



Lecture 5

Colloidal Dispersions

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Overview

Dispersed Systems

Classification

Colloidal Systems

Properties of Colloids

Optical Properties

Kinetic Properties

Electrical Properties

Pharmaceutical Applications

Learning Objectives

1. Differentiate between different types of colloidal systems and their main characteristics.
2. Understand the main optical properties of colloids and applications of these properties for the analysis of colloids.
3. Appreciate the major kinetic properties of colloids.
4. Understand the main electrical properties of colloids and their application for the stability of colloids.
5. Understand the benefits of modern colloidal drug delivery systems.



Dispersed Systems

Classification

Colloidal Systems

Classification

Dispersed systems consist of a *dispersed phase* distributed throughout a *continuous or dispersion medium*.

Based on the size of the dispersed phase, three types of dispersed systems are generally considered:

- (a) *molecular* dispersions
- (b) *colloidal* dispersions
- (c) *coarse* dispersions

Molecular dispersions are homogeneous in character and form true solutions. Colloidal and coarse dispersions are examples of heterogeneous systems.



Classification

Class	Particle size	Characteristic of system	Examples
Molecular dispersion	< 1 nm	Invisible in electron microscope Pass through semipermeable membrane Undergo rapid diffusion	Oxygen molecules and glucose
Colloidal dispersion	1–500 nm	Invisible by ordinary microscope Visible in electron microscope Pass through filter paper Do not pass semipermeable membrane Diffuse very slowly	Colloidal silver sols, natural and synthetic polymers
Coarse dispersion	> 500 nm	Visible under microscope Do not pass through normal filter paper Do not pass semipermeable membrane Do not diffuse	RBCs, most Pharmaceutical suspensions and emulsions



Colloidal Systems

All kinds of dispersed phases might form colloids in all possible kinds of media, except for a gas–gas combination. Because all gases mix uniformly at the molecular level, gases only form solutions with each other.



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Colloidal Systems Classification

Dispersed Phase	Dispersion Medium	Colloid Type	Examples
Solid	Solid	Solid sol	Pearls, opals
Liquid	Solid	Solid emulsion	Cheese, butter
Gas	Solid	Solid foam	Pumice, marshmallow, sponge
Solid	Liquid	Sol, gel	Jelly, paint, blood
Liquid	Liquid	Emulsion	Milk, mayonnaise
Gas	Liquid	Foam	Whipped cream, shaving cream
Solid	Gas	Solid aerosol	Smoke, dust
Liquid	Gas	Liquid aerosols	Clouds, fog
Gas	Gas	---	None (A gas in a gas always produces a solution)

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Colloidal Systems

Classification

Colloidal systems are best classified into three groups on the basis of the interaction of the dispersed phase with the dispersion medium.

1. *Lyophilic* colloids
2. *Lyophobic* colloids
3. *Amphiphilic* colloids



Colloidal Systems

Classification

Lyophilic (Solvent-loving) Colloids

Systems containing colloidal particles that readily interact with the dispersion medium

Due to their affinity for the dispersion medium, such materials can easily form colloidal dispersions; simply by dissolving the material in the solvent being used.

Most lyophilic colloids are organic molecules, for example, gelatin, acacia, insulin, albumin, rubber, and polystyrene.



Colloidal Systems

Classification

Lyophobic (Solvent-hating) Colloids

Systems composed of materials that have little attraction, if any, for the dispersion medium

It is necessary to use special methods to prepare lyophobic colloids.

They are generally composed of inorganic particles dispersed in water. Examples of such materials are gold, silver, sulfur, arsenous sulfide, and silver iodide.



Colloidal Systems

Classification

Amphiphilic Colloids

Systems composed of *amphiphiles* or *surface-active agents*, that are characterized by having two distinct regions of opposing solution affinities within the same molecule or ion.

When present in a liquid medium at low concentrations (below the CMC), the amphiphiles exist separately and are of subcolloidal size

As the concentration is increased (above the CMC), micelles are formed which may contain 50 or more monomers, the diameter of each micelle is of 5 nm (colloidal size).

