UNIT 1

COLLOIDAL DISPERSIONS

1.1 Introduction

A disperse phase system consists essentially of one component. The disperse phase is dispersed as particles or droplets throughout another components the continuous phase.

The word colloid was coined by Graham in 1861 from the Greek word "Rodla" (means glue).

1.1.1 Definition

"The dispersions in which the size of the dispersed particles is within the range of 10^{-9} m (1 nm) to about 10^{-6} m (1μm) are termed as colloids".

However the upper size limit is often extended to include emulsions and suspensions which are very polydispersed systems in which the droplet size frequently exceeds 1μm, but which show many of the properties of colloidal systems. Many natural systems such as suspensions of microorganisms, blood and isolated cells in culture are also colloidal dispersions.

Some examples of colloidal systems of pharmaceutical interest are given in Table 1.1. Based on the size of the dispersed phase, three types of dispersed systems are generally considered. (a) molecular dispersions (b) colloidal dispersions and (c) coarse dispersions. The size range of these classes and their associated characteristics are given in Table 1.2. Colloidal dispersions are more stable usually than coarse dispersions since the larger particles in the latter settle rapidly under the influence of gravity and unlike colloidal systems, the maintenance of their dispersions is not aided by Brownian movement.

Table 1.1 Types of colloidal systems Pharmaceutical Interest

Dispersion medium	Dispersed phase	Colloid type	Examples
Solid	Solid	Solid sol	Pearls, opals
Solid	Liquid	Solid emulsion	Cheese, butter
Solid	Gas	Solid foam	Pumice, marshmallow
Liquid	Solid	Sol. Gel	Jelly, paint
Liquid	Liquid	Emulsion	Milk, mayonnaise
Liquid	Gas	Foam	Shaving cream
Gas	Solid	Solid aerosols	Smoke, dust
Gas	Liquid	Liquid aerosols	Clouds, mist, fog

Table 1.2 Classification of dispersed systems based on particle size

Class	Range of particle size	Characteristics of System	Examples
Molecular dispersion	Less than 1 nm	Invisible in electron microscope. Pass through ultrafilter and semipermeable membrane rapid diffusion	Oxygen molecules, ordinary ions, glucose
Colloidal dispersion	From 1 nm to 0.5 μm	Visible in electron microscope, pass through filter paper but not semipermeable membrane. Diffuse very slowly	Colloidal silver solutions, neutral and synthetic polymer, cheese, butter, jelly, milk etc.
Coarse dispersion	Greater than 0.5 μm	Visible under microscope. Do not pass through filter paper and through semipermeable membrane. Do not diffuse	Grains of sand, RBC, most pharmaceutical emulsions and suspensions

1.2 Classification of Colloids

On the basis of interaction between the particles or macromolecules of the dispersed phase with the molecules of the dispersion medium, colloidal systems are classified into three groups.

1. Lyophilic – solvent "loving" colloidal in which the disperse phase is dissolved in the continuous phase.

2. Lyophobic – solvent "hating" colloids in which the disperse phase is insoluble in the continuous phase and

3. Association colloids in which the dispersed phase molecules are soluble in the continuous phase and spontaneously "self assemble" or "associate" to form aggregates in the colloidal size range.

1.2.1   Lyophilic Colloids

Dissolution of acacia of gelatin in water or celluloid in amyl acetate leads to the formation of a solution. This is an example of this class as the disperse phase is dissolved in the continuous phase. The attachment of solvent molecules to molecules of the dispersed phase is due to attraction between the dispersed phase and the dispersion medium. This is termed as "Hydration" in case of hydrophilic colloids in which water is the dispersion medium. Most lyophilic colloids are organic molecules, for example gelatine, acacia, insulin, albumin, rubber and polystyrene of these first four produce lyophilic colloids in aqueous dispersion media (hydrophilic solution). Rubber and polystyrene forms lyophilic colloids in non-aqueous, organic solvents. These materials are referred to as lipophilic colloids. A material that forms lyophilic colloidal system is one liquid (e.g.: water) may not do so in another liquid (benzene).

1.2.2   Lyophobic Colloids

They differ from lyophilic colloids due to the absence of a solvent sheaths around the particle. Lyophobic colloids are generally composed of inorganic particles dispersed in water. Examples of such materials are gold, silver, sulphur, arsenous sulphide and silver iodide.

The preparative methods for lyophobic colloids may be divided into those methods that involve the breakdown of larger particles into particles of colloidal dimensions (dispersion methods) and these in which the colloidal particles are formed by aggregation of smaller particles such as molecules (condensation methods).

1.3   Dispersion Methods

The breakdown of coarse material may be affected by several means.

Colloid mills: These mills cause the dispersion of coarse materials by shearing in a narrow gap between a static cone and a rapidly rotating cone.

Electrical dispersion (bredig's method): Certain materials may be dispersed by the passage of an electric are between electrodes made of the metal and immersed in the dispersion medium.

Ultrasonic irradiation: The passage of ultrasonic waves through a dispersion medium produces alternating regions of cavitations and compression in the medium. The cavities collages with great force and cause the breakdown of coarse particles dispersed in the liquid.

Peptisation: Because the charges necessary for stabilising colloidal dispersions may originate from the preferential adsorption of specific ions at the surface of the particles, a finely divided solid may be converted into a colloidal dispersion by the addition of such ions to the dispersion medium. This process is known as peptisation.

