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5. Colloidal Solutions

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5.1 Introduction:

Colloids are mixes in which insoluble particles of one substance are suspended in another substance at a microscopic level. In a colloid, the size of the suspended particles can range from 1 to 1000 nanometers. Colloids are defined as a mixture in which one of the components is broken down into very small particles that are spread throughout a second material. Colloidal particles are the tiniest particles.

As a result, the particles in a colloidal solution are bigger and known as colloidal particles. Even though colloidal particles are larger, they are too small to be seen with the human eye. They can, however, be spotted with the use of an ultra-microscope.

Colloidal solutions can flow through standard filter paper but not through an animal membrane. When dispersed in water, gum Arabic, gelatin, glue, and other substances produce colloidal solutions.

5.1.1 Definition:

The colloidal state is the state of subdivision in which molecules or polymolecular particles with at least one dimension in the range of 1 nanometer and 1 micrometer are scattered in some medium," according to the IUPAC definition.

Colloids are made up of chemicals that are uniformly distributed in one another. The dispersed phase is the substance that is dispersed in these combinations, while the continuous phase is the substance through which it is disseminated.

A typical solution consists of a solvent and a solute. In a normal solution, the particles of solute are usually either normal molecules or ions, and their size ranges from 1 to 10 or 0.1 to 1mm. There are systems in which the particles are much larger, ranging from the highest limit for ordinary solutions to several microns in size.

Colloids are media that contain dissolved or scattered particles ranging in size from a few microns to several millimeters. Smaller than coarse, filterable particles, colloidal particles are larger than atoms and tiny molecules.

Thomas Graham (1861) discovered that certain chemicals in the dissolved state, such as sugar, urea, sodium chloride, and others, may diffuse across a mammalian membrane. Certain dissolved substances, such as sugar, urea, sodium chloride, and others, went through the membrane, but solutions of glue, gelatin, gum Arabic, and other substances did not. However, it was quickly apparent that Graham's classification of dissolved substances was untenable since some chemicals may operate as crystalloids and colloids at the same time.

The infusibility of crystalloids and the non-infusibility of colloids via a mammalian membrane were later discovered to be attributable to particle size differences. Crystalloids in solution break down into smaller particles, which pass through the membrane. Colloids, on the other hand, produced bigger particles in solutions and were unable to pass through the membrane.

5.2 Colloids Examples:

a) **Blood:** A water-soluble respiration pigment-containing albumin protein. The dispersed phase in the pigment component is albumin, and the dispersion medium is water. It's a type of hydrosol.
b) **The Cloud:** It has air as the dispersion medium and water droplets as the dispersed phase. These are aerosol canisters.
c) **Gold Sol:** It's a metallic sol made up of gold particles suspended in water.

5.2.1 Classification of Particles:

The systems containing scattered particles can be classified into the three categories below based on particle size.

a. **True solutions:** True solutions are homogenous systems with scattered particles that are less than 1 nm in size, i.e. 10-9. In a genuine solution, the solute particles are either single molecules or ions that are uniformly dispersed throughout the solution.
b. Even a microscope cannot see these particles since they are invisible. True solutions pass through standard filter paper as well as animal membranes due to the tiny size of dispersed particles. In water, sodium chloride, sugar, urea, and other compounds form real solutions.
c. **Colloidal solutions:** Colloidal solutions are heterogeneous systems with scattered particle sizes ranging from 1 nanometer to 1000 nanometers. Colloidal solutions are transitional between genuine solutions and suspensions, as evidenced by the preceding explanation. Colloidal solutions can be made from any substance by subdividing or aggregating its particles in the size range of 1 nm-1000 nm, as indicated above. In theory, any substance can be produced to exist as a colloidal particle.
d. **Suspensions:** Suspensions, are heterogeneous systems with bigger particles. The particles in a suspension have a diameter of greater than 1000 nm. These particles can either be observed with the naked eye or using a microscope. Neither an animal membrane nor conventional filter paper can pass through the suspensions. A suspension is a murky water that has been stirred. The suspended particles in a combination must not settle to be categorized as a colloid. The Tyndall Effect is a phenomenon in which light beams incident on colloids are scattered due to interactions between the light and the colloidal particles.