The formation of amphiphilic colloids is spontaneous, if the concentration of the amphiphile exceeds the CMC.





Properties of Colloids

Optical Properties

Kinetic Properties

Electrical Properties

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Optical Properties Faraday–Tyndall Effect

When a strong beam of light is passed through a colloidal sol, a visible cone, resulting from the scattering of light by the colloidal particles, is formed. This is the *Faraday–Tyndall effect*.

Non-
colloidal
solution



Colloidal
solution



Optical Properties

Faraday–Tyndall Effect



Optical Properties

Light Scattering

This property depends on the Faraday–Tyndall effect and is used for determining the molecular weight of colloids, in addition to the shape and size of these particles.

Scattering can be described in terms of the turbidity, τ , which is the intensity of light scattered I_s , divided by the intensity of the incident light, I .

At a given concentration of dispersed phase, the turbidity is proportional to the molecular weight of the colloid, which can be obtained from the following equation:

$$\frac{Hc}{\tau} = \frac{1}{M} + 2Bc$$

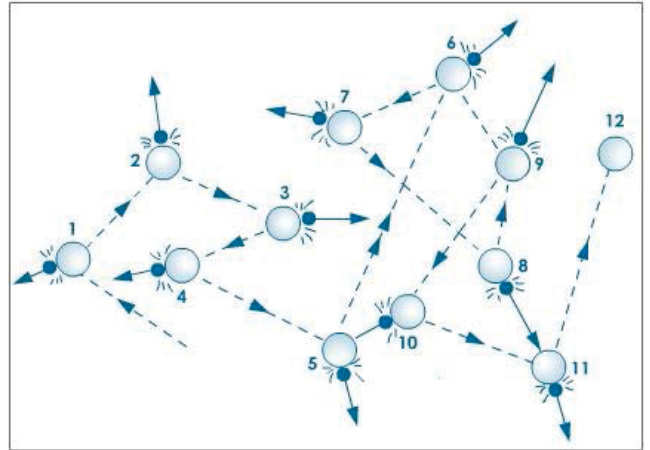
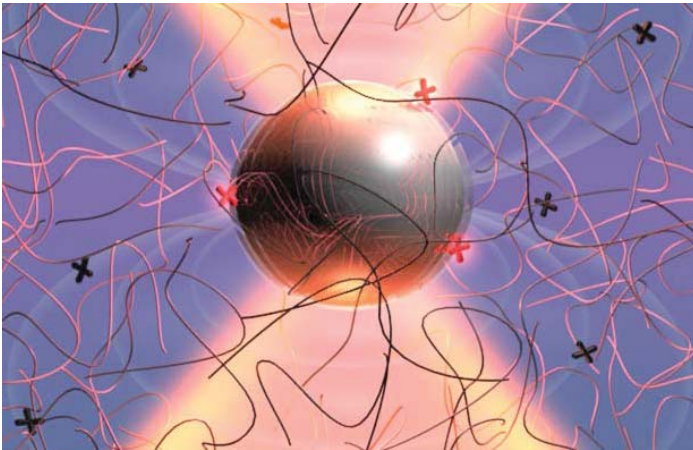
H = optical constant; c = concentration of the solute; M = molecular weight;
 τ = turbidity; B = interaction constant



Kinetic Properties

Brownian Motion

Brownian motion is the erratic motion that results from the uneven collision of the particles by the invisible molecules of the dispersion medium. It is observed with particles as large as about $5\text{ }\mu\text{m}$,



Kinetic Properties

Diffusion

Particles diffuse spontaneously from a region of higher concentration to one of lower concentration until the concentration of the system is uniform.

Diffusion is a direct result of Brownian movement.



