Colloids and Surfaces
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Lecture-01
Colloidal Dispersions, Terminology and Classification

Okay yeah, so this course is called colloids and surfaces. So, you will see that there are okay and so before I begin, why this course is kind of called colloids and surfaces. So, what I will do is I will first give you a okay.

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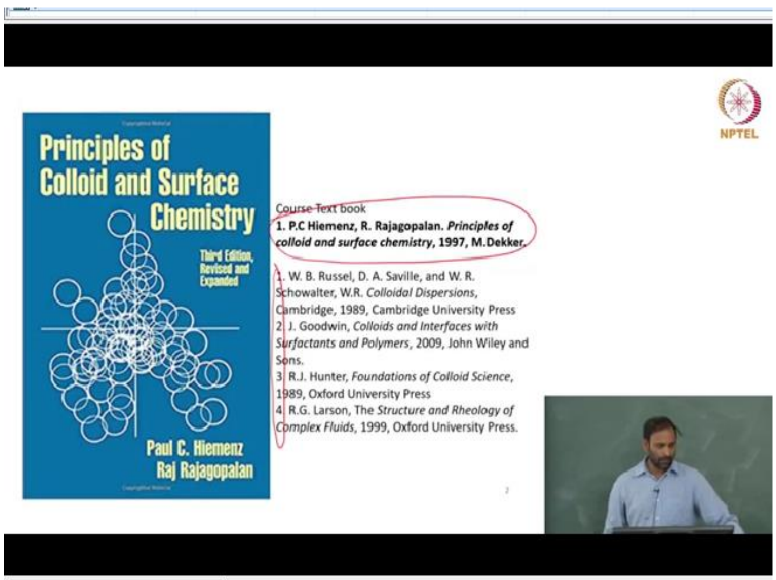

So, this is the course sub, you know, book that I am going to follow okay, so that is a picture of you know the front cover. And this textbook is titled colloids and surface chemistry, which is you know written by Hiemenz and Rajagopalan okay, it is a good book very basic okay. I have learned a lot of things by you know reading this book, that is going to be the course textbook, I have a copy of it in case if you want to take a look.

Of course library will also have a copy in case if you would like to go and refer. Apart from the course book I have a lot of reference books listed here about four of them. Some of them are advanced, some of them are very basic okay, you can take a look at them you know in case if you would like to refer to some specific topic okay. So, what I will do is I will begin with talking to you about introduction to the course okay.

The aim of today's class is to essentially define what is colloids. I will just do that, followed by I am going to give you several examples, you know where you know we have we used colloids and, you know, different, different fields okay. So, you know that is to motivate you from learning colloids okay. So, I am going to take some examples from different, different fields. And then tell you, you know how the colloids principles are exploited to learn some make some new materials and things like that okay that is okay.

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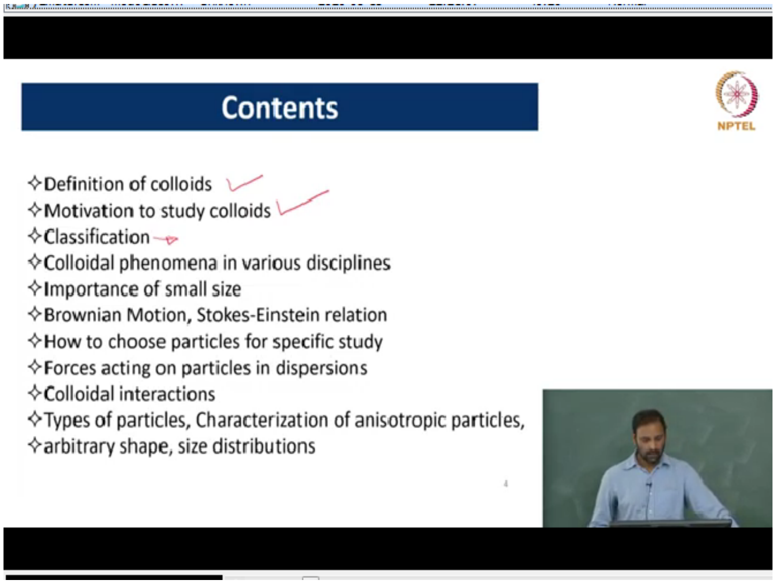

So, that is a long list of what I am going to cover in the maybe next few lectures. But for today most likely, I will just define what is colloids and then I will follow it up with talking to you a little bit about motivation to study colloids okay, why are we trying to look at this colloids. And if there is some time I may look at you know something on classification of colloids okay that is for today.

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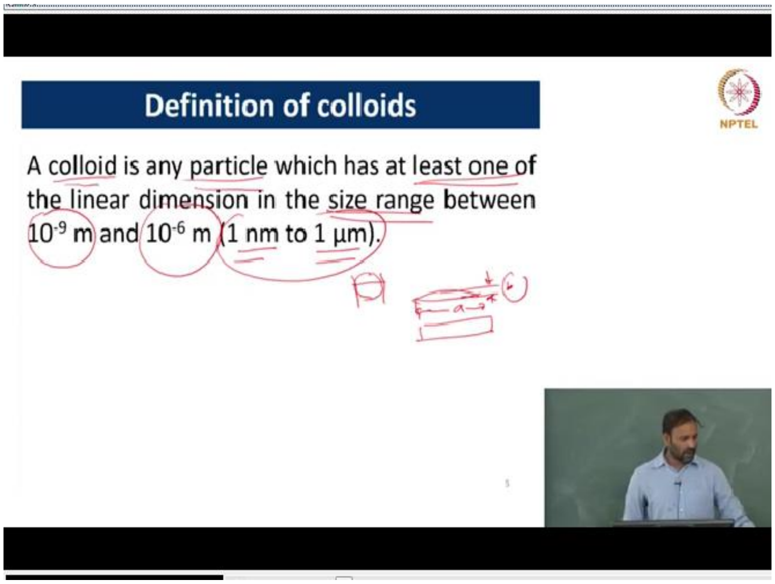

Now, definition is a textbook definition, you will see in a lot of forums as well. A colloid okay is any particle okay, which has at least one dimension, at least one dimension in the size range between 10 power - 9 meter and 10 power - 6 meter that corresponds to one nanometer to about a micro meter particle okay. So, the moment you have any particle in this size range. That is what is called as a colloid.

