be categorized into:
   a. Positive Colloids: In this category, the dispersed phase bears a positive charge. Particles of $Fe(OH)_3$ sol in water exemplify positively charged colloids. Other examples include methylene blue and TiO_2 sols.

b. Negative Colloids: Here, the dispersed phase carries a negative charge. For instance, particles of As_2S_3 sol in water exhibit a negative charge. Additional examples encompass copper or gold sols and certain dye-stuffs like eosin, Congo red, etc.

5. Depending on the structure of colloid particles:
As per Lumiere and other researchers, colloids can be categorized into molecular and micellar colloids. The particles in molecular colloids consist of single macromolecules with a structure similar to that of small molecules. On the other hand, the particles in micellar colloids are aggregates of many molecules or groups of atoms held together by cohesive or van der Waal's forces. Examples of molecular colloids include albumin, silicon, rubber, etc., while examples of micellar colloids include sulfur, gold, soap detergents, etc.

a. Multimolecular colloids: These colloidal particles consist of aggregates of atoms or small molecules with a diameter less than 10^{-9} m or 1 nm. For instance, a gold sol contains particles of various sizes with several atoms. A sulfur sol consists of particles containing a thousand or so S_2 molecules. These particles are held together by van der Waal's forces and are typically lyophobic sols.

b. Macromolecular colloids: The colloidal particles in macromolecular colloids are large molecules with very high molecular weights ranging from thousands to millions. These substances are generally polymers, including naturally occurring macromolecules such as starch, cellulose, and proteins, as well as artificial macromolecules like polyethylene, nylon, polystyrene, Dacron, synthetic rubber, plastics, etc. The size of these molecules is comparable to colloidal particles, and their dispersion is known as macromolecular colloids. Their dispersion shares some similarities with true solutions.

c. The associated colloids or miscellas:
At low concentrations, these colloids exhibit behavior similar to normal electrolytes, but at higher concentrations, they transform into aggregated particles known as miscellas. Examples of associated colloids include soap and synthetic detergents. These substances provide ions that may possess colloidal dimensions.

$$RCOONa \rightarrow RCOO^- + Na^+$$

Sod. Stearate soap (R = $C_{17}H_{35}$)

The long-chain $RCOO^-$ ions associate or aggregate at higher concentrations and form miscellas and behave as colloids. They may contain 100 or more molecules.
Sodium stearate $C_{17}H_{35}COONa$ is an example of an associated colloid. In what it gives Na^+ and state, $C_{17}H_{35}COO^-$ ions. These ions associate to form miscellas of colloidal size.

Emulsion and Gels

Emulsion

An emulsion is a colloidal system comprising two or more non-homogeneous liquids, where one of the liquids contains the dispersion of another form of liquid.

Properties of Emulsions

- Emulsions consist of both a continuous and dispersed phase, with the boundary between the phases referred to as the "interface."
- The cloudy appearance of emulsions is attributed to numerous phase interfaces scattering light as it passes through.
- Emulsions exhibit a white color when light is dispersed in equal proportions.

- Dilute emulsions scatter higher-frequency and low-wavelength light in greater fractions, resulting in a blue color appearance, known as the Tyndall effect.

Types of Emulsion

Emulsions can be categorized based on the properties of the dispersed phase and the dispersion medium.

1. Oil in Water (O/W): In this emulsion type, the dispersed phase is oil, and the dispersion medium is water. A classic example of O/W emulsion is milk, where fat globules (the dispersed phase) are suspended in water (the dispersion medium).
2. Water in Oil (W/O): In this type, water serves as the dispersed phase, and oil acts as the dispersion medium. Margarine, a spread commonly used in flavoring, baking, and cooking, exemplifies water in oil emulsion.