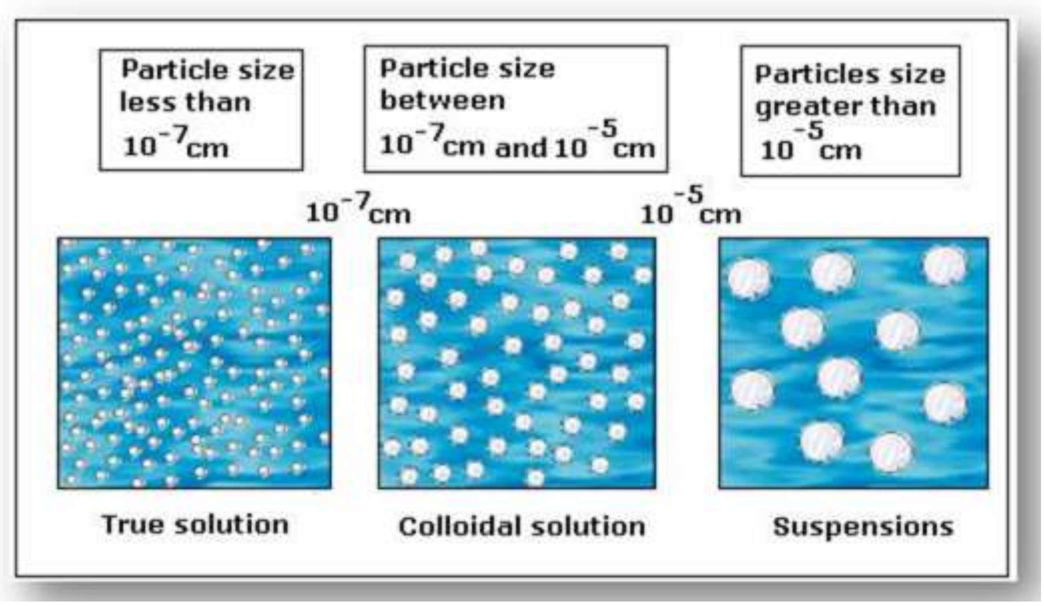


Figure 5.1: Particle Size Distribution and Their Classification

Table 5.1: Comparative Study of Properties of Particles

Property	True solution	Colloidal solution	Suspension
Particle size	Less than 1 nm	Between 1 nm-1000nm	Greater than 100nm
Nature	Homogeneous	Heterogeneous	Heterogeneous
Visibility of particles	Invisible	Visible under ultra-microscope	Visible to the naked eye or under a microscope
Appearance	Transparent	Generally transparent	Opaque
Filterability	It easily passes through both regular filter paper and animal membranes	Passes through regular filter paper without difficulty, but not through mammalian membranes.	Neither conventional filter paper nor mammalian membranes allow it to pass
The setting of particles under gravity	Particles do not settle	Colloidal particles do not settle due to gravity. High-speed centrifugation, on the other hand, can be used to compel them to settle.	Particles settle on standing

Property	True solution	Colloidal solution	Suspension
Diffusion of particles	Diffuses rapidly	Diffuses slowly	Does not diffuse
Scattering of light by particles (Tyndall Effect)	Light is not scattered	Light is scattered and the Tyndall effect is seen.	It's possible to see the Tyndall effect.

A colloidal system is made up of two phases: a dispersed phase and a dispersion medium. The dispersed phase, also known as the discontinuous phase, is the phase that is distributed or scattered through the dispersion medium. The dispersion media, also known as the continuous medium, is the phase in which scattering takes place.

(OR)

A colloidal solution is the dispersion of a solid (dispersed phase) in a liquid (dispersion medium). Solid aerosol is the dispersion of a solid (dispersed phase) in a gas (dispersion medium).

5.3 There Are Numerous Different Types of Colloids:

Colloids are characterized as lyophilic or lyophobic depending on the nature of the interaction between the dispersion medium and the dispersed phase.