The reason why you have at least one linear dimension is because often you may be working with particles that are spherical okay. In such a case, you know, you need only one dimension to characterize such particles. The moment you think about other shaped particles, it could be, you know, ellipsoids, it could be cylinder like or rod like okay, then you have more than one dimension okay.

So, if I take a two dimensional ellipsoid you need, you know the length of the major axis and length of the minor axis okay, to define the size of the, you know particles. So, therefore, in such a case, if one of them, you know in this case b is smaller as long as b is, you know, in the size range from 1 nanometer to 1 micrometer, that is still called colloidal dispersion. So, as long as one of the dimension, one of the linear dimension of the particle that we are dealing with is in this size range. That is what is called as a colloidal dispersion okay.

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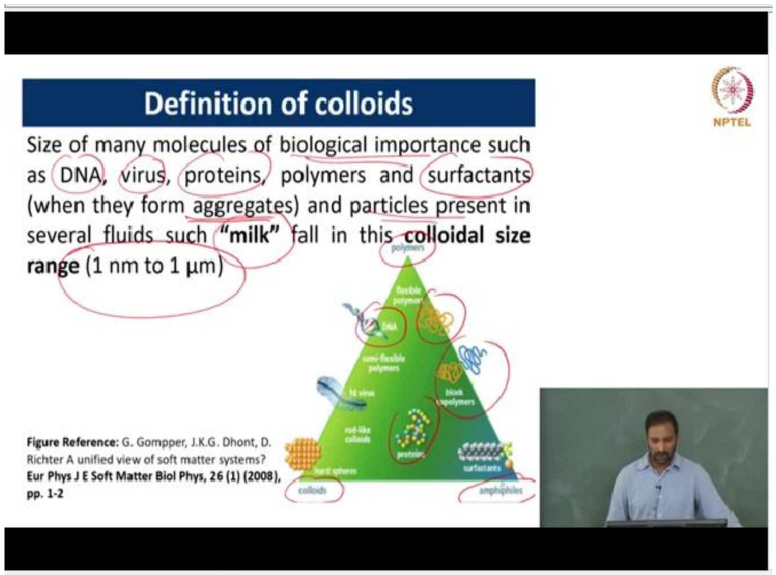

Now, it turns out that a lot of materials that people work with okay and a lot of materials that are biologically important, for example, DNA, virus, proteins okay and a lot of, you know, consumer products which have, for example, detergents and shampoos which have surfactants right. So, all these molecules okay. When you put them in solution, when you put them in water, they form aggregates okay, whose size again, comes in the size range between 1 nanometer to 1 micrometer okay.

Or you could have a particles present in some fluids, for example milk, okay milk contain some particulate matter. Again, the size of these particular matter, you know is in this in a 1 nanometer to 1 micrometer**,** size range. Therefore, there is a lot of relevance, looking at colloids in many different fields. So, this is a triangular diagram on one apex you have polymers, the other apex you have particles, solid particles.

And other apex you have, you know, surfactant molecules which are also called as amphiphiles okay and several different things that will unite this DNA, polymers block of polymers, proteins right. So, all these materials, okay when people are working with them in solution, they invariably form okay, aggregates of 1 nanometer to 1 micrometer dimension, therefore there is a lot of interest in looking at such systems okay.

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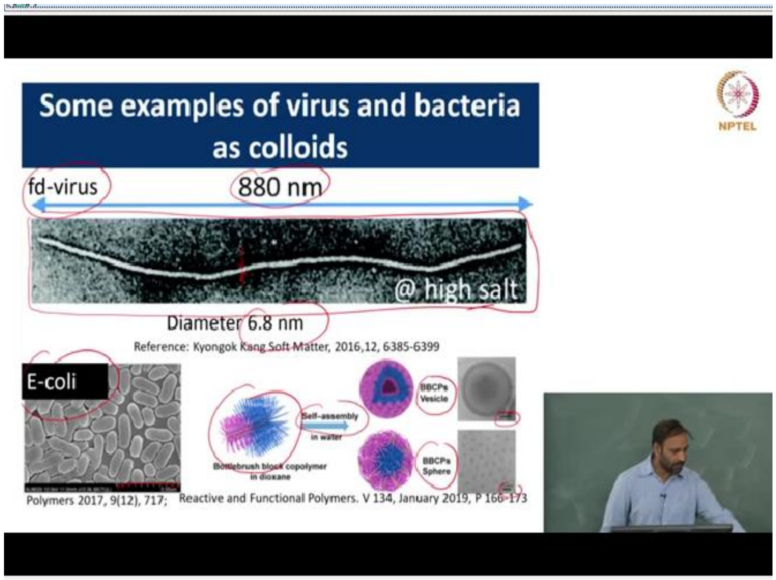

So, just to give you some examples. Again, I have taken a few examples from again biology. So, what you are looking at is this is an image of a virus is what is called as a fd-virus okay. And so this fd-virus has a length of about 800 nanometers and the diameter this dimension right, it is about 6.8 nanometer okay that is an, you can think about this an example of a rod like, you know, a particle right. So, people are working with you know such virus particles.

If you put them in fluid in water for example, they form a nice model system to look at a rod like particles in water okay, or dispersion of rod like particles, right and another example again from biology is this E-Coli which, you know, is looks elliptical in shape right and that is a scale bar that you have you and that is scale bar is about 5 micrometer okay. Therefore, if I look at the dimensions of these things again, they are you know in that 1 nanometer 1 micrometer size range okay.

So, that is so therefore, these are again classic example of colloids, but in the field of biology okay. Now I have another example here, so what you are looking at here is a polymer. It is an example of what is called a block of polymer okay, so go back here. So, this is a schematic that you see this is a polymer. So, typically people show polymer as you know some kind of a chain right, which basically has several repeating units which are connected by some covalent bond.

But you could have a system where I can have 2 polymers, which are connected by a covalent bond is an example that is given here. So, that is orangish color is one type of polymer and the blue is another type of polymer, again they are connected by a covalent bond okay, that is an example of a block of polymer. You have 2 different, you know, polymer molecules which are joined together right. That is why it is called as a di-block polymer.

You can have 3 different chains, some of those are tri-block polymer and so on and so forth okay. So, when such polymers which are again represented by, you know the pink and the blue color here. So, when you take such things and put them in water they can form different structures, they could again I am going to introduce these terms a little later something called as vesicles, some kind of spherical aggregates.

