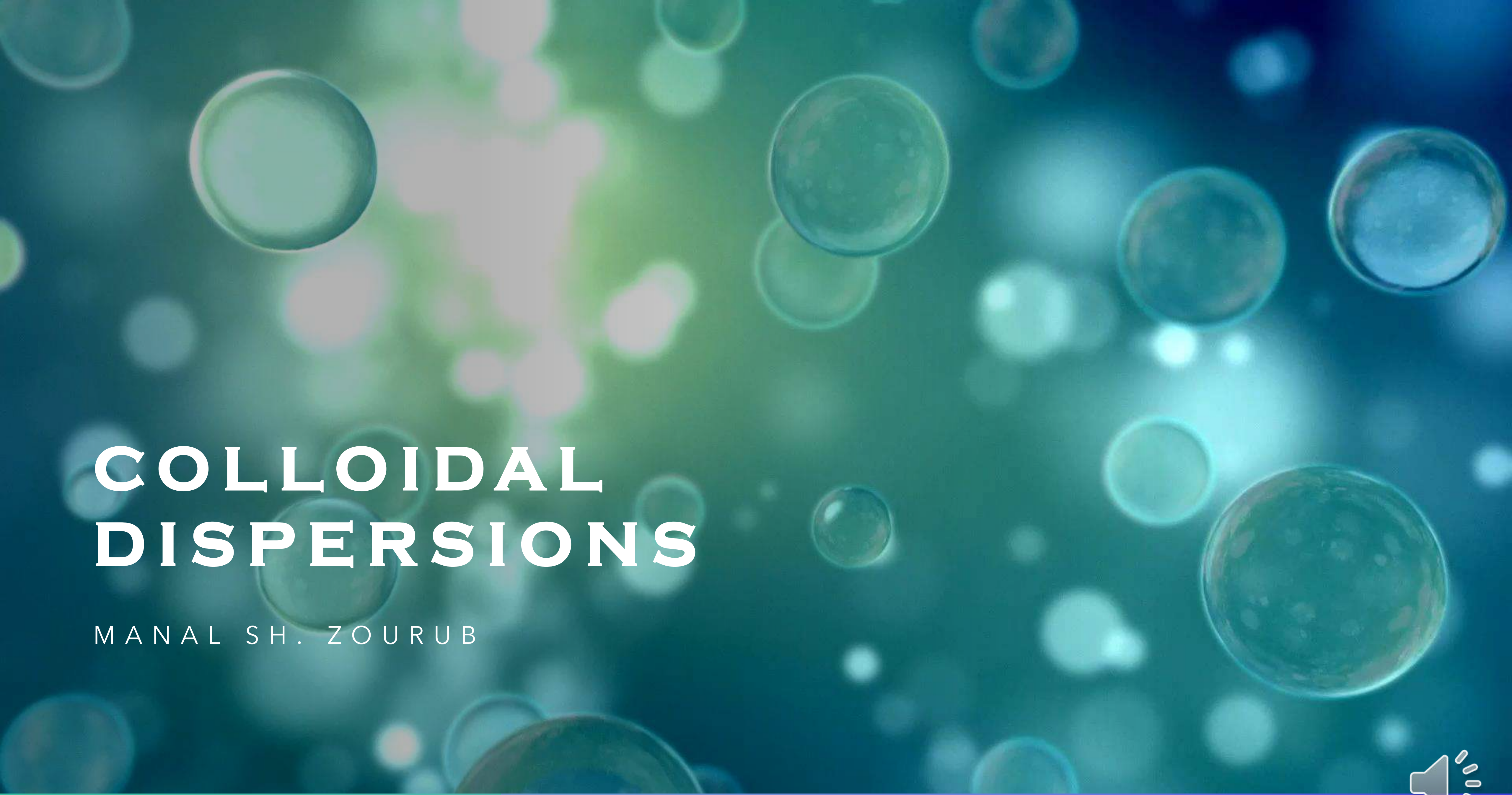


COLLOIDAL DISPERSIONS

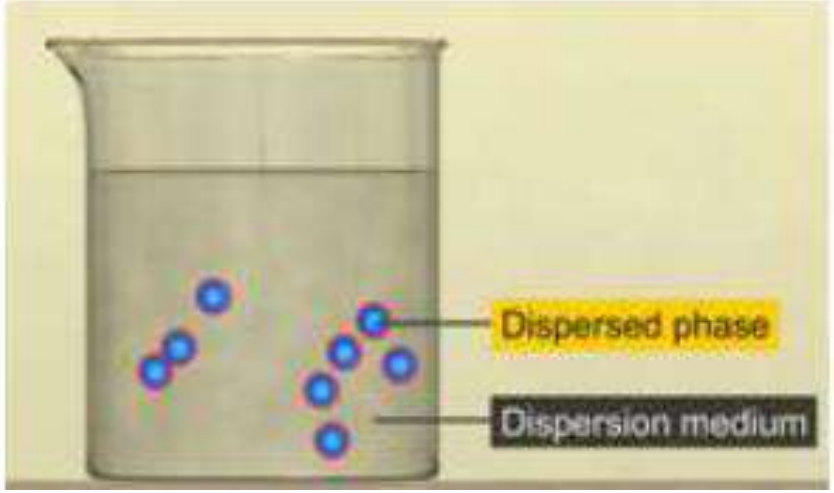
MANAL SH. ZOURUB

- **Dispersed systems consist of :**

a) particulate matter (dispersed phase).

b) dispersion medium (continuous medium).

- **Dispersed systems** consist of particulate matter, known as the dispersed phase, distributed throughout a continuous or dispersion medium

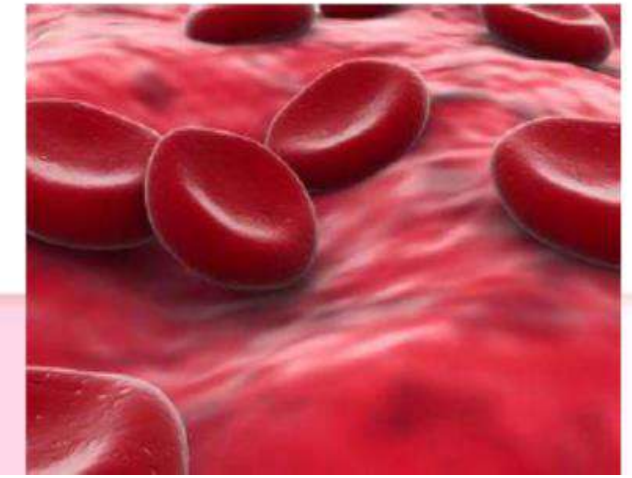


- The dispersed material may range in size from particles of atomic and molecular dimensions to particles whose size is measured in millimeters.
- Accordingly, a convenient means of classifying dispersed systems is on the basis of the mean particle diameter of the dispersed material.

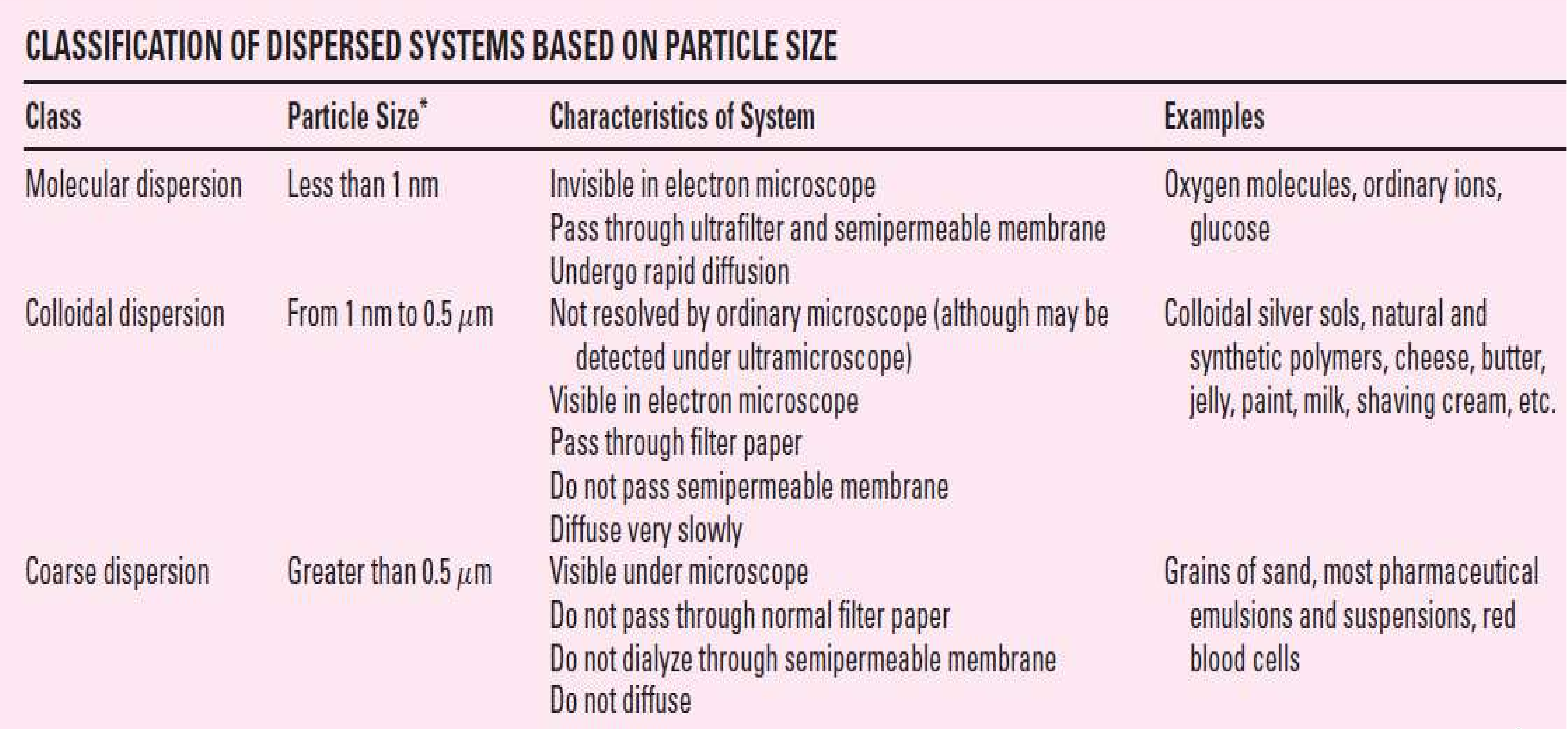
- Based on the size of the dispersed phase, three types of dispersed systems are generally considered:
  (a) molecular dispersions,
  (b) Colloidal dispersions,
  (c) coarse dispersions.

- The size limits are somewhat arbitrary, there being no distinct transition between either molecular and colloidal dispersions or colloidal and coarse dispersions.
- For example, certain macro (i.e., large) molecules, such as the polysaccharides, proteins, and polymers in general, are of sufficient size that they may be classified as forming both molecular and colloidal dispersions.
- Some suspensions and emulsions may contain a range of particle sizes such that the smaller particles lie within the colloidal range, whereas the larger ones are classified as coarse particles.

- It is important to know that the only difference between them is the size of the dispersed phase and not its composition.
- Dispersions consist of at least one internal phase that is dispersed in a dispersion medium.
- The **Blood** is an example of a complex dispersed system that we are all very familiar
- Nutrients such as peptides, proteins, and glucose are dissolved in plasma forming a **molecular dispersion**



- Oxygen, however, is carried to cells and tissues by red blood cells. Given the size of red blood cells (~6 μm in diameter and 2 μm in width) they would be considered to form a **coarse dispersion in blood.**
- However, the size of the individual serum albumin particles in solution is >1 nm, which puts them into the **colloidal dispersion** group.
- As you can now see, blood is a **complex bodily fluid** that is an example of the three types of dispersed systems that you will encounter in the pharmaceutical sciences.

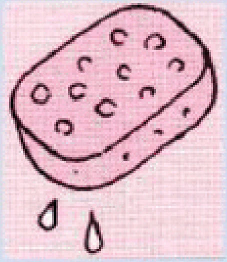
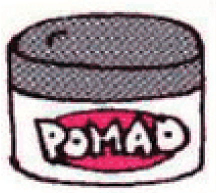
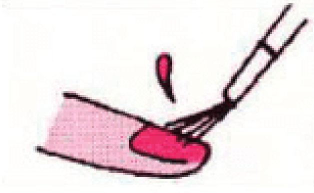
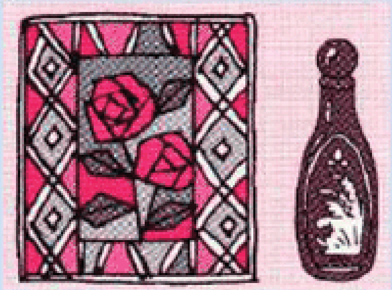


CLASSIFICATION OF DISPERSED SYSTEMS BASED ON PARTICLE SIZE

Class	Particle Size*	Characteristics of System	Examples
Molecular dispersion	Less than 1 nm	Invisible in electron microscope Pass through ultrafilter and semipermeable membrane Undergo rapid diffusion	Oxygen molecules, ordinary ions, glucose
Colloidal dispersion	From 1 nm to 0.5 μm	Not resolved by ordinary microscope (although may be detected under ultramicroscope) Visible in electron microscope Pass through filter paper Do not pass semipermeable membrane Diffuse very slowly	Colloidal silver sols, natural and synthetic polymers, cheese, butter, jelly, paint, milk, shaving cream, etc.
Coarse dispersion	Greater than 0.5 μm	Visible under microscope Do not pass through normal filter paper Do not dialyze through semipermeable membrane Do not diffuse	Grains of sand, most pharmaceutical emulsions and suspensions, red blood cells

COLLOIDS

- A colloid is a mixture consisting of tiny particles that are intermediate in size between those in solutions and those in suspensions and that suspended in a gas, liquid or a solid.