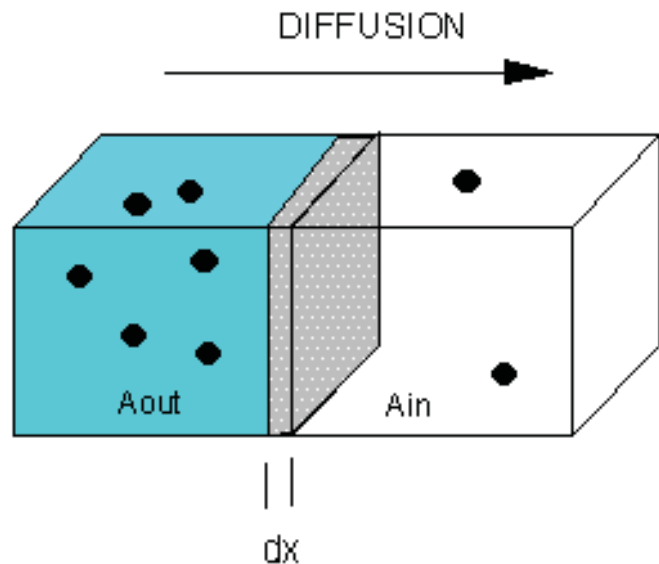
Kinetic Properties

Diffusion

According to *Fick's first law*, the amount of substance diffusing per unit time (*flux*, J), across a plane of area, S , is directly proportional to the change in concentration, dc , with distance traveled, dx :

$$J = -DS \frac{dc}{dx}$$

D = diffusion coefficient



Kinetic Properties

Diffusion

Assuming particles are spherical, diffusion coefficient can be used in *Stokes-Einstein* equation to obtain the radius of the particle :

$$D = \frac{RT}{6\pi\eta rN}$$

R = molar gas constant; T = absolute temperature;
 η = viscosity of the solvent; r = radius of the spherical particle; N = Avogadro's number.

Diffusion coefficient can also be used to obtain the molecular weight of approximately spherical molecules, such as egg albumin and hemoglobin, by use of the equation:

$$D = \frac{RT}{6\pi\eta N} \sqrt[3]{\frac{4\pi N}{3M\bar{v}}}$$

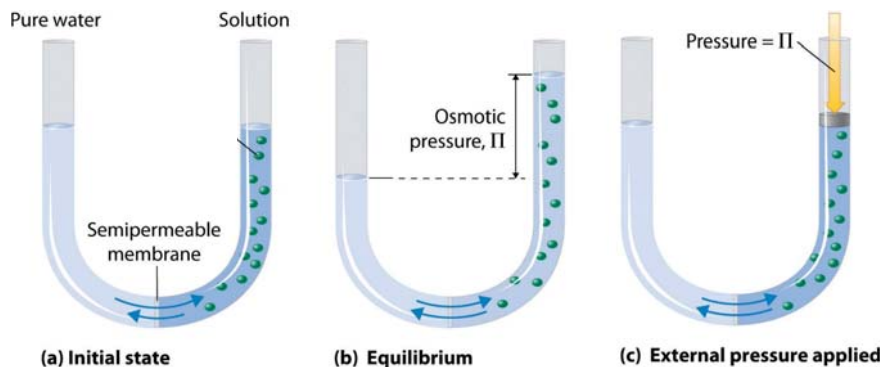
\bar{v} = partial specific volume
(volume of 1 g of the solute)



Kinetic Properties

Osmotic Pressure

The pressure necessary to balance the osmotic flow.



The osmotic pressure π can be used to obtain the molecular weight using a modified van't Hoff equation:

$$\frac{\pi}{c_g} = RT \left(\frac{1}{M} + Bc_g \right)$$

c_g = concentration of solute (g/L);
 B = a constant for any particular solvent/solute system



