

**Introduction to colloids**  
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**Lecture-28**

**Suspensions, emulsions and foams; nanoparticle application; aggregation, sedimentation and phase separation**

Welcome back, so in today's video lecture, I mean, from now onwards, we will look at the module number four that is liquid solid interfaces, okay, so we'll first start with the overview of the colloids, okay, we have taken colloid as as a best example of liquid solid interface okay We'll first start with some understanding of colloids and then we can, you know, as we move on, we'll try to cover the other topics that are listed under the module number four. Okay. So, let's begin. Right

(Time: 1:02 min)

**Importance of colloids from the perspective of liquid-solid interface**

**Surface area** 

- ✓ High surface to volume ratio

**Electrostatic** 

- ✓ Charged colloidal particles create electric double layers at the interface.
- ✓ This leads to phenomena like zeta potential, which influences particle-particle interactions and overall system stability.

**Surface Energy and Stability** 

- ✓ The interaction bw the dispersed phase and the continuous phase governs the stability of colloids.
- ✓ Electrostatic and steric forces at the liquid-solid interface determine the aggregation or dispersion.

**Adsorption** 

- ✓ Colloidal particles readily adsorb molecules, ions, or surfactants at their surface.
- Water purification (adsorbing pollutants onto colloidal surfaces).
- Drug delivery systems (adsorbing active ingredients).

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So why one has to study the colloidal particles is something we need to understand, in this slide. So, let's say, whenever we deal with the liquid solid interface system, often that we encounter is the colloidal system. For example, you know, you may deal with, you

know, dispersion, emulsion and various formulations, let's say in pharmaceutical industries, cosmetic industries, paint industries.

So we often encounter, you know, in various applications, we deal with the colloidal systems, right? one or other the ways we always deal with colloidal system so which is a good example of liquid solid interface okay so we have taken this system as an example so that you know by understanding you know the concept of stability of colloidal system we can understand various fundamental forces that are required to understand, to keep them stable, to improve the stability of the colloidal system. So that is why we need to understand the different types of forces, like Van der Waals forces of attraction, electrostatic repulsion, the DLVO force, steric repulsion, and all those aspects is very important. when we talk about the stability of colloids. From now onwards, we are going to look at the types of forces that is from the fundamental point of view.

You will also understand in a general case how you can compute the interaction between the pairwise interaction between two macro objects or planar objects. Later, you can apply the same concepts for, you know, between the particle system, colloidal system. It can be spherical particle, it can be non-spherical particle, but you will be able to still apply those concepts later on. uh, so we want to, uh, as we move on we will also look at several ,uh ,you know, topics like you know, uh ,the uh, electro-kinetic phenomena, right ,that is also going to be covered in this module okay that is also a very good example, uh ,there also we will look at the colloidal system, charge the colloidal system which is a very good example for liquid solid interface system right and why, how we measure zeta potential and all those aspects okay so what is known as electrophoresis those concept we will be able to see in this module number four okay and so the question that we asked to us why we should understand colloid that is very much important because we have chosen you know as a liquid solid interface so we have chosen colloid as a good example of liquid solid interface system okay and it is also useful it will also be helpful in a way that we will be able to connect very well with you know based on the You know, our day-to-day, you know, examples, right, that we often encounter, right?

Various formulations that we know very well, right? Say, for example, dispersion, emulsion, right? And in these cases, you will be dealing with colloidal system. And this is a very good example of a liquid-solid interface system. So, to start with, we'll understand what the importance of colloid from the perspective of liquid-solid interface is. So let us understand there are various advantages when we want to study the colloidal system under liquid-solid interface. So, the surface area is drastically varied when we deal with the colloidal system. okay and the electrostatic concepts can be readily applied say for example if you deal with charged colloidal particle okay there is something called electrical double layer concept at the interface that we are going to look at as we move on And so the phenomena in, you know, at least in electro-kinetic phenomena, we will see

how the zeta potential, right, which is basically due to the electrical...uh double layer at the interface, right and how it influences the particle particle interactions and overall system stability, how by measuring zeta potential one can, uh, you know, comment on the stability of the system ,okay, that is something we can understand from the electrostatic point of view there is something called surface charge surface energy and stability