5.3.1 Lyophilic:

A lyophilic colloid is one in which the dispersed phase has an affinity for the dispersion medium. The words lyo and philic, respectively, signify "liquid" and "loving." Even if the dispersed phase and the dispersion medium are separated, they can easily be reconstituted by simply mixing them. Furthermore, because of their sturdy nature, they are difficult to coagulate.

Lyophilic colloids or intrinsic colloids are substances that readily form colloidal solutions when mixed with a suitable liquid (dispersion medium), and lyophilic sols are the resulting sols.

Such colloids are known as hydrophilic colloids when water is utilized as the dispersion medium, and their colloidal dispersion in water is known as hydrophilic sols. Lyophilic colloids include things like Arabic gum, gelatin, starch, rubber, protein, and other materials are examples. Intrinsic colloids are another name for them.

Lyophilic sols are very stable and do not readily precipitate. They are self-stabilized, which means they don't need any stabilizing agents to stay in good shape. The fact that if the dispersed phase is isolated from the dispersion medium, the dispersed phase may be brought back into the sol form simply by mixing it with the dispersion media is a key feature of these sols. Lyophilic sols include gum sol, starch sol, protein sols in water, polymer sols in organic solvents, and so on.

5.3.2 Lyophobic:

A lyophobic colloid is one in which the dispersed phase has little or no affinity for the dispersion medium. The words lyo and phobic, respectively, denote "liquid" and "fear." As a result, they despise liquids. Because the dispersed phase does not readily form a colloid with the dispersion medium, they are difficult to manufacture and necessitate the employment of special techniques. They are brittle and require stabilizing substances to stay alive. Extrinsic colloids are another name for them. Sols of metals such as silver and gold, as well as sols of metallic hydroxides, are examples.

Sols are a colloidal system with a liquid or gas as the dispersion medium. Hydrosols or equal sols are the terms used to describe them. If water is used as the dispersion medium. They are called alcohols or benzo sols when the dispersion medium is alcohol or benzene. Aerosols are colloidal systems with air as the dispersion medium.

Gels are colloids in which the dispersion medium is a solid, such as cheese. Their structure is more rigid. Some colloids, such as gelatin, have can the ability to act as both sol and gel. The colloids are hydrosol at high temperatures and low gelatin content. The hydrosol, however, can gel at low temperatures and high gelatin concentrations.

5.4 Classification Based on Physical State:

The solid and the dispersion medium are both present in this dispersed phase. Example, gemstones

- **Aerosol:** The dispersion medium for these colloids is air. Cloud is an example. The dispersion medium is air, and the dispersed phase is water drops. Dust is example number two. The dispersion medium is air, and the dispersed phase is a dent particle. Smoke is an example of the third type of example. Carbon particles are present in the air.
- **Gels:** There is a solid dispersion medium and a liquid dispersed phase in these. Cheese and butter, for example.
- **Emulsion:** These are liquid-liquid solutions with a liquid dispersed medium and a liquid dispersed phase. The emulsion is primarily made up of two components.
- **Type of oil in water:** The dispersed phase is oil, while the dispersion medium is water. Milk is an example.
- **Type of water in oil:** The dispersed phase is water, while the dispersion medium is oil/fat. Vanishing cream is a good example. Sols and gels are interconvertible and reversible. This is referred to as thixotropic.
- **Dispersion Medium-Based Classification:** Sols are classed as follows based on their dispersion medium:
- **Hydrosol:** Water acts as a dispersion medium in these colloids. Starch is a good example.
- **Alcoholic beverages:** Alcohol is used as a dispersion medium in this case.
- **Aerosol:** In the air, these comprise distributed phase particles. Smoke is an example. Colloids can also be classed according to how the dispersed phase interacts with the medium:

Dispersed Phase	Dispersion Medium	Name
Solid	Liquid	Sol
Solid	Solid	Solid sol
Solid	Gas	Aero sols
Liquid	Solid	Gel
Liquid	Liquid	Emulsion
Liquid	Gas	Liquid aerosol
Gas	Solid	Solid foam
Gas	Liquid	Foam

We've already established that the colloidal particles in a colloidal system range in size from 1nm to 100nm. Colloidal solutions can be categorized into three categories based on how different chemicals creating colloidal solutions acquire particle sizes in this range.