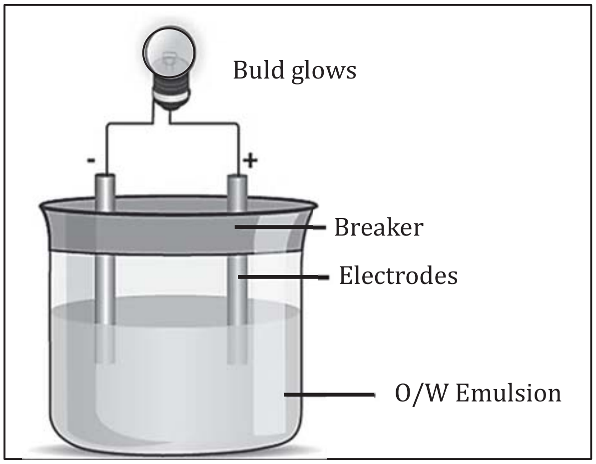
Methods to Identify the Type of Emulsions

1. Dilution Test

When water is added to an O/W emulsion, it remains stable since water is the dispersion medium. Conversely, the addition of oil will destabilize it, as oil and water are immiscible. Similarly, a W/O emulsion can be diluted with oil and remain stable, but the introduction of water will lead to destabilization.

2. Conductivity Test

In this test, the emulsion is placed between two electrodes, and a bulb is incorporated into the circuit, as illustrated in the diagram. An O/W emulsion will conduct electricity, akin to water, while a W/O emulsion will not exhibit conductivity.



3. Dye test

In this method, a water-soluble dye is introduced to the emulsion. For an O/W emulsion, the dispersion medium adopts a red color while the dispersed phase remains colorless, and vice versa.

Separation of Emulsions

Various methods can be employed to separate emulsions into their constituent liquids, including:

1. Heating
2. Centrifuging
3. Freezing, etc

Applications and Uses of Emulsion

Emulsions play a significant role in various scientific fields, finding applications in the tanning and dyeing industries, as well as contributing to the manufacturing processes of plastics and synthetic rubber.

- Commonly employed in cosmetics, pharmaceuticals, and personal hygiene products.
- Microemulsions serve as a delivery system for vaccines aimed at eradicating various microbes.
- Utilized in chemical synthesis, particularly in the production of polymer dispersions.
- Applied in firefighting.
- Nano emulsions, like soybean oil, are effective in eliminating microbes.
- Mayonnaise represents an oil-in-water emulsion containing ingredients such as egg yolk or sodium stearoyl lactylate

Gels

A gel constitutes a colloidal system where a liquid is dispersed within a solid medium. Lyophilic sols can undergo coagulation, resulting in the formation of a semi-solid, jelly-like mass that encompasses all the liquid contained in the sol. The formation process of a gel is referred to as gelation, and the colloidal system produced is termed a gel.

Common examples of gels include gum Arabic, gelatin, processed cheese, silicic acid, ferric hydroxide, among others.

Gels may be Classified into Two Types

1. Elastic gels
2. Non-elastic gels

1. Elastic Gels

Elastic gels exhibit the characteristic of elasticity, readily altering their shape under applied force and returning to their original form when the force is removed. Upon dehydration, they transform into a solid mass, which can be reversed by reintroducing water, followed by heating and cooling. When these gels come into contact with water, they absorb it and undergo swelling, a property known as Imbibition.

Examples include gelatin, agar, and starch.

2. Non-elastic Gels

Non-elastic gels are rigid and lack elasticity. Dehydration causes them to solidify into a rigid mass that cannot revert to its original form through heating with water. These gels do not exhibit the phenomenon of imbibition.

An example is silica gel.

Lyophilic and Lyophobic Sols on the Basis of Type of Dispersed Phase

Generally, lyophilic sols exhibit greater stability compared to lyophobic sols. The enhanced stability is attributed to the existence of a solvent envelope, such as water, surrounding the colloidal particle, a phenomenon known as hydration. Coagulating a hydrophilic sol requires the addition of a dehydrating agent along with an electrolyte. The key distinctions between these two types are summarized in the table below:

Preparation of sols

Preparation of Lyophilic sols

Numerous organic substances such as gelatin, starch, agar, egg albumin, and glycogen readily dissolve in water, either in its cold state or upon warming, forming colloidal solutions directly. These substances are classified as lyophilic colloids. For instance, sols of egg albumin or glycogen can be prepared by dissolving 1-2 g of the finely ground substance in 100 mL of distilled water and allowing it to stand for two hours with constant stirring. After this period, the solutions are filtered. Gelatin, considered a typical lyophilic linear colloid, exhibits unique behavior. Unlike egg albumin and glycogen, gelatin does not dissolve in cold water, although it swells. The swollen gelatin can be dissolved by heating it with water at 80-90°C. If two grams of gelatin are dissolved in 400 mL of distilled water, a clear sol is obtained upon cooling.