So basically, when you deal with the system like emulsion, where you have dispersed phase, like let's say you are dealing with oil water system, oil in water emulsion. So, oil will be dispersed phase and water will be a continuous phase. And what governs the stability of colloids? So, that is something very important when we talk about surface energy and stability. And what is the role of electrostatic and steric forces at the liquid-solid interface? How you can actually prevent the aggregation, right? okay, how you can improve the stability of the dispersion. So, those aspects we can, you know, one has to, you know, study from the perspective of liquid-solid interface and adsorption.

So, let us say if we study, you know, if you understand the role of the colloidal particle, okay, on adsorb on, you know, in adsorbing molecules ions or surfactants at the surface ,okay, so where it is important is in water purification you can use this colloidal system this you know based on this adsorption phenomena we can try to you know eliminate pollutants by adsorbing them onto the colloidal surface so, so by looking them in details about the adsorption of the pollutants onto the colloidal surface we can explore ,exploit these colloidal particles right so we can explore the explore various possibility of you know the colloidal particles and its application in water purification and also in drug delivery systems. So, in drug delivery, what is so important is how you can carry these active ingredients. So, if the particle has good affinity towards the active ingredients, can this be absorbed onto the colloidal surface? In such case, colloidal particle can be used as a carrier, right? So that is, so we need to understand, so there are various, you know, advantages, right, when we understand, when we study the importance of colloids, right, from the perspective of liquid-solid interface, right, right, in details, okay?

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### Colloids: Introduction

Colloid is a substance dispersed in a medium and have a size range between 1 nm to few microns

Continuous phase	Dispersed phase	Examples
Gas	Liquid	Fog, mist, aerosol
Gas	?	Smoke
Liquid	?	Foam
Liquid	Liquid	Emulsion
Liquid	Solid	Sol, Colloidal solution

**Common Examples**



**Milk**

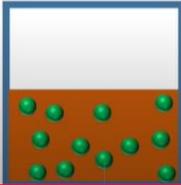
Glass of milk diagram by Marina Shemesh is licensed under CC by SA 2.0



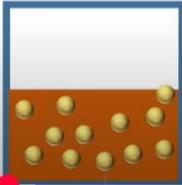
**Drop of ink**

Clear drinking glass with blue ink diagram by unknown author is labelled for reuse

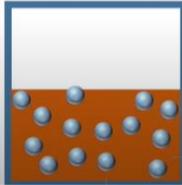
Liquid-Solid  
(Suspension)



Liquid-Liquid  
(Emulsions)



Liquid-Gas  
(Foams)



Dispersed phase  
Continuous phase

9:03 / 29:33

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So, let's understand, you know, the, some of the basics of, you know, let us try to give you, let me try to give you some overview of colloids and particles. Okay. So, as you know, colloid is a substance dispersed in a medium and usually in the size range between one nanometer to a few microns. Okay. Right. This is the typical definition for colloid. Right. So, I have listed several examples, you know, for you to relate, you know, quickly. Say, for example, if we talk about system, liquid solid system, sorry, liquid gas system.

So we are talking about liquid gas system. But although this model is all about liquid solid system, we will also understand colloidal particles from other perspectives. For example, liquid gas system. We know some examples like fog, mist, aerosol. So, these are examples of colloidal system where Here, liquid is dispersed in gas.

Gas phase is going to be the continuous phase. In the case of smoke, the dispersed phase will be, although I have given here a question mark, the dispersed phase here will be solid. And in the case of foam, the dispersed phase here will be gas. Right. And in the case of liquid-liquid interface system, although we mentioned emulsion, here you also have, unlike the surfactant, if you use, you know, nanoparticle or particle system, such emulsion is called a pickering emulsion. So, in such case, you can still put this system under the, you know, liquid-solid brackets, right, under the liquid-solid interface systems. So, this one is a good example of you know colloidal solution where you have a

continuous phase which is a medium and dispersed phase is a solid which is nothing but colloidal particle right. So, a good example is the dispersion or colloidal solution okay.