5.4.1 Multimolecular Colloids:

Multimolecular colloids are colloidal solutions created when a large number of atoms or tiny molecules (with diameters less than 1nm) of a substance interact in a dispersion medium to form aggregates with sizes in the colloidal range. Vander Waals forces hold the species (atoms or molecules) that make up the scattered particles of Multimolecular colloids together.

Multimolecular colloids include gold sol, sulfur sol, and others. A gold sol may have particles of varying sizes made up of several gold atoms. Sulfur sol, on the other hand, is made up of particles containing thousands of S8 molecules.

5.4.2 Macromolecular Colloids:

Certain compounds generate macromolecular colloids, which are huge molecules with diameters similar to colloidal particles. The resulting colloidal solutions are known as macromolecular colloids when such compounds are dispersed in a suitable dispersion medium. The scattered particles in macromolecular colloids are thus big molecules with extremely high molecular masses.

Macromolecular colloids make up the majority of lyophilic sols. Macromolecular colloids, for example, are colloidal dispersion of naturally occurring macromolecules such as starch, proteins, gelatin, cellulose, nucleic acids, and so on. When dispersed in suitable solvents, synthetic polymers such as polyethylene, polypropylene, and synthetic rubber create macromolecular colloids.

Example: Starch, proteins, cellulose, enzymes, polystyrene, etc.

5.4.3 Associated Colloids (Micelles):

Associated colloids are strong electrolytes that act normally at low concentrations but exhibit colloidal features at greater concentrations due to the production of aggregated particles termed micelles. Micelles are created by the association of scattered particles over a specific concentration, and the process of aggregation requires a particular minimum concentration. Micelle production requires a minimum concentration called critical micellization concentration (CMC), which varies depending on the composition of the dispersed phase. CMC is 10^{-3} mol L^{-1} for soaps. Surfactants (surface active agents) such as soaps and synthetic detergents frequently form the related colloids. When these agents are present in solution at a concentration higher than the critical micellization concentration, they produce micelles (CMC).

Example: Soap, synthetic detergents.

5.4.4 Colloidal Solution Preparation:

Because of their strong affinity for the dispersion medium, lyophilic colloids rapidly form a sol when brought into contact or warmed with it. For example, simply heating with water is sufficient for making starch, gelatin, and gum Arabic sols. However, because lyophobic colloids have no affinity for the dispersion medium, it is difficult to create these sols in practice. The manufacture of lyophobic sols necessitates the use of certain techniques.

There are several different methods for making lyophobic sols, which can be grouped into two categories.

- Dispersion methods and
- Condensation or aggregation methods

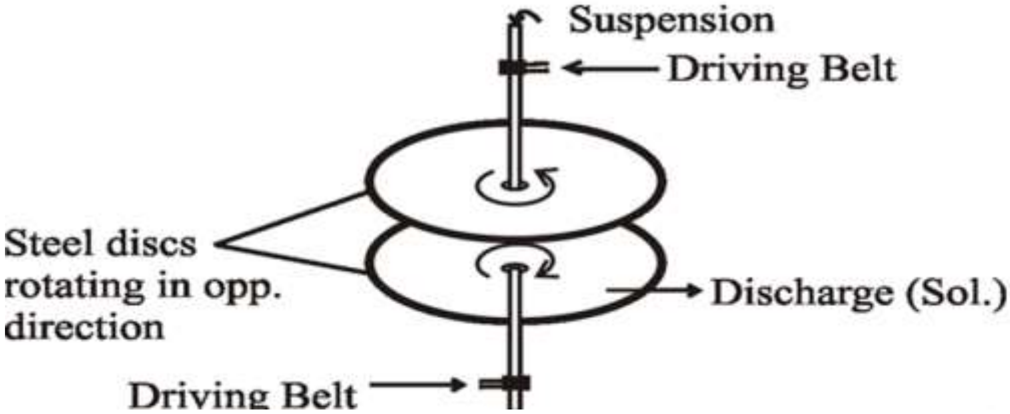
5.5 Methods of Dispersion:

The larger particles of any substance are broken down into minute colloidal particles via dispersion processes. The resulting tiny particles are stabilized by the addition of stabilizing agents.