Condensation methods: These involve the rapid production of supersaturated solutions of the colloidal material under conditions in which it is deposited in the dispersion medium as colloidal particles and not as precipitate. The supersaturation is often obtained by means of a chemical reaction that results in the formation of the colloidal material. For example, colloidal silver iodide may be obtained by reacting together dilute solutions of silver nitrate and potassium iodide; colloidal sulfur is produced from sodium thiosulfate and hydrochloric acid solutions; and ferric chloride boiled with excess of water produces colloidal hydrated ferric oxide.

A change of solvent may also cause the production of colloidal particles by condensation methods. If a saturated solution of sulfur in acetone is poured slowly into hot water, the acetone vaporizes, leaving a colloidal dispersion of sulfur. A similar dispersion may be obtained when a solution of a resin such as benzoin in alcohol is poured into water.

1.4   Purification of Colloids

1.4.1 Dialysis

Colloidal particles are too large to diffuse through the pores of certain membranes such as cellophane. The smaller particles in true solution are able to pass through these membranes. Dialysis method is used to separate micro molecular impurities from colloidal dispersions. The process is known as dialysis.

A colloidal dispersion may become diluted during dialysis because water pass through the membrane under the influence of the osmotic pressure of the colloid. Such dilution may be prevented by applying to the colloid a pressure that is equal to or greater than its osmotic pressure. This procedure is referred to as dialysis under pressure.

1.4.2 Electro Dialysis

An electrical potential may be used to increase the rate of movement of ionic impurities through a dialysing membrane and so provide a more rapid means of purification. This method is of little use if any of the impurities are uncharged and care should be taken to ensure that the electrical potential does not effect the stability of the colloid.

1.4.3   Ultrafiltration

Colloidal particles are too small to be retained by ordinary filter papers. In filtration through dialysing membrane the rate of flow of the liquid dispersion medium is slow so it is carried out under the influence of positive pressure or vacuum. Since the sizes of the colloidal particles and the pores in the membrane are so small the process is referred to as ultrafiltration.

It is possible to manufacture membrane with different droppers of porosity. The use of a series of ultrafilters with gradually decreasing pore size allows the particle size of a colloid to be determined. The pore size of an ultrafilter can be determined by the use of a series of colloidal dispersions of different particle sizes.

1.4.4   Association Colloids

The third type of colloids is association or amphiphilic colloids. Association colloids are aggregates or "associations" of amphipathic surface active molecules. These molecules are soluble in the solvent and their molecular dimensions are below the colloidal size range. When present in solution at concentration above a certain critical value (the CMC), these molecules tend to form association colloids. These aggregate which may contain 50 or more monomers are called micelles. The concentration of monomers at which micelles formed is termed the critical micelle concentration (CMC). The number of monomers that aggregate to form a micelle is known as the aggregation number of the micelle.

The phenomenon of micelle formation can be explained as follows. Below the CMC, the concentration of amphiphiles undergoing adsorption at the air-water interface increases as the air-water increases as the total concentration of amphiphiles is raised. Eventually a point is reached at which both the interface and the bulk phase become saturated with monomers. This is the CMC. Any further amphiphiles added in excess of this concentration aggregates to form micelles in the bulk phase and in this manner the free energy of the system is reduced.

In the case of amphiphiles in water, the hydrocarbon chains face inward into the micelle to form, hydrocarbon core. Surrounding this core are the polar portions of the amphiphiles associated with the water molecules of the continuous phase. Aggregation also occurs in non polar liquids. The orientation of the molecules is now reversed. These situations are shown in Fig. 1.1.

Amiphiphiles may be anionic, cationic, non ionic or ampholytic (Twitter ionic) and this provides a means of classifying association colloids. A typical example of each type is given in Table 3. Thus Fig. 1.1 represents the micelle of an anionic association colloid. A certain number of the sodium ions are attracted to the surface of the micelle reducing the overall negative charge somewhat. These bound ions are called gegenious.
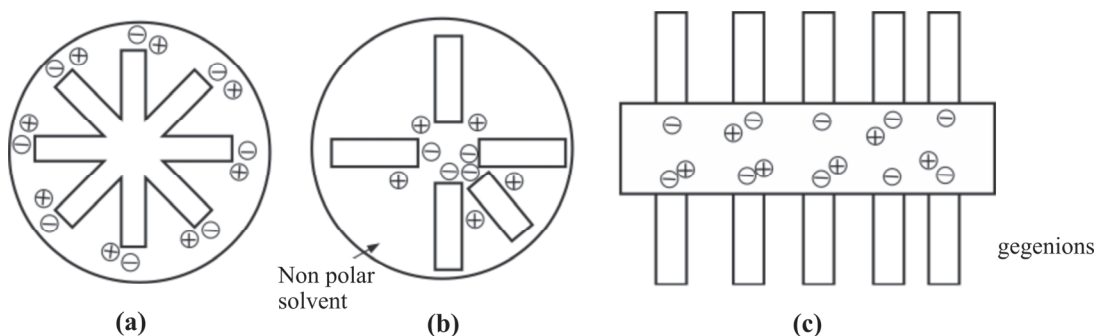

Fig. 1.1 Some probable shapes of micelles

(a) Spherical micelle in aqueous media,
(b) Reversed micelle in non-aqueous media, **(c)** Laminar micelles

