

Review Article

Properties and Uses of Colloids: A Review

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Abstract: Colloid science is the science of both large molecules and finely subdivided multiphase systems. It is the system of more than one phase that colloid and surface science meet. Colloid science is interdisciplinary in many respects; its field of interest overlaps physics, biology, materials science, and several other disciplines. It is the particle dimension – not the chemical composition (organic or inorganic), sources of the sample (e.g., biological or mineralogical), or physical state (e.g., one or two phases). The colloidal solutions or colloidal dispersions are intermediate between true solutions and suspensions. In other words, the diameter of the dispersed particles in a colloidal dispersion is more than that of the solute particles in a true solution and smaller than that of a suspension. The knowledge of colloid chemistry is required in various aspects of chemistry. It is a field that has offered more and still has much more to offer; therefore chemists should be studious to extract more uses from this field as it still has more to offer. This article is aimed at reviewing the properties as well as some of the uses of colloids.

Keywords: Colloid, Dispersion, System, Phase, Brownian, Tyndall

1. Introduction

A solution consists of two components- a solute and a solvent. If a solution of ferric chloride is poured into boiling water, a clear deep brown liquid is obtained. The change in colour shows that a chemical reaction has occurred; in fact ferric oxide has been formed. The latter is practically insoluble in water and would normally precipitate but if formed under the right conditions, it may remain dispersed throughout the liquid in the form of very small particles. The presence of these particles is shown by the colour but they are not large enough to cause the liquid to appear cloudy. This is an example of a colloidal system [1]. In ordinary true solution, the solute is dispersed throughout the solvent in the form of single molecules or ions. On the other hand, suspension contains particles that are large enough to be seen by the naked eye or through the microscope [1].

In a true solution as sugar or salt in water, the solute particles are dispersed in the solvent as single molecules or ions. Thus the diameter of the dispersed particles ranges from 1 Å to 10 Å. On the other hand, in a suspension of sand stirred into water, the dispersed particles are aggregates of millions of molecules. The diameter of these particles is of the order 2,000

Å or more [2]. It is obviously impossible to draw a boundary line between true solution and colloidal solutions. Colloidal behavior can be connected with greatly increased surface area compared with the volume as the size is reduced. The essential properties of colloidal dispersions can be ascribed to the fact that the ratio of the surface area to volume of the particles is very large. In true solution, the system consists of one phase only and there is no true surface of separation between the molecular particles of solute and solvent. The size of particles in colloidal state ranges between 5mμ- 200mμ [1].

Thomas Graham in 1861 studied the ability of dissolved substances to diffuse into water across a permeable membrane. He observed that crystalline substances such as sugar, urea, and sodium chloride passed through the membrane, while others like glue, gelatin and gum arabic did not. The former he called crystalloids and the latter colloids (Greek, *kolla* = glue; *eidos* = like). Graham thought that the difference in the behavior of 'crystalloids' and 'colloids' was due to the particle size. Later it was realized that any substance, regardless of its nature, could be converted into a colloid by subdividing it into particles of colloidal size [3]. Any particle that has some linear between 10^{-9} m (10 Å) and 10^{-6} m (1 μm or 1 μ) is considered a colloid. Linear dimensions rather than particle weights or the

number of atoms in a particle will define the colloidal size range [3]. When the diameter of the particles of a substance dispersed in a solvent ranges from about 10 Å to 2,000 Å, the system is termed a colloidal solution, colloidal dispersion, or simply a colloid. The material with particle size in the colloidal range is said to be in the colloidal state [2].

Common examples of colloids: The colloidal particles are not necessarily corpuscular in shape. In fact, these may be rod-like, disc-like, thin films, or long filaments. For matter in the form of corpuscles, the diameter gives a measure of the particle size. However, in other cases one of the dimensions (length, width and thickness) has to be in the colloidal range for the material to be classed as colloidal. Thus in a broader context we can say: A system with at least one dimension (length, width, or thickness) of the dispersed particles in the range 10 Å to 2,000 Å is classed as a colloidal dispersion [2].

Many of the interesting properties of colloids are the result of their dimension, which lies between atomic dimensions and bulk dimensions. There are two important consequences of the size range of colloids are:

- (i) Colloidal materials have enormous surface areas and “surface energies”.
- (ii) The properties of colloidal particles are not always those

of the corresponding bulk matter or those of corresponding atoms/molecules. The colloidal size range lies between microscopic chunks of material and individual atoms [4].

Colloidal systems are regarded as heterogeneous in character, consisting of two phases. The substance distributed as the colloidal particles is called the Dispersed phase. The second continuous phase in which the colloidal particles are dispersed is called the Dispersion medium. For example, for a colloidal solution of copper in water, copper particles constitute the dispersed phase and water the dispersion medium [2].