		Continuous Phase		
		Gas	Liquid	Solid
Dispersed Phase	Gas	None	(Foam) Hair mousse, Shave foam 	(Xerogel) Sponge, Styrofoam, Silica gel 
	Liquid	(Aerosol) Hair spray 	(Emulsion) Cream, Lotion 	(Gel) Pomade, Food gelatin, 
	Solid	(Aerosol) Powdery Spray 	(Suspension) Nail enamail, Foundation 	(Solid colloid) Colored glass 

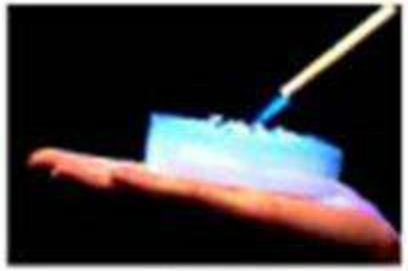
Examples of colloidal systems from daily life

Foams

Milk

Fog, smoke

Detergents



Aerogel

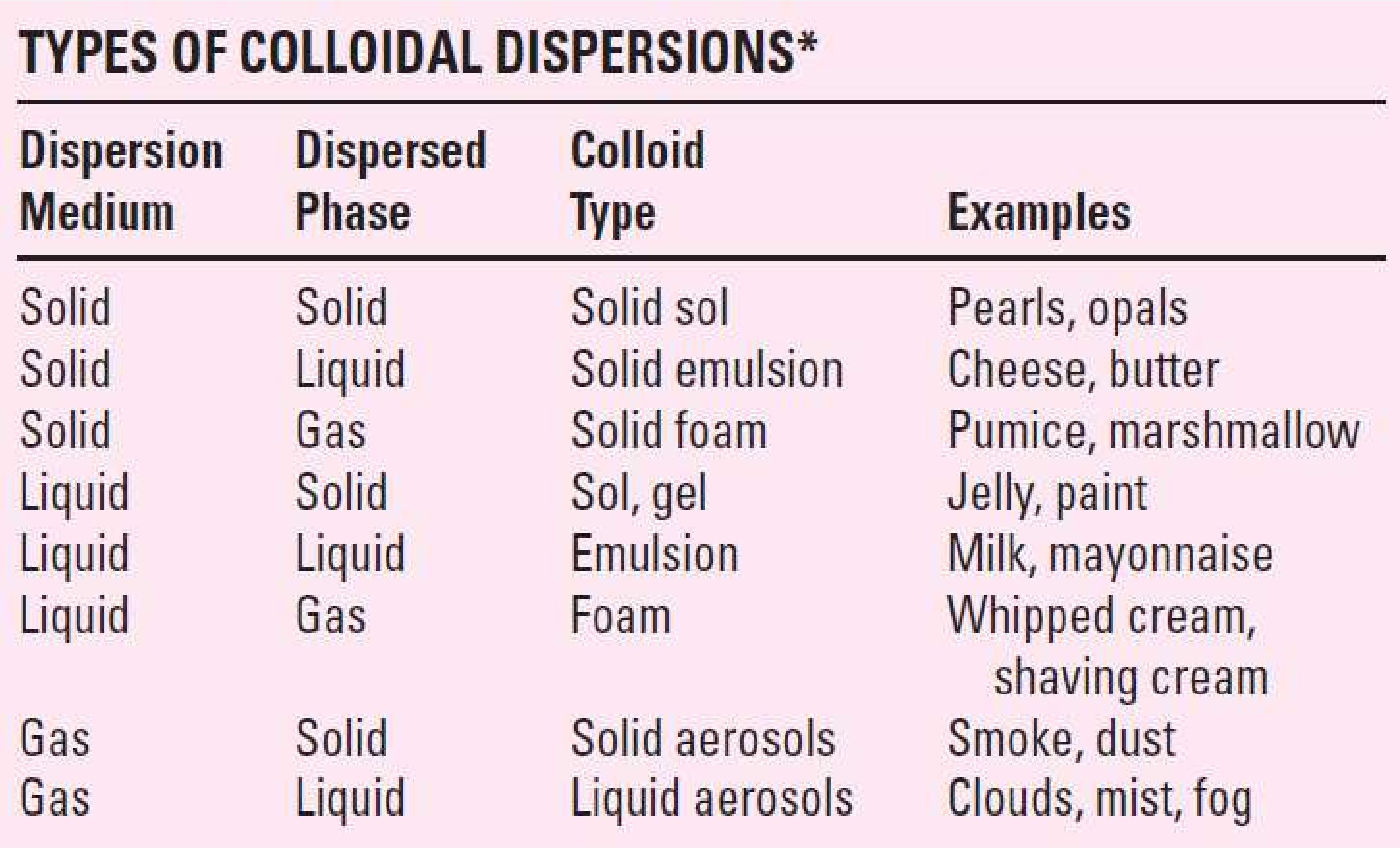
Blood

Paints

Cosmetics

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.
- Possible types of colloidal dispersions are shown in the accompanying table.

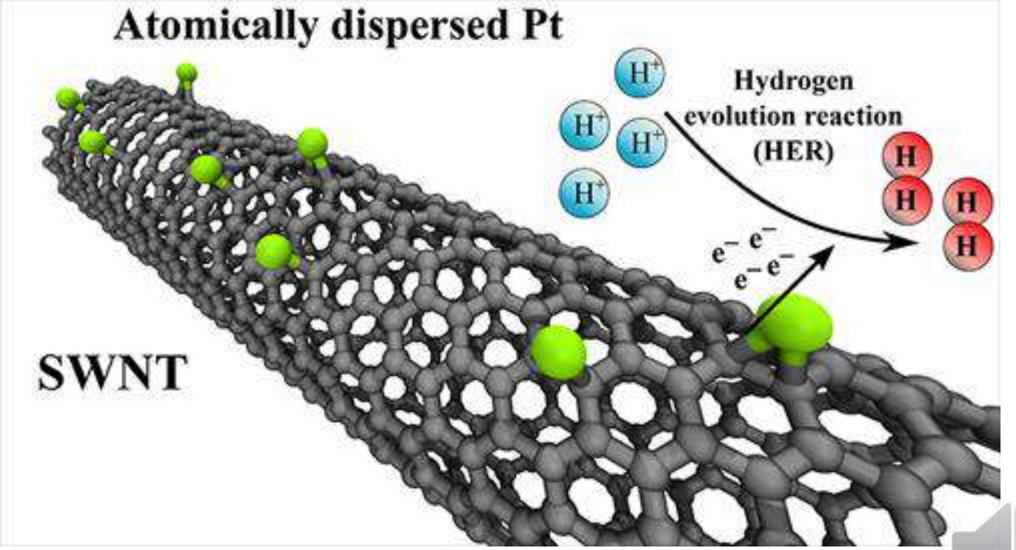


TYPES OF COLLOIDAL DISPERSIONS*

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	Whipped cream, shaving cream
Gas	Solid	Solid aerosols	Smoke, dust
Gas	Liquid	Liquid aerosols	Clouds, mist, fog

SIZE AND SHAPE OF COLLOIDAL PARTICLES

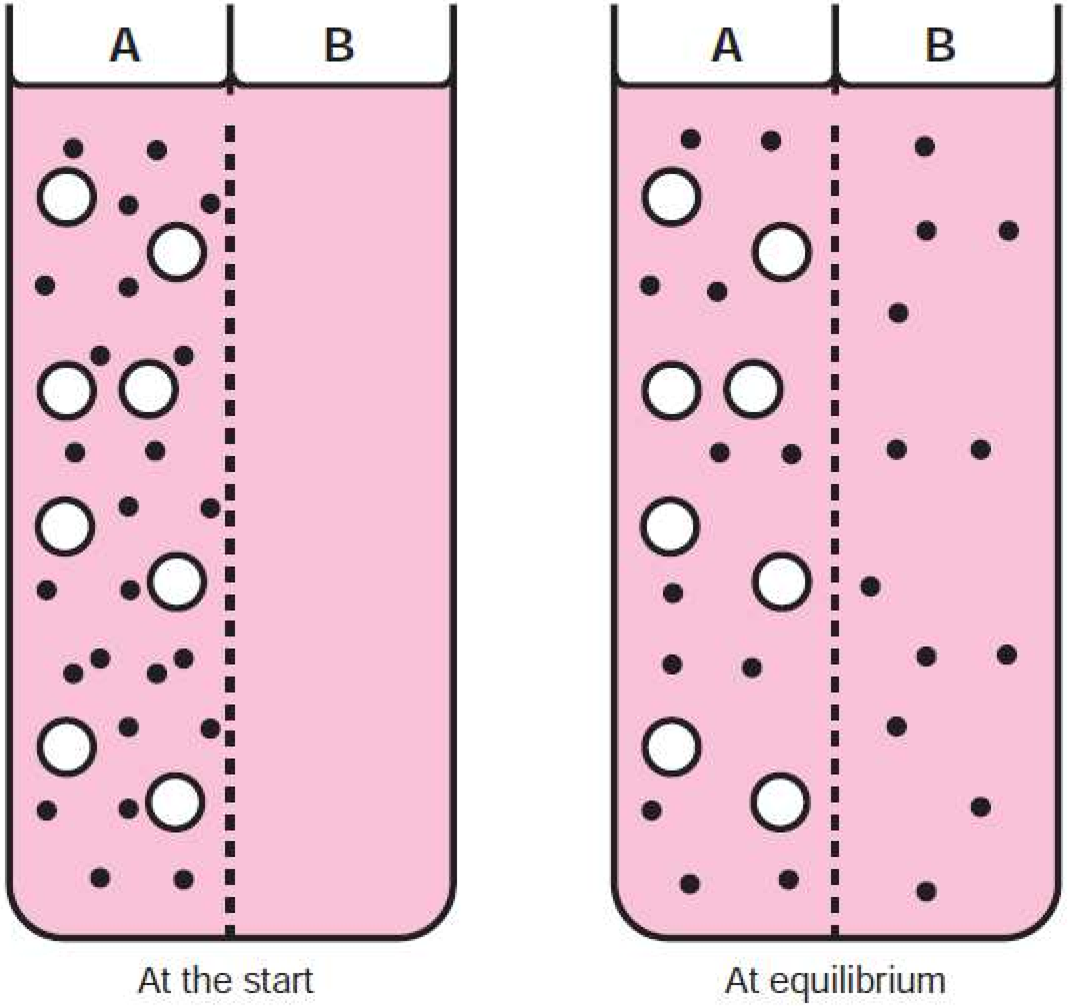
- Particles in the colloidal size range possess a surface area that is enormous compared with the surface area of an equal volume of larger particles
- The large specific surface results in many of the unique properties of colloidal dispersions
- For example, platinum is effective as a catalyst only when in the colloidal form as platinum black. This is because catalysts act by adsorbing the reactants onto their surface.



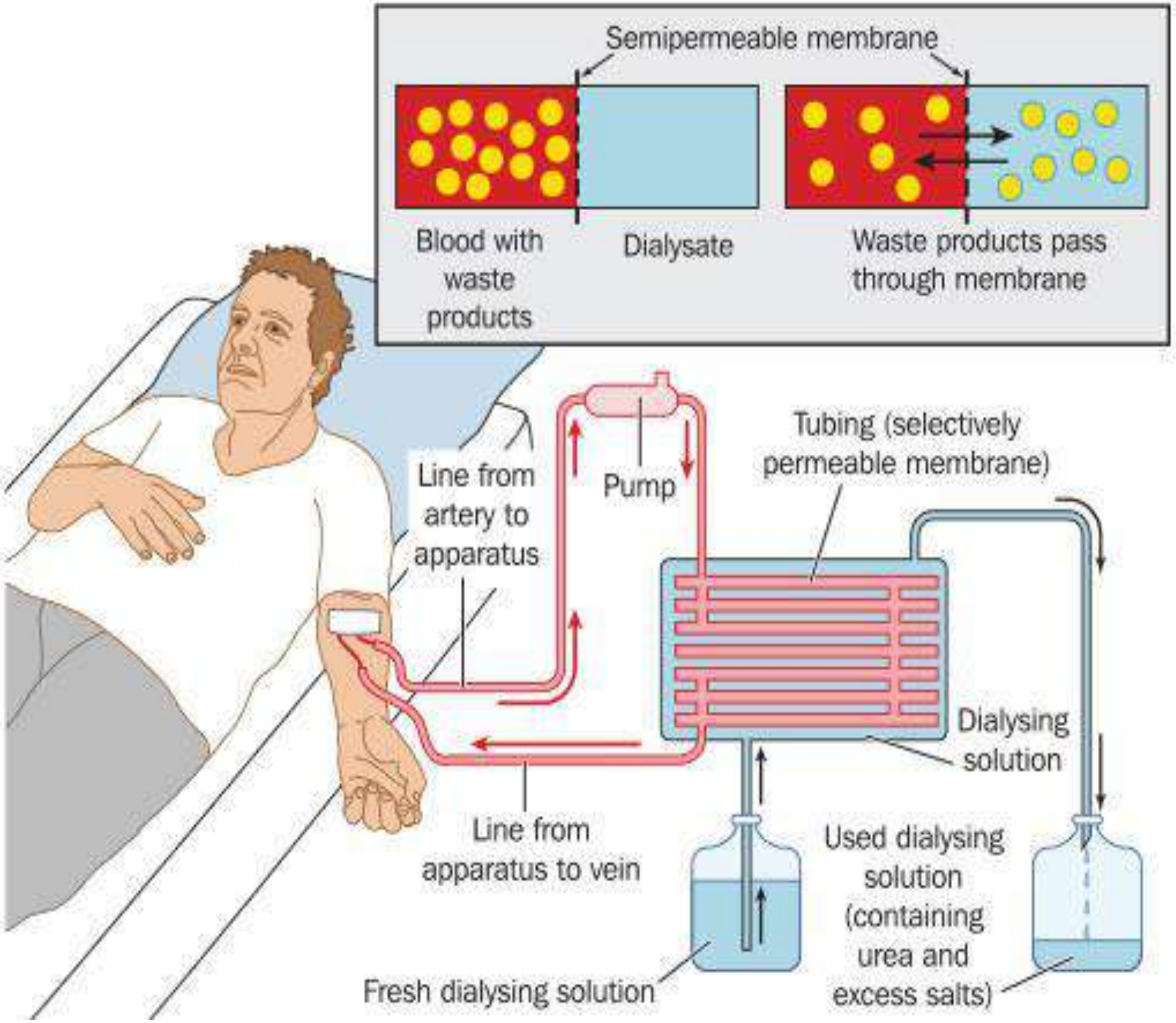
- The color of colloidal dispersions is related to the size of the particles present.
- Thus, as the particles in a red gold sol increase in size, the dispersion takes on a blue color.
- Antimony and arsenic trisulfides change from red to yellow as the particle size is reduced from that of a coarse powder to that within the colloidal size range.

- because of their size, colloidal particles can be separated from molecular particles with relative ease.
- The technique of separation, known as **dialysis,** uses a semipermeable membrane, the pore size of which will prevent the passage of colloidal particles, yet permit small molecules and ions, such as urea, glucose, and sodium chloride, to pass through.

- at equilibrium, the colloidal material is retained in compartment A, whereas the subcolloidal material is distributed equally on both sides of the membrane.
- By continually removing the liquid in compartment B, it is possible to obtain colloidal material in A that is free from subcolloidal contaminants
- Dialysis can also be used to obtain subcolloidal material that is free from colloidal contamination



- **Dialysis** occurs in vivo.
- Thus, ions and small molecules pass readily from the blood, through a natural semipermeable membrane, to the tissue fluids; the colloidal components of the blood remain within the capillary system.
- The principle of dialysis is utilized in the artificial kidney, which removes low-molecular-weight impurities from the body by passage through a semipermeable membrane.



- The shape adopted by colloidal particles in dispersion is important because **the more extended the particle, the greater is its specific surface and the greater is the opportunity for attractive forces** to develop between the particles of the dispersed phase and the dispersion medium
- A colloidal particle is something like a hedgehog–in a friendly environment, it unrolls and exposes maximum surface area.
- Under adverse conditions, it rolls up and reduces its exposed area.
- Properties as flow, sedimentation, and osmotic pressure are affected by changes in the shape of colloidal particles.
- Particle shape may also influence pharmacological action.

