Nanomaterials and their Properties
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Lecture - 02
Nanomaterials: An Overview (Part - II)

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Hello students. So, we are going to continue our discussions in the class 2. First, we will have some recap I have discussed some basic facts about nanomaterials. Today we are going to reiterate those, what, why? And then I am going to talk about some examples from nature as well as manmade nanomaterials, so that you understand why nanomaterials are important.

But you know because this is an online lecture and many of you watch these videos mostly on your mobile phones or maybe in pads and very few of you watch the videos on the computer. It has been observed and reported that watching videos on a mobile phone is requires you to leaning forward.

And that is quite painful and that is why the average concentration of its any student, in fact, anybody and a particular video is about 10 to 15 minutes. So, we are going to divide this lecture, which is about 50 minutes duration into 3 parts and in between I am going to change over. So, let us see how we can do it.

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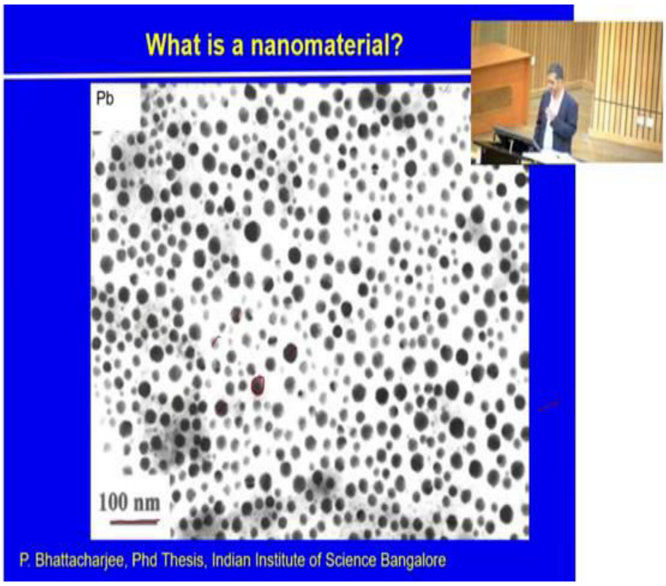

So, first of all about the recap you know what is the nanomaterial? And, in the last lecture I showed you this particular image. This is basically image obtained for lead nano-particles using transmission electron microscope. What is the transmission electron microscope and how does it operate? We are going to discuss about it later when we talk about characterization. For the time being we focus on the image.

What you see in the image is a small black color or gray color particles dispersed on the screen right and at the left hand corner on the bottom part you see a bar which says this much distance is equal to 100 nanometers. Now, this is a linear scale. So, using this we can measure this size or diameter of each of these particles like this and you can see some of them are very small of the order of 5 to 10 nanometers.

But some are the big about 20-25 nanometers. So, that means what? This is a two-dimensional position of the actual particle in a transmission electron microscope. So, that means, that in a real material you have 3 different direction x, y, and z, right, they are perpendicular to each other.

So, it says if for any nanometric pieces or any kind of a material whose one of the dimensions out of these 3 falls below 100 nanometer is called a nanomaterial right. That is what we should remember. So, you need not have to have all the dimensions falling in nanometric design that is between 1 to 100 nanometers.

If you have only one of these 3 dimensions as less than 100 nanometers then you can call the material as nanomaterials. And you must remember these aspects because this is something which will becoming again and again, and the properties of the nanomaterial will depends upon this dimensionality.

