## Lecture 11 “Properties and behavior of colloidal systems and nanoparticles”

**Goal of the lecture:** To study the formation, properties, and stability of colloidal systems and nanoparticles, understand their similarities and differences, and explore how surface phenomena, particle size, and interfacial effects determine their physical and chemical behavior in various scientific and industrial applications.

**Brief lecture notes : Colloidal systems** are mixtures in which one substance (the dispersed phase) is finely divided and distributed throughout another substance (the dispersion medium). The size of colloidal particles lies between **1 and 1000 nanometers**, which is intermediate between true solutions and suspensions. Colloids play an essential role in nature and technology — examples include **milk, fog, paints, rubber latex, and gels**. In recent decades, materials with particle sizes below 100 nm are also called **nanoparticles**, which exhibit unique physical and chemical properties due to their extremely small size and large surface area.

### 1. Classification of Colloidal Systems

Colloids can be classified according to:

- **Nature of the dispersed phase and medium** (e.g., solid in liquid, gas in liquid, liquid in gas).
- **Type of interaction** between particles and medium.

| Type of Colloid | Dispersed Phase | Dispersion Medium | Example |
|---|---|---|---|
| Sol | Solid | Liquid | Paints, gold sol |
| Gel | Liquid | Solid | Jelly, cheese |
| Aerosol | Liquid or solid | Gas | Fog, smoke |
| Foam | Gas | Liquid | Soap foam, whipped cream |
| Emulsion | Liquid | Liquid | Milk, mayonnaise |

### 2. Properties of Colloidal Systems

Colloidal particles are small enough to remain suspended for long periods but large enough to scatter light and be affected by surface forces. Their main properties include:

- **Tyndall effect:** Scattering of light by colloidal particles, making the path of light visible (e.g., sunlight through fog).
- **Brownian motion:** Continuous random movement of colloidal particles caused by collisions with molecules of the dispersion medium. This motion prevents particles from settling under gravity.
- **Adsorption:** Colloidal particles have a large surface area, allowing adsorption of ions or molecules, which stabilizes the system.
- **Charge on particles:** Colloids usually carry an electric charge that keeps them from aggregating. The **electrical double layer** formed around particles provides stability.
- **Coagulation (precipitation):** The process by which colloidal particles lose their charge and aggregate into larger particles, often caused by adding electrolytes.

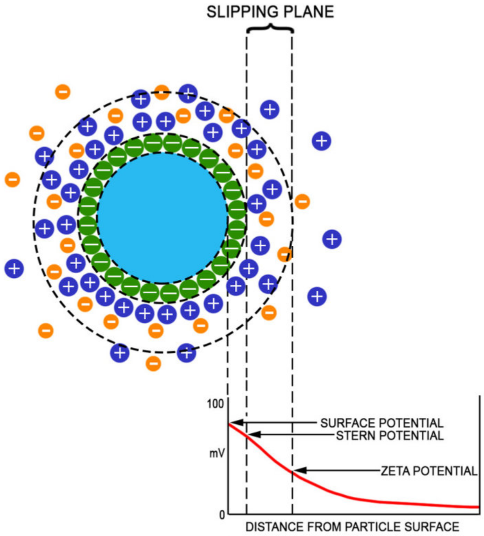


**Figure 1 – The electrical double layer at the surface of a colloidal particle**

The fixed layer of ions adsorbed on the particle and the diffuse layer of opposite ions in the medium together form the **electric double layer**, which is responsible for colloidal stability.

### 3. Preparation of Colloids

Colloids can be prepared by two general methods:

1. **Dispersion methods** – breaking down larger particles into colloidal size (e.g., by grinding, ultrasonic vibration, or electric arc).
2. **Condensation methods** – aggregating smaller molecules to form colloidal particles (e.g., by reduction, oxidation, or hydrolysis reactions).

**Example:** Preparation of gold sol by reduction:

$$2AuCl_3 + 3HCHO + 3H_2O \rightarrow 2Au + 3HCOOH + 6HCl$$

### 4. Behavior of Colloids in Electric Fields – Electrophoresis

When an electric potential is applied to a colloidal solution, charged particles move toward the oppositely charged electrode — this process is called **electrophoresis**. It is used to determine particle charge and separate components (as in biochemical systems and DNA gel electrophoresis).