- Some shapes that can be assumed by colloidal particles:

(a) spheres and globules,

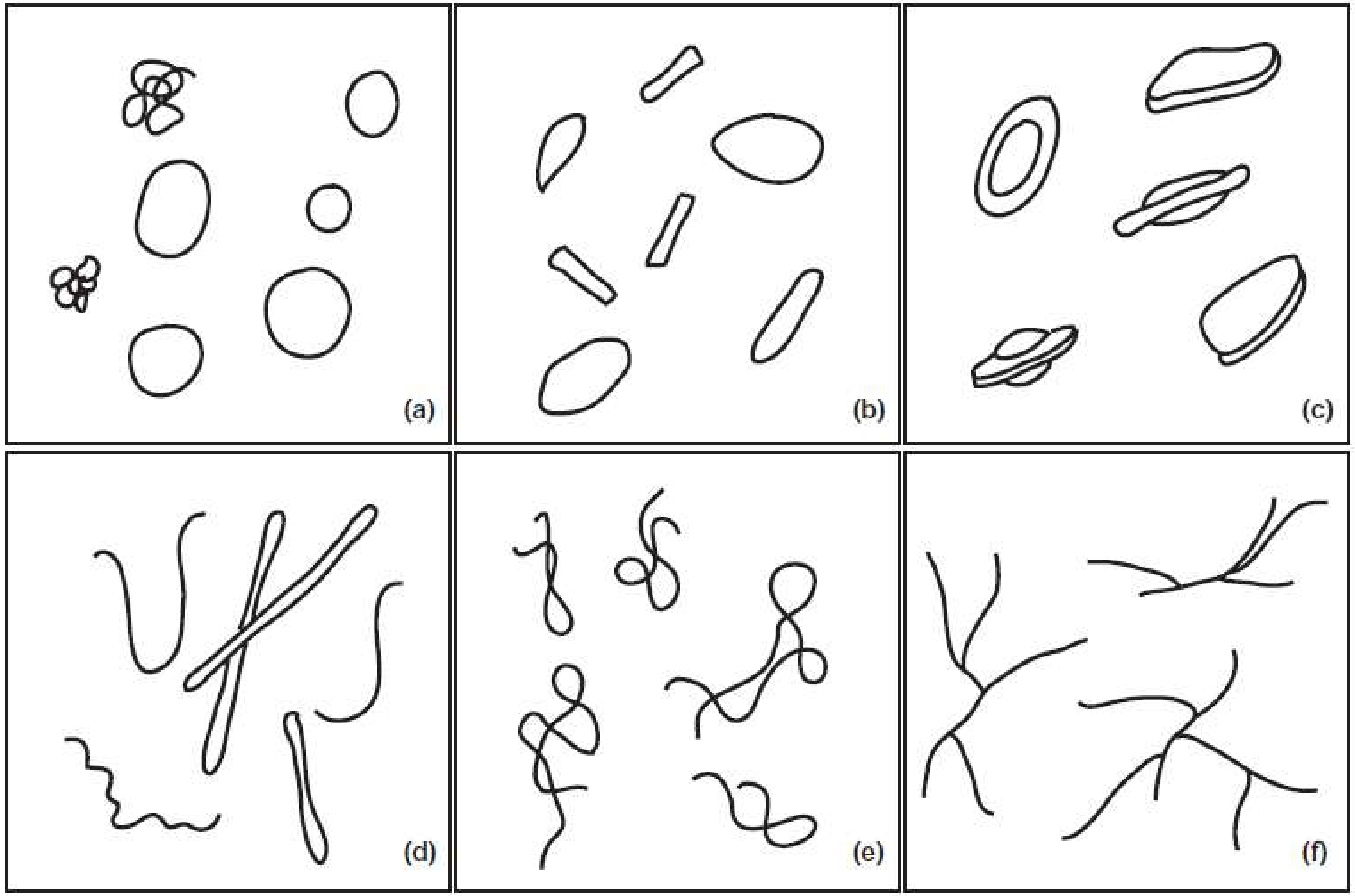
(b) Short rods

(c) oblate ellipsoids and flakes,

(d) long rods and threads,

(e) loosely coiled threads,

(f) branched threads.



TYPES OF COLLOIDAL SYSTEMS

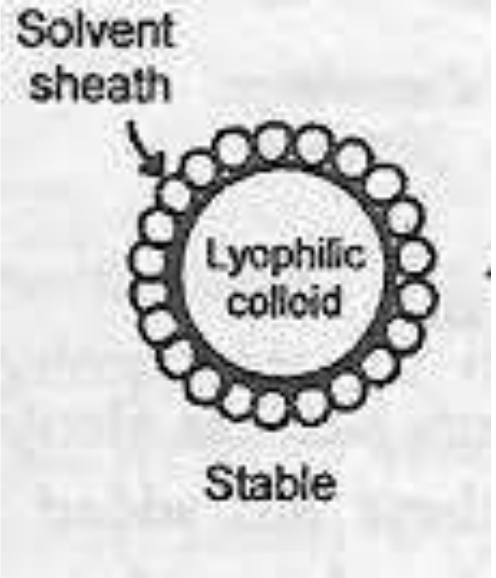
- According to the **interaction** between particles of dispersed phase & those of dispersion medium:

1) Lyophilic (solvent loving).
2) Lyophobic (solvent hating).
3) Association (amphiphilic).

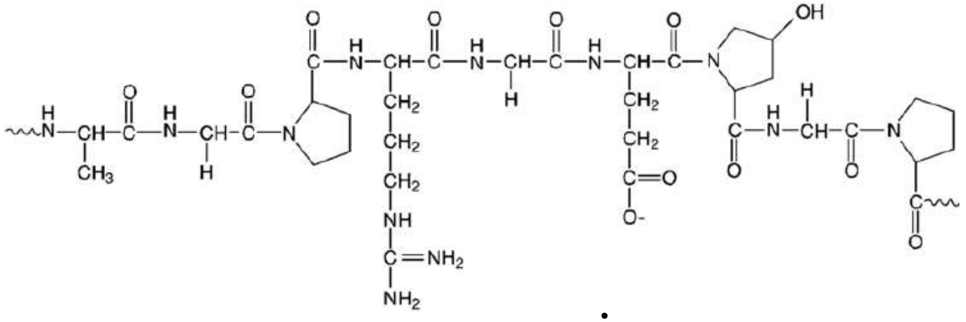
1- LYOPHILIC COLLOIDS

- Systems containing colloidal particles that interact to an appreciable extent with the dispersion medium are referred to as lyophilic (solvent-loving) colloids.
- Owing to their affinity for the dispersion medium, such materials form colloidal dispersions, or sols, with relative ease.
- Thus, lyophilic colloidal sols are usually obtained simply by dissolving the material in the solvent being used

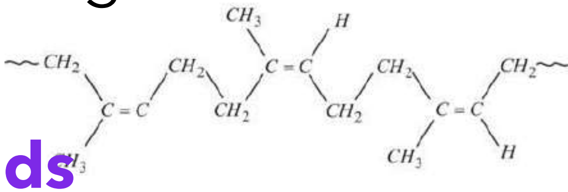
- The various properties of this class of colloids are due to the attraction between the dispersed phase and the dispersion medium, which leads to solvation, the attachment of solvent molecules to the molecules of the dispersed phase.
- In the case of hydrophilic colloids, in which water is the dispersion medium, this is termed **hydration**.



- Most lyophilic colloids are **organic** molecules, for example, gelatin, acacia, insulin, albumin, rubber, and polystyrene.
- Of these, the first four produce lyophilic colloids in aqueous dispersion media (**hydrophilic sols**).



- Rubber and polystyrene form lyophilic colloids in nonaqueous, organic solvents.
- These materials accordingly are referred to as **lipophilic colloids**



- These examples illustrate the important point that the term lyophilic has meaning only when applied to the material dispersed in a specific dispersion medium.
- A material that forms a lyophilic colloidal system in one liquid (e.g., water) may not do so in another liquid (e.g., benzene).

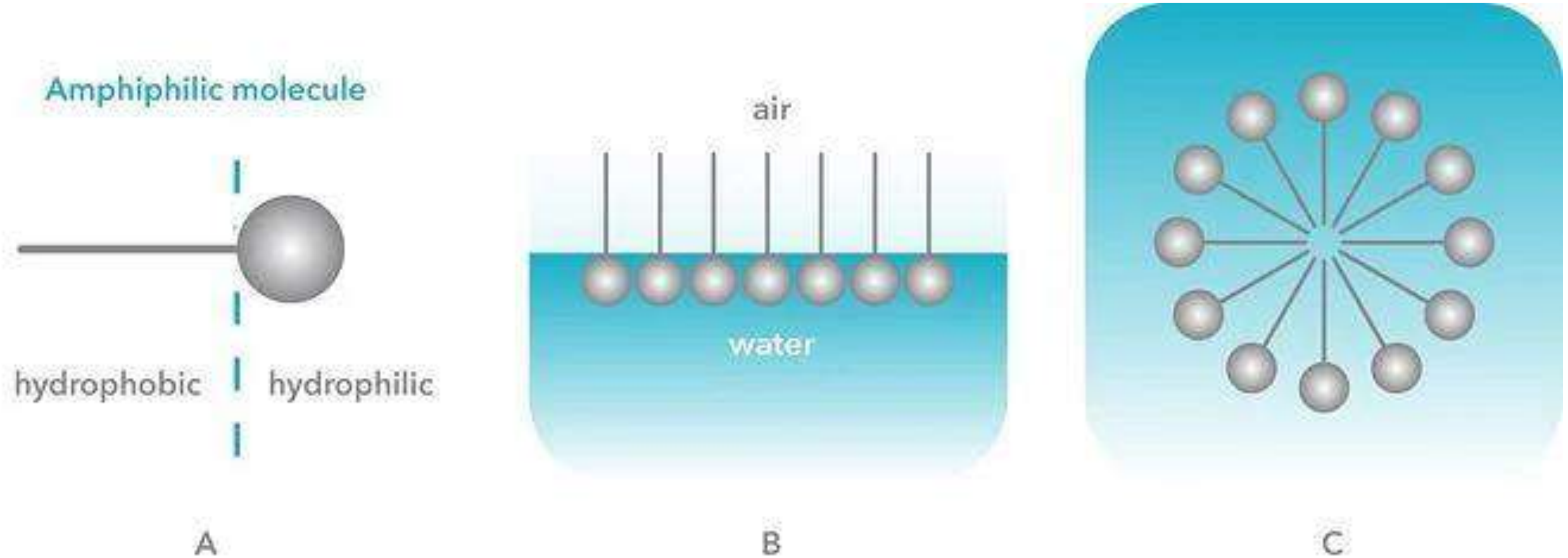
2- LYOPHOBIC COLLOIDS

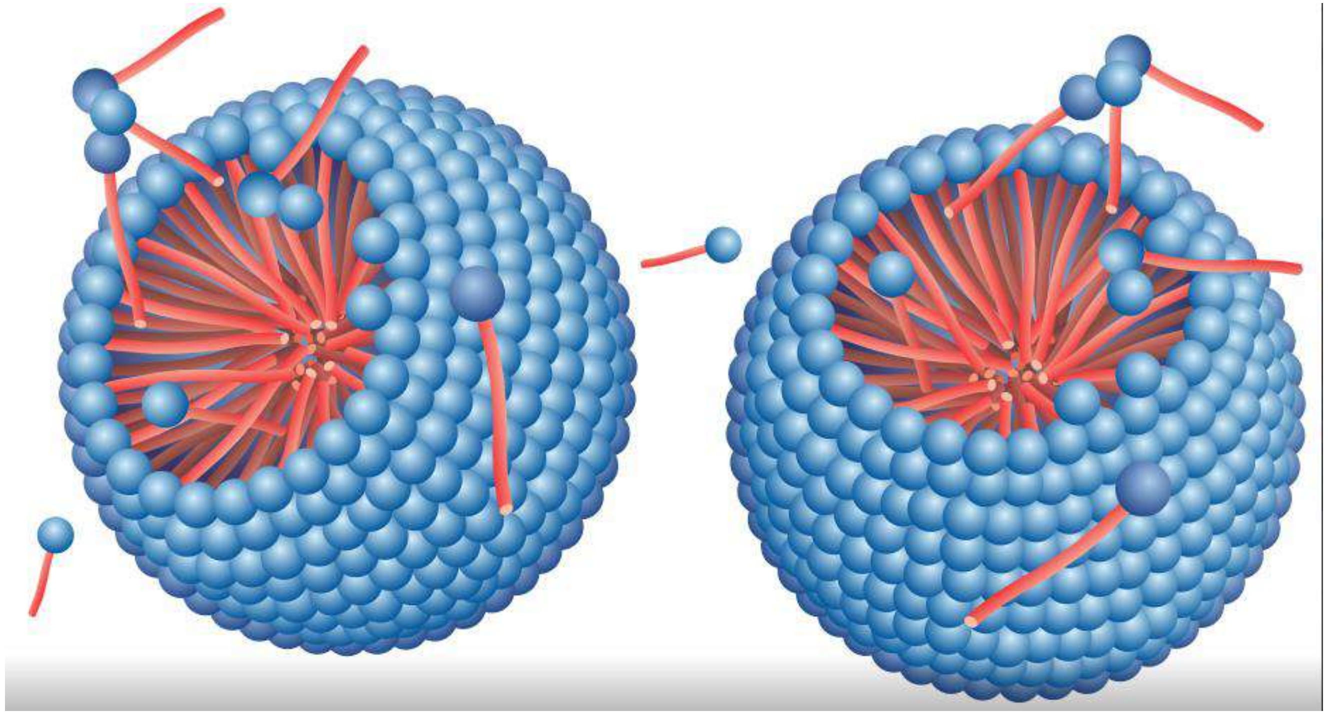
- composed of materials that have little attraction, if any, for the dispersion medium.
- These are the lyophobic (solvent-hating) colloids and, predictably, their properties differ from those of the lyophilic colloids.
- This is primarily due to the absence of a solvent sheath around the particle.
- Lyophobic colloids are generally composed of **inorganic** particles dispersed in water.
- Examples of such materials are gold, silver, sulfur, arsenous sulfide, and silver iodide.

- In contrast to lyophilic colloids, it is necessary to use special methods to prepare lyophobic colloids.
- These are:
  - (a) dispersion methods, in which coarse particles are reduced in size
  - (b) condensation methods, in which materials of subcolloidal dimensions are caused to aggregate into particles within the colloidal size range.

