

Properties and Types of Colloids: A Comprehensive Review

Palapala Durga, Assistant professor Viswanadha institute of pharmaceutical sciences,
Mindhivanipalem, Visakhapatnam, 531173

Abstract

Colloids are heterogeneous systems in which particles ranging from 1–1000 nm are dispersed in a continuous medium, exhibiting properties distinct from both true solutions and coarse suspensions. Their intermediate nature gives rise to unique optical phenomena such as the Tyndall effect, kinetic behaviors like Brownian motion, and electrical properties including electrophoresis and electro-osmosis. These features are governed by particle size, surface charge, and interaction with the dispersion medium, making colloids highly versatile in scientific and industrial contexts. Colloidal systems are classified into sols, gels, emulsions, foams, and aerosols, and further into lyophilic (solvent-loving, stable) and lyophobic (solvent-hating, unstable) types^[1]. Their stability is influenced by adsorption, ion charge, and coagulation phenomena, which are exploited in processes such as water purification, pharmaceutical suspensions, and food emulsions. In pharmaceuticals, colloids play a critical role in drug delivery systems, diagnostic assays, and controlled release formulations. In food science, they explain the stability of products like milk, butter, and ice cream. Industrially, colloids are essential in paints, detergents, rubber processing, and nanomaterials. With the advent of nanotechnology, colloids are increasingly applied in biosensors, targeted therapeutics, and environmental remediation. This review consolidates the fundamental properties and classifications of colloids, highlighting their scientific principles, practical applications, and future potential in diverse fields such as medicine, food technology, and nanoscience.

Key words: Colloids, Tyndall effect, Brownian motion, electrophoresis, emulsions, lyophilic, lyophobic, nanotechnology, pharmaceutical applications.

History and Introduction of Colloids

The study of colloids has a long and fascinating history. The term “colloid” was first introduced by Thomas Graham in 1861, who classified substances into *crystalloids* (like salt and sugar, which diffuse rapidly) and *colloids* (like glue and starch, which diffuse slowly)^[2]. Graham’s pioneering work established colloid chemistry as a distinct branch of science. Later, Michael Faraday’s experiments on colloidal gold sols revealed their striking optical properties, such as intense colors that varied with particle size. This discovery demonstrated that colloids could behave very differently from bulk matter, foreshadowing the principles of nanoscience. In the early 20th century, Richard Zsigmondy (Nobel Prize, 1925) used ultramicroscopy to directly observe colloidal particles, proving their existence and measuring their size. Theoretical advances followed: Albert Einstein (1905) explained Brownian motion, showing how random particle movement stabilizes colloids, while the DLVO theory (Derjaguin–Landau–Verwey–Overbeek, 1940s) described colloidal stability in terms of electrostatic repulsion and van der Waals attraction. These contributions provided the scientific framework for understanding colloidal systems. Today, colloid science has merged with nanotechnology and biotechnology, with colloidal nanoparticles (gold, silver, silica) applied in drug delivery,

biosensors, imaging, and environmental remediation)^[3]. Thus, colloid chemistry has evolved from Graham's glue experiments to a cornerstone of modern nanoscience and advanced materials research. Colloids are heterogeneous systems in which particles ranging from 1–1000 nm are dispersed in a continuous medium. Their intermediate nature between true solutions and suspensions gives rise to unique properties:

- Optical (Tyndall effect, color variations),
- Kinetic (Brownian motion, diffusion),
- Electrical (electrophoresis, electro-osmosis),
- Adsorption and Coagulation phenomena.

These properties make colloids stable and versatile, bridging physical chemistry, biology, and materials science. Everyday examples include milk, blood, fog, paints, rubber latex, and gels. Pharmaceutical science relies heavily on colloids: emulsions for drug delivery, suspensions for pediatric formulations, and colloidal gold nanoparticles in diagnostics. In food science, colloids explain the stability of milk, butter, and ice cream, while in industry they are crucial for paints, detergents, rubber processing, and wastewater treatment. Biological colloids such as blood plasma and cytoplasm are essential for life, highlighting their fundamental role in physiology. With the advent of nanotechnology, colloids are increasingly applied in targeted therapeutics, biosensors, smart materials, and environmental remediation. Their ability to combine stability, reactivity, and versatility makes colloids a cornerstone of both classical chemistry and cutting-edge scientific innovation)^[4].

Properties of Colloids

Colloids are heterogeneous systems with particle sizes between 1–1000 nm, dispersed in a continuous medium. Their intermediate nature between true solutions and suspensions gives rise to distinctive properties. These properties are grouped into optical, kinetic, electrical, adsorption, coagulation, colligative, mechanical, and biological categories)^[5].

1. Optical Properties

- **Tyndall Effect:** Scattering of light by colloidal particles makes the path of light visible.
 - *Mechanism:* Colloidal particles scatter light due to their size being comparable to the wavelength of visible light.
 - *Examples:* Headlights in fog, blue color of the sky, gold sol showing red/purple color.
 - *Applications:* Used to distinguish colloids from true solutions, applied in nephelometry for protein estimation.
- **Color of Colloids:** Depends on particle size, shape, and dispersion medium.
 - *Example:* Gold sol appears red when particles are small, purple or blue when larger.

2. Kinetic Properties

- **Brownian Motion:** Random zig-zag movement due to collisions with solvent molecules.
 - *Mechanism:* Prevents sedimentation, stabilizes colloids)^[6].
 - *Example:* Smoke particles under microscope.

- **Diffusion:** Colloidal particles diffuse slowly compared to true solutions.
 - *Application:* Important in dialysis, drug release, and nutrient transport in biological colloids.
- **Sedimentation:** Colloids resist settling due to Brownian motion and small particle size.