If you again look at these, you know, images here. If you look at the scale bar here again 200 nanometer here and 50 micrometer. So, the moment you put these things in water, they automatically assemble okay, what is called as a self assembly, they self assemble to form these aggregates and these aggregates have a dimension 1 nanometer to 1 micrometer, there is a lot of interest in looking at such systems as well okay.

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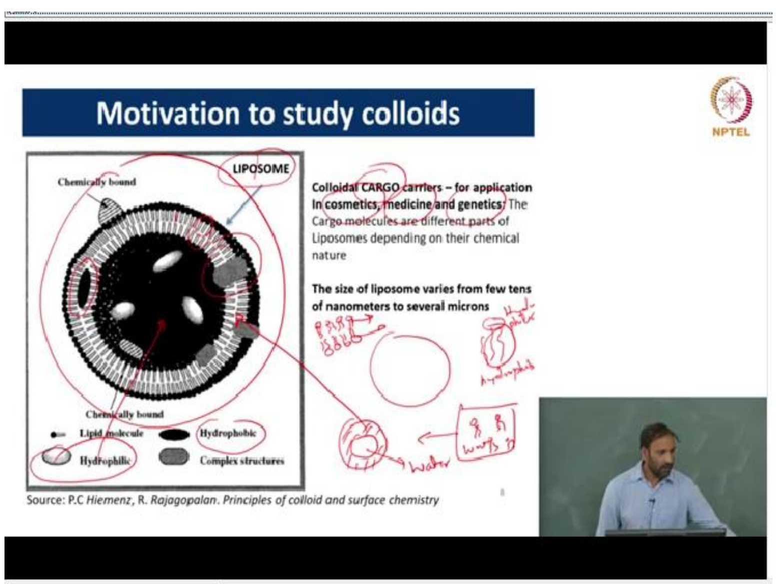

Now, to, again further motivated you, why people are looking at colloids, you will see several examples where people talk about drug delivery people are using, you know, some kind of containers for drug delivery, one common object or one common kind of a container which is used a lot in such application is something called a liposome. I do not know how many of you have heard this term.

A lipo means lipid okay, so this is a spherical structure. It looks like a sphere okay, again, example was shown here, right this is an example of a structure, very similar to liposome, but it is made by polymer. Therefore it is called as a polymerizome okay. Similarly, if you make such structures which lipids, is what is called as a liposome. So, the way these structures are made is you take a lipid molecule.

So, lipid molecules are represented by something like this, they have a chemical group, which is hydrophilic okay. And it has some group, which is hydrophobic okay, typically lipids have one head group, which is hydrophilic okay and 2 tail groups which are hydrophobic. So, when you take several such molecules okay, in water what I do is I simply mix it up okay, I just put in a sonicator or you know or a high energy mixer.

I just mix it up. In the end, what you do is you basically get structures which look like spheres okay and the inside this, you can think about this as a core shell kind of a structure where the core has water because the surfactant molecules or these lipid molecules are put in water okay. And inside has water, this region here okay, the shaded region is actually this layer okay, and that layer is made up of what is called as a lipid bilayer okay.

What lipids do is, they kind of arrange, you know, kind of arrangement like this. There is one layer of lipid, this is a second layer. That is what is called as a lipid bilayer okay. And these lipid bilayers fold to make these spherical structures okay, So, what you are looking at here is a cross section of one such liposome. If you cut it up okay, what do you see is, these lipid molecules are nicely arranged in a bilayer fashion okay.

Now, because these, the tails, okay because these are hydrophobic right these lines that you see here, they are hydrophobic. I can use this region for incorporating a hydrophobic molecules, for example, what is put here is a what you are looking at this elliptical looking like thing is a hydrophobic thing that can happily sit in the bilayer region okay and I can have this hydrophobic part, which could be happily being in water.

Therefore, I can use such containers to either carry hydrophilic material or a hydrophobic material or any complex structures which can be there, both in the hydrophilic part and the hydrophobic part. So, you can actually use them as cargo carriers. That means, if I take such things and if I, you know make such formulations and you know, give it as a medicine for example, okay, I can put both a hydrophilic drug and a hydrophobic drug in such things.

And I can easily transport them into the body okay. So, therefore, people are looking at such colloidal structures for as cargo carriers for applications and cosmetics, medicine, genetics and things like that okay. So, this is, you know, one of the motivations why one would be interested in looking at you know colloids. This is an example where people have taken surfactant molecules or lipid molecules and make structures which are colloidal in lengthscale and then looking at some of these interesting aspects okay.

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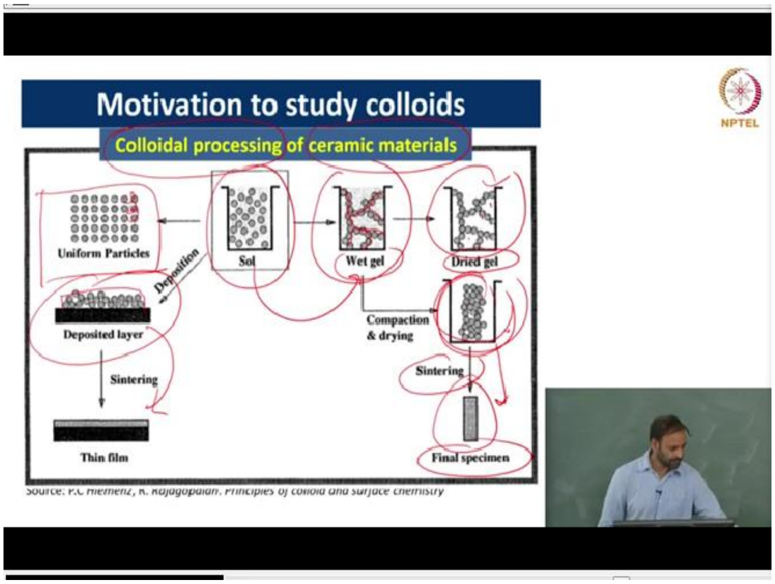

Now, we come to a second example of why should one look at and I have taken some examples from materials, where there is a specific key field called colloidal processing of ceramic materials okay. So, ceramic material is one could be interested in looking at SiO_2 or aluminum oxide, you know, or any such system. And one of the ways of making such materials is by using what is called as a you know colloidal processing group in which what you do is you start with a uniform.