Such sols can be prepared by the two general ways.

1. Through the dispersion method, larger particles are initially taken and then reduced to colloidal size.
2. In the condensation method, particles with molecular dimensions are brought together to form larger aggregates, ultimately achieving colloidal dimensions.

S. No.	Property	Lyophilic (Intrinsic sol.)	Lyophobic (extrinsic sol.)
1	Preparation	They are easy to prepare. Only contact with the dispersion medium is needed to stabilize them	They are difficult to prepare. Special methods are used. Addition of stabilizers is essential for their stability.
2	Size of particles	The particles are just bigger molecules	The particles are aggregates of thousands of molecules.
3	Nature	Reversible; once precipitated casily pass back into the colloidal state by contact with dispersion medium	Irreversible, once precipitated does not easily pass into colloidal state
4	Conductivity	With lyophilic salts high conductivities can generally be measured	Owing to their sensitivity in electrolytes the conductivity of lyophobic sol can rarely be measured over a considerable range of concentration
5	Tyndall effect	Less distinct	More distinct
6	Viscosity	Higher than that of water	Almost same as that of water
7	Surface Tension	Lower than that of water	Almost same as that of water
8	Hydration	Particles are heavily hydrated	Particles are poorly hydrated
9	Stability	Very stable, coagulated with difficulty	Less stable, coagulated easily
10	Charge	Depends on the pH of the medium. It can be even zero.	Have characteristic charge (Positive or negative)

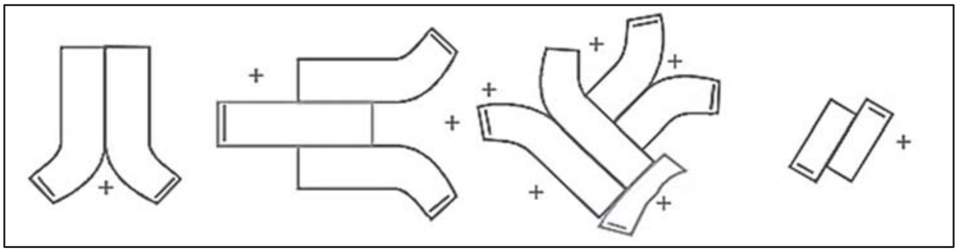
11	Concentration of the dispersed phase	Higher concentrations of dispersed phase are possible	Only low concentrations of the dispersed phase are possible
12	Examples	Albumin, Glycogen, Rubber, Silicic acid etc.	Au, Ag, some emulsions etc.

Critical Micelle Concentration (CMC)

In extremely dilute solutions, sodium and potassium oleate, along with similar substances, exist as separate molecules, ionizing into positive and negative ions. Davies and bury introduced the term "critical micelle concentration" (CMC) to describe the concentration at which micelle formation becomes noticeable. At this concentration, there is a sudden alteration in properties, and it diminishes with rising temperature. Each colloidal electrolyte exhibits a specific CMC value.

Type of Ionic Micelles

McBain proposed the existence of multiple types of ionic micelles in a specific solution of a colloidal electrolyte. Several of these are outlined below:



1. **Lamellar Micelle**

   A lamellar micelle is formed by arranging soap molecules in a double leaflet, positioned end to end and side by side. X-ray studies have unveiled an alternative micelle type, where molecules align similarly in an end-to-end, side-by-side fashion, akin to lamellar micelles. These micelles differ from each other and are segregated by layers of water, the separation dependent on concentration. Hoffman's research indicates a 55° rotational angle of molecules within the micelle. Stuff suggests that these molecules are densely packed in an irregular manner, resembling a liquid crystal.

2. **Spherical Micelle**

   Ionic micelles, as per Hartley, can assume a spherical shape. However, this assertion, while commonly accepted, remains subject to criticism.

3. **Ellipsoidal or Cylindrical Micelle**

   Kelvin has proposed the possibility of micelles taking on an elongated ellipsoidal or cylindrical form.