The **electrokinetic potential (ζ-potential)** is a measure of particle stability. A high ζ-potential prevents aggregation, while a low ζ-potential promotes coagulation.

### 5. Nanoparticles and Their Properties

**Nanoparticles** are materials with dimensions between **1 and 100 nanometers**. They represent a special case of colloidal systems with exceptional surface and quantum effects. Due to their small size, nanoparticles show properties different from bulk materials, such as:

- Enhanced **surface reactivity** and **adsorption capacity**.
- **Optical effects** (surface plasmon resonance in metallic nanoparticles).
- **Magnetic properties** (superparamagnetism in $Fe_3O_4$ nanoparticles).
- **Catalytic activity** due to large surface area-to-volume ratio.

**Nanoparticles can be** metallic (Au, Ag, Fe)**,** oxide-based ($TiO_2$, ZnO)**,** carbon-based (graphene, fullerenes)**, or** polymeric**.**

Their synthesis methods include **sol–gel processes**, **chemical reduction**, **precipitation**, **CVD (chemical vapor deposition)**, and **electrochemical synthesis**.

**6. Applications of Colloids and Nanoparticles**

| Field | Application |
|---|---|
| Medicine | Drug delivery systems, diagnostic imaging, cancer therapy (gold nanoparticles) |
| Industry | Paints, inks, cosmetics, food emulsions |
| Environmental science | Water purification, adsorption of pollutants |
| Catalysis | Nanoparticle catalysts in fuel cells and chemical synthesis |
| Energy | Solar cells, hydrogen storage, supercapacitors |

**7. Stability and Coagulation**

Colloidal stability depends on the balance between **repulsive electrostatic forces** and **attractive van der Waals forces**.
Addition of electrolytes compresses the double layer, reducing repulsion and causing coagulation.
The minimum concentration of electrolyte required to cause coagulation is called the **flocculation value**.

For example, $\mathbf{Na^+}$, $\mathbf{Ca^{2+}}$, and $\mathbf{Al^{3+}}$ ions have increasing coagulating power, following the **Schulze–Hardy rule**:

$$Coagulating\ power\ \propto (valency)^6$$

**8. Relationship Between Colloids and Nanomaterials**

Colloids are precursors to many nanomaterials. Controlled aggregation of colloidal particles or growth of nuclei in solution leads to nanoparticles with defined size and shape. Thus, colloid chemistry forms the **foundation of nanotechnology**, which manipulates materials at the atomic and molecular level to create advanced functional systems.

**Table 1 – Comparison of Colloidal Systems and Nanoparticles**

| Property | Colloidal Systems | Nanoparticles |
|---|---|---|
| Particle size | 1–1000 nm | 1–100 nm |
| Stability | Stabilized by surface charge | Stabilized by surfactants or capping agents |

| | | |
|---|---|---|
| Optical properties | Show Tyndall effect | Exhibit quantum and plasmonic effects |
| Motion | Brownian motion | Quantum and surface effects dominate |
| Applications | Paints, food, gels | Catalysis, medicine, electronics |

**Questions for self-control**

1. What are colloidal systems, and how do they differ from true solutions?
2. Explain the Tyndall effect and Brownian motion in colloids.
3. What is the electric double layer, and how does it provide stability to colloids?
4. Write the chemical equation for the preparation of gold sol by reduction.
5. How do nanoparticles differ from bulk materials in their physical properties and applications?

**Literature:**


1. Atkins, P., de Paula, J. *Atkins' Physical Chemistry*, 11th Edition, Oxford University Press, 2018.
2. Moran, M.J. *Fundamentals of Engineering Thermodynamics*, 9th Edition, Wiley, p.156.
3. House, J.E. *Fundamentals of Quantum Chemistry*, 2nd Edition, Academic Press, 2004.
4. Hammes-Schiffer, S. et al. *Physical Chemistry for the Biological Sciences*, University Science Books, 2009.
5. Zhdanov, V.P. *Elementary Physicochemical Processes on Solid Surfaces*, Springer, 1991.