Kinetic Properties

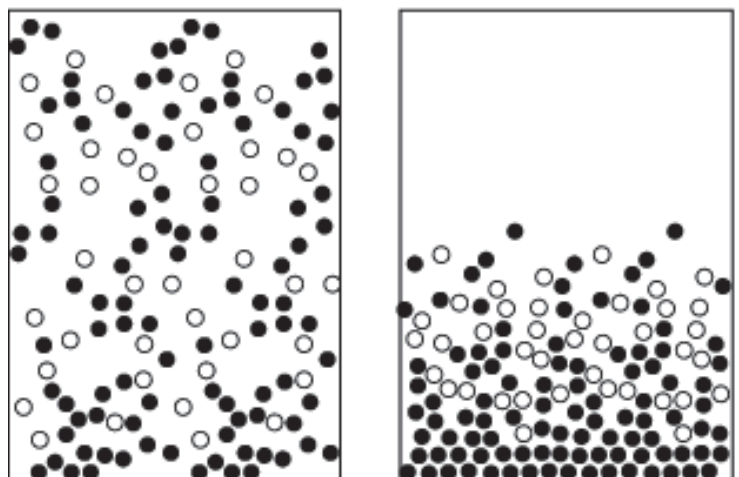
Sedimentation

The velocity of sedimentation (v) of spherical particles having a density (ρ) in a medium of density (ρ_0) and a viscosity (η_0) is given by Stokes's law:

$$v = \frac{r^2 (p - p_0)g}{18 \eta_0}$$

g = acceleration due to gravity
 r = radius of particles

The equation is used to determine particle size larger than $0.5 \mu\text{m}$



Kinetic Properties

Sedimentation

Particles lower than 0.5 μm in size don't obey Stokes's equation because brownian movement becomes significant and tends to offset gravity sedimentation.

Stronger force (ultracentrifugation) must be applied to generate the sedimentation of colloidal particles in a measurable manner.

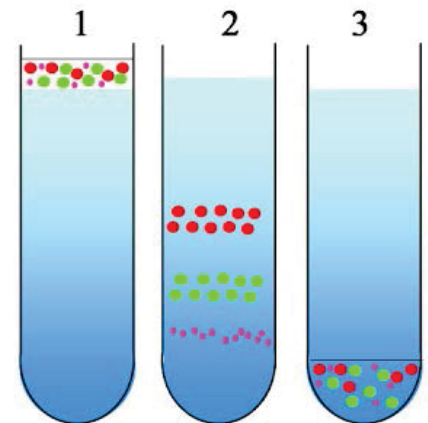
Stokes's equation is modified to:

$$v = \frac{r^2 (p - p_0) \omega^2 x}{18 \eta_0}$$

Where gravity g is replaced by $\omega^2 x$

ω = angular velocity

x = distance of particles from the center of rotation



Kinetic Properties

Viscosity

Viscosity is the resistance of a system to flow under an applied stress. The more viscous a liquid is, the greater is the applied force required to make it flow at a particular rate.

Einstein developed an equation of flow applicable to dilute colloidal dispersions of spherical particles, namely,

$$\eta = \eta_0 (1 + 2.5\phi)$$

η_0 = viscosity of the dispersion medium

η = intrinsic viscosity of the dispersion when the volume fraction of colloidal particles present is ϕ .



Kinetic Properties

Viscosity

Several viscosity coefficients can be defined with respect to this equation. These include *intrinsic viscosity* (η), *relative viscosity* (η_{rel}), and *specific viscosity* (η_{sp}).

$$\eta_{rel} = \frac{\eta}{\eta_0} = 1 + 2.5\phi$$

$$\eta_{sp} = \frac{\eta - \eta_0}{\eta_0} = 2.5\phi$$

Viscosity can be used to obtain the molecular weight (M) of material forming the dispersed phase according to *Mark-Houwink equation*:

$$\eta = KM^a$$

K & a = constants for each particular dispersion



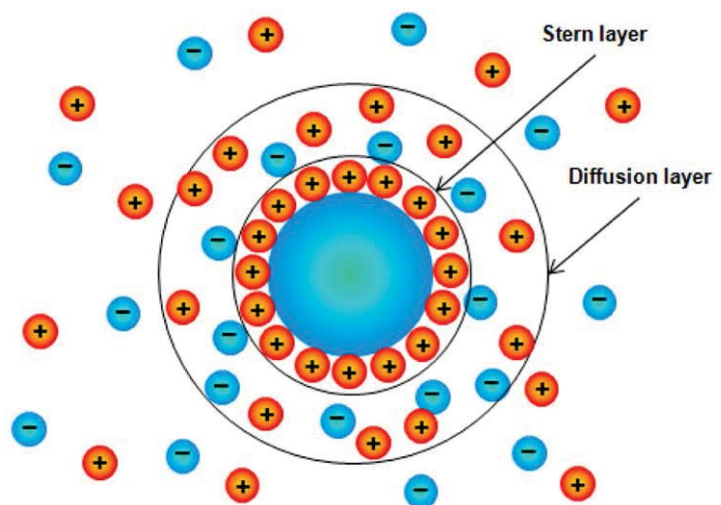
Electrical Properties

Electric Double Layer

Particles dispersed in liquid may become charged as a result of:

Adsorption of a particular ionic species present in solution.