So, if you want to understand the milk is a good example of an emulsion right. OK, because it contains about 90 to 92 percent water and you have about, you know, fat and fat globules and protein particles. So here fat globules are dispersed in the continuous medium that is water and protein particles are used as a stabilizer to stabilize these fat globules. Right. This is a good example of emulsion. That's why you can't see this, you know, although there are immiscible mixtures, because these fat globules are readily, I mean, you know, finely dispersed in the continuous medium, that is water, using the stabilizer called protein particles, right? That's why this milk is .. called as an emulsion, right ,it's a good example of an emulsion, we talk about ink, okay, ink particle is colloidal system because the pigment and or the dye that is dispersed in water is colloidal system , okay ,it shows a good you can see that this pigment particle if you shine a light you can see this pigment particles are scattered everywhere so it can display you know Tyndall effect so this system you know can, you know, respond to Tyndall effect okay and it can scatter the lights right uh so that's why this glowing uh color comes because of the Tyndall effect right ,right so that you know already uh let's say we uh so here I have illustrated three uh best examples for you, right, to uh to understand uh various systems, let's say we talk about suspension okay liquid solid suspension right and here The solid here is the particle itself. The spherical object given here is the particle system itself, right.

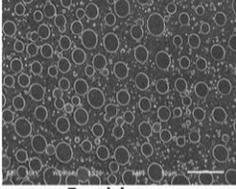
So, it is dispersed in the medium called water, right. This is a good example of dispersion, and it is a good example of liquid-solid interface, okay. Right. In the case of emulsion, we talk about pickering emulsion. Let's say pickering emulsion means when we use particle as a stabilizer instead of surfactant, such emulsion is called pickering emulsion. Right. So, in this case, you see that the droplet, let's say if we talk about water in oil or oil in water emulsion, here oil, these droplets are oil droplets. okay, but stabilized by the particle system or stabilizers, right? So, this spherical object represents the droplet only, but around this droplet, the particles are also, you know, confined to the, I mean, particles are, you know, acting as a stabilizer and they stabilize these droplets, right? Right.

So this spherical object as such is a droplet. Okay. But the particles are part of this spherical objects that is a droplet. Right. The third one is the foam. Here it is a good example of a liquid gas system. Okay. So here the spherical object is nothing but a bubble. Okay. It could be a nano, or micron sized bubble stabilized by the particle system. Here, the spherical particle or particle is part of the bubble shown here, right? And the bubble is a dispersed phase, which is nothing but a gas phase dispersed in

a medium called liquid. So, this is a good example of foam. I mean, foam is a good example of liquid gas system, okay? Right.

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**Colloids: Application as stabilizers in food, cosmetics, pharmaceuticals, etc.**



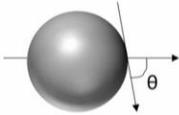
**Emulsion**



**Foam**

Wikipedia contributors. (2020, January 18). Microfoam.

Contact angle ( $\theta$ ), Just like HLB for surfactant, is an important parameter to describe w/o or o/w emulsion.



**Emulsion:**

- Dispersion of one liquid into another liquid in the form of droplets stabilized by surfactants.

**Pickering Emulsion:**

- If the droplets are stabilized by particles then it is called as Pickering emulsion.

**Foam:**

- Dispersion of one gas into another liquid in the form of droplets stabilized by surfactants.

**Significance:**

$$\Delta G = -\gamma_{ow}A_{ow}(1 \pm \cos \theta)^2$$

$$-\Delta G_a = \Delta G_{detachment}$$

Colloidal silver of size lesser than 100 nm dispersed in paint is used as antimicrobial coating

15:30 / 29:33

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So where is this colloidal system, I mean, colloidal particles are, you know, applicable. I mean, the application, where are these particle systems, I mean, where we can use these colloidal systems, right? That is the question that we are asking now.

uh so it can be uh you know uh you can see that there are various applications as in uh emulsion, in food cosmetics and pharmaceutical applications okay and these are emulsion droplets uh SEM images of emulsion droplets right and and uh you know uh What is shown in this schematic is a foam. It is a good example of liquid gas system. Like we have seen in our module number 2, when we dealt with the contact angle, surfactant and all, we described that the contact angle is just like HLB number that we defined for surfactant. The contact angle is very important for the particle system because that is what decides whether it will stabilize water in oil emulsion or oil in water emulsion, okay.