The following are some of the dispersion methods:

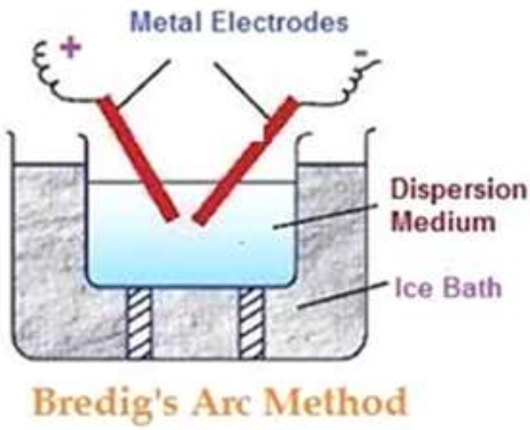
5.5.1 Mechanical Dispersion Method:

The big particles of the material whose sol is to be created are broken down in a machine called a colloid mill in the mechanical dispersion procedure. Two hefty steel discs are separated by a small space in a colloid mill. The particle size can be modified to suit your needs. The two discs spin in opposite directions at a fast rate. The material is suspended in water and added to the mill. The particles in the suspension are ground to form colloidal particles, which are then dispersed in water to form a sol.



5.5.2 Bredig's Arc Method or by Electrical Dispersion:

The electrical dispersion method (Bredig's arc method) is used to prepare sols metals such as gold, silver, platinum, and other precious metals. Two electrodes of the metals whose sol is to be made are immersed in the dispersion medium and a high voltage current is sent through them to create an electric arc. By enclosing the dispersion medium in a freezing liquid, it is kept chilly. The metal begins to vaporize due to the heat created by the electric arc, and the vapor condenses into the cold dispersion media to form colloidal particles upon cooling.



5.5.3 Ultrasonic Dispersion:

High-frequency sound waves are commonly referred to as ultrasonic waves. When quartz crystal discs are coupled to a high-frequency generator, these waves can be generated. In 1927, Wood and Loomis were the first to use ultrasonic waves to prepare colloidal solutions. With the use of ultrasonic waves, many compounds such as oils, mercury, sulfides, and metal oxides can be easily dispersed into a colloidal condition.

5.5.4 Peptization:

Peptization is the process of breaking down freshly formed precipitate particles into colloidal-sized particles. This is accomplished by incorporating appropriate electrolytes. A peptizing agent is an electrolyte that is added.

The addition of ferric chloride solution to newly precipitated ferric hydroxide produces a brown-colored colloidal solution. The adsorption of ferric ions on the surface of the precipitate caused this. The formation of positively chafed ferric ions on the surface generates repulsion between them, resulting in the breakdown of large precipitate particles into small colloidal particles.

5.5.5 Method of Condensation/Aggregation:

Some chemical reactions can be utilized to clump together with smaller atomic or ionic particles to generate giant colloidal particles. In these reactions, the scattered phase forms as an insoluble reaction product. Here are a few key processes involved in the creation of hydrophobic soils.

a) By Exchange of Solvents: Due to the limited solubility of sulfur or phosphorus in water, a colloidal solution of sulfur or phosphorus is formed when a solution of sulfur or phosphorus is made in alcohol is put into water. As a result, colloidal solutions of various compounds can be made by taking a solution of the substance in one solvent and pouring it into a solvent in which the substance is less soluble.

b) By change of physical state: Colloidal solutions of some elements, such as mercury and sulfur, are produced by passing their vapors through cold water containing a stabilizer.

c) Oxidation: Sol sulfur is made by oxidizing an aqueous solution of hydrogen sulfide (H_2S) with bromine water, nitric acid, SO_2, or any other suitable oxidizing agent.

$$H_2S + Br_2 \rightarrow \frac{S}{Colloidal\ sulphur} + 2HBr$$

$$2H_2S + SO_2 \rightarrow \frac{3S}{Colloidal\ sulphur} + 2H_2O$$

a) **Reduction:** Sols of gold, silver, platinum, and other metals are made by reducing dilute salt solutions with an appropriate reducing agent. Gold sol, for example, can be made by reducing a dilute aqueous gold solution with stannous chloride.