3. Electrical Properties

- **Charge on Particles:** Arises from ion adsorption or dissociation. Responsible for stability.
 - *Example:* Arsenic sulfide sol carries negative charge.
- **Electrophoresis:** Movement of charged colloidal particles under an electric field.
 - *Application:* Protein separation, DNA analysis, medical diagnostics.
- **Electro-osmosis:** Movement of dispersion medium under electric field while particles remain stationary.
- **Cataphoresis:** Migration of colloidal particles toward electrodes.

4. Adsorption Properties

- Colloidal particles adsorb ions or molecules on their surface).
 - *Mechanism:* Stabilizes colloids, influences reactivity.
 - *Examples:* Charcoal adsorbing dyes, colloidal gold adsorbing proteins.
 - *Applications:* Purification of water, decolorization of sugar, drug delivery.

5. Coagulation & Flocculation

- **Coagulation:** Neutralization of particle charge by electrolytes → aggregation.
- **Hardy–Schulze Rule:** Coagulating power $\propto$ ion valency ($\text{Al}^{3+} > \text{Ca}^{2+} > \text{Na}^{+}$).
- *Applications:*
 - Water purification (alum coagulates impurities) ^[7].
 - Wastewater treatment.
 - Latex coagulation in rubber industry.

6. Colligative Properties

- Colloids exhibit osmotic pressure, but depression of freezing point and elevation of boiling point are negligible due to large particle size.
- *Application:* Osmotic pressure measurement used to determine molecular weight of macromolecules and polymers.

7. Mechanical Properties

- Colloids can form gels with elasticity and rigidity.
- *Examples:* Gelatin gel, agar gel, cheese.
- *Applications:* Food industry (jelly, cheese), pharmaceuticals (gel bases, ointments).

8. Stability of Colloids

- Stability arises from Brownian motion, charge repulsion, and solvation.
- Destabilization occurs by coagulation, heating, or addition of electrolytes.
- *Applications:* Controlled destabilization in industrial processes (e.g., latex coagulation in rubber industry).

9. Biological Properties

- Many biological fluids (blood plasma, cytoplasm) are colloidal in nature.
- Colloidal properties explain nutrient transport, enzyme activity, and drug dispersion in the body.
- *Examples:* Plasma proteins maintain osmotic balance; cytoplasmic colloids aid in intracellular transport

10. Special Properties

- **Protective Colloids:** Lyophilic colloids stabilize lyophobic colloids.
 - *Example:* Gelatin protects gold sol from coagulation.
- **Peptization:** Breaking down precipitates into colloidal particles by adding suitable ions.
 - *Example:* Ferric hydroxide precipitate converted into sol by Fe^{3+} ions^[8].

Applications of Colloids^{[9][10]}

Colloids are not only of theoretical interest but also of immense practical importance. Their unique properties — optical, electrical, adsorption, and stability — make them indispensable in pharmaceuticals, food, medicine, industry, and environmental science.

1. Pharmaceutical Applications

- **Drug Delivery Systems:** Colloidal carriers such as liposomes, nanoparticles, and micelles improve solubility, bioavailability, and targeted delivery.
- **Suspensions and Emulsions:** Pediatric formulations, topical creams, and injectable emulsions rely on colloidal stability.
- **Diagnostic Tools:** Colloidal gold and latex particles are used in immunoassays (e.g., pregnancy test kits).
- **Controlled Release:** Hydrogels and colloidal matrices allow sustained drug release.

2. Food Industry Applications

- **Emulsions:** Milk, butter, mayonnaise, and ice cream are stabilized colloidal systems.
- **Foams:** Whipped cream, bread dough, and aerated chocolates depend on colloidal foams.
- **Gels:** Jelly, cheese, and yogurt are colloidal gels with controlled texture.
- **Stabilization:** Colloids prevent separation of oil and water phases in food products.

3. Industrial Applications

- **Paints and Dyes:** Colloidal dispersions provide uniform color and stability.
- **Rubber Industry:** Latex coagulation is a colloidal process.
- **Detergents and Soaps:** Micelles (colloidal aggregates) trap dirt and oil, aiding cleaning.
- **Cement and Construction:** Colloidal silica improves strength and durability.
- **Cosmetics:** Creams, lotions, and sunscreens are colloidal emulsions.

4. Medical and Biological Applications

- **Blood Plasma:** A natural colloid maintaining osmotic balance.
- **Diagnostic Imaging:** Colloidal contrast agents used in X-ray and MRI.
- **Protein Separation:** Electrophoresis of colloidal proteins in labs.
- **Drug Formulations:** Colloidal silver and gold nanoparticles used for antimicrobial and therapeutic purposes.

5. Environmental Applications

- **Water Purification:** Alum coagulates colloidal impurities in water.
- **Wastewater Treatment:** Coagulation and flocculation remove suspended colloids.
- **Air Pollution Control:** Aerosol studies help understand smog and particulate matter.
- **Soil Science:** Clay colloids influence fertility and water retention.

6. Nanotechnology Applications

- **Nanoparticles:** Colloidal gold and silver used in biosensors, cancer therapy, and drug targeting.
- **Smart Materials:** Colloidal gels and suspensions form responsive materials.
- **Electronics:** Colloidal quantum dots used in solar cells and LED displays.

7. Miscellaneous Applications

- **Photography:** Silver bromide colloids in photographic films.
- **Ink and Printing:** Colloidal dispersions provide smooth printing quality.
- **Agriculture:** Pesticide formulations often use colloidal suspensions for better spread.
- **Household Products:** Toothpaste, shaving foam, and deodorant sprays are colloidal systems.

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