You start with the particles okay I have particles I could buy them as like a powder form okay, and it has uniform particles of exactly same size okay. Now what I do is I take such particles, I put them in a fluid okay. To make what is called a sol okay, which essentially is a dispersion of particles in a fluid okay, that is about it okay. Now, what do I do, from the sol. Now what I do is I have a sol.

And from this sol if I know everything about the particles that are present in the sol I am going to talk a little bit about, you know, a few things later on in the course. If I know what is called as how the particles are interacting in the fluid. Again, as I said, I am going to talk about these things a little later in the course okay, but at this point what you should remember is that I have something like this which can easily flow okay, it has fluid plus particles, I have this.

That is my sol and I think exactly the same thing. I do some simple manipulation to go from such a state to something where things don't flow okay, this is an example where I have gone from a sol, where I have a nice dispersion of particles into a kind of a solid like thing, which does not flow anymore right. And I will tell you how we do that**,** in the meantime. Now, that is an example of what is called a wet gel.

Because it still has a fluid okay and the particles that I have in the sol are kind of they form a nice network okay. And this network spans the entire volume okay, I can go from one end of the sample into the other end, just along the particle network okay that's what is called as wet gel is. Now what I do with this. I take this and then I evaporate the fluid to get what is called as a dry gel okay. And you can do other processing I can actually do what it was a compaction.

If I want a porous material I can process this. If I want a more denser material I can go to this route okay. In the end, what you do is I take this and I do what is called a sintering okay, sintering is a process where I take some sample like this, which has particles. And then I heat that to a very high temperature, close to the melting point of the particles. And what this does is it facilitates what is called as a solid state diffusion, because of which the particles can form a nice bond okay.

And once that bond is formed I finally have a hard ceramic material. okay, so that's the final specimen that people have made either I can get a final hard specimen like this or I can also get a porous material like this, which will essentially have all the void that you had in the sample I can do that just by sintering process okay, I can either do this, or the other way of doing this would be, I take the sol and I deposited a small layer of fluid on a substrate okay.

And I let the particles deposited on the substrate and I can still sinter it and I can also get a thin film okay. So, there is a lot of interest in looking at such studies where in order to do colloidal processing, where you start with a powder, make sol, gel and ultimately ceramic material. So, all of this can be done if you have a really good understanding of colloid's principles okay. So, what are colloids, you know, how do I go from a solid state to gel state okay, how to handle these matters right, things like that.

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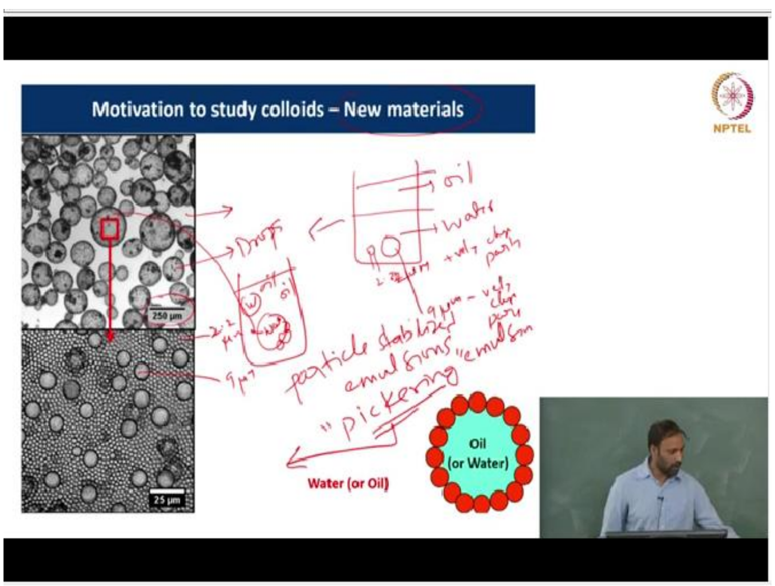

So, another example again, I am going to talk about some new material development. So, what you are looking at is, they look like spherical objects right. They look like spherical objects to you. And that's your that's 250 micrometer right, really large right. So, therefore, these are actually droplets okay, these are drops, how these are made by a simple experiment. What you do is I take water okay. And I have an oil. I put in particles.

So, in this case, this contains about 2.2 micrometer positively charged particles and a little larger this is 9 micrometre negatively charged particles. You take that we have oil, and you just simply mix it. That's it okay. That's it right. Now what you do is you create what are called as emulsions okay, when you do that, you make emulsions. In this case, the emulsions that form their water droplets in oil.

Now whatever particles that you had in the fluid, they go and sit at the interface okay. So, what you are, this is a droplet like this. And if I, because these particles are big enough right 2 micrometer 9 micrometer they are big enough, I can do microscopy, if I look on the droplet surface, what you have is this nice arrangement of 9 micrometer particles and 2.2 micrometer particles okay.

You are able to emulsify 2 fluids, which otherwise don't mix. I am able to make an emulsion by using particles okay. So, this is an example of what are called as particle stabilized emulsions, also called as Pickering emulsion okay. Pickering because, Pickering was a scientist who found this for the first time in the 1900s okay. Now, you can ask me what is the use of such things.

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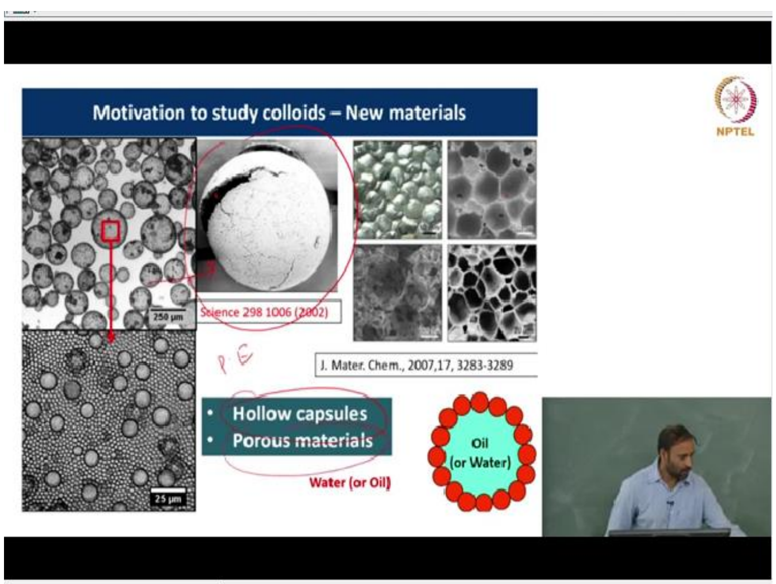

So, I am going to show some examples. So this is a, I talked about liposome right. I talked about polymerizome, similarly, these structures that you see, they what are called us colloidosomes. Because, these again a shell, which is made up of particles. What you are looking at is a hollow shell. Inside is hollow okay and outside as a layer of single layer particles, can you see that those particles here, right, you can see these nice spherical particles are very nicely arranged right.