3- ASSOCIATION COLLOIDS

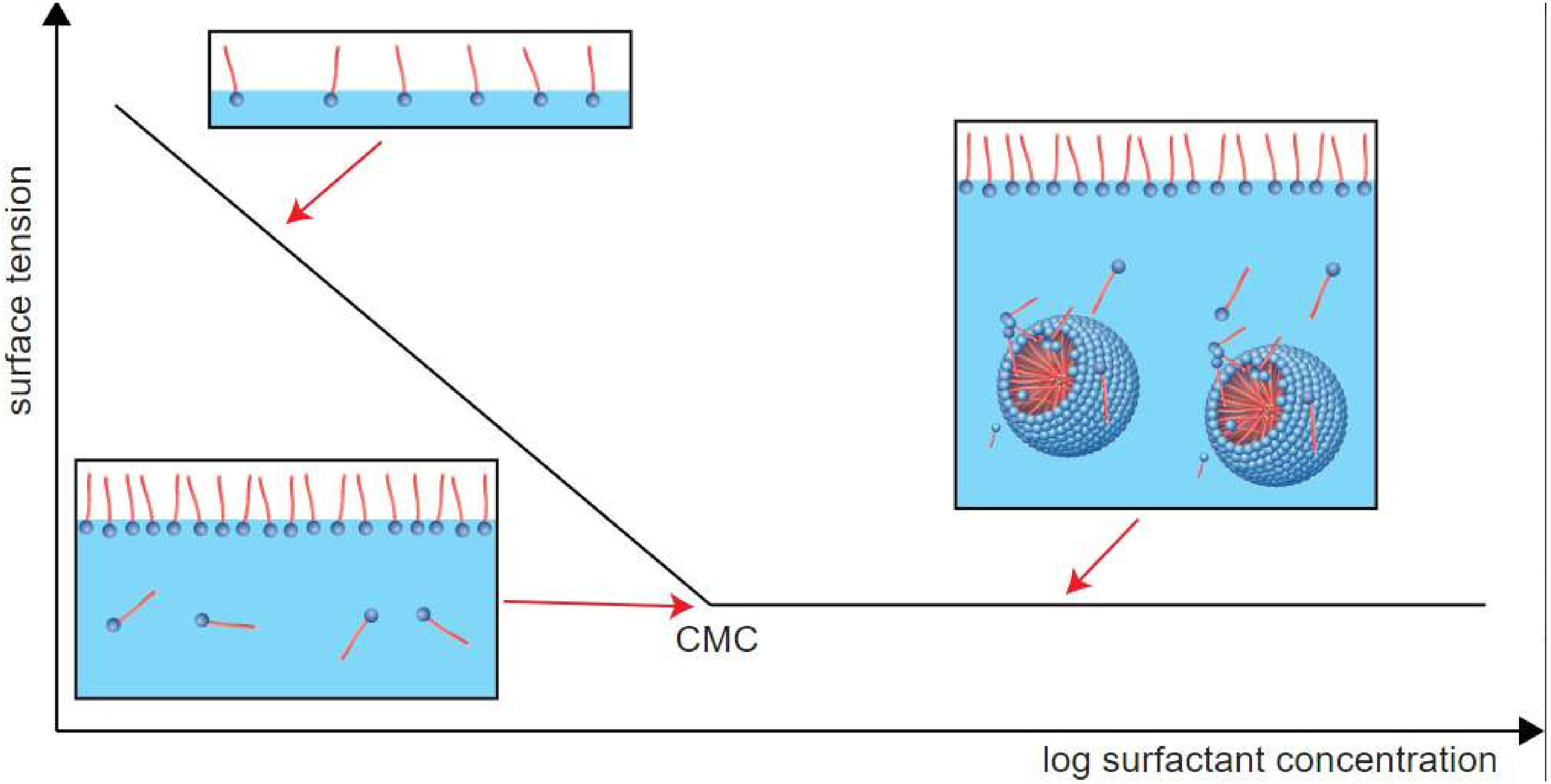
- certain molecules or ions, termed amphiphiles or surface-active agents, are characterized by having two distinct regions of opposing solution affinities within the same molecule or ion.
- When present in a liquid medium at low concentrations, the amphiphiles exist separately and are of such a size as to be subcolloidal.
- As the concentration is increased, aggregation occurs over a narrow concentration range.
- These aggregates, which may contain 50 or more monomers, are called **micelles.**


Amphiphilic molecule
hydrophobic
hydrophilic
air
water
A
B
C

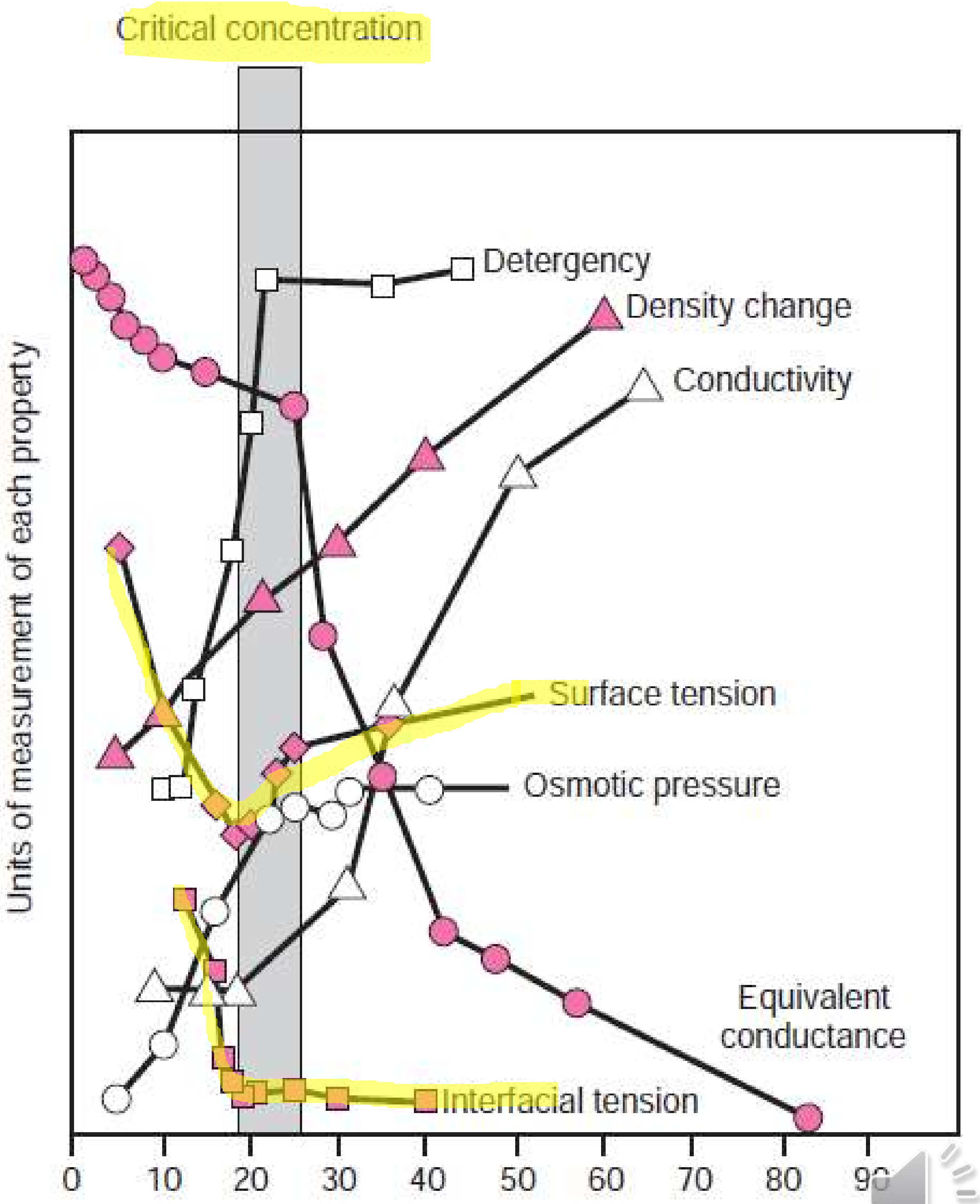


- Because the diameter of each micelle is of the order of 50 Å, micelles lie within the size range we have designated as colloidal.
- The concentration of monomer at which micelles form is termed the **critical micelle concentration(CMC).**
- The number of monomers that aggregate to form a micelle is known as the **aggregation number of the micelle.**

- **At low concentration:** amphiphiles exist separately (subcolloidal size)
- **At high concentration:** form aggregates or micelles (50 or more monomers) (colloidal size)



- **Properties of surface-active agents** showing changes that occur **sharply** at the critical micelle concentration.
- Note particularly that **surface tension** decreases up to the CMC.
- Above the CMC, the surface tension remains essentially constant, showing that the interface is saturated and micelle formation has taken place in the bulk phase



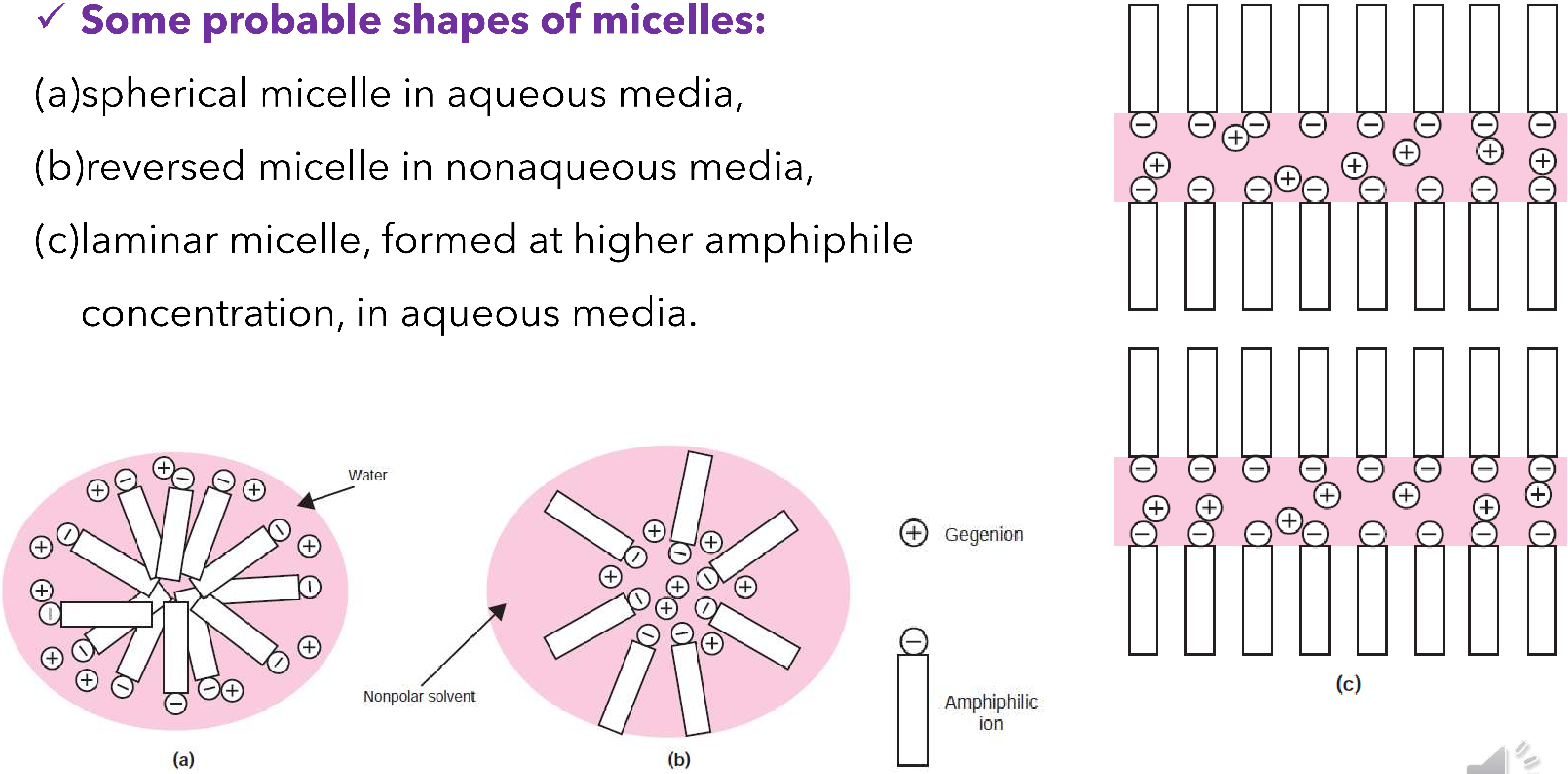
- In the case of amphiphiles in water, the hydrocarbon chains face inward into the micelle to form, in effect, their own hydrocarbon environment.
- Surrounding this hydrocarbon core are the polar portions of the amphiphiles associated with the water molecules of the continuous phase.
- Aggregation also occurs in nonpolar liquids.
- The orientation of the molecules is now reversed, however, with the polar heads facing inward while the hydrocarbon chains are associated with the continuous nonpolar phase.

✓ Some probable shapes of micelles:

(a)spherical micelle in aqueous media,

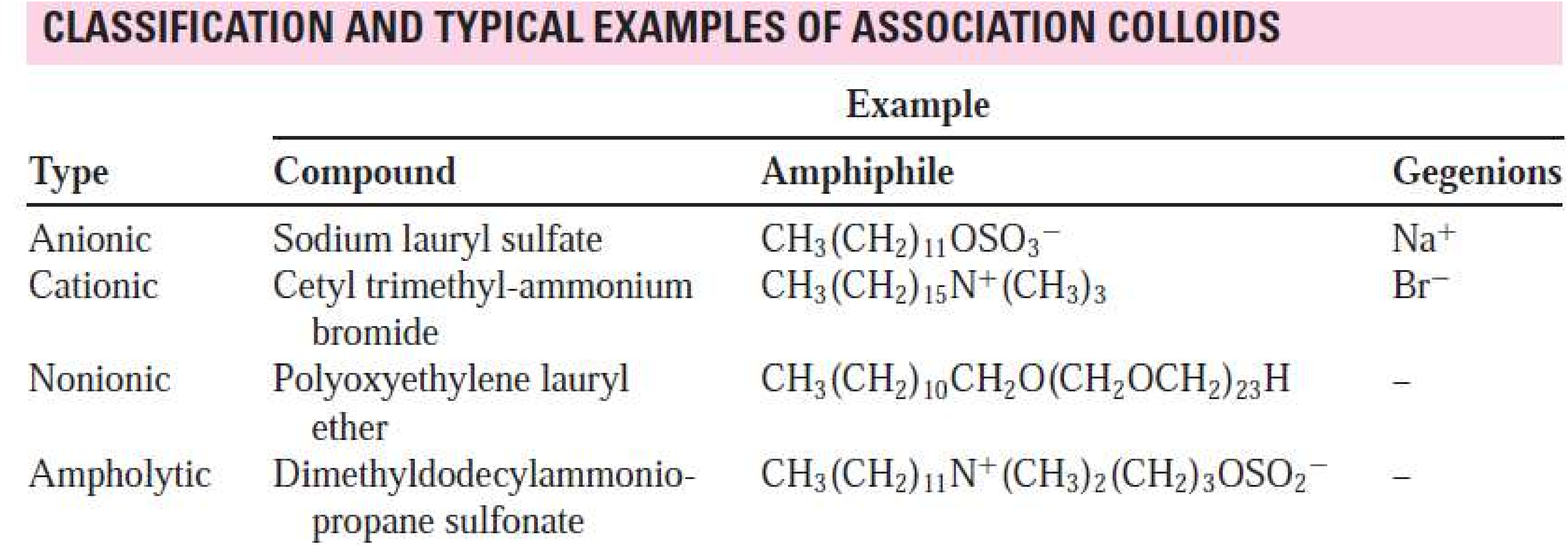
(b)reversed micelle in nonaqueous media,

(c)laminar micelle, formed at higher amphiphile concentration, in aqueous media.