So, theta or contact angle or theta is, you know, a very important parameter, right, in this context, okay. So, you know what emulsion is, Pickering emulsion, foam. And this part of this, you know, this equation that gives detachment energy equation, we have also discussed during module number, I think, 2, right? So, and this equation, you know, signifies that, you know, as a function of the size of the particle, if the size of the particle goes up, the Gibbs detachment energy also goes up. And it can also be controlled using the theta, that is, contact angle of the particles, right? Okay, so just to give you another

example, let's say silver nanoparticle of size less than under nanometer dispersed in paint is used as antimicrobial coating in hospital setting. This kind of coating is developed to, you know, you know, to eliminate or to, you know, to prevent microbial and bacterial, you know, from the bacterial diseases, right? So, in hospital setting, this kind of special coatings, right, paints are applied on the wall so that, you know, this paint can act as an antimicrobial coating, right? It can keep the surface away from the bacteria and, you know, other microorganisms, right so that is the one important this is actually, you know, the latest example I mean latest development, right, that took place in paint industry, right yeah ,

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**What is colloidal stability?**



❖ Colloidal stability stands for the ability of dispersion to resist coagulation.

Electrostatic stability	Steric stability
<ul style="list-style-type: none"><li>• When the electrical double layers of two particles overlap, electrostatic force results.</li><li>• It serves to counteract the attraction due to vdw force.</li><li>• It depends on the charges of the system, electrolyte of the medium, and separation distance.</li></ul>	<ul style="list-style-type: none"><li>• A suitable polymer that adsorbs on the particle surface may be added to the dispersion.</li><li>• The resulting polymer layer masks the attraction and provide a repulsive force due to steric effect.</li><li>• The role of polymers in a dispersion is more complex</li></ul>

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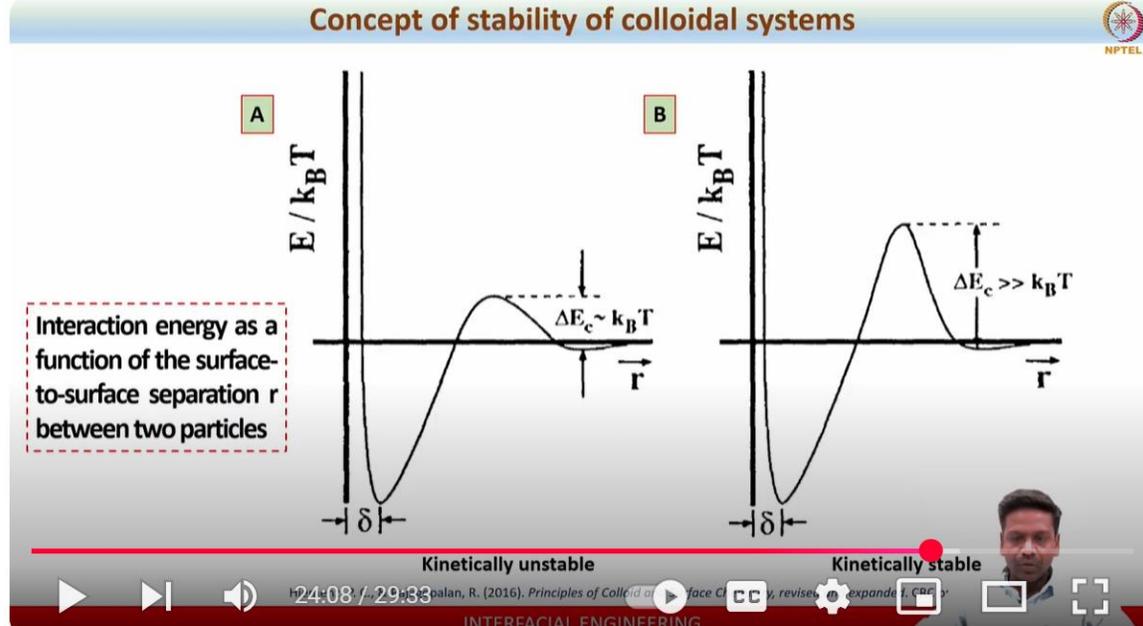
So, colloidal stability is very important that we are going to address now. So, in understanding colloidal suspension, emulsion and all that, what we are trying to emphasize is that it is important for us to, let's say, prepare a stable system, whether it is an emulsion, whether it is a formulation, important formulation, whether you want to maintain a good shelf life of the product. So, in every aspect, what is very important to address is what is the colloidal, I mean, how you can maintain the stability of, you know, colloidal system or suspension or dispersion, right? So, that is the question. So, what is causing them, you know, to attain that stability is the uh coagulation or dispersion okay this is because of the aggregation tendency uh driven by the van der waals force of attraction so whenever there is um van der waals force uh you know but take you know act i mean uh between particles take place there will be they will tend to aggregate right so we want to avoid such aggregation uh so you know by means of some, uh you know ,counteracting force right so one such force is the electrostatic repulsive force, right, that