$$2AuCl_3 + 3SnCl_2 \rightarrow \frac{2Au}{Colloidal\ sulphur} + 3SnCl_4$$

The gold sol thus obtained is called purple of Cassius.

b) Hydrolysis: Ferric and aluminum hydroxide sols are made by boiling the aqueous solution of the appropriate chlorides.

$$FeCI_3 + 3H_2S \rightarrow Fe\,(OH)_3 + 3HCI$$

c) Double decomposition: A double decomposition reaction can be used to make sols of inorganic insoluble salts such as arsenous sulfide, silver halides, and other insoluble salts. Arsenous sulfide sol, for example, can be made by passing hydrogen sulfide gas through a dilute aqueous solution of arsenous oxide.

$$\mathbf{As_2O_3 + 3H_2S \rightarrow As_2S_3\,(sol) + 3H_2O}$$

5.6 Colloidal Solutions and Their Physical Properties:

Below are some of the most important features of colloidal solutions.

- **Heterogeneous nature:** There are two phases to the colloidal system: (a) Dispersed phase and (b) dispersion phase. Each particle in a colloidal solution is contained by boundary surfaces that separate it from the dispersion medium.
- **Colligative properties:** Colloidal particles have relatively low mole fractions in colloidal solution due to their high average molecular masses. As a result, colligative qualities such as relative lowering of vapor pressures, the elevation of boiling point, depression of freezing point, and osmotic pressure have very low values.
- **Visibility:** Colloidal solutions are heterogeneous, and they are made up of two phases: dispersed phases and the dispersion medium. Although colloidal solutions are heterogeneous, the dispersed particles present in them are not visible to the naked eye, giving the impression that they are homogeneous. Because colloidal particles are too minute to be seen with the human eye, this is the case.
- **Filterability:** Colloidal particles pass through regular filter paper due to their small size. Animal membranes, cellophane membranes, and ultrafilters, on the other hand, can retain them.
- **Stability:** Lyophilic sols in general, and lyophobic sols in the absence of significant electrolyte concentrations, are quite stable, and the dispersed particles contained in them do not settle down even after keeping. However, after a long period of standing, a few colloidal particles of comparably greater size may progressively sediment.

5.7 Optical properties:

1. Tyndall effect: Tyndall discovered in 1869 that when a powerful beam of light is sent through a colloidal solution in a dark room, the path of the beam is illuminated by a bluish light. This process, known as the Tyndall effect, was first detected by Faraday and later investigated in depth by Tyndall. Tyndall cone refers to the lighted path of a beam. The phenomenon occurs as a result of colloidal particles dispersing light in all directions.

2. Color: The wavelength of the light scattered by the dispersed particles determines the color of the colloidal sol. The wavelength is also affected by the size and composition of colloidal particles. Larger particles absorb longer wavelength light and so transmit shorter wavelength light. A silver with particles of size 150nm, for example, appears violet, whereas one with particles of size 60nm appears orange-yellow. The hue of colloidal sol is also determined by how the dispersed light is received by the viewer. When viewed by reflected light, a mixture of milk and water appears blue, but when viewed by transmitted light, it appears red.

3. Mechanical properties: (a) Brownian movement: A botanist named Robert Brown observed in 1827 that pollen grains placed in water do not stay still but move around randomly. This behavior was later noticed when colloidal particles were examined under an ultra-microscope. The particles were observed to be moving in a zig-zag pattern in all directions. Brownian movement refers to the zig-zag motion of colloidal particles.

Because the repulsive forces between similarly charged particles prevent them from aggregating when they get closer to one another, the presence of equal and similar charges on colloidal particles is also primarily responsible for providing stability to the colloidal solution.