Also, Dispersed phase refers to the phase forming the particles. Dispersion medium is the medium in which dispersion of the particles takes place [1]. As stated above, a colloidal system is made of a dispersed phase and the dispersion medium. Because either the dispersed phase or the dispersion medium can be a gas, liquid or solid, there are eight types of colloidal systems possible. A colloidal dispersion of one gas in another is not possible since the two gases would give a homogeneous molecular mixture. The various types of colloidal systems are listed below in table 1;

Table 1. Types of colloidal dispersion.

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	Fog, 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.

This article is aimed at reviewing the properties as well as some of the uses of colloids.

2. Properties of Colloids

2.1. Optical Properties of Colloids

Tyndall Effect

When a strong beam of light is passed through a sol and viewed at right angles, the path of light shows up as a hazy beam or cone. This is due to the fact that sol particles absorb light energy and then emit it in all directions in space. This ‘scattering of light’, as it is called, illuminates the path of the beam in the colloidal dispersion.

The phenomenon of the scattering of light by the sol particles is called Tyndall effect. The illuminated beam or cone formed by the scattering of light by the sol particles is often referred as Tyndall beam or Tyndall cone.

The hazy illumination of the light beam from the film projector in a smoke-filled theatre or the light beams from the headlights of car on a dusty road, are familiar examples of the Tyndall effect. If the sol particles are large enough, the sol may even appear turbid in ordinary light as a result of Tyndall scattering.

True solutions do not show Tyndall effect. Since ions or solute molecules are too small to scatter light, the beam of light passing through a true solution is not visible when viewed from the side. Thus Tyndall effect can be used to distinguish a colloidal solution from a true solution.

- (i) Ultramicroscopic nature of particles: Sol particles cannot be seen with a microscope. Zsigmondy used the Tyndall phenomenon to set up an apparatus named as the ultramicroscope. An intense beam of light is focused on a sol contained in a glass vessel. The focus of light is then observed with a microscope at right angles to the beam. Individual sol particles appear as bright specks of light against a dark background (dispersion medium). It may be noted that under the ultramicroscope, the actual particles are not visible. It is the larger halos of scattered light around the particles that are visible. Thus an ultramicroscope does not give any information regarding the shape and size of the sol particles.
- (ii) Electron microscopy: In an electron microscope, beam of electrons is focused by electric and magnetic fields on to a photographic plate. This focused beam is allowed to pass through a film of sol particles. Thus it is possible to get a picture of the individual particles showing a magnification of the order of 10,000. With the help of

this instrument, we can have an idea of the size and shape of several sol particles including paint pigments, viruses, and bacteria. These particles have been found to be spheroid, rod-like, disc-like, or long filaments.

2.2. Kinetic Properties of Colloids

Brownian Motion: When a sol is examined with an ultramicroscope, the suspended particles are seen as shining specks of light. By following an individual particle it is observed that the particle is undergoing a constant rapid motion. It moves in a series of short straight-line paths in the medium, changing directions abruptly [2].

The continuous rapid zig-zag movement executed by a colloidal particle in the dispersion medium is called Brownian movement or motion. This phenomenon is so named after Sir Robert Brown who discovered it in 1827. Suspension and true solutions do not exhibit Brownian movement.

Explanation of Brownian movement. The explanation of Brownian movement was advanced by Albert Einstein around 1955 by mathematical considerations based on the kinetic molecular theory. According to him, at any instant a colloidal particle was being struck by several molecules of the dispersion medium. The movement of the particle was caused by unequal number of molecules of the medium striking it from opposite directions. When more molecules struck the particle on one side than on another, the direction of movement change.

In a suspension, the suspended particles being very large the probability of unequal bombardments diminishes. The force of the molecules hitting the particle on one side is cancelled by the force of collisions occurring on the other side. Hence they do not exhibit Brownian movement. The phenomenon of Brownian movement is an excellent proof of the existence of molecules and their ceaseless motion in liquids. It also explains how the action of gravity, which would ordinarily cause the settling of colloidal particles, is counteracted. The constant pushing of the particles by the molecules of the dispersion medium has a stirring effect which does not permit the particles to settle.

2.3. Electrical Properties of Colloids

- (i) **Electrostatic nature of sols:** The most important property of colloidal dispersions is that all the suspended particles possess either a positive or a negative charge. The mutual forces of repulsion between similarly charged particles prevent them from aggregating and settling under the action of gravity. This gives stability to the sol.