- It seems likely that spherical micelles exist at concentrations relatively close to the CMC.
- At higher concentrations, laminar micelles have an increasing tendency to form and exist in equilibrium with spherical micelles.
- The individual molecules forming the micelle are in dynamic equilibrium with those monomers in the bulk and at the interface

- As with lyophilic sols, formation of association colloids is spontaneous, provided that the concentration of the amphiphile in solution exceeds the CMC.
- Amphiphiles may be anionic, cationic, nonionic, or ampholytic (zwitterionic), and this provides a convenient means of classifying association colloids.



CLASSIFICATION AND TYPICAL EXAMPLES OF ASSOCIATION COLLOIDS

	Example		
Type	**Compound**	**Amphiphile**	**Gegenions**
Anionic	Sodium lauryl sulfate	$CH_3(CH_2)_{11}OSO_3^-$	Na^+
Cationic	Cetyl trimethyl-ammonium bromide	$CH_3(CH_2)_{15}N^+(CH_3)_3$	Br^-
Nonionic	Polyoxyethylene lauryl ether	$CH_3(CH_2)_{10}CH_2O(CH_2OCH_2)_{23}H$	–
Ampholytic	Dimethyldodecylammonio-propane sulfonate	$CH_3(CH_2)_{11}N^+(CH_3)_2(CH_2)_3OSO_2^-$	–

- Mixtures of two or more amphiphiles are usual in pharmaceutical formulations.
- 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:

$$\frac{1}{\mathrm{CMC}} = \frac{x_1}{\mathrm{CMC}_1} + \frac{x_2}{\mathrm{CMC}_2}$$

EXAMPLE

Compute the CMC of a mixture of *n*-dodecyl octaoxyethylene glycol monoether ($C_{12}E_8$) and *n*-dodecyl β-D-maltoside (DM). The CMC of $C_{12}E_8$ is $CMC_1 = 8.1 \times 10^{-5}$ M (mole/liter) and its mole fraction is $x_1 = 0.75$; the CMC of DM is $CMC_2 = 15 \times 10^{-5}$ M.

$$x_2 = (1 - x_2) = (1 - 0.75) = 0.25$$

$$\frac{1}{\mathrm{CMC}} = \frac{x_1}{\mathrm{CMC}_1} + \frac{x_2}{\mathrm{CMC}_2}$$

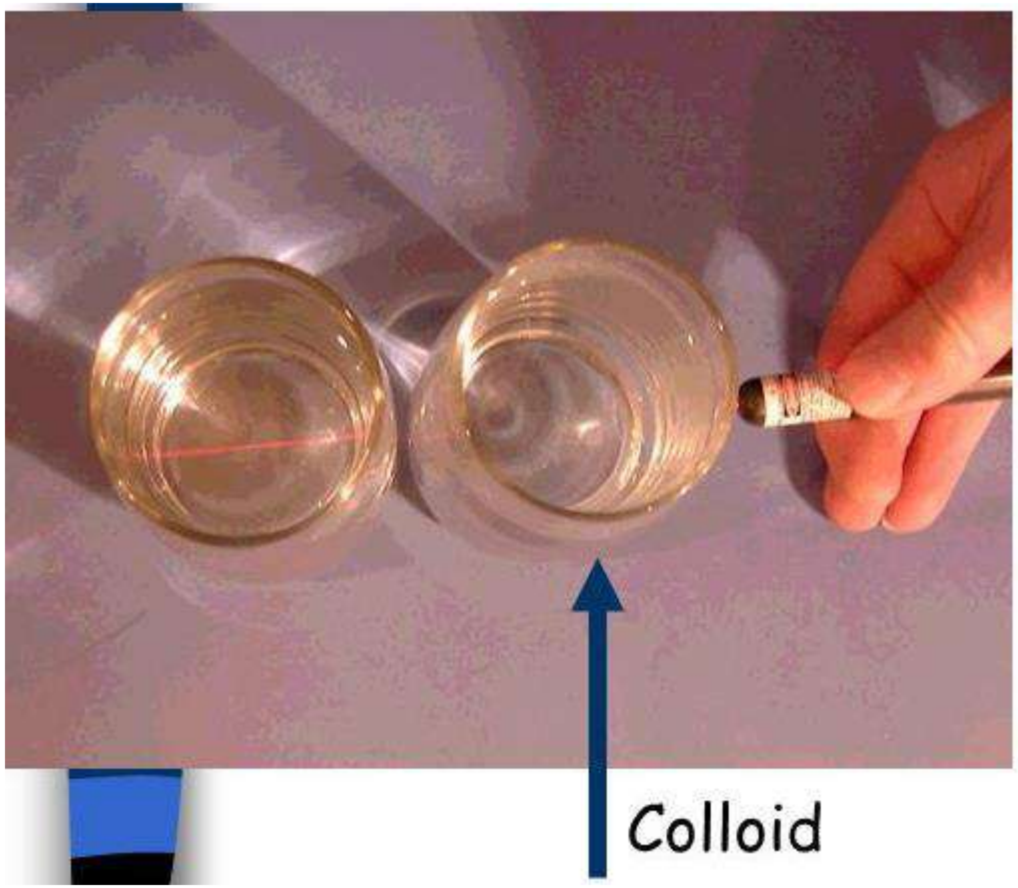
$$\frac{1}{\mathrm{CMC}} = \frac{0.75}{8.1 \times 10^{-5}} + \frac{0.25}{15 \times 10^{-5}} = 10{,}926$$

$$\mathrm{CMC} = \frac{1}{10{,}926} = 9.15 \times 10^{-5}\mathrm{M}$$

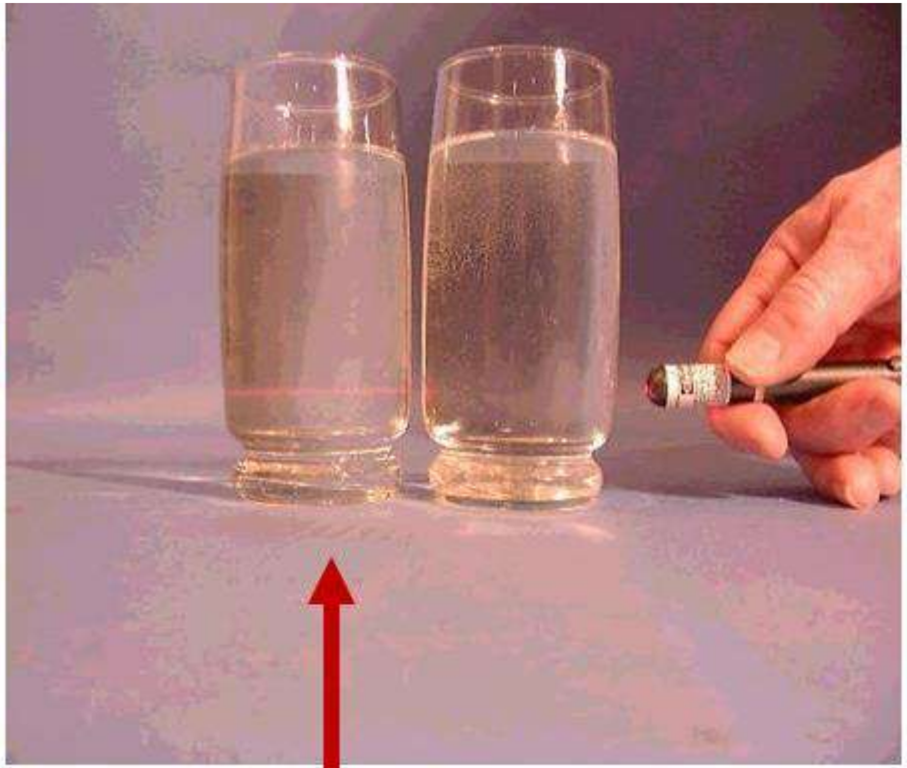
OPTICAL PROPERTIES OF COLLOIDS

1- THE FARADAY-TYNDALL EFFECT

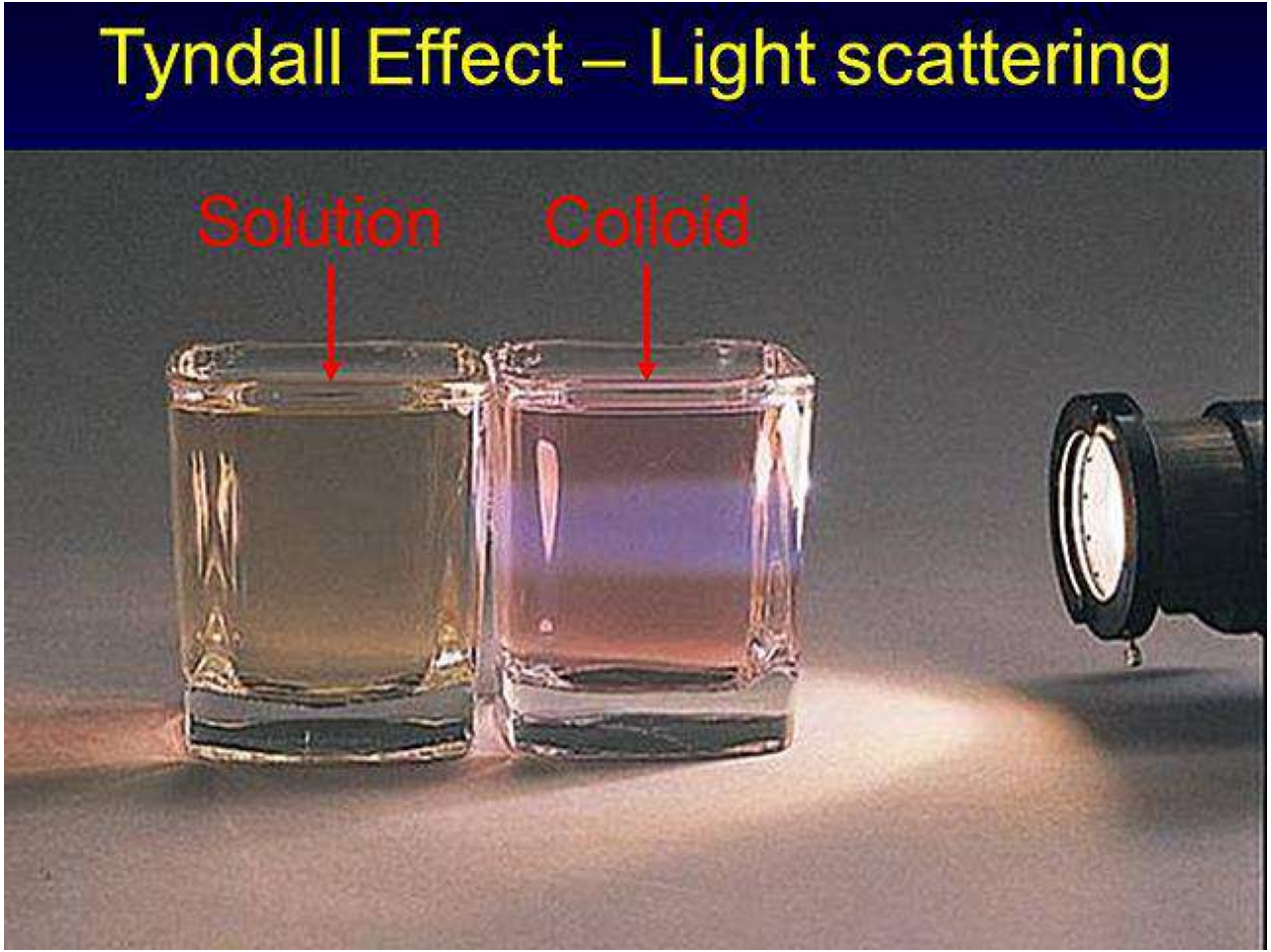
- When a strong beam of light is passed through a colloidal sol, a visible cone, resulting from the scattering of light by the colloidal particles, is formed.
- This is the Faraday–Tyndall effect.
- The ultramicroscope allows one to examine the light points responsible for the Tyndall cone.
- An intense light beam is passed through the sol against a dark background at right angles to the plane of observation, and the bright spots corresponding to particles can be observed and counted.



Colloid



Solution

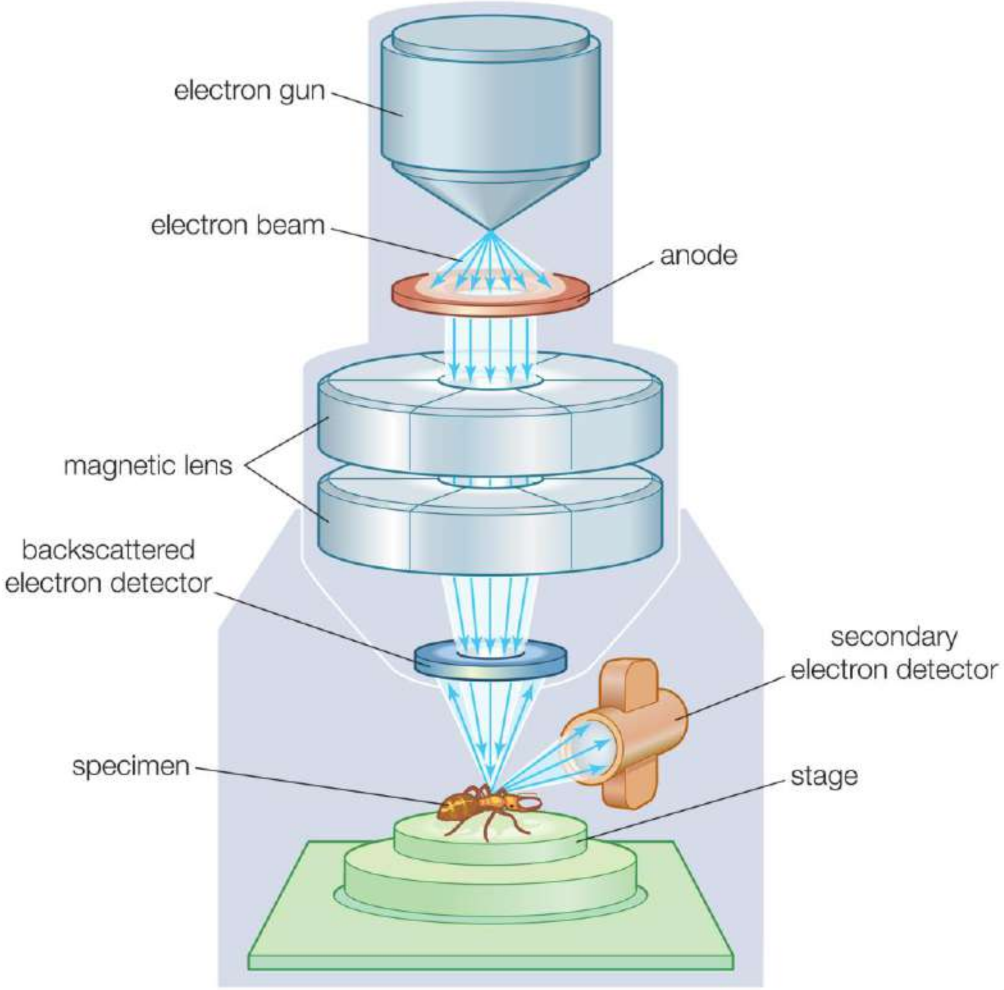


Tyndall Effect – Light scattering

2- ELECTRON MICROSCOPE

- The electron microscope, capable of yielding pictures of the actual particles, even those approaching molecular dimensions, is now widely used to observe the size, shape, and structure of colloidal particles.
- The success of the electron microscope is due to its high resolving power, which can be defined in terms of d, the smallest distance by which two objects are separated and yet remain distinguishable.
- The smaller the wavelength of the radiation used, the smaller is d and the greater is the resolving power.
- The optical microscope uses visible light as its radiation source and is able to resolve only two particles separated by about 20 nm (200 Å).