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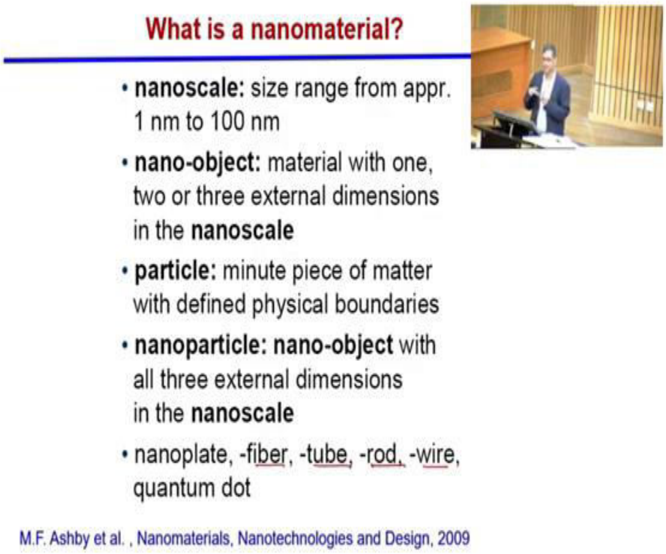

So, you know, so that is size range should be of between, 1 to 100 nanometers that I have already told you. So, material can have 1, 2, or 3 external dimension in the nanoscale, ok. And you can have different forms it, like you can have rod, you can have wire, tube, fibers, plates, and there are many many 100s of different kinds of types.

And you can also have quantum dots. These are very important from the perspectives of magnetic memory, electronic applications, which we will discuss later. You know particles are what? Particles are minute piece of matter which defined by some physical boundaries that is what is said here. There is a physical boundary here you see.

So, the small mass of leads they are within that boundary that is what is called particle, correct. So, this is different from your fiber, fiber is looks like a sheet, ok. Tube will look like a you know hollow things, rod is a solid thing, long, and wire is you know it looks like a thin and quantum dots is something different which we will discuss later. So, this is what is called nanomaterials.

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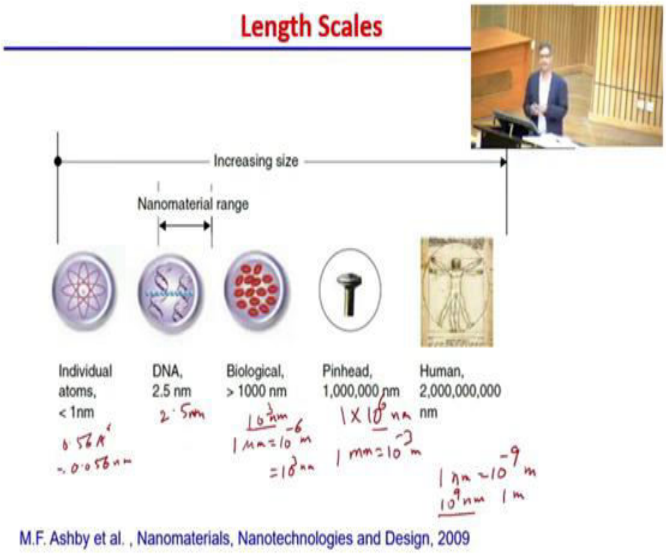

Now, the question is length scales. So, many of you may not be able to understand or may not be able to grasp the length scale. So, let us start with you know a human, ok. I am not so tall I am just 1.67 meters. But there are people who are as close as 1.8, 1.9 m and tallest one will be even 2m. So, let us talk about the tallest one, ok. It is about 2 m.

So, 2 m means, 2×10^{-9} nanometers because we know 1 nanometer is 10^{-9} m. So, if 1 nanometer is 10^{-9} m, ok, so 1m is 10^{-9} nm that is very easy. So, that means, a human has a length of 2×10^{-9} nanometers, ok. But, we never tell that, it always tells 2 m.

Now, if you know that sometime we use a screw or we use a pinhead to tighten something you must have done in your home or you must have done in your some kind of repairing a cycle or so, so pinhead it is of 1×10^{-6} that is its nanometer.

That means what? 1×10^{-6} nanometers that means it is about millimeter that is it because 1 mm is 10^{-3}m. So, that means, 1 mm is 10^{6} nanometers that is what it is. And you can see that actually because millimeter you can really see.

Now, if you look at red blood cells this approximately a what? 10^{3} nanometers. That means what? 1 micron, because 1 micron is 10^{-6} m. So, therefore, this is about 10^{3} nanometers, right. This is easily you can understand it.