Table 1.3 Classification of association colloids

Type	Compound	Amphiphile	Genome
Anionic	Sodium lauryl sulphate	$CH_3(CH_2)_{11}OSO_3$	Na^+
Cationic	Cetyl trimethyl Ammonium bromide	$CH_3(CH_2)_{15}$ $N^+(CH_3)_{13}$	Br^-
Non ionic	Polyoxyethylene lauryl ether	$CH_3 (CH_2)_{10}$ CH_2O $(CH_2OCH_2)_2$ 3H	-
Ampholytic	Dimethyl dodecyl ammonium propane sulfonate	$CH_3 (CH_2)_{11}$ $N^+(CH_3)_2 (CH_2)_3$ OSO_2	-

Mixtures of two or more amphiphiles are common. Assuming an ideal mixture, one can predict the CMC of the mixture from the CMC values of the pure amphiphiles and their mole fractions 'x' in the mixture, according to the equation.

$$\frac{1}{CMC} = \frac{x_1}{CMC_1} + \frac{x_2}{CMC_2}$$

The properties of Lyophilic, Lyophobic and association colloids are given in the Table 1.4.

Table 1.4 Comparison of properties of colloidal solution

Lyophilic	Association (Amphiphilic)	Lyophobic
1. Dispersed phase consists generally of large organic molecules lying within colloidal size range	Dispersed phase consists of aggregates (micelles) of small organic molecules or ions whose size individually is below colloidal range	Dispersed phase ordinarily consists of inorganic particles, such as gold or silver
2. Molecules of dispersed phase are solvated i.e., they are associated with the molecular comprising the dispersion medium	Hydrophilic or lipophilic portion of the molecules is solvated depending on whether the dispersion medium is aqueous or non-aqueous.	Little if an interaction occurs between particles and dispersion medium
3. Molecules disperse spontaneously to form colloidal solution	Colloidal aggregate are formed spontaneously when the concentration of amphiphiles exceeds the critical micelle concentration.	Material does not disperse spontaneously, and special procedures therefore must be adopted to produce colloidal dispersion

Lyophilic	Association (Amphiphilic)	Lyophobic
4. Viscosity of the dispersion medium ordinarily is increased greatly by the presence of the dispersed phase; at sufficiently high concentrations, the solution may become a gel, viscosity and gel formation are related to saturation effects and to the shape of the molecules, which are usually highly asymmetric	Viscosity of the system increases as the concentration of the amphiphiles increases as micelles increase in number and become asymmetric	Viscosity of the dispersion medium is not greatly increased by the presence of lyophilic colloidal particles, which tend to be unsolvated and symmetric
5. Dispersions are stable generally in the presence of electrolyte, they may be salted out by high concentrations of very soluble electrolyte; effect is the primarily to degradation of lyophilic molecules	In aqueous solutions, the critical micelle concentration is reduced by the addition of electrolytes; salting out may occur at higher salt concentrations	Lyophilic dispersions are unstable in the presence of even small concentration of electrolytes; effect is due to neutralization of the charge on the particles; lyophilic colloids exert a protective effect.

1.5   Properties of Colloids

1.5.1 Optical Properties

The Faraday-Tyndall Effect

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

Ultramicroscopy

Colloidal particles are too small to be seen with an optical microscope. Light scattering is employed in the ultramicroscope, first developed by Zsigmondy in which a cell containing the colloid is viewed against a dark background at right angles to an intense beam of incident light. The particles which exhibit Brownian motion, appears as spots of light against the dark background. The ultramicroscope is used in the technique of micro electrophoresis for measuring particle size.

Electron Microscopy

The electron microscope capable of giving actual pictures of the particles is used to observe the size, shape and structures of colloidal particle. The success of electron microscope is due to its high resolving power, defined is terms of d, the smallest distance by which two objects are separated get remain distinguishable. The smaller the wavelength of the radiation used, the smaller is d and the greater the resolving powers.

A microscope using visible light as its radiation source, gives a 'd' of about 0.2 μm. The radiation source of the electron microscope is a beam of high energy electrons having wave lengths in the region of 0.01 nm; 'd' is thus about 0.5 nm. The electron beams are focussed using electro magnet and the whole system is under a high vacuum of about 10^{-3}-10^{-5} Pa to give the electrons a free path.

A major disadvantage of electron microscope for viewing colloidal particles is that normally only dried samples can be examined. Consequently it is usually gives no information on solution or configuration in solution and the particles may be affected by sample preparation. A recent development which overcomes these problems is "Environmental scanning electron microscopy" (ESEM) which allows the observation of material in the wet state.

Light Scattering

When a beam of light is passed through a colloidal solution, some of the light may be absorbed, some is scattered and the remainder transmitted undisturbed through the sample. Due to the light scattered, the solution appears turbid, this is known as the "Tyndall effect". The turbidity of a solution is given by the expression.

$$I = I_0 \exp^{-1\tau}$$

where I_0 = intensity of the incident beam

   I = intensity of transmitted light beam

   l = length of the sample

   τ = the turbidity.

Light scattering measurement is of great value for estimating particle size, shape and interactions, particularly of dissolved macro molecular materials as the turbidity depends on the size (mol. wt) of the colloidal material involved. As most colloids show very low turbidities, instead of measuring the transmitted light it is more convenient and accurate to measure the scattered light at an angle (usually 90°) relative to the incident beam.