- The radiation source of the electron microscope is a beam of high energy electrons having wavelengths in the region of 0.01 nm (0.1 Å).



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3- LIGHT SCATTERING

- This property depends on the Faraday–Tyndall effect and is widely used for determining the **molecular weight of colloids.**
- It can also be used to obtain information on the shape and size of these particles.
- Scattering can be described in terms of the **turbidity, τ,** the fractional decrease in intensity due to scattering as the incident light passes through 1 cm of solution.
- At a given concentration of dispersed phase, the turbidity is proportional to the molecular weight of the lyophilic colloid.

- The turbidity can then be calculated from the intensity of the scattered light
- The molecular weight of the colloid can be obtained from the following equation:

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

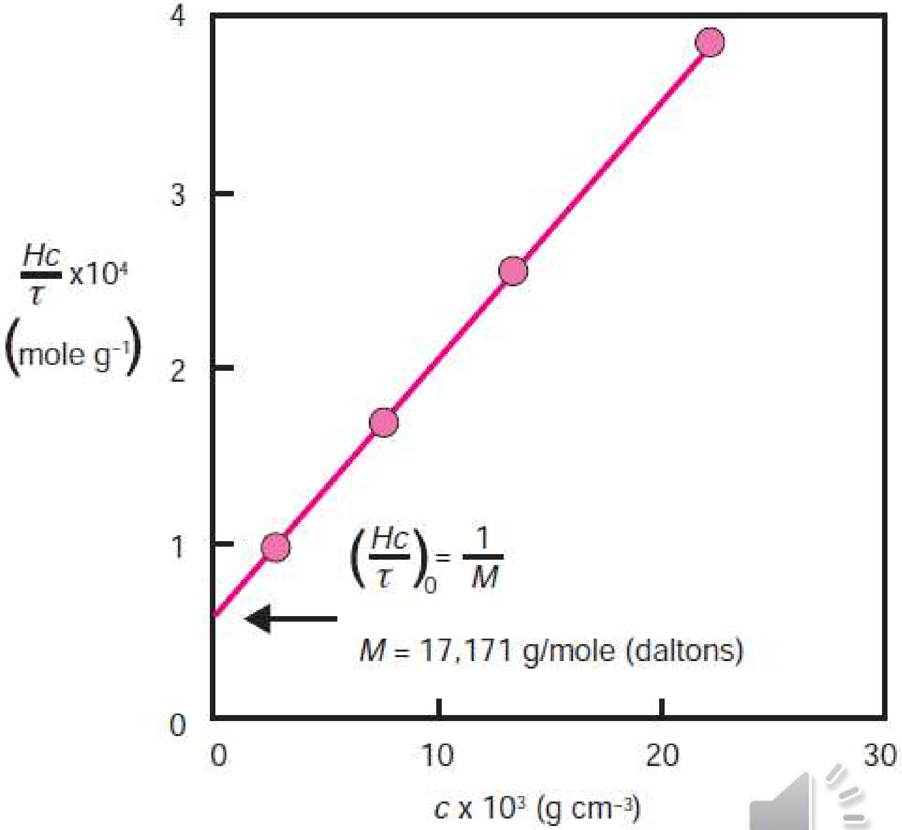
  - where τ is the turbidity in cm-1, c is the concentration of solute in g/cm3 of solution, M is the weight average molecular weight in g/mole or daltons, and B is an interaction constant. H is constant for a particular system

- H is constant for a particular system and is written as

$$\boxed{H = \frac{32\pi^3 n^2 (dn/dc)^2}{3\lambda^4 N}}$$

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

- where n (dimensionless) is the refractive index of the solution of concentration c(g/cm3) at a wavelength λ in cm-1, dn/dc is the change in refractive index with concentration at c, and N is Avogadro’s number.
- A plot of Hc/τ against concentration results in a straight line with a slope of 2B.
- The intercept on the Hc/τ axis is 1/M, the reciprocal of which yields the molecular weight of the colloid



4- 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 present 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 nearly constant; that is, $C_{monomer}$. The concentration of micelles can therefore be written as

$$\boxed{c_{\mathrm{micelle}} = c - c_{\mathrm{monomer}} \cong c - c_{\mathrm{CMC}}}$$

- The corresponding turbidity of the solution due to the presence of micelles is obtained by subtracting the turbidity due to monomers**, τmonomer = τCMC,** from the total turbidity of the solution:

$$\tau_{\text{micelle}} = \tau - \tau_{\text{CMC}}$$

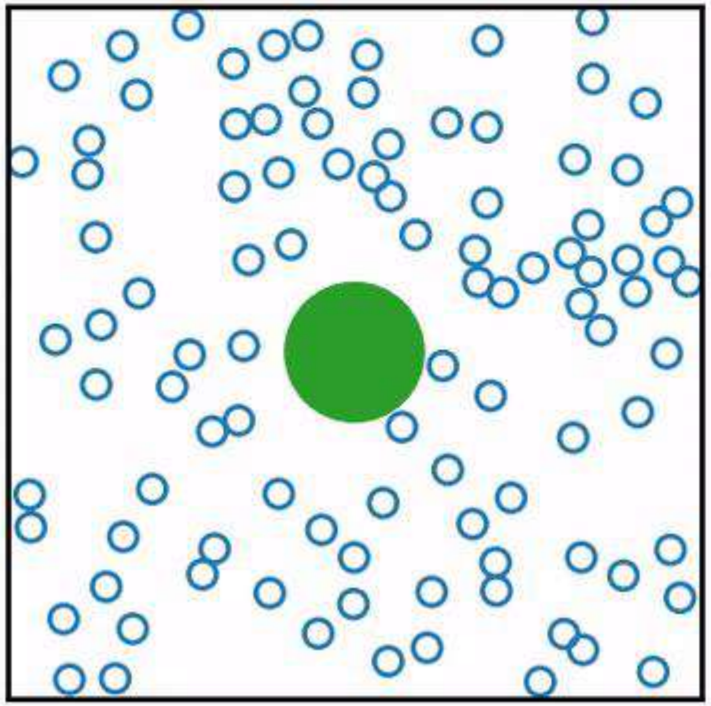
Accordingly, the equation is modified to

$$\frac{H(c - c_{\text{CMC}})}{(\tau - \tau_{\text{CMC}})} = \frac{1}{M} + 2B(c - c_{\text{CMC}})$$

KINETIC PROPERTIES OF COLLOIDS

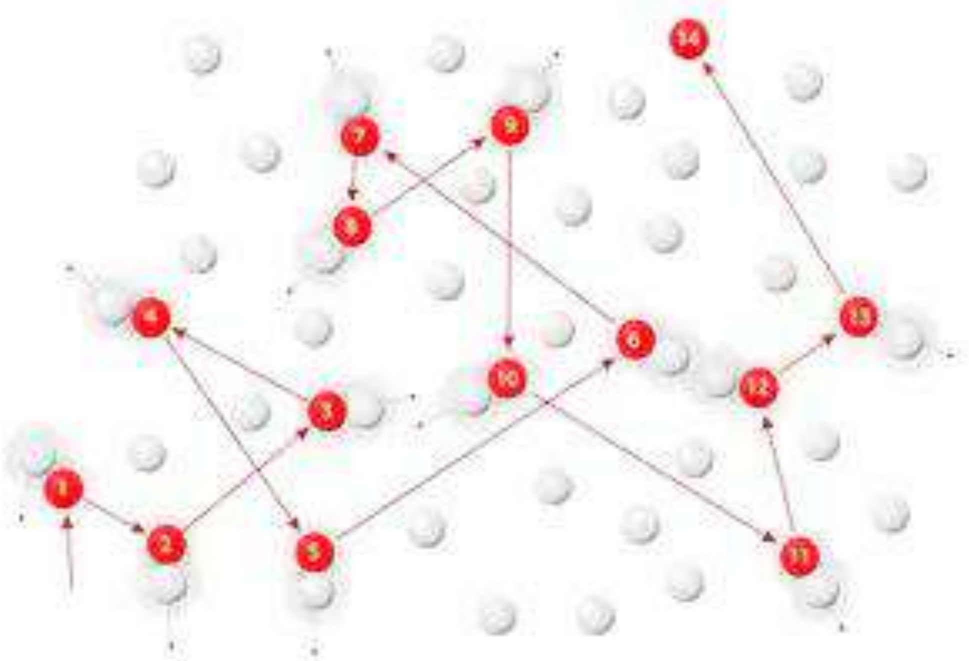
- several properties of colloidal systems that relate to the **motion** of particles with respect to the dispersion medium.

- The motion may be:
  - ✓thermally induced (Brownian movement, diffusion, osmosis),
  - ✓gravitationally induced (sedimentation),
  - ✓or applied externally (viscosity).

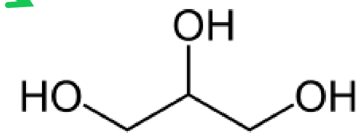


A-BROWNIAN MOTION

- Brownian motion describes the random movement of colloidal particles.
- The erratic motion, which may be observed with particles as large as about 5 μm, was explained as resulting from the bombardment of the particles by the molecules of the dispersion medium.
- The motion of the molecules cannot be observed, of course, because the molecules are too small to see.


Brownian motion

- The velocity of the particles increases with decreasing **particle size.**
- Increasing the **viscosity** of the medium, which may be accomplished by the addition of glycerin or a similar agent, decreases and finally stops the Brownian movement



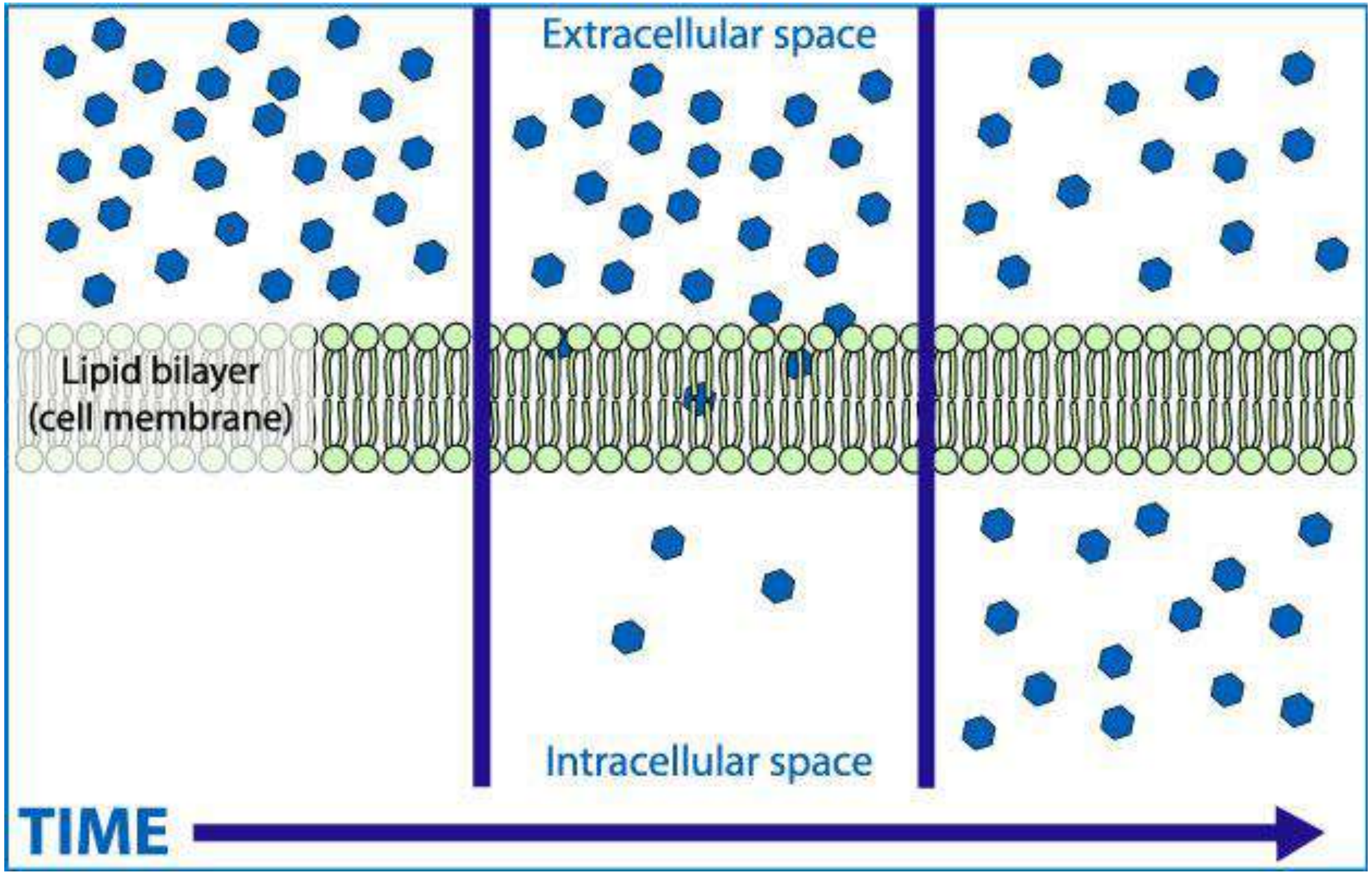
colorless,
odorless, viscous
liquid that is
sweet-tasting
and non-toxic

B- DIFFUSION

- Diffusion is a direct result of Brownian movement.
- Particles diffuse spontaneously from a region of higher concentration to one of lower concentration until the concentration of the system is uniform throughout.
- According to **Fick's first law**, the amount, dq, of substance diffusing in time, dt, across a plane of area, S, is directly proportional to the change of concentration, dc, with distance traveled, dx.
- Fick's law is written as

$$dq = -DS\frac{dc}{dx}dt$$

D is the diffusion coefficient, the amount of material diffusing per unit time across a unit area when dc/dx, called the concentration gradient, is unity. D thus has the dimensions of area per unit time.


Extracellular space
Lipid bilayer (cell membrane)
Intracellular space
TIME

- If the colloidal particles can be assumed to be approximately spherical, the following equation, suggested by Sutherland and Einstein6, can be used to obtain the **radius** of the particle and the particle **weight** or **molecular weight**:
- Sutherland–Einstein or the Stokes–Einstein equation

$$D = \frac{kT}{6\pi \eta r}$$

or

$$D = \frac{RT}{6\pi \eta r N}$$

- where D is the diffusion coefficient obtained from Fick's law as already explained, k is the Boltzmann constant, R is the molar gas constant, T is the absolute temperature, η is the viscosity of the solvent, r is the radius of the spherical particle, and N is Avogadro's number.