Ionization of groups (such as COOH) that may be situated at the surface of the particle. In this case, the charge depends on pK and pH .



As a result, dispersed solid particles usually are surrounded by a double layer of electric charge made of ions.



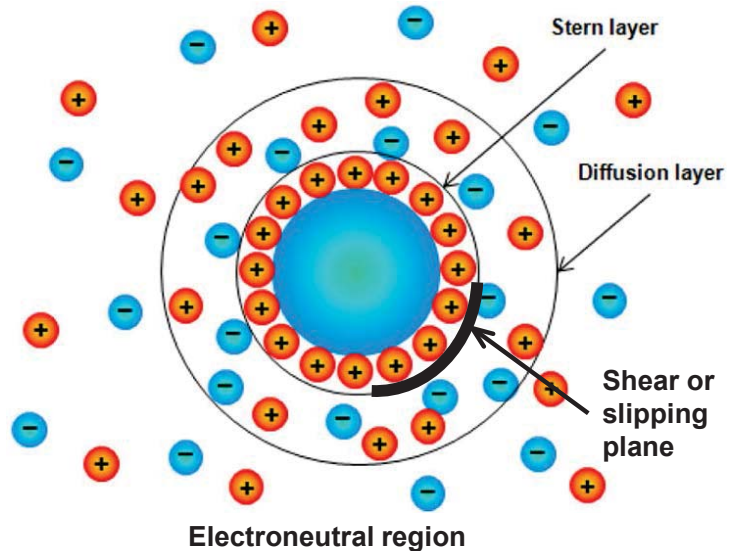
Electrical Properties

Electric Double Layer

The electric double layer consists of Layer of ions bounded firmly to the surface called *Stern layer*, surrounded by oppositely charged ions that form a loose *diffuse layer* in the adjacent liquid phase.

The surface separating the two layers is called (*shear or slipping plane*).

The region outside the double layer with equal distribution of anions and cations is called *electroneutral region*.



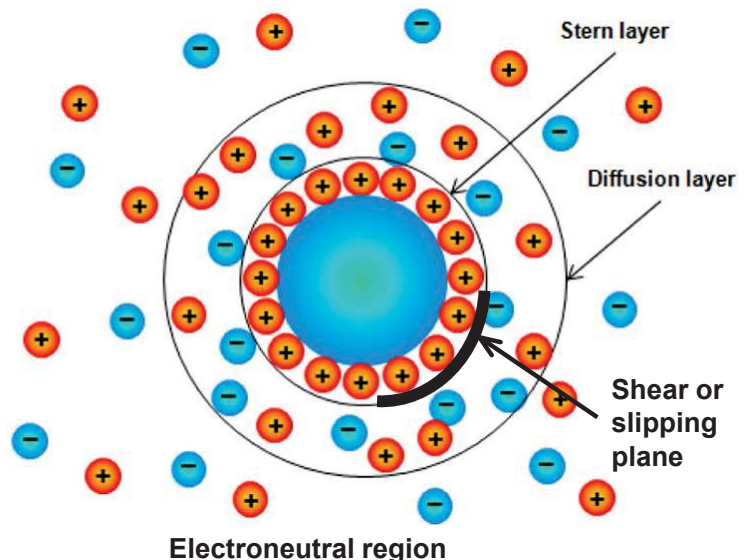
Electrical Properties

Nernst and Zeta Potentials

The *electrothermodynamic* (**Nernst**) potential (E) is the difference in potential between the actual surface and the electroneutral region of the solution.