The turbidity can be calculated from the intensity of the scattered light, provided the dimensions of the particle are small compared to the wavelength of the incident light by the expression

$$\tau = \frac{16\,\pi}{3}\ R_{90}$$

   R_{90} – Raleigh ratio

The light scattering theory was modified by Debye and derived the following relationship between turbidity and molecular weight.

$$\frac{HC}{\tau} = \frac{1}{M} + 2BC \qquad\qquad ....(1.1)$$

where,

τ = turbidity (cm^{-1})

C = concentration of solute (g/cm^3) of solution

M = weight – average mol.wt in g/mole or Daltons

B = an interaction constant

H = constant for a particular system and is written as

$$H = \frac{32 \, \pi^3 \, n^2 \, (dn \, / \, dc)^2}{3 \, \lambda^4 \, N} \qquad \qquad \text{.....(1.2)}$$

where,

n (dimensionless) = refractive index of the solution

c = concentration (g/cm^3)

λ = wavelength (cm^{-1})

$\dfrac{dn}{dc}$ = change in refractive index with concentration C.

N = Avogadro's number.

A part of HC/τ against concentration is result in a straight line with a scope of 2B. The intercept on the HC/τ axis is 1/M, the reciprocal of which yields the molecular weight of the colloid. The plot is given in Fig. 1.2.
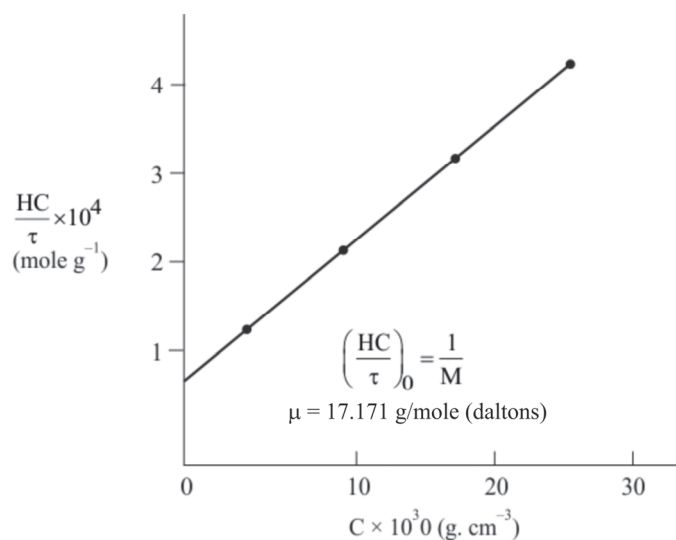

Fig. 1.2 A plot of $\dfrac{HC}{\tau}$ against the concentration of a polymer

Light scattering measurement are particularly suitable for finding the size of the micelles of surface active agents and for the study of proteins and natural and synthetic polymers.

Light Scattering and Micelle Molecular Weight

When amphiphilic molecules associate to form micelles, the turbidity of the micellar dispersion differs from the turbidity of the solution of the amphiphilic molecules because micelles are now also percent in equilibrium with the monomeric species. Below the CMC, the concentration of monomers increases linearly with the total concentration, c; above the CMC, the monomer concentration remains linearly constant; i.e.,

$$C_{monomer} \cong CMC.$$

The concentration of micelles can therefore be written.

$$C_{micelle} = C - C_{monomer} \cong C - C_{CMC} \qquad .....(1.3)$$

The corresponding turbidity of the solution due to the presence of micelles is obtained by subtracting the turbidity due to monomers, $Y_{monomer} = Y_{CMC}$, from the total turbidity of the solution.

$$\tau_{micelle} = \tau - T_{CMC} \qquad .....(1.4)$$

Accordingly, equation 5.1 is modified to

$$\frac{H(C - C_{CMC})}{(\tau - \tau_{CMC})} = \frac{1}{M} + 2B(C - C_{CMC}) \qquad .....(1.5)$$

Subscript CMC indicates the turbidity of concentration at the critical micelle concentration.

B and H are the constants

M = molecular weight of micelle

M and B are obtained from the intercept and the slope respectively of a plot of $\dfrac{H(C - C_{CMC})}{(\tau - \tau_{CMC})}$ verses $(C - C_{CMC})$ in figure.

Equation (1.5) is valid for two component systems, i.e., for a micelle and a molecular surfactant in this instance.

1.5.2 Kinetic Properties of Colloids

In this section several properties of colloidal systems which relate to the motion of particles with respect to the dispersion medium will be considered. Thermal motion manifest itself in the form of Brownian motion diffusion and osmosis. Gravity (or a centrifugal fluid) leads to sedimentation. Viscous flow is the result of an externally

applied force. Measurement of these properties enables molecular weights or particle size to be determined.

Brownian Motion

Colloidal particles are subject to random collisions with the molecules of dispersion medium with the result that each particle attains an irregular path. If the particles are observed under a microscope or the light scattered by colloidal particles is viewed using an ultramicroscope, an erratic motion is seen. This movement is referred to as Brownian motion.