Electrical Double Layer

The surface of a colloidal particle undergoes the acquisition of a positive or negative charge through the selective adsorption of ions carrying corresponding charges. This charged layer then attracts counter ions from the surrounding medium, giving rise to a secondary layer. Consequently, a distinctive electrical double layer forms on the particle's surface, consisting of one layer from absorbed ions and another from oppositely charged ions, resulting in the creation of a diffused layer. This diffused layer encompasses ions of both positive and negative signs, yet its overall charge equals and opposes that absorbed by the colloidal particles. The coexistence of charges with opposite signs on the fixed and diffused segments of the double layer generates a potential difference between these layers. This potential difference, known as electrokinetic potential or zeta potential, characterizes the electrical charge distribution within the colloidal system.

Properties of Colloidal Solutions

1. Colligative Properties

Colligative properties such as osmotic pressure, vapor pressure reduction, freezing point depression, and boiling point elevation exhibit magnitudes that are relatively small when compared to the values observed in true solutions at the same concentration.

2. Tyndall Effect

The Tyndall effect can be described as the phenomenon wherein colloidal particles in a colloidal solution scatter light.

3. Colour

The color of a colloidal solution is contingent upon the wavelength of light scattered by the dispersed particles. This wavelength, in turn, is influenced by the size and nature of the particles.

4. Brownian Movement

The continuous, zigzag movement of colloidal particles within a colloidal solution is referred to as Brownian movement.

5. Charge of Colloidal Particles

Colloidal particles consistently carry an electric charge. The nature of this charge remains uniform across all particles in a given colloidal solution, and it may be either positive or negative.

Example:

(a) **+ve charged solution:**
Hemoglobin
Hydrated Metallic oxides
E.g., $AS_2S_3.xH_2O$

(b) **–ve charged solution:**
Metals
E.g., Cu, Ag, Au
Metallic sulphides
E.g., AS_2S_3, Sb_2S_3, CdS solutions.

Hardy Schulze rule

According to their perspective, the coagulation strength is directly proportional to the valency of the active ion. The active ion plays a crucial role in inducing coagulation. In the case of positively charged sols, the coagulation effectiveness of anions follows the sequence

$$[Fe(CN)_4]^{-4} > [PO_4]^{3-} > [SO_4]^{-2} > [Cl]^{-}$$

Conversely, for negatively charged sols, the coagulation efficiency is ordered as:

$$Al^{+++} > Ba^{++} > Na^{+}$$

The coagulation values for silver sol with NaCl, $BaCl_2$, and La $(NO_3)_3$ are 30, 0.5, and 0.003 millimoles/liter, respectively. The reciprocal of the coagulation value is considered the coagulating or flocculating power.

$$\frac{1}{30}:\frac{1}{0.5}:\frac{1}{0.003}$$

i.e., $1:60:1000$

Coagulation sols of Lophius

Coagulation or Flocculation

The stability of colloidal sols is attributed to the presence of electric charges on the colloidal particles. Due to the electrostatic repulsion, these particles avoid close proximity and coalescence. Any removal of these charges, by various means, results in the aggregation of particles and immediate precipitation. The phenomenon through which the dispersed phase particles in a sol are precipitated is referred to as coagulation or flocculation.

Lyophobic particles can have their electric charges eliminated by applying an electric field, such as in electrophoresis. Alternatively, the addition of electrolytes is a common method for inducing precipitation. The resulting coagulated precipitate is termed coagulum.

Methods for Coagulating a sol

Several techniques are employed to induce coagulation in a sol, and some of them are outlined below:

By the addition of Electrolytes

In this approach, a substantial quantity of electrolytes is introduced into the soil, leading to precipitation. Colloidal particles selectively absorb ions with charges opposite to their own, causing neutralization of the colloidal particle charge and subsequent coagulation.

For instance, in the case of arsenious sulphide sol (negatively charged), coagulation occurs upon adding $BaCl_2$. The negatively charged particles in the arsenious sulphide sol absorb barium ions, resulting in the neutralization of colloidal particle charges and a decrease in sol stability. Generally, the greater the valency of the added ion, the more potent its coagulating effect. The ion responsible for coagulation, which has an opposite charge to that of the sol particles, is commonly referred to as the active ion.

For example, calcium chloride exhibits approximately 100 times greater activity than NaCl in the coagulation of a silver sol. The valency of the cation is influential in the coagulation of negatively charged sols, whereas the valency of the anion is crucial for positively charged sols. Additionally, the precipitating power of an electrolyte increases significantly with an increase in the valency of the cation or anion. The coagulation sequence for ferric hydroxide sol is $Cl^- > SO0_4^- -> PO_4^{---}$ $Fe(CN)_6^{----}$, while for arsenious sulphide sol, it is $Na^+ > Ba^{++}$, Al^{+++}.