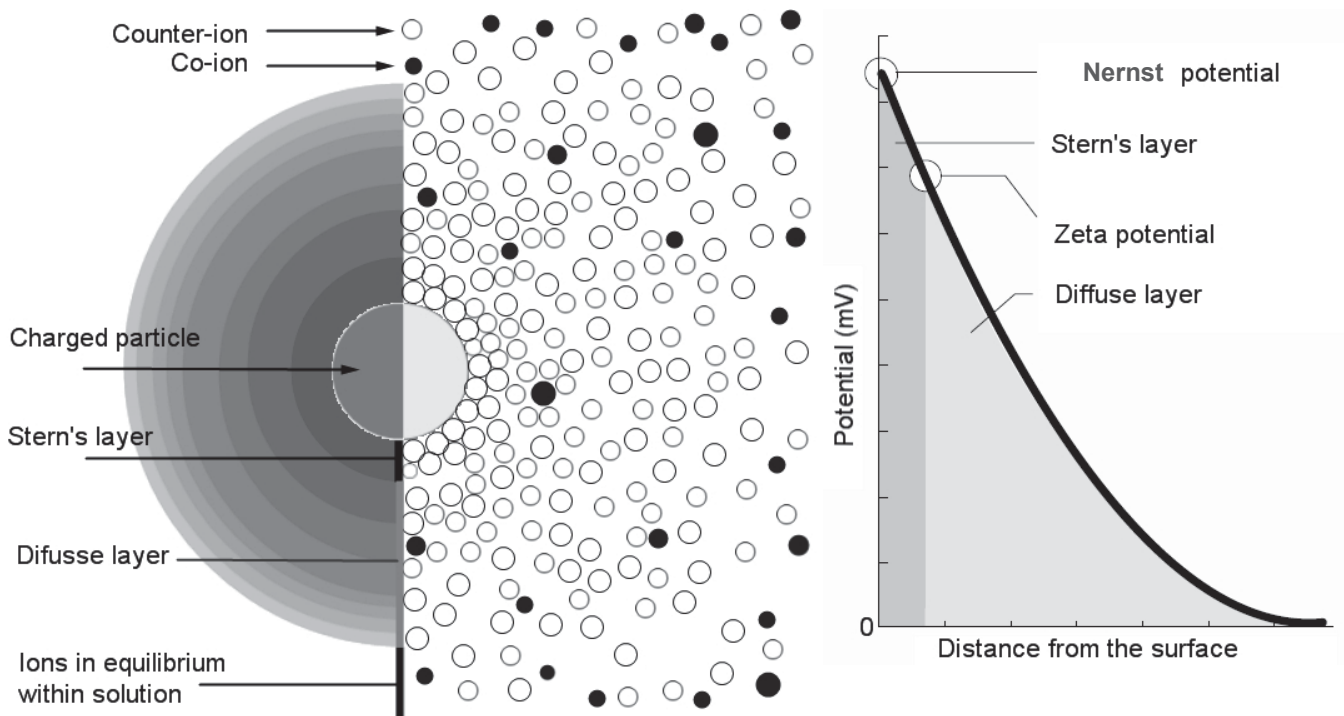
The *electrokinetic* (**zeta**) potential (ζ) is the difference in potential between the surface of the stern layer and the electroneutral region of the solution.

The zeta potential is measured to monitor and predict the stability of dispersion systems



Electrical Properties

Nernst and Zeta Potentials



Electrical Properties

Electrokinetic Phenomena

The movement of a charged surface in a liquid phase is the basic principle for four electrokinetic phenomena:

1. *Electrophoresis*
2. *Electroosmosis*
3. *Sedimentation potential*
4. *Streaming potential*