Diffusion

As a result of Brownian motion, colloidal particles spontaneously diffuse from a region of higher concentration to one of lower concentration. The rate of diffusion is expressed by Fick's first law.

$$\frac{dm}{dt} = -DA\,\frac{dc}{dx} \qquad\qquad .....(1.6)$$

where, dm is the mass of substance diffusing in time dt across an area A under the influence of a concentration gradient dc/dx (minus sign denotes that diffusion takes place in the direction of decreasing concentration).

D is diffusion coefficient and has dimension of area per unit time. The diffusion coefficient of a dispersed material is related to the frictional coefficient f of the particles by Einstein's law of diffusion.

$$Df = k_B T \qquad\qquad .....(1.7)$$

k_B = Boltzmann constant

T = temperature

$\therefore$ The frictional coefficient is given by the Stoke's equation

$$f = 6\pi\eta a \qquad\qquad .....(1.8)$$

η = viscosity of the medium

a = the radius of the particle then

$$D = \frac{k_B T}{6\pi\eta a} = \frac{RT}{6\pi\eta a N_A} \qquad\qquad .....(1.9)$$

where, N_A = Avogadro constant

R = universal gas constant

$$K_B = \frac{R}{N_A}$$

The diffusion coefficient may be used to obtain the molecular weight of an approximately spherical particle, such as egg albumin and haemoglobin by using eq. 1.9 in the form:

$$D = \frac{RT}{6\pi\eta N_A} \sqrt[3]{\frac{4\pi N_A}{3M\bar{v}}} \qquad \dots\dots(1.10)$$

M = molecular weight

$\bar{v}$ = partial specific volume of the colloidal material.

Sedimentation

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

$$v = \frac{2r^2 (\rho - \rho_0)g}{9\eta_0} \qquad \dots\dots(1.11)$$

g = acceleration due to gravity

If the particles are only subjected to the force of gravity then, due to Brownian motion, the lower size limit of particles obeying stoke's equation is about 0.5 μm. A stronger force than gravity is therefore needed for colloidal particles to sediment and this is done by using high speed centrifuge, termed as ultracentrifuge, which can produce a force of about 10^6g.

In a centrifuge g is replaces by w^2x, where w is the angular velocity and x is the distance of the particle from the centre of rotation and eq. (1.11) becomes

$$v = \frac{2r^2 g(\rho - \rho_o) w^2 x}{9\eta_o} \qquad \dots\dots(1.12)$$

The ultracentrifuge is used in two distinct ways in investigating colloidal material.

In the *sedimentation velocity* method, a high centrifugal field is applied, upto about 44×10^5 g and the movement of the particles, monitored by changes in concentration, is measured at specific time intervals.

In the *sedimentation equilibrium* method, the colloidal material is subjected to much lower centrifugal field until sedimentation and diffusion tendencies balance one another an equilibrium distribution of particles throughout the sample is attained.

Sedimentation velocity: The velocity $\frac{dx}{dt}$ of a particle in a unit centrifugal force can be expressed in terms of the svedberg coefficient is:

$$S = \frac{\frac{dx}{dt}}{w^2 x} \qquad \qquad ......(1.13)$$

Under the influence of centrifugal force, particles pass from portion x, at time t_1 to position x_2 at time t_2. The difference in concentration which can be measured by using changes in refractive index. Integration of eq. (1.13) using the above limits

$$S = \frac{ln\frac{x_2}{x_1}}{w^2(t_2 - t_1)} \qquad \qquad .....(1.14)$$

By suitable manipulation of equations 1.12, 1.13, 1.14 an expression giving mol. wt 'M' can be obtained

$$M = \frac{RT_s}{D(1 - \bar{v}\rho)} = \frac{RT ln\frac{x_2}{x_1}}{D(1 - \bar{v}\rho)(t_2 - t_1)w^2} \qquad \qquad .....(1.15)$$

where $\bar{v}$ is the partial specific volume of the particles combination of sedimentation and diffusion equation is made in the analysis giving

$$M = \frac{2RT ln\frac{C_2}{C_1}}{w^2(1 - \bar{v}\rho)(x_2^2 - x_1^2)} \qquad \qquad .....(1.16)$$

where C_1 and C_2 are the sedimentation equilibrium concentrations at distances x_1 and x_2 from the axis of rotation.

A disadvantage of the sedimentation equilibrium method is the length of time required to attain equilibrium is often as long as several days.

Osmotic Pressure

The osmotic pressure π of a dilute colloidal solution is described by the van't Hoff equation.

$$\pi = CRT \qquad \qquad .....(1.17)$$

Where, C is molar concentration of solution. This equation can be used to calculate the molecular weight of a colloidal in a dilute solution. Replacing C with c_g/M in eq. (1.17) in which C_g is the grams of solute per liter of solution.

M is the molecular weight, we get

$$\pi = \frac{C_g}{M} RT \qquad \qquad .....(1.18)$$

Then

$$\frac{\pi}{C_g} = \frac{RT}{M} \qquad \qquad .....(1.19)$$

which applies in a very dilute solution. The quantity π/C_g for a polymer having a molecular weight of say 50,000 is often a linear function of the concentration, C_g and the following equation can be written.

$$\frac{\pi}{C_g} = RT\left(\frac{1}{M} + BC_g\right) \qquad \qquad .....(1.20)$$

where, B is a constant for any particular solvent/solute system.

BC$_g$ in eq. (1.20) is needed because eq. (1.19) holds only for ideal solutions i.e., only those containing low concentrations of sphero colloids.