5.8 Applications of Colloids:

Colloids have a wide range of applications in our daily lives, from food to medicine to industries such as rubber. Colloids have a wide range of applications in the food and pharmaceutical industries. Many of the foodstuffs we consume are colloidal. Many milk products, such as cheese, cream butter, and so on, are colloids. Milk is an emulsion, to be precise (liquid in a liquid colloidal system). Butter and fat are diffused in water in milk. Air is disseminated in the cooked dough, making bread a colloidal system. Colloids are widely used in industries, medicine, and everyday life. Syrup, Halwa, and Soup are examples of colloidal systems in cuisine. Colloidal silver, also known as Argosols, is used as an antimicrobial for eye infections Colloids can also be used in the form of medications. Colloidal drugs are more effective than traditional medicines because they are easily absorbed by the body. Some important antibiotics, such as penicillin and streptomycin, are injected into the body as colloidal sol to ensure that they are quickly absorbed.

5.9 The following are some of the applications of colloids.

- **Water Purification:** We all know that adding electrolytes such as potash alum to water is one of the most common techniques of water purification. The addition of these electrolytes is predicated on the fact that colloidal systems are common in dirty water. It frequently comprises scattered colloidal particles that filtration cannot remove. The addition of these electrolytes causes the impurity to coagulate, allowing it to be removed by filtration.
- **Sewage disposal:** As previously stated, sewage water contains colloidal pollutants such as mud and dirt, which are disseminated in the water. Sewage colloidal particles are charged particles, just like any other colloidal system. Electrophoresis can be used to remove the charged particles of pollutants found in sewage.
- The sewage water is routed via a tunnel equipped with metallic electrodes and kept at a high potential difference for this purpose. The charged impurity particles in the sewage water travel to the electrodes with opposing charges, causing them to coagulate.

- **Smoke precipitation:** Smoke is a colloidal system made primarily of charged carbon particles that are depressed in the air. Smoke is a significant environmental issue since it is a major source of air pollution. The problem will be solved by removing the dispersed colloidal particles from the air. Electrophoresis is used once more for this purpose.
- This is accomplished using the Cottrell precipitator. Smoke is forced through a chamber containing numerous metal plates connected by a metal wire to a high-potential source. When electrically charged colloidal carbon particles in the air come into touch with oppositely charged plates, they are discharged and fall to the bottom. A near-top exit lets clean hot air out of the precipitator.
- **Artificial Rain:** Clouds, like artificial rain, are colloidal systems. Water vapors are present in clouds, along with dust particles. In a cloud, the water molecules contain an electric charge and are colloidal in size. As a result, if the charge on the molecules is neutralized in any way, the rain will begin to fall. It is sometimes done by spraying electrolytes over the clouds, and the rain that results is referred to as manufactured rain.
- **Rubber industry:** You should be aware that rubber is made from latex collected from rubber trees. This latex is an emulsion of rubber particles that are negatively charged and distributed in the water. This latex is cooked to obtain rubber, which causes the rubber particles to coagulate. Vulcanization is used to solidify the coagulated substance into natural rubber.
- **Tannery:** Tanning refers to the practice of processing animal skins to obtain leather. When animal skins are immersed in a solution of tannin, which has the opposite charge as the animal skin, particles coagulate and the skin becomes hard. This process is known as tanning. The charged particles of the skin are coagulated using negatively charged materials such as tannin and some aluminum and chromium compounds.
- **Soap cleansing action:** As previously stated, the soap solution is a colloidal system that eliminates oil and filth by generating water-soluble emulsions.
- **Smokescreen:** A smoke screen is a device that uses a layer of smoke to conceal something. In general, it is employed to conceal army movements. Smokescreens are a colloidal system in which titanium oxide particles are spread in the air.
- **Delta formation:** A delta is a large deposit of sand and clay generated at the mouth of any river in the sea at the point where the river meets the sea. The formation of the delta is a fascinating natural process in which the presence of negatively charged colloidal sand and clay particles in river water is unsurprising. Salty seawater, on the other hand, includes several positive ions. When river water meets seawater, the negative charge on colloidal clay particles in river water is neutralized by the positively charged ions in the sea, causing them to congeal and deposit at the spot.
- **Blue Sky:** The blue tint of the sky is caused by the dispersion of the blue color of sunlight by colloidal dust particles scattered in the air existing in the atmosphere. (This is known as the Tyndall effect.)

Nanomaterial preparation: Reverse micelles are utilized to make nanomaterials that are used as catalysts.