- The measured diffusion coefficient can be used to obtain the **molecular weight** of approximately spherical molecules, such as egg albumin and hemoglobin, by use of the equation:

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

- where M is molecular weight and [v with bar above] is the partial specific volume (approximately equal to the volume in cm3 of 1 g of the solute, as obtained from density measurements).

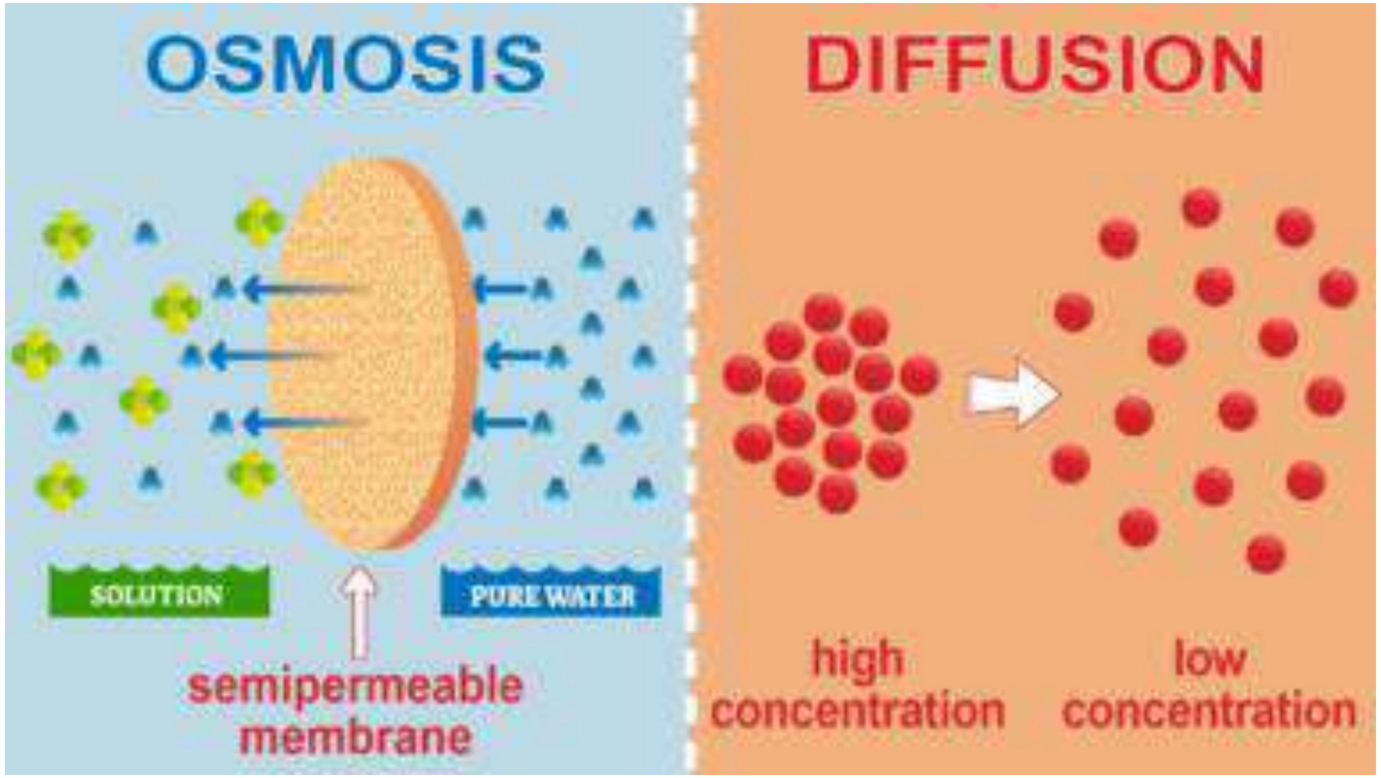
- Analysis of the equations allows us to formulate the following three main **rules of diffusion:**

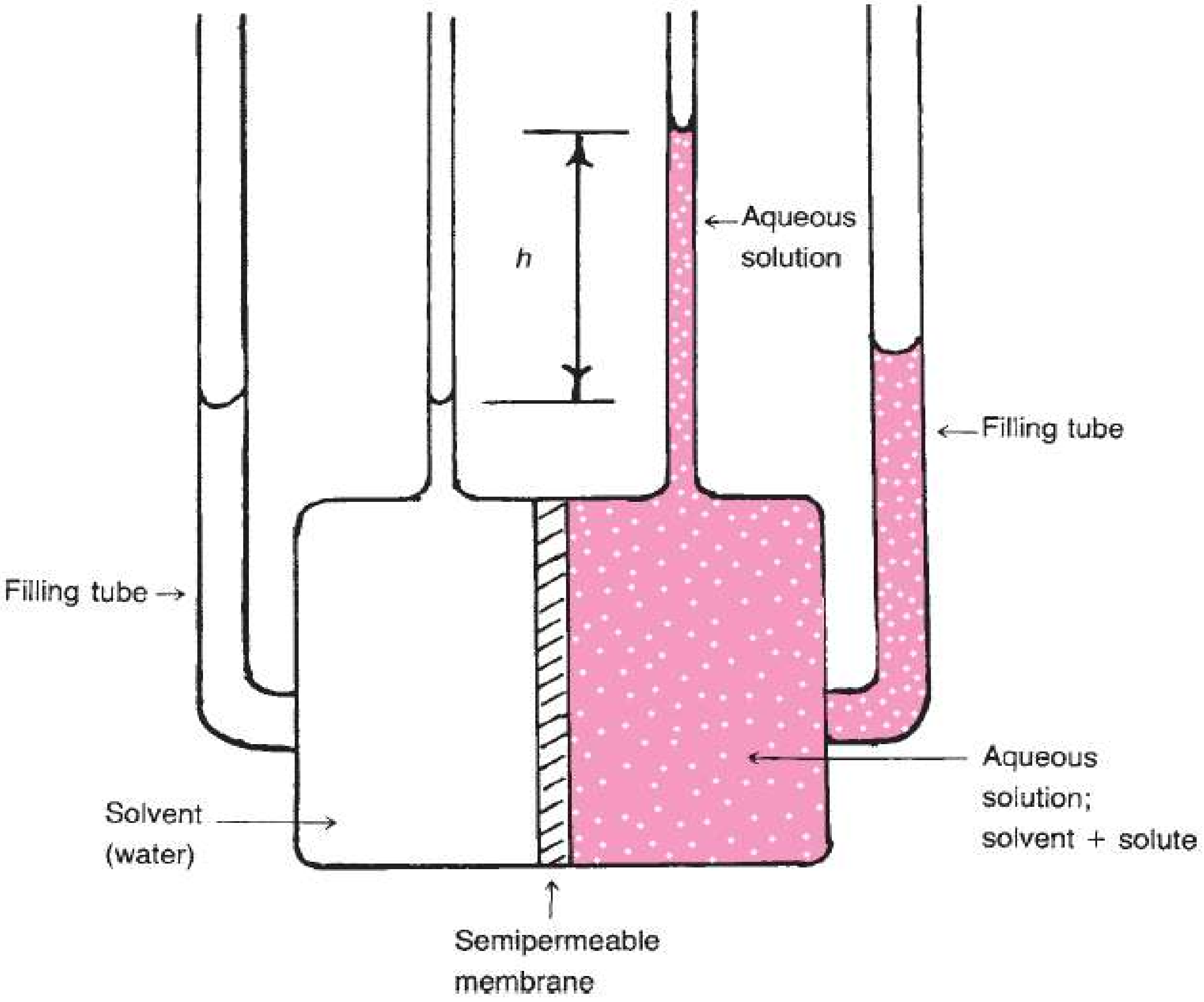
  (a) the velocity of the molecules increases with decreasing particle size;

  (b) the velocity of the molecules increases with increasing temperature;

  (c) the velocity of the molecules deceases with increasing viscosity of the medium

C- OSMOTIC PRESSURE




h
Aqueous solution
Filling tube
Filling tube
Aqueous solution; solvent + solute
Solvent (water)
Semipermeable membrane

- The osmotic pressure, π, of a **dilute** colloidal solution is described by the **van't Hoff equation**:

$$\boxed{\pi = cRT}$$

where c is molar concentration of solute.

- This equation can be used to calculate the **molecular weight** of a colloid in a dilute solution.
- Replacing c with cg/M, in which cg is the grams of solute per liter of solution and M is the molecular weight, we obtain

$$\boxed{\pi = \frac{c_g}{M} RT}$$

then,

$$\boxed{\frac{\pi}{c_g} = \frac{RT}{M}}$$

- The quantity π/cg for a polymer having a molecular weight of, say, 50,000 is often a linear function of the concentration, cg, and the following equation can be written:

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

where B is a constant for any particular solvent/solute system and depends on the degree of interaction between the solvent and the solute molecules

$$y = \overset{\text{slope}}{m}x + \underset{\text{y-intercept}}{b}$$

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

- plot of π/cg against cg generally results in one of three lines depending on whether the system is ideal (line I) or real (lines II and III).

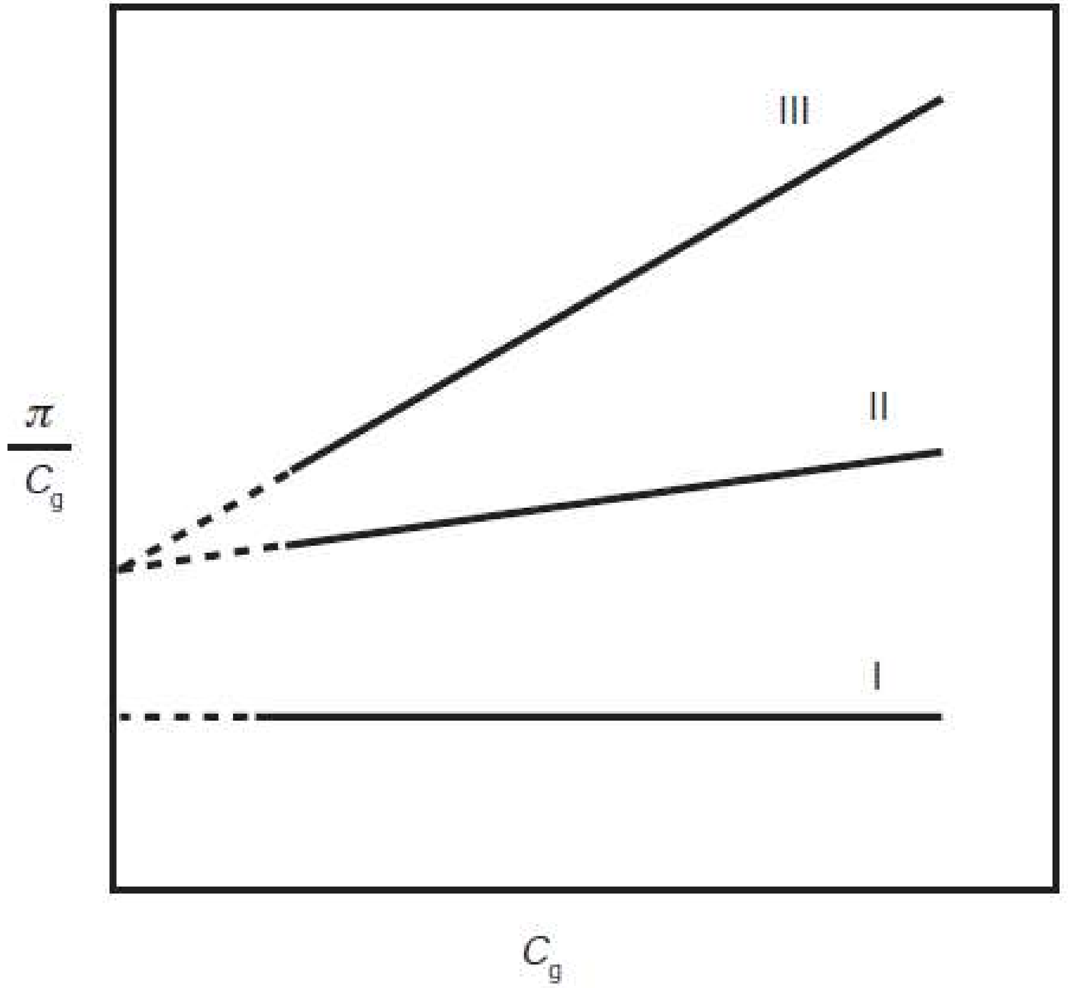
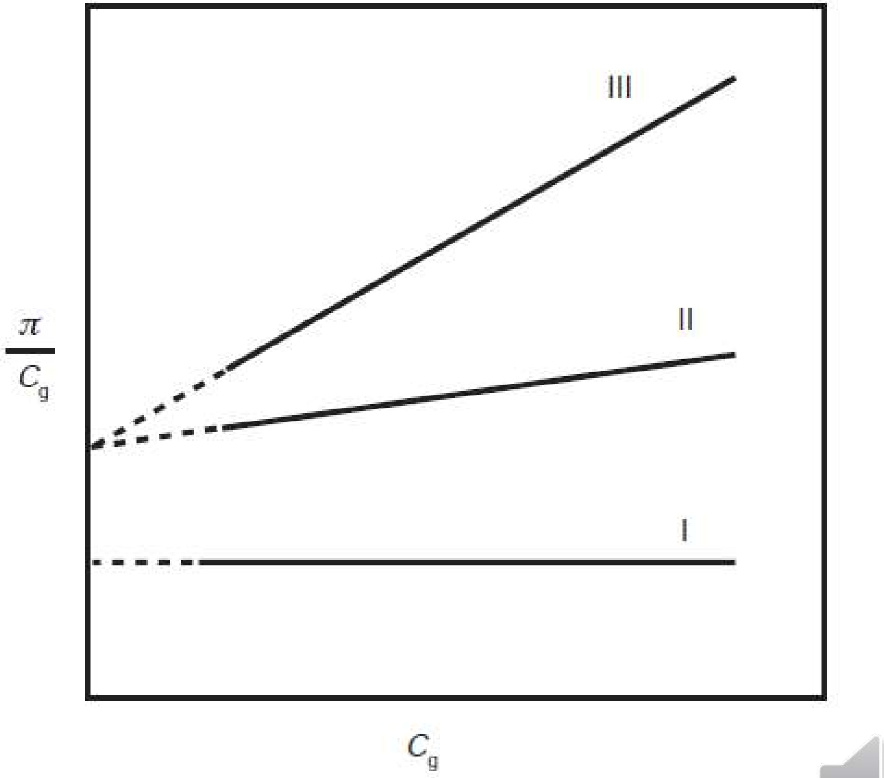


Fig. 16–8. Determination of molecular weight by means of the osmotic pressure method. Extrapolation of the line to the vertical axis where $c_g = 0$ gives RT/M, from which M is obtained. Refer to text for significance of lines I, II, and III. Lines II and III are taken to represent two samples of a species of hemoglobin.