These are actually made, starting with particle stabilized emulsions okay, in which the emulsions are stabilized by single type of particles. I take these structures. And then I evaporate the fluid. I can make a hollow structure and I can this empty space that is within these containers right, I can again use them for again some drug delivery applications right or I can have several such things.

I can compact them and I can do the sintering I was talking about right, I can take particle size stabilized emulsions and I can do sintering and I can actually get porous materials okay. So, these are examples of porous materials in which people have taken these Pickering emulsions or the particle stabilized emulsions and you compact them. And you remove the fluid and then you sinter them, people have done metallic materials in a porous metallic materials porus ceramic materials and stuff like that okay.

And we have another example here, which is kind of made by a similar technique okay, this is the work of one of the PhD student. So, what you are looking at is a, you can imagine a some container like this okay, which has a, you know, Pickering emulsion or particle stabilized emulsions. And what was done is now what I can do is, now I have these droplets. When the droplets are touching what I can do is I can do a cross link right.

I can actually connect the droplets by doing some simple reactions okay, now what will happen is, in such a case, I can actually get a it looks like a you know the chalk piece right, piece of chalk but it is not okay, it is a material which is made from some particles, some polymer is very soft I can squish it. Whoops, it broke, not strong enough okay, it’s brittle, but I can make materials like this right, again done everything from starting with colloids understanding them and things like that okay.

So, therefore people can make either oil in water emulsions or water in oil emulsions stabilized particles and they can use them for making either hollow capsules for again applications in medicine or you can make porous materials okay.

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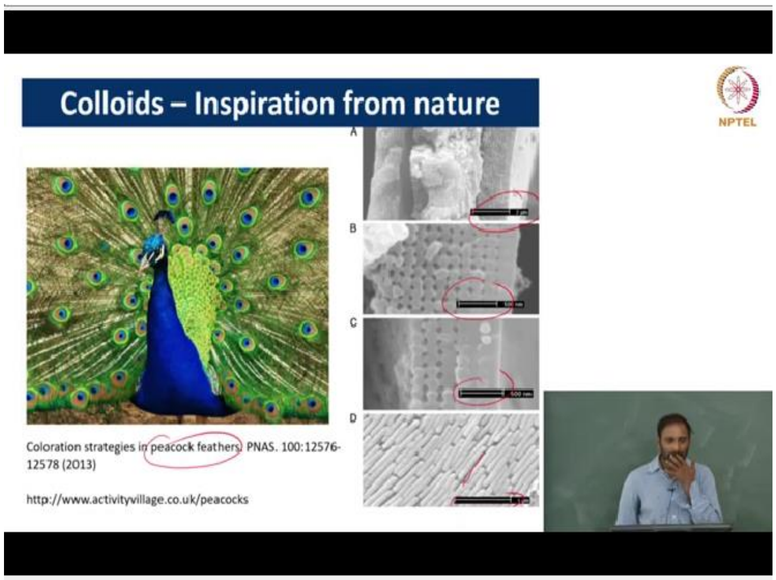

Okay, I am going to talk about some inspiration from nature okay. So, what we are going to do is I am going to take some examples from nature and then tell you that look the colloidal scale structures do exist in nature and there is an interest in looking at such things from you know that point as well okay. Any examples that you may have you have anything that you think is in nature and that is colloidal in length scale.

So, milk was one example of course Yeah, so anything else. How about this, within this some connection between this and colloids. Yes. No. okay, so there is a whole lot of people looking at what is called structural colours okay, so, you know in chemical engineering right when people look at things like paints right, paints of different colors. One of the understanding is that there are a lot of pigments that have a specific color. And you can make paint of a specific color by right that is one thing, but there are a lot of things in nature, where the fascinating colors that you see that comes about.

Because these things have some structures, whose length scale is such that, so when the, the light falls on them right, like the light that is reflected okay, because of the nature of the colloidal scale structure, that are there on these species okay, those colors okay come about because of the interaction of light, with the way the colloidal scale materials are arranged on such fascinating creatures okay.

Now, so if you look at a peacock, right. So, these are some, you know, the micro structures that are from peacock feathers okay, again I would like you guys looks at the land scale okay 5 nanometers 2 micrometer and look at these rod like things right. These are about 1 micrometer, you know, so this is 1 micrometre, therefore the length is about the order of 1 micrometer or the diameter would be may be about, you know, less than 100 nanometers, right. So, therefore, so this is not the only example.

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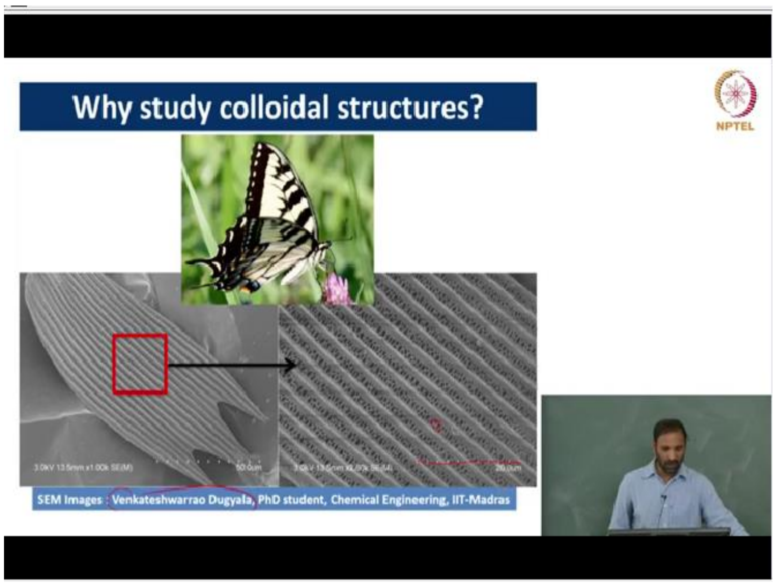

So these are again some pictures of a student of mine who took some years ago again, butterfly wings okay, this is a about 20 micrometer, but if you look at these structures here that again very much colloidal in land scale, 1 nanometer to 1 micrometer.