The sol particles acquire positive or negative charge by preferential adsorption of positive or negative ions from the dispersion medium. For example, a ferric hydroxide sol particles are positively charged because these adsorb Fe^{3+} ions from ferric chloride (FeCl_3) used in the preparation of the sol. Since the sol as a whole is neutral, the charge on the particle is counterbalanced by oppositely charged ions termed counter-ions (in this

case Cl^-) furnished by the electrolyte in medium.

- (ii) **Electrical Double layer:** The surface of colloidal particle acquires a positive charge by selective adsorption of a layer of positive ions around it. This layer attracts counter-ions from the medium which form a second layer of negative charges. The combination of the two layer of +ve and -ve charges around the sol particle was called Helmholtz Double layer. Helmholtz thought that positive charges next to the particle surface were fixed, while the layers of negative charges along with the medium were mobile. More recent considerations have shown that the double layer is made of: (a) Compact layer of positive and negative charges which are fixed firmly on the particle surface. (b) Diffuse layer of counterions (negative ions) diffused into the medium containing positive ions.

The combination of the compact and diffuse layer is referred to as the Stern Double layer after the colloid chemist who first realized its significance. The diffuse layer is only loosely attached to the particle surface and moves in the opposite direction under an applied electric field. Because of the distribution of the charge around the particle, there is a difference in potential between the compact layer and the bulk of solution across the diffuse layer. This is called by Electrokinetic or Zeta potential. The presence of the double layer accounts for the electrical properties: (a) Cataphoresis; and (b) Electro-osmosis of colloids. It has been made possible to estimate the magnitude of the zeta potential with the help of these properties.

3. Applications of Colloids

Colloids play an important role in our daily life and industry. A good knowledge of colloid chemistry is essential to understand some of the various natural phenomena around us. Colloids make up some of our modern products. A few of the important applications of colloids are listed below.

- (i) **Foods:** Many of our foods are colloidal in nature. Milk is an emulsion of butterfat in water protected by a protein, casein. Salad dressing, gelatin deserts, fruit jellies and whipped cream are other examples. Ice cream is a dispersion of ice in cream. Bread is a dispersion of air in baked dough.
- (ii) **Medicines:** Colloidal medicines being finely divided are more effective and are easily absorbed in our system. Halibut-liver oil and cod-liver that we take are, in fact, the emulsions of the respective oils in water. Many ointments for application to skin consist of physiologically active components dissolved in oil and made into an emulsion with water. Antibiotics such as penicillin and streptomycin are produced in colloidal form suitable for injections.
- (iii) **Non-drip or thixotropic paints:** All paints are colloidal dispersions of solid pigments in a liquid medium. The modern non-drip or thixotropic paints also contain long-chain polymers. At rest, the chains of molecules are coiled and entrap much dispersion medium. Thus

the paint is a semisolid gel structure. When shearing stress is applied with a paint brush, the coiled molecules straighten and the entrapped medium is released. As soon as the brush is removed, the liquid paint reverts to the semisolid form. This renders the paint 'non-drip'.

- (iv) **Electrical precipitation of smoke:** The smoke coming from industrial plants is a colloidal dispersion of solid particles (carbon, arsenic compounds, and cement dust) in air. It is a nuisance and pollutes the atmosphere. Therefore, before allowing the smoke to escape into air, it is treated by Cottrell Precipitator (See Fig. 1). The smoke is let past a series of sharp points charged to a high potential (20,000 to 70,000 V). The points discharge high velocity electrons that ionize molecules in air. Smoke particles adsorb these positive ions and become charged. The charged particles are attracted to the oppositely charged electrodes and get precipitated. The gases that leave the Cottrell precipitator are thus freed from smoke. In addition, valuable materials may be recovered from the precipitated smoke. For example, arsenic oxide is mainly recovered from the smelter smoke by this method.

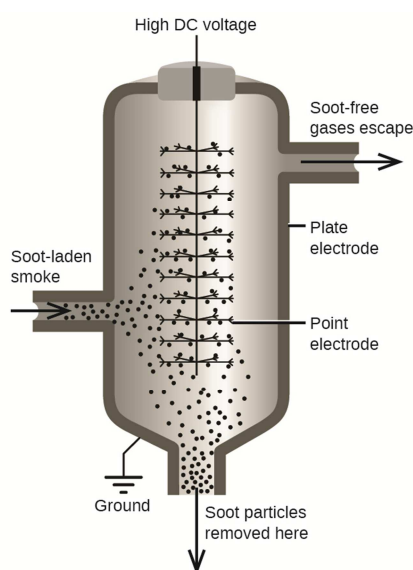
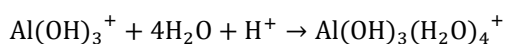
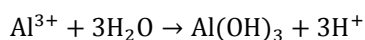


Figure 1. Cottrell Precipitator.