Thus a plot of π/C versus C is linear with the value of intercept at $C \rightarrow 0\, C$ giving $\frac{RT}{M}$ enabling the molecular weight of the colloid to be calculated. The molecular weight obtained from osmotic pressure measurements is a number average value.

Viscosity

Viscosity is an expression of the resistance to flow of a system under an applied stress. An equation of flow applicable to colloidal dispersions of spherical particles was developed by Einstein

$$\eta = \eta_o (1 + 2.5\phi) \qquad \qquad .....(1.21)$$

where,

η_o = viscosity of the dispersion medium

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

A number of viscosity coefficients may be defined with respect to above equation these include relative viscosity.

$$\eta_{rel} = \eta / \eta_o = 1 + 2.5\ \phi \qquad\qquad .....(1.22)$$

and specific viscosity

$$\eta_{SP} = \frac{\eta}{\eta_o} - 1 = \frac{(\eta - \eta_o)}{\eta_o} = 2.5\ \phi \qquad\qquad .....(1.23)$$

or

$$\frac{\eta_{SP}}{\phi} = 2.5$$

Since volume fraction is directly proportional to concentration, the eq. (1.23) can be written as

$$\frac{\eta_{SP}}{C} = k$$

where,

C = concentration expressed as grams of colloidal particles per 100 ms of total dispersion.

K = a constant

If η is determined for a number of concentrations of macromolecular material in solution and $\frac{\eta_{SP}}{C}$ is plotted against C then the intercept obtained on extrapolation of the linear plot to infinite dilution is known as the intrinsic viscosity (η). The plot is given in Fig. 1.3.
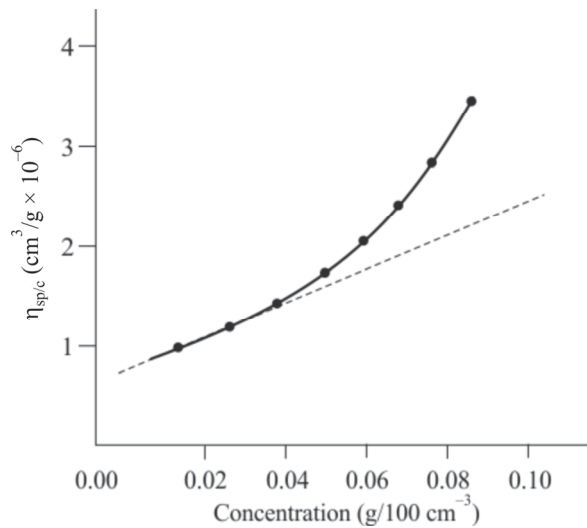

Fig. 1.3 Determination of molecular weight using viscosity data

This constant may be used to calculate the molecular weight of the macromolecular material by making use of Mark-Houwink equation.

$$[\eta] = KM^a$$

where, K and a are constants characteristic of the particular polymer solvent system. These constants are obtained initially by determining (η) for a polymer fraction whose mol. wt has to be determined by another method such as sedimentation, osmotic pressure or light scattering.

1.5.3 Electrical Properties

The properties of colloids that depend on or are effected by the presence of a charge on the surface of a particle are discussed here.

Electrokinetic Phenomena

The movement of a charged surface with respect to an adjacent liquid phase is the basic principle underlying four electrokinetic phenomena; electrophoresis, electro osmosis, sedimentation potential and streaming potential.
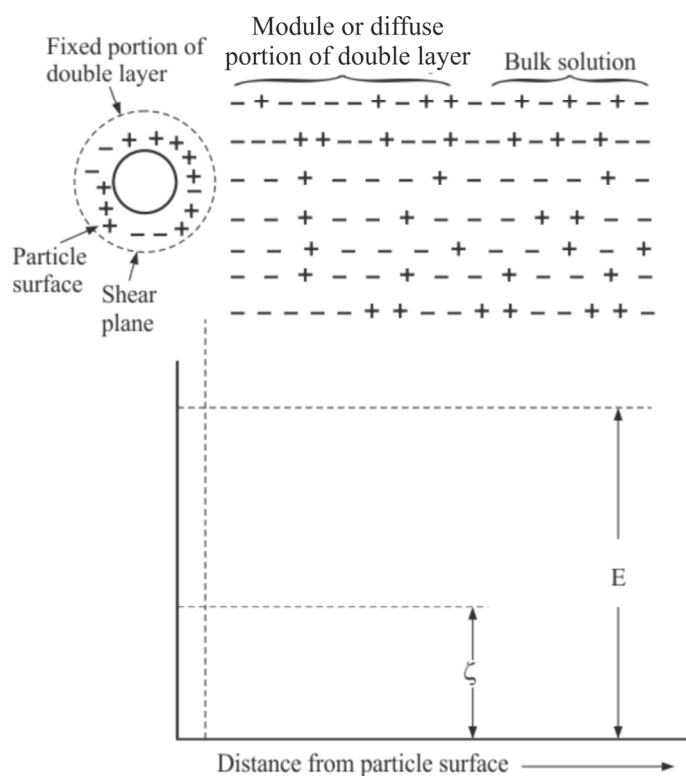