actually this electrostatic repulsive force, uh you know, will help achieve the required stability, right? So, it can overcome the aggregation, right, which is caused due to the Van der Waals force of attraction. So, when the electrical double layers of two particles overlap, we are going to look at different double layer models. There you will understand what is known as the electrical double layer overlap. And the electrostatic force results.

So it can be if it results in electrostatic repulsive force, it will prevent or it will help us overcome the aggregation and all those aspects. So, it serves to counteract the attraction due to Van der Waals force.

So, this electrostatic force is very important. to counteract the attraction due to Van der Waals force and so this electrostatic force depends on the charges of the system okay and if you tune the charges of the system you can tune the electrostatic repulsion, electrolyte of the medium okay and separation distance, these things we will see these are the parameters that govern the electrostatic repulsion and the other hand you can also understand you know maintain stability you know by you know imparting the steric stability right so let's say if you have particle system And there is some polymer that can absorb on the particle surface. And by adding the polymer into the colloidal suspension, we can improve the stability of the system because this polymer absorbs on the particle surface. And what will happen is this polymer layer marks the attraction and provide a repulsive force due to steric effect because when polymer layer is formed around the surface let's say if you have particle surface here and you have the polymer brushes when you grab these polymer brushes on the surface of the particles So basically what happens is that, you know, when two particles, you know, come very close to each other and there will be overlap, right? The polymer molecules will overlap and there will be a steric hindrance that will not allow the particle to, you know, come very close or penetrate, right? So, this will act as a repulsion, right? It will provide a repulsive force, right? So due to this steric effect, so because this repulsive force is, you know, generated due to this steric effect, we call such forces, forces, steric, you know, repulsive force, right? Repulsive force due to steric action, right? right or steric hindrance right here the role of polymers in a dispersion is more complex although it is you know you know one can improve the stability, but it is very important to understand the interaction between particle and polymer and sometime it becomes very complex system okay right

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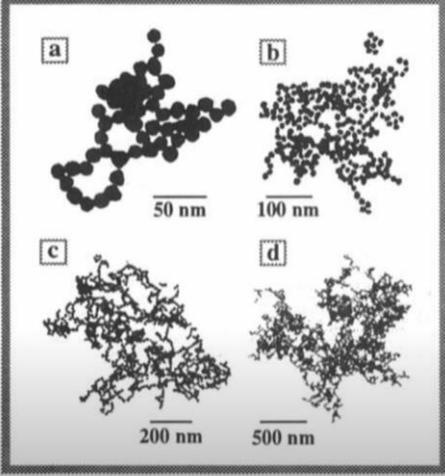
So here, if you can look at the stability of colloidal system based on the electrostatic force, right? Let's say if there are, you know, when two charged particles come closer, right? As they approach... as they approach each other very closely, uh you know, they will uh experience right there will be they will experience uh different forces at different uh you know, uh surface to surface separation distance between the particles right so, So the best example of kinetically stable system will be when they go through this profile compared to this one. If you look at here, the secondary minimum and primary minimum, whenever particle reaches this distance of separation, there will be a primary minimum and when it goes through this primary minimum there will be irreversible attraction.