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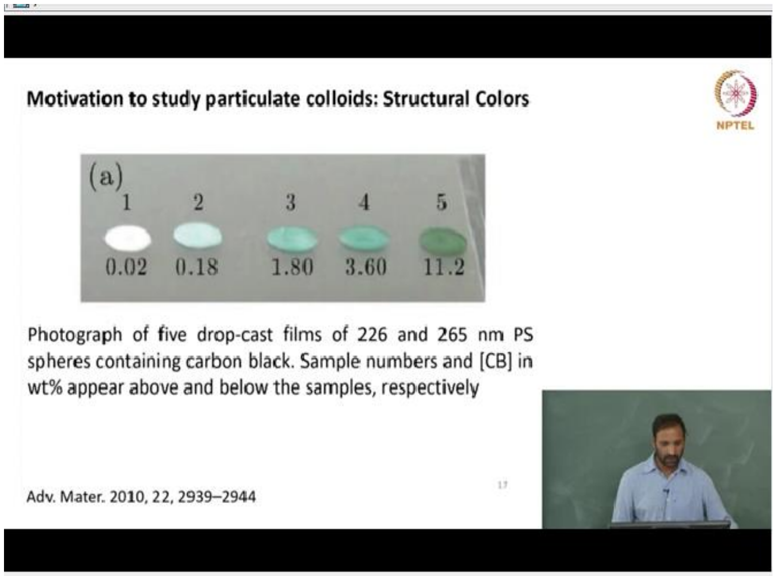

Plus, you have, again some examples from literature. So, these are 2 birds. okay, which have, you know, both of them are bluish in color right one is, you know, the light blue and other one is slightly different, right. Now, if you look at the feathers of these creatures right these birds. They have different structures okay. So, this is again the length scale is about 500 nanometers. Therefore, you look at this small dots okay.

That is definitely sub 100 nanometers in length scale, right. So, therefore, so the interaction of, you know the light with such structures, whose you know size is smaller than the wavelength of visible light right**.** So, that those interactions is what leads to such colors, which is an example of what is called as structural color which are not created by pigments, but the way these nanostructures interact with light okay.

Now, so what people do is they kind of use these as inspiration and you can make such colors in the lab okay, there are some examples.

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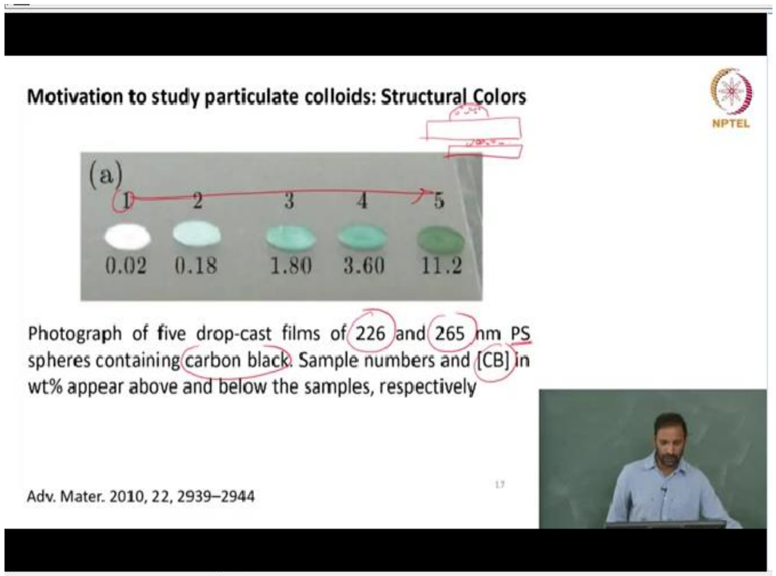

So, this is an example where what you are looking at is 5 different samples okay. What they have done is what is was a drop casting okay. Drop casting is a simple technique where you basically have a substrate and I just put a liquid drop okay, that is called drop casting. And this has some particles in there okay. And once the liquid is gone, what you have is a deposition of particles on the substrate right.

The liquid is gone and the particles are deposited on the substrate. So, you have 5 different samples okay. And in all these samples they contain particles which are 226 and 265 nanometer in size is a polystyrene particles. And what is being changed in the sample from 1 to 5 is the fraction of some carbon black okay. That is added to the sample okay, the concentration is given in weight percentage.

That goes from 1 weight percentage to 5 weight percentage and you can clearly see that the colors are very different right. And, if you can do microscopy.

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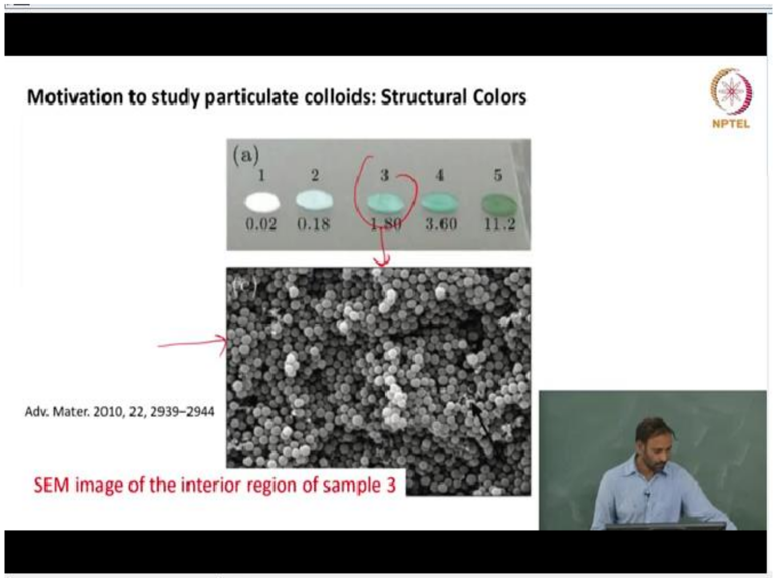

You know the microscopy of the sample 3 will look something like this okay. Therefore, so when you have such drop casting and the particles are finally deposited okay, so they kind of, you can clearly see from this, you know it is not a regular arrangement right is more like a amorphous you know irregular kind of arrangement okay. So, therefore, so that you are trying to kind of mimic. Know, the kind of structures that you kind of obtain when you know there is a amorphous.