Fig. 1.4 Diffuse double layer and the zeta potential

Electrophoresis involves the movement of a charged particle through a liquid under the influence of an applied potential difference. An electrophoresis cell fitted with two electrodes contains the dispersion. When a potential is applied across the electrodes, the particles migrate to oppositely charged electrode. It is given in Fig. 1.4. The rate of particle migration is observed by means of an ultramicroscope and is a function of the charge on the particle. Because the shear plane of the particle is located at the periphery of the tightly bound layer, the rate determining potential is the zeta potential. The relevant equation is

$$\zeta = \frac{v}{E} \times \frac{4\pi\eta}{\in} \times \left(9 \times 10^4\right)$$

ζ = zeta potential (in volts)

v = velocity of migration (cm/sec)

l = length of electrophoresis tube (in cm)

η = viscosity of the medium (in poises)

$\in$ = dielectric constant of the medium (volts/cm)

E = potential gradient (volts/cm)

The term $\dfrac{v}{\in}$ is known as the mobility.

Electroosmosis is essentially opposite to electrophoresis. In the latter, the application of a potential causes a charged particle to move relative to the liquid which is stationary. If the solid is rendered Immobile, (e.g., by forming a capillary or making the particles into a porous plug), however, the liquid now moves relative to the changed surface. This is electroosmosis, so called liquid moves through a plug or a membrane across when a potential is applied. The zeta potential can be obtained by determining the rate of flow of liquid through the plug under standard conditions.

Sedimentation Potential

Sedimentation potential, the reverse of electrophoresis, is the creation of a potential when particles undergo sedimentation. E.g., a glass tube or packed powder bid streaming potential: differs from electroosmosis in that the potential is created by forcing a liquid to flow through a plug or bed of particles. E.g., a glass tube, by an applied electric field.

Whereas the technique of micro electrophoresis finds application in the measurement of zeta potentials.

To test colloid stability e.g.: polystyrene latex dispersions

To test stability of coarse dispersions e.g.: suspensions and emulsions.

In identification of charge and other surface characteristics of water insoluble drugs and cells such as blood and bacteria.

Donnan Membrane Equilibrium

If sodium chloride is placed in solution on one side of a semipermeable membrane and a negatively charged colloid together with its concentrations R^-Na^+ is placed on the other side, the sodium and chloride ions can pass freely across the barrier but not the colloidal anionic particles. In the system R^- is the non-diffusible colloidal anion and vertical line separating the various species represents the semipermeable membrane. The volumes of solution on the two sides of the membrane are considered to be equal.

Outside (o)	inside (i)
Na^+	Na^+
Cl^-	Cl^-

After equilibrium has been established, the concentration in dilute solutions of sodium chloride must be the same on both sides of the membrane, according to the principle of escaping tendencies.

$$\therefore \qquad [Na^+]_o \, [Cl^-]_o = [Na^+]; \, [Cl^-] \, i \qquad\qquad .....(1.24)$$

The condition of electroneutrality must also apply that is, the concentration of positively charged ions in the solutions on either side of the membrane must balance the concentration of negatively charged ions. Therefore, on the outside,

$$[Na^+]_o = [Cl^-]_o \qquad\qquad .....(1.25)$$

and inside,

$$[Na^+]_i = [R^-]_i + [Cl^-]_i \qquad\qquad .....(1.26)$$

Equations (1.25) and (1.26) are substituted in (1)

$$[Cl^-]_o^2 = ([Cl^-]_i + [R^-]_i) \, [Cl^-]i = \left[Cl^-\right]_i^2 \left(1 + \frac{\left[R^-\right]i}{\left[Cl^-\right]i}\right) \quad .....(1.27)$$

$$\frac{\left[Cl^-\right]_o}{\left[Cl^-\right]i} = \sqrt{1 + \frac{\left[R^-\right]i}{\left[Cl^-\right]i}} \qquad\qquad .....(1.28)$$

Eq. (1.28), the donnan membrane equilibrium gives the ratio of concentrations of the diffusible anion outside and inside the membrane at equilibrium. The equation shows that a negatively charged polyelectrolyte inside a semipermeable sac would influence the equilibrium concentration ratio of a diffusible anion. It tends to drive the ion of the charge out through the membrane.

When $[R^-]i$ is large compared with $[Cl^-]i$ the ratio roughly equals $\sqrt{\left[R^-\right]i}$, if $[Cl^-]i$ is quite large with respect to $[R^-]i$, the ratio becomes equal to unity, and the concentration of the salt is thus equal on both sides of the membrane. If $[Cl^-]$ in equation (1.28) is

replaced by the concentration of the diffusible drug, anion at [D⁻] at equilibrium and [R⁻] is used to represent the concentration of polyelectrolyte at equilibrium then the equation becomes

$$\frac{\left[D^-\right]_o}{\left[D^-\right]i} = \sqrt{1 + \frac{\left[R^-\right]i}{\left[D^-\right]i}}$$

.....(1.29)