The significance of valency in coagulation was initially recognized by Schulze in 1882, and subsequent research by Linder, Picton, Hardy, and Freundlich further substantiated this concept. The coagulation values for NaCl, $BaCl_2$, and $La(NO_3\ )_3$ in the silver sol, prepared by reducing silver carbonate with tannin, are 30, 0.5, and 0.003 milli/mol per liter, respectively. The coagulation or flocculation power is then expressed as the reciprocal of these flocculation values.

$$\frac{1}{30}:\frac{1}{0.5}:\frac{1}{0.003}$$

i.e. $NaCl: BaCl_2: La(NO_3)_3$ as $0.033: 2: 33.3$ or $1.60: 10000$

1. Physical Methods

The coagulation of certain sols can be achieved through various means, such as: (a) mechanical treatment, (b) heating or cooling, (c) irradiation, (d) vigorous shaking, (e) treatment with electric current, and other methods.

2. By Continuous Dialysis

It is understood that colloidal systems contain traces of electrolytes essential for stability. Subjecting the sol to continuous dialysis renders the colloidal system unstable.

3. Salting Out

The coagulation of lyophilic sols can be induced by introducing sufficiently high concentrations of specific ions. The salting out of lyophilic colloids occurs as ions exhibit a tendency to solvate, leading to the removal of adsorbed water from dispersed particles.

4. By Hydrated Ions

Considering that ions vary in their degree of hydration or solvation, this factor also significantly influences the precipitation of sols.

5. By Removal of Electric Charge

The application of an electric field to lyophobic particles results in the removal of their electric charge, leading to precipitation. This process is achieved through electrophoresis.

	Arsenious sullied sol		Ferric hydroxide sol	
S. No.	Electrolyte	Coagulation value miles mole/Liter	Electrolyte	Coagulation value miles mole/Liter
1	NaCI	52	KCI	132
2	KCI	51	K_2CrO_3	0.225
3	$BaCI_2$	0.69	K_2SO_4	0.21
4	$MgSO_4$	0.22	$K_3Fe(CN)_6$	0.096
5	$AICI_3$	0.093	$K_4Fe(CN)_6$	0.085

Colloid Applications

A colloid is a heterogeneous mixture where minute particles of one substance are dispersed in another substance, known as the dispersion medium.

Properties of Colloids

Colloids exhibit the following characteristics:

- They are heterogeneous mixtures.
- The size of colloidal particles is very small, ranging between 1-1000 nanometers.
- Colloids demonstrate the Tyndall effect, scattering light and revealing its path.
- They remain stable and do not settle when left undisturbed.
- Filtration processes cannot separate colloids, but they can be separated through centrifugation.
- Colloidal particles display Brownian movement.

Applications of Colloids

Colloids find various applications across multiple fields:

- In the food industry, many consumed items like milk and cheese are colloidal in nature.
- Medicinally, colloids, in the form of emulsions, are used for efficient absorption of antibiotics like penicillin and streptomycin.

- Water purification employs colloids to remove impurities in sewage water through electrophoresis.
- Smoke, a colloidal system of carbon particles, can be purified using electrophoresis.
- Colloids play a role in artificial rain.
- Rubber is obtained through the coagulation of a colloidal solution called latex.
- Tanning, a process in leather production, involves the use of colloids.
- Colloidal micelles are formed during the cleansing action of soaps.
- In military applications, colloids are used in smoke screens.
- The blue color of the sky results from colloidal properties scattering sunlight.
- Nanomaterials are prepared using colloids.
- Metallurgy utilizes colloids in froth flotation.
- Colloids are employed in the treatment of hypovolemic patients.
- Silver colloids serve as germicidal agents.
- Certain colloids, like copper colloids, are used as anticancer drugs.
- Colloids are instrumental in preparing anti-syphilis antibodies.
- Proteins, being colloids, have diverse applications, including targeted drug delivery.
- Cosmetic products often contain colloids as ingredients.
- Colloids are used as fungicides and pesticides.
- In plastic surgery, colloids find applications in various body parts.
- Dentistry and wound dressing materials also utilize colloids.