You know, or not so regular arrangement of colloidal scale structure that represent in such things okay, you can think about designing such things in the lab where I take particles of different sizes, slightly different sizes and you know I add an additive. And then I make a kind of a deposit of particles that kind of exhibits different colors depending upon the concentration or some of the additives okay.

So, therefore, there is a lot of interest in kind of looking at nature and mimicking that you know by looking at colloid science as a field. And then, you know, so one of the motivation could be along these lines.

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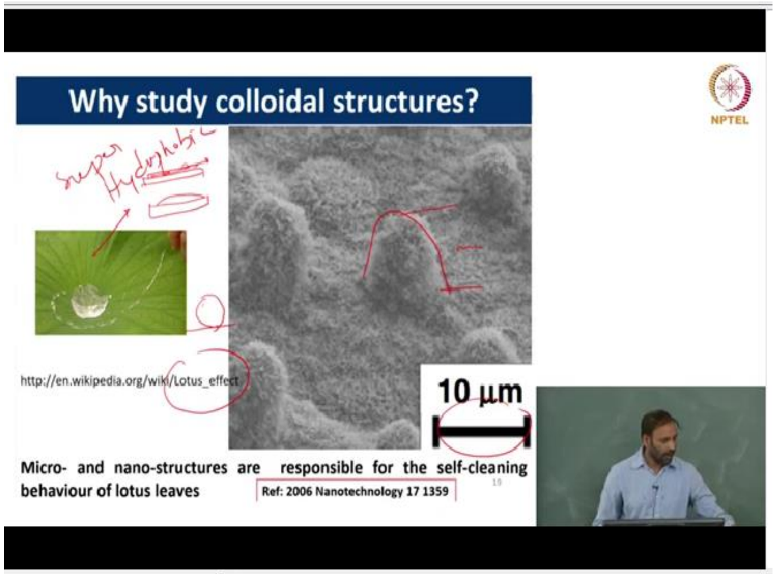

Now so, this is another example of again a common example that everybody gives right. Something called is a lotus leaf effect okay, that means it is a lotus leaf is an example of a self cleaning surface right the moment if you have a lotus leaf, the moment water drops fall on it, they just roll down right. And in that process they take whatever dirt that is there on the lotus leaf they just carried okay.

And it turns out that this lotus leaf effect okay is comes because of what is called a hydrophobic. Not only hydrophobic what is called as a super hydrophobic nature of the material that means if I have a lotus leaf okay. And if I put a water drop it will. So, there are, if I put a water drop any surface it can take a shape like that okay or it can completely spread like a thin film or I can have a case where the droplet may form something like this right okay.

Everything depends on the nature of the substrate that you are dealing with okay, so if it makes a perfect sphere there is an example of a super hydrophobic surface or completely hydrophobic surface okay, where the. So, if form something like this is an example of a hydrophilic surface right. Now, so it turns out that the, this the self cleaning nature arises because if you look at these lotus leaf under a microscope.

So, there are large structures okay, there are hills okay. The size of this could be as much as about 10 micrometer. Plus you also have this small nanoscale roughness right a combination of this nanoscale and microscale roughness is what leads to such. So, you know, self cleaning or superhydrophobic, you know nature of lotus leafs okay. So, therefore, there is a lot of interest in looking at these things understanding again nature. And then try and come up with a way of creating such structures in the lab.

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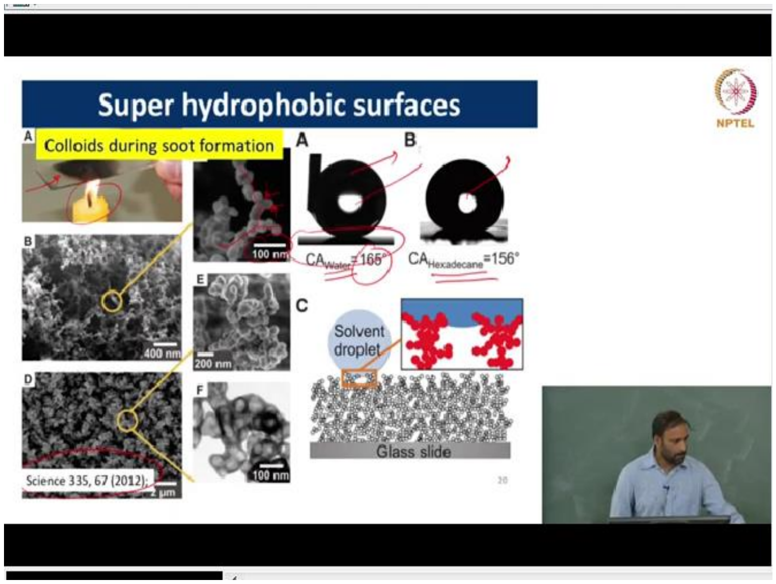

And one of the way of doing that by is again by a simple technique okay, which is the this is what is done in this particular example if you are interested, you can go and read up a little bit more about this, very simple example anybody could have done it right. So, what you have is a, a glass substrate. Take a candle right and you burn it. And when you burn a candle you get a soot right. And you just deposit that soot on the glass substrate okay.

And the soot essentially consists of some carbon particles right. So, the soot it looks flaky, right, the flakiness of the soot actually comes because it has very, you know, open network of particles like this okay it is not individual particles. The way it comes out it is, they are kind of connected, they form some kind of loose kind of aggregates. And so, these loose kind of aggregates or kind of deposited on the glass substrate.

And I can take that I can do some simple treatment in the lab okay, I can expose that to different molecules and stuff like that. So the bottom line is, there is a suit that deposited on the particle on the substrate. And if you look at again the land scale is about 100 nanometers and the size of individual particles would be again much, much smaller than that okay. So, you have colloidal scale particles. They are deposited on a substrate.

And that gives you a contact angle of 165 which is an example of a superhydrophobic surface right, very close to 180 okay. Non only water I can create surface which have a contact angle of 165 not only for water also for hexadecane, it is an oil right. Therefore I can create both water liking substrates or water hating substrate or a oil hating substrates right. Therefore I can create what are called as omniphobic okay. These are materials which even like water nor like oil okay, so you can make things like that .