1.6   Solubilisation

The property of surface active agents to cause an increase in the solubility of organic compounds in aqueous system is called solubilisation. This property is observed only at and above the CMC, thus indicating that the micelles are involved in the phenomenon. In general, the increased solubility of the solubilised material (solubilisate) can be explained in terms of partition between the aqueous phase and the hydrocarbon interior of the micelles or by adsorption at the micellar surface. Thus it is believed that non-polar hydrocarbons are taken into solution in the interior of the micelles, and polar water soluble compounds such as sugar and glycerol are absorbed at the micelle/water interface as shown in (a) and (b) in Fig. (1.5). Compounds with amphipathic character, such as octonol and phenol, are believed to become oriented in the palisade layer in a similar manner to the surface active agent, i.e., with their polar groups directed towards the aqueous phase and their lipophilic groups inside the micelle as shown at (c) in Fig. (1.5). A possible additional mechanism for the effect of non-ionic micelles on the solubility of certain compounds e.g.: Phenol involves inclusion of these compounds between the long hydrophilic polyoxy ethylene chains as shown at (d) in Fig. (1.5).
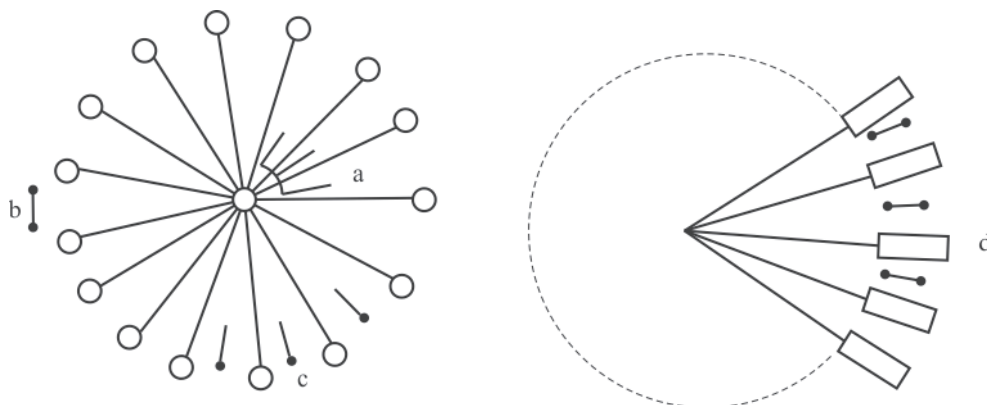

Fig.1.5 Solubilisation within micelles

(a) non-polar tail, **(b)** polar lead, **(c)** Amphipathic molecules oriented in palisade layer, **(d)** Polar molecules oriented between polyoxy ethylene chains of a non-ionic surface active agent

CMCs may be determined by solubilisation measurements preferably using a solid dye stuff that is virtually insoluble in water. The amount of dye stuff in solution remains reasonably constant until the CMC of the surface active agent is reached and then increases rapidly. Dyes are commonly used in such determinations because of the ease of analysis of the solutions by optical methods. The advantage of this method includes long periods of stirring necessary to ensure that equilibrium conditions have been reached.

1.6.1 Factors Affecting Solubilization

A. Molecular Structure of the Surface Active Agent

1. **Hydro Carbon Chain**

   (a) *Chain length*: An increase in the hydrocarbon chain length causes a logarithmic decrease in the CMC at constant temperature as shown by eq (1.30).

$$\log C = A - B_m \qquad \qquad .....(1.30)$$

   where, C is the CMC, m is the number of carbon atoms in the chain, A and B are constants for a homologous series of compounds.

   (b) *Branched Hydrocarbon chains*: Branching of a hydrocarbon chain causes an increase in CMC since the decrease in free energy arising from the aggregation of branched chain molecules is less than that obtained with the value for the analogous saturated compound.

   (c) *Unsaturation*: The CMC is increased by about three to four times by the presence of one double bond when compared with the value for the analogous saturated compound.

2. **The Hydrophilic Group**

   (a) *Type of Hydrophilic Group*: The value of the constant A in eq. (1.30) varies with the type of hydrophilic group common to each homologous series. However, the effect of different ionic groups on the CMC is small, provided complete ionic dissociation occurs, because the amount of work necessary to overcome the electrical repulsion between the ions of same charge is similar.

   (b) *Number of Hydrophilic Groups*: The electrical repulsive force between adjacent ions in a micelle increases at the no. of ionic groups increases. Increase in no. of hydrophilic group increases the solubility of the surface active agent. Both these effects will lead to an increase in the CMC.

   (c) *Position of Hydrophilic Group:* The CMC tends to increase as the polar group is moved from the terminal position towards the middle of the hydrocarbon chain.

B. Effect of Addition

1. *Simple Electrolytes*: The CMC decreases on addition of salts. The most important factors concerned in the overall effect are the concentration and no. of charges on the ions of opposite charge (gegenious) to that carried by that micelle. The effect of these factors is given by eq. (1.31).

$$ln\ c = -k.\ ln\ c_1 + constant \qquad .....(1.31)$$

k = a constant with a value of 0.4 app

c = CMC

c_1 = total gegerion concentration

For surface active acute with two ionic groups eq. (1.31) becomes.

$$ln c = -2k\ .\ ln c_1 + constant \qquad .....(1.32)$$

2. *Other Surface Active Agents*: The CMCs of mixtures of surface active agents appear to vary between the limiting values of the highest and lowest CMCs of the individual components.

3. *Alcohol*: CMCs are decreased by the addition of alcohol.

4. *Hydrocarbons*: Solubilization of hydrocarbons causes an increase in micellar size, which results in an increase in the radius of curvature of the micellar surface which may cause a slight separation of adjacent ions and therefore, a decrease in the repulsive forces.