- (v) **Clarification of Municipal water:** The municipal water obtained from natural sources often contains colloidal particles. The process of coagulation is used to remove these. The sol particles carry a negative charge. When aluminium sulphate (alum) is added to water, a gelatinous precipitate of hydrated aluminium hydroxide (floc) is formed,



The positively charged floc attracts to it negative sol

particles which are coagulated. The floc along with the suspended matter comes down, leaving the water clear.

- (vi) **Formation of Delta:** The river water contains colloidal particles of sand and clay which carry negative charge. The sea water, on the other hand, contains positive ions such as Na^+ , Mg^{2+} , Ca^{2+} . As the river water meets sea water, these ions discharge the sand or clay particles which are precipitated as delta.

- (vii) **Artificial Kidney machine:** The human kidneys purify the blood by dialysis through natural membranes. The toxic waste products such as urea and uric acid pass through the membranes, while colloidal-sized particles of blood proteins (haemoglobin) are retained. Kidney failure, therefore, leads to death due to accumulation of poisonous waste products in the blood. Now-a-days, the patient's blood can be cleansed by shunting it into an 'artificial kidney machine'. Here the impure blood is made to pass through a series of cellophane tubes surrounded by a washing solution in water. The toxic waste chemicals (urea, uric acid) diffuse across the tube walls into the washing solution. The purified blood is returned to the patient. The use of artificial kidney machine saves the life of thousands of persons each year.

- (viii) **Adsorption indicators:** These indicators function by preferential adsorption of ions onto sol particles. Fluorescein (Na^+Fl^-) is an example of adsorption indicator which is used for the titration of sodium chloride solution against silver nitrate solution. When silver nitrate solution is run into a solution of sodium chloride containing a little fluorescein, a white precipitate of silver chloride is first formed. At the end-point, the white precipitate turns sharply pink.

- (ix) **Explanation:** The indicator fluorescein is a dye (Na^+Fl^-) which gives coloured anion Fl^- in aqueous solution. The white precipitate of silver chloride formed by running AgNO_3 solution into NaCl solution is partially colloidal in nature.

- (a) Before the end-point, Cl^- ions are in excess. The AgCl sol particles adsorb these ions and become negatively charged. The negative AgCl/Cl^- particles cannot adsorb the coloured fluorescein anions (Fl^-) due to electrostatic repulsion. Thus the precipitate remains white.

- (b) After the end-point, Ag^+ ions become in excess. AgCl sol particles adsorb these and acquire positive charge. The positive AgCl/Ag^+ particles now attract the coloured fluorescein anions (Fl^-) and turn rose-red. Thus the end-point is marked by white precipitate changing to pink.

- (x) **Blue colour of the sky:** This is an application of Tyndall effect. The upper atmosphere contains colloidal dust or ice particles dispersed in air. As the sun rays enter the atmosphere these strike the colloidal particles. The particles absorb sunlight and scatter light of blue colour (4600–5100Å). The light that is incident at earth's surface is considerably reddened

due to the removal of most of the blue light in the upper atmosphere.

- (xi) Leather tannin: Leather tannin is a process which utilizes colloidal properties. Raw hides contain giant molecules arranged in long tangled fibres. Tanning materials which include tannin and compounds of chromium and aluminium are in colloidal state and the positively charged protein fibres adsorb negative charges from these metallic ingredients.
- (xii) In textile dyeing: Colloidal substances called "mordants" are used to fasten dyes.
- (xiii) The cleansing action of detergents: This is due to former's emulsifying properties. They form an emulsion with oil and dirt particles in water.
- (xiv) Sewage: Sewage usually contains considerable amounts of deflocculating substances such as soap, organic matter and the like which tend to keep it full of colloidal dispersed particles. The successful treatment of sewage, backwaters and trade effluents involves the separation from them these colloids by coagulation, absorption, filtration or destruction (usually by bacteria in septic tank).
- (xv) Smoke screens: Smoke screens consist of titanium dioxide particles dispersed in air and are used in warfare for the purpose of concealment.
- (xvi) Fire-foam: Fire-foam is a carbon dioxide froth made by mixing solution of sodium bicarbonate and alum. The protective colloid such as glue, dextrin or saponin is added to stabilize the foam and keep the bubbles in finely dispersed form.

4. Conclusion

Colloids are heterogenous solutions that have large surface areas and surface energies and whose properties are sometimes different from those of the corresponding bulk matter, atoms or molecules. Its ability to scatter light (Tyndall effect), undergo Brownian motion, and possess a net charge are some of the reasons its principle is applied in industries such as; the food industry, the pharmaceutical industry, In hospitals and in water purification.

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