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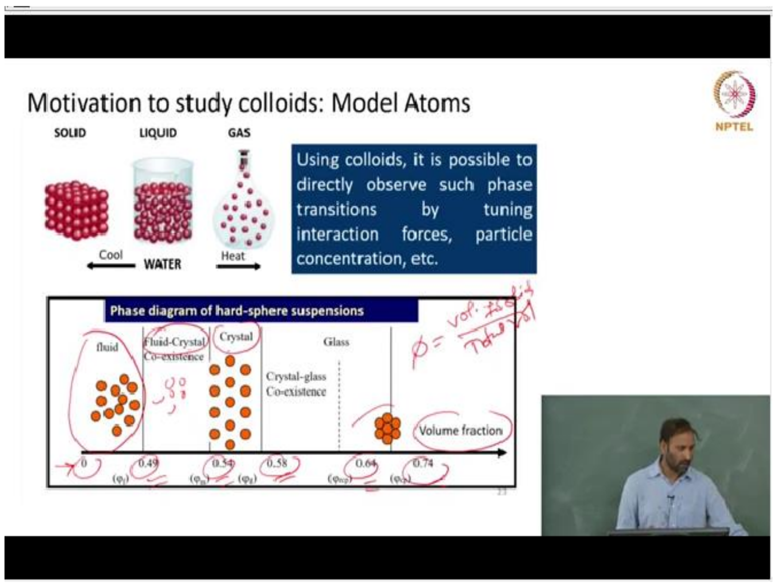

Final motivation hopefully okay is there is a lot of interests looking at colloids also what are called as model atoms okay. If you look at atoms or molecules right they are sub nanometer in size, right, they are very small. You cannot see them okay. And we know that anything that is made up of atoms or molecules does exist in, you know, 3 forms right solid, liquid and gases right.

Now, of course, there have been large developments and people know what these materials are. But one of the ways of achieving all these states, the gas like state and liquid like state and solid like state and visualize them live okay, is I can use colloidal particles okay. And I can actually create all these structures, okay all these materials. So, therefore, so there is, lot of interest in using colloidal particles okay, as it is possible to directly observe okay.

I can make a material. I can take something which can go from a liquid like to a solid like state. I can in-situ observe how does that happened. How does something go from a liquid state to a solid state, I can observe it, you know, in-situ okay, with doing microscopy and things like that okay. And how is it done, as we learn in the course. It is done by tuning interaction forces okay, the way the particles interact with each other.

And it can also be done by playing particle concentration, again, I will give you some examples. So, this is a something called as a phase diagram okay, that people first found from simulations. So, the number that you are seeing here it is these numbers. These are what are called as volume fractions okay, which is defined as the volume of solids or the particles that you have in the fluid, divided by the total volume okay.

So, all this is telling you is depending upon the, volume fraction of the particles in the fluid. It either exists as a fluid state okay, or there is a coexistence of fluid crystal, fluid you know where there is a disorder arrangement of particles and a crystal like arrangement okay, or ultimately a glass like arrangement okay. So, this is a phase diagram that was a kind of depict, that is kind of found from several simulations you know several decades ago okay.

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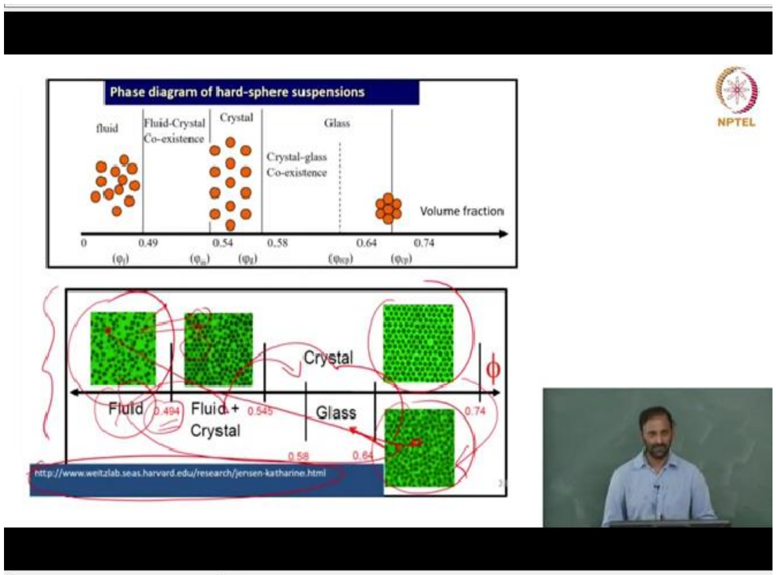

Now so, this is an example where what has been done is experimental visualization of what was predicted by simulation is done through experiments. If you want you can just look at more details at this page. Now what can you say about things here right, this is so the dark thing that you see the spherical looking things. These are particles okay, about 1 micrometer in size. And what can you say about the arrangement here right, it is very irregular right.

They are kind of, you know, distributed in space. There is no specific arrangement. The arrangement is very much like what will happen if you take a liquid right. Now, you increase the concentration of the particles, this is about, you know, if you go beyond 0.494 volume fraction, there is more than 50% a little bit about 50% more. You clearly see that there are regions where the crystalline arrangement.

Can you see that, what is marked that every particle has 6 neighbors. Very nice arrangement, but of course there are you know regions, you know, like here, where it is still a fluid like right. So, that is a fluid crystal coexistence. You go up in concentration, very periodic arrangement, every particle has 6 neighbors. Example of a crystal right. And if you go further up in concentration okay, you are at some concentration rates you essentially get again a disordered arrangement.

What is called as a glass okay, the microstructure is very much similar to, you know, I can roughly say like glass, like fluid. But only thing the particle concentration is larger that is all okay, the arrangement here and here, arrangement, here, and here, very much similar. The only thing that is different is a concentration of the particle that glasses, glasses, a little larger than what you see right.

So, therefore, all that has been done in this example is that they have taken the fluid and you go on adding particles okay, If I systematically increase the concentration of particles, you see a transition from a fluid state to a fluid crystal state to a crystalline state to a glass like state okay. And because these objects are micrometer in size I can do this experiment under a microscope, and I can observe these transitions live okay in-situ I can do it okay.

So, therefore, these are a few different examples from different sources to tell you that look, there is an interest in studying colloids from lot of different backgrounds okay. And, and I do not know what is motivating you guys from learning collides. But that you would have to, you know, think a little bit and then you know take this course. So, you know, you kind of adopt some of the principles that you are going to learn in this course in your, you know work.