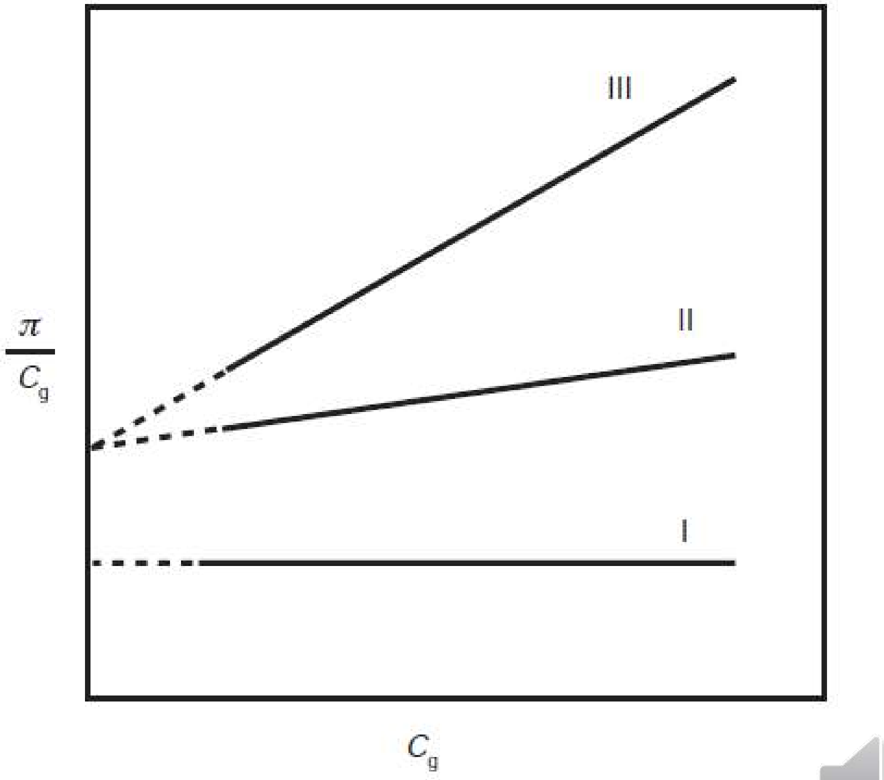
- The intercept is RT/M, and if the temperature at which the determination was carried out is known, the molecular weight of the solute can be calculated.
- In lines II and III, the slope of the line is B, the **interaction constant**.
- In line I, B equals zero and is typical of a dilute spherocolloidal system.
- Line III is typical of a linear colloid in a solvent having a high affinity for the dispersed particles.
- Such a solvent is referred to as a —good‖ solvent for that particular colloid.

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



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

- Line II depicts the situation in which the same colloid is present in a relatively poor solvent having a reduced affinity for the dispersed material.

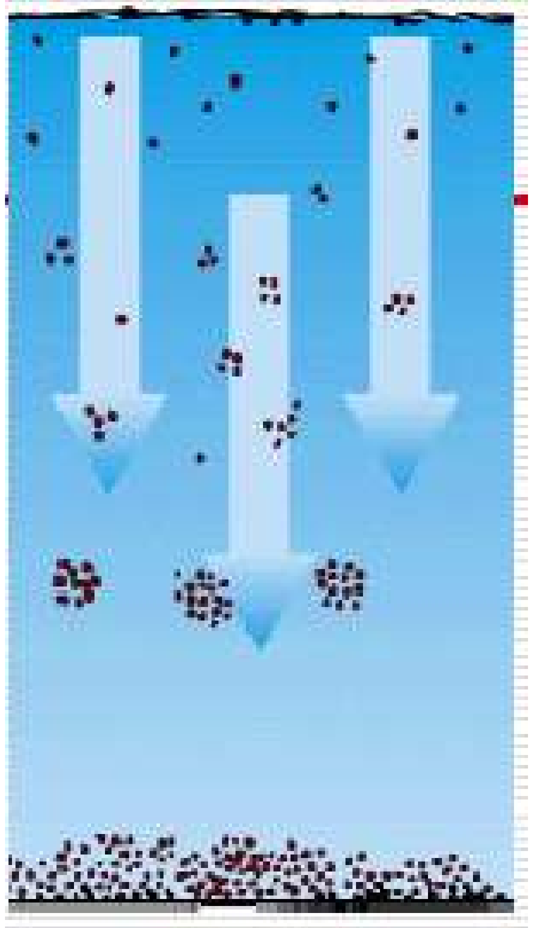


D- SEDIMENTATION

- The velocity, v, of **s**edimentation of spherical particles having a density ρ in a medium of density ρ0 and a viscosity η0 is given by **S**tokes's law:

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

where g is the acceleration due to gravity.



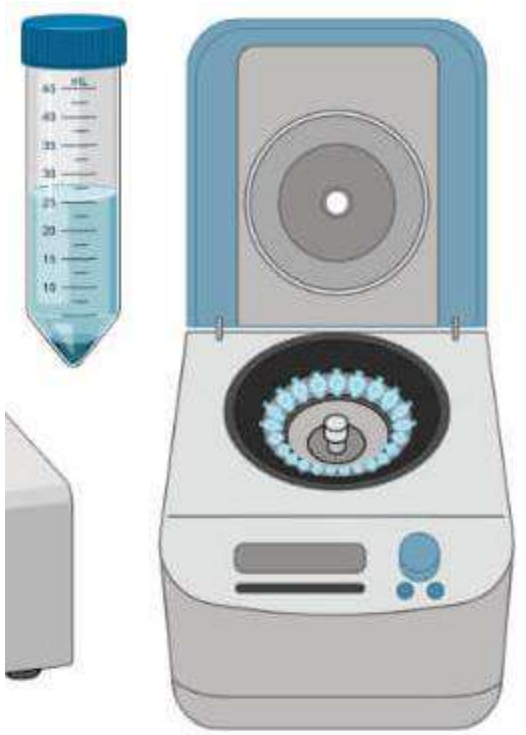
$$\boxed{v = \frac{2r^2(\rho - \rho_0)g}{9\eta_0}}$$

- If the particles are subjected only to the force of gravity, then the lower size limit of particles obeying Stokes's equation is about 0.5 μm.
- This is because Brownian movement becomes significant and tends to offset sedimentation due to gravity and promotes mixing instead.
- Consequently, a stronger force must be applied to bring about the sedimentation of colloidal
- This is accomplished by use of the ultracentrifugecan produce a force one million times that of gravity.

- In a centrifuge, the acceleration of gravity is replaced by ω 2 x, where ωis the angular velocity and x is the distance of the particle from the center of rotation

$$v = \frac{dx}{dt} = \frac{2r^2(\rho - \rho_0)\omega^2 x}{9\eta_0}$$

- The speed at which a centrifuge is operated is commonly expressed in terms of the number of revolutions per minute (rpm) of the rotor. It is frequently more desirable to express the rpm as angular acceleration (ω 2 x) or the number of times that the force of gravity is exceeded.



EXAMPLE

A centrifuge is rotating at 1500 rpm. The midpoint of the cell containing the sample is located 7.5 cm from the center of the rotor (i.e., $x = 7.5$ cm). What is the average angular acceleration and the number of g's on the suspended particles?

$$\begin{aligned}\text{Angular acceleration} &= \omega^2 x \\ &= \left(\frac{1500 \text{ revolutions}}{\text{minute}} \times \frac{2\pi}{60}\right)^2 \times 7.5 \text{ cm} \\ &= 1.851 \times 10^5 \text{ cm/sec}^2\end{aligned}$$

$$\text{Number of } g\text{'s} = \frac{1.851 \times 10^5 \text{ cm/sec}^2}{981 \text{ cm/sec}^2} = 188.7\ g\text{'s}$$

that is, the force produced is 188.7 times that due to gravity.

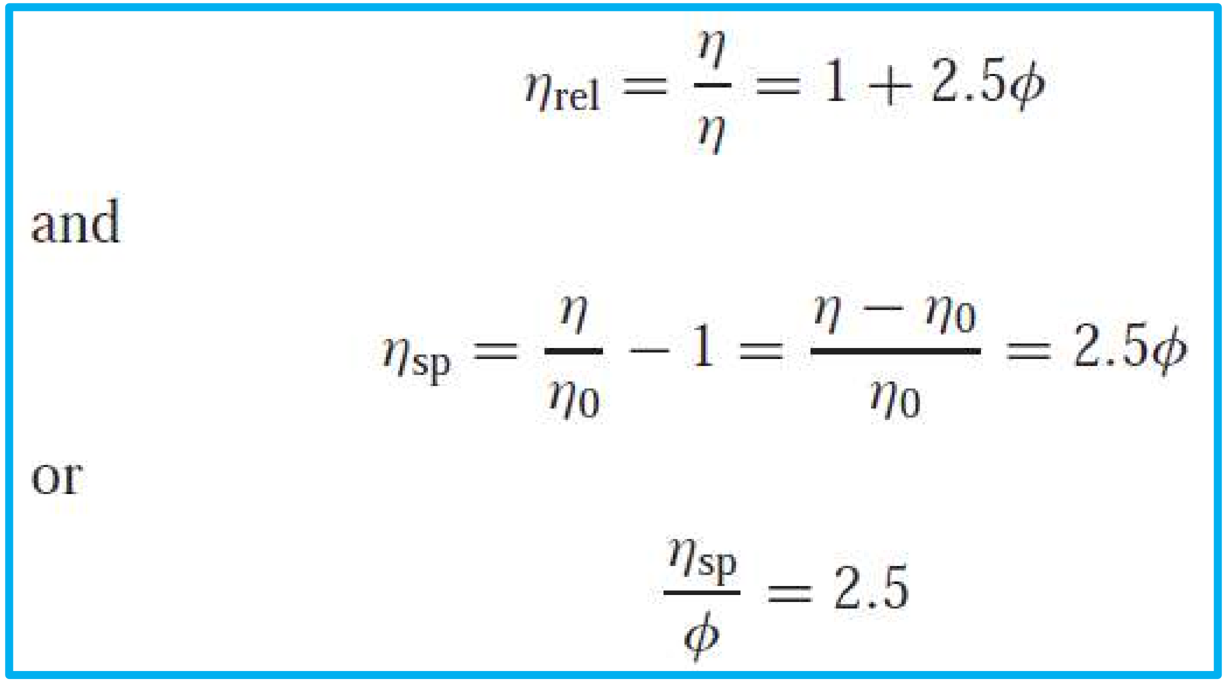
E- VISCOSITY

- Viscosity is an expression of the resistance to flow of a system 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.
- viscosity data can be used to obtain the **molecular weight** of material comprising the disperse phase
- equation of flow applicable to dilute colloidal dispersions of spherical particles

$$\boxed{\eta = \eta_0(1 + 2.5\phi)}$$

$\eta 0$ is the viscosity of the dispersion medium and η is the viscosity of the dispersion when the volume fraction of colloidal particles present is ϕ.

- The volume fraction is defined as the volume of the particles divided by the total volume of the dispersion; it is therefore equivalent to a concentration term.
- Both η0 and η can be determined using a capillary viscometer
- Several viscosity coefficients can be defined with respect to this equation.
  - ✓These include relative viscosity (ηrel), specific viscosity(ηsp), and intrinsic viscosity (η).



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

and

$$\eta_{\mathrm{sp}} = \frac{\eta}{\eta_0} - 1 = \frac{\eta - \eta_0}{\eta_0} = 2.5\phi$$

or

$$\frac{\eta_{\mathrm{sp}}}{\phi} = 2.5$$

- Because volume fraction is directly related to concentration

$$\boxed{\frac{\eta_{\mathrm{sp}}}{c} = k}$$

where c is expressed in grams of colloidal particles per 100 mL of total dispersion

- For highly polymeric materials dispersed in the medium at moderate concentrations, the equation is best expressed as a power series

$$\boxed{\frac{\eta_{\mathrm{sp}}}{c} = k_1 + k_2 c + k_2 c + k_3 c^2}$$

- By determining η at various concentrations and knowing η0, one can calculate ηsp
- If ηsp/c is plotted against c and the line extrapolated to infinite dilution, the intercept is k1
- This constant, commonly known as the intrinsic viscosity, [η], is used to calculate the approximate molecular weights of polymers.

$$\boxed{[\eta] = KM^a}$$

where K and a are constants characteristic of the particular polymer–solvent system

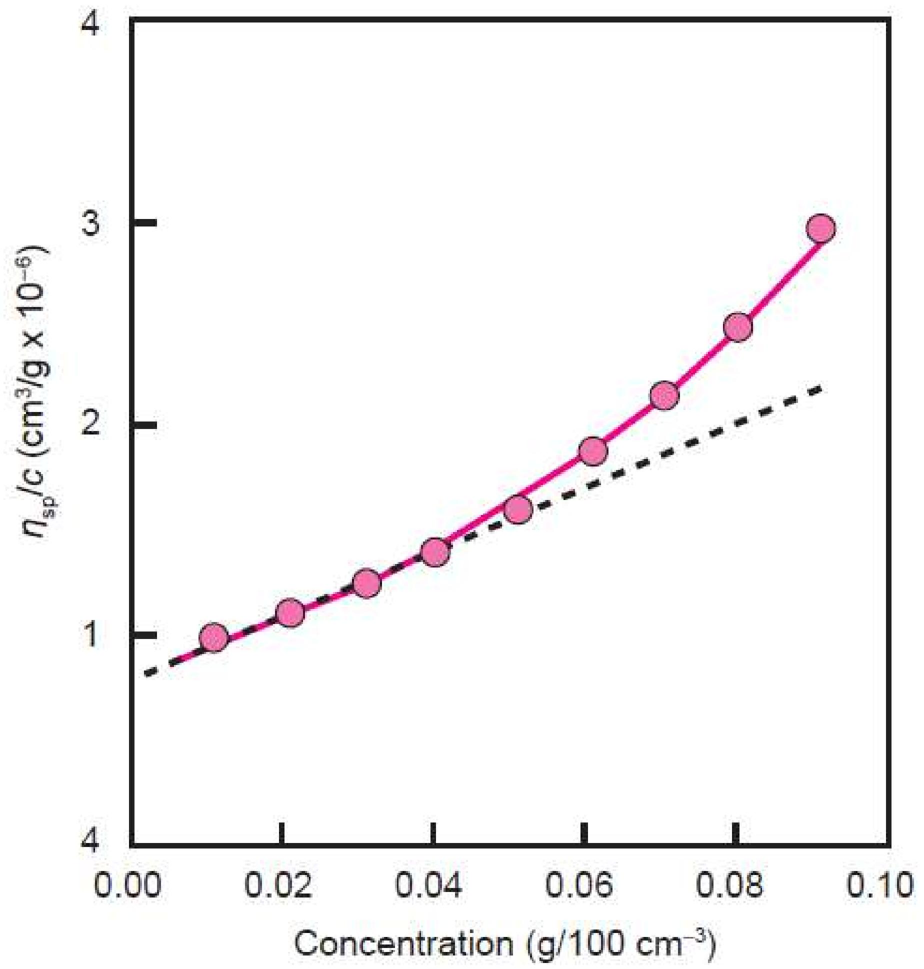


Fig. 16–10. Determination of molecular weight using viscosity data.

- The characteristics of polymers used as substitutes for blood plasma (plasma extenders) depend in part on the molecular weight of the material.
- The shapes of particles of the disperse phase affect the viscosity of colloidal dispersions.
- Spherocolloids form dispersions of relatively low viscosity, whereas systems containing linear particles are more viscous