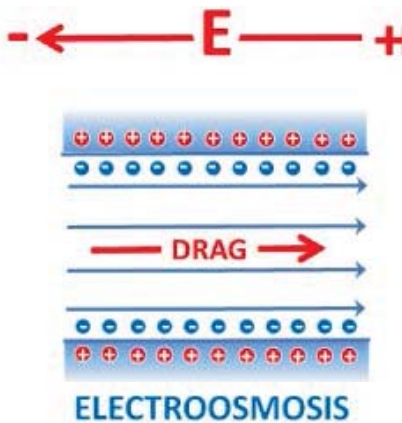
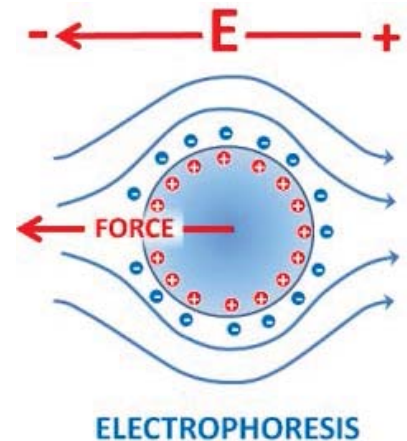
Electrokinetic phenomena can be used to obtain zeta potential.



Electrical Properties

Electrokinetic Phenomena

1. *Electrophoresis* involves the movement of a charged particle through a liquid under the influence of an applied potential difference to an oppositely charged electrode.



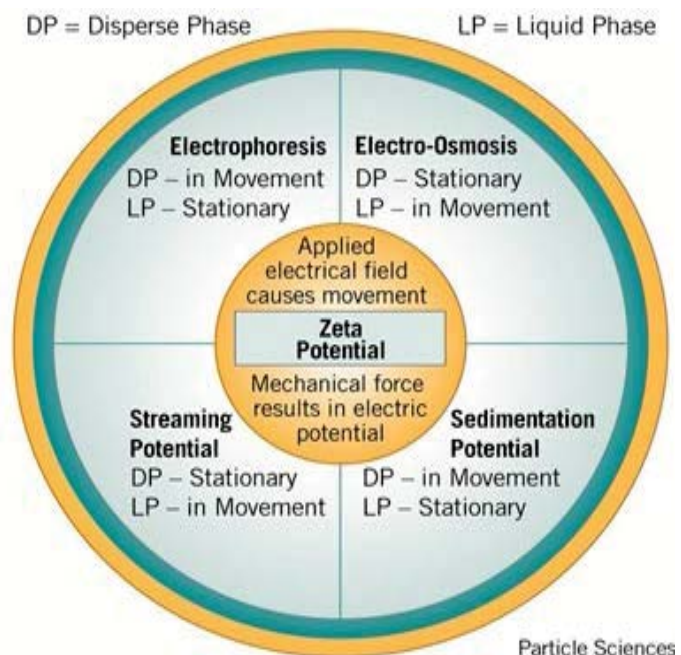
2. *Electroosmosis* involves the movement of a liquid through a porous plug containing immobilized charged particles under the influence of an applied potential difference.



Electrical Properties

Electrokinetic Phenomena

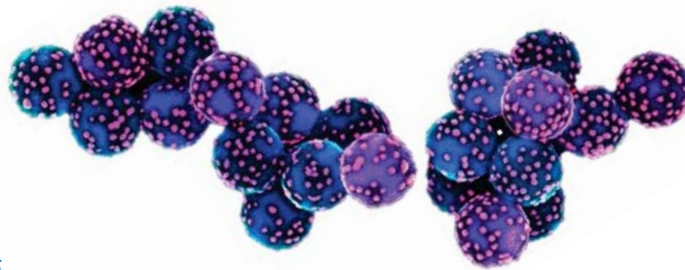
3. *Sedimentation potential*, the reverse of electrophoresis, is the creation of a potential when particles undergo sedimentation.
4. *Streaming potential* differs from electroosmosis in that forcing a liquid to flow through a plug or bed of particles creates the potential.



Pharmaceutical Applications

Colloidal dosage forms (e.g. hydrogels, microemulsions, liposomes, micelles, and nanoparticles) have many pharmaceutical benefits:

1. Modifying the properties of pharmaceutical agents, especially the solubility and stability of the drug.
2. Prolonging drug action (Sustained drug delivery systems).
3. Enhancing drug bioavailability and decreasing their side effects (targeted drug delivery systems).



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References

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