Due to irreversible attractions there will be aggregation. Once the aggregates are formed it is very difficult to separate them. right so what is important to not driving them up to this point is to increase this barrier this is primary maxima okay if the barrier here is increased several fold higher ,then what will happen is this particle will not reach the you know this primary minima at all right so there will be no question of aggregation or coagulation at all ,so for that so one so the electrostatic repulsive force between the particles if it is very much pronounced right then one can avoid the or prevent the aggregation or agglomeration right so such system is called kinetically stable system okay so here it is given this primary maxima this barrier is in terms of  $k_B T$  is given so if the energy barrier is several times greater than the  $k_B T$  which is the thermal energy , then the particle will not be driven up to this point. That is the primary minimum, right? So, such a system is called kinetically stable system.

(Time: 26:42 min)

**TEM of aggregates of gold nanoparticles**

Aggregates were made from a gold colloid to study the relation between the kinetics of aggregation and the resulting structures.



Characteristic dimensions of fractals or aggregates can be measured by evaluating the Martin diameter or the diameter of an equivalent circle.

Aggregation diminishes the optical properties of gold nanoparticles.

Hiemenz, P. C. & Rajagopalan, R. (2016). Principles of Colloid and Surface Chemistry. Second and expanded edition. CRC Press. INTERFACIAL ENGINEERING

So, a good example of aggregates of gold nanoparticles given here, these are TEM images of gold nanoparticles. You can see different aggregations of gold nanoparticles, different sizes. Okay, so because of the huge surface energy, these nanoparticles, you know, develop a tendency to aggregate each other. When they aggregate, they form a factor like structures, right? Factors are aggregate structures. The disadvantage of these aggregates is that the aggregation diminishes the optical properties of gold nanoparticles, right? Or its catalytic properties are, you know, reduced by the aggregation of these gold nanoparticles, right? Yeah. So, these are the TEM images of gold nanoparticles. That is what's shown here.

(Time: 27:48 min)

## Why colloidal stability is important?

  
NPTEL

- ❖ Colloidal stability is essential to ensure that the dispersed particles remain uniformly distributed within the continuous phase without aggregation, sedimentation, or phase separation.
- ❖ This stability is crucial for both scientific understanding and practical applications

**1. To Maintain Functional Properties**

- **Desired Performance:** Many colloidal systems, like paints, cosmetics, and pharmaceuticals, rely on their uniformity to function effectively.
- **Loss of Stability:** Aggregation or sedimentation can lead to uneven performance, such as streaks in paints or ineffective drug delivery.

**2. To Enhance Product Lifespan**

- **Shelf Life:** Stable colloidal suspensions ensure that products remain effective over time.
- **Prevention of Phase Separation:** Stability prevents the separation of phases, which can render a product unusable.

**3. To Prevent Aggregation**

- **Surface Area and Activity:** Colloidal particles have high surface areas. Aggregation reduces this surface area and diminishes their functionality.
- **Applications:** Catalysts or drug delivery systems, aggregation reduces efficiency.

  
27:48 / 29:33



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So, let's ask a question, why colloidal stability is important, okay? It is essential to ensure that the dispersed particles remain uniformly distributed within the continuous phase, right? And, you know, without aggregation, sedimentation, or phase separation. So we want to avoid aggregation, sedimentation, sometime creaming, or phase separation right so for that we need to improve the stability of colloidal system uh so it is also important for you know various other practical applications one of there are three points I have listed uh one of them is to maintain functional properties right if you want to maintain the functional properties we need to avoid this aggregation and sedimentation Okay, so why we need to maintain functional property because if you want to extract the actual function from the various products like paints and cosmetics and pharmaceuticals, we need to retain this functional property so that you get a desired performance output. The loss of stability, so that is important. Shelf life, so if you want to improve the shelf life of the product, one has to avoid this aggregation and all those things, right? And prevention of phase separation, this is also very important from the perspective of the finished product, right?