But you cannot see a red blood cell, you can cut your vein and get blood out of it, but you will never going to see your red blood cells to see it you have to go to on a optical microscope or some kind of a microscopes. Microscopes allows, you see something which is cannot be seen by normal naked eyes.

Now, we can still go down because you know the basic unit of a living being is DNA or RNA. We are talking about Corona virus. Virus contains mostly RNA ribo nucleic acid. But the higher order people are like human or even primates or even fishes there many they have basic building block as a deoxyribonucleic acid and deoxyribonucleic acid looks like a double helix structure.

We have must have read in your biology, if you have not read you can still go into it. So, DNA is something about 2.5 nanometers. So, as you see here it is 10^{-9}, 10^{-6}, 10^{-3}, here 2.5 nanometer. So, we are going down right this scale. So, slowly you are going down. A taller human cut it down to blood cells, then cut it down to DNA, and then if you want to go to a matter because DNA consist of carbon, hydrogen, nitrogen.

If you want to go to a loop, one hydrogen atom what is the size of that? It is about 0.56 nanometers, right. No, it is less than that. It is about carbon atom is about 0.89 angstrom and you know 1 angstrom is 10^{-1}nm, ok. So, that is basically a hydrogen atom is about 10 to 0.56 angstrom; that means, equal to 0.056 nanometer. That is what it is. That is the building block.

So, atoms build DNAs, DNA builds cells, cells built a human. So, that is these length scale you must remember. So, that means, what? Nanomaterial scales varies between 1 to 100 nanometers and almost everything of DNA or even atoms all of them will come into that pictures.

Most of the atoms actually sub-nanometers whose there in angstrom scale, that is why this new scale was discovered by in the name of angstrom which is a which is Swedish things. So, that is what it.

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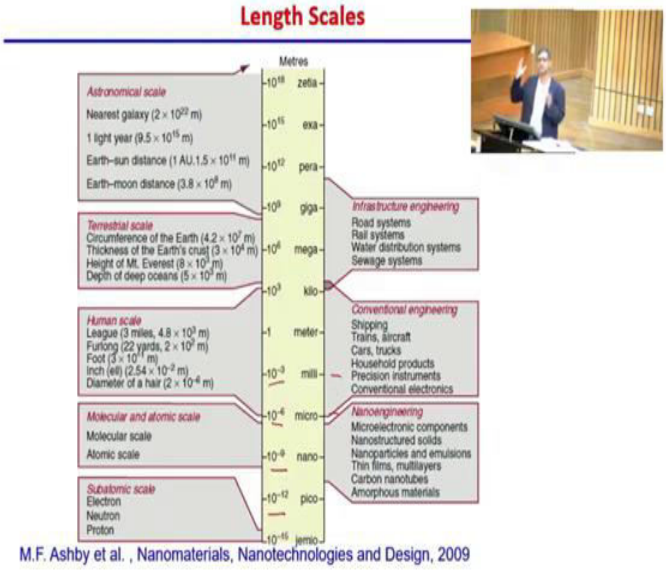

Now, only if you put all the scales together your astronomical scales like galaxies, ok, they are very big galaxies, you know they can be of the order of 10^{22} m, ok. They are like a light years distance from each other. 1 light year is how much? 1 light year is point 9.5× 10^{15} m.

1 light years where a light traveling at the speed of 186000 m/sec. for a year that is what is 1 light year. So, that is what you will get. Earth to sun distance is much smaller than that, its 1.5×10^{11} m, earth to moon distance is much smaller that is why we can go to moon actually and make colonies, you can hear a lot of talks about it, correct.

So, now you can also then come down to 10^7 m, 10^4 m, human, ok. You know that diameter of the hair is 10^{-6} m, then you can molecular scale atomic scale electron, neutron, proton all kinds of things.

So, you can go down from 10^{18} to 10^{-15}m that is the scale. And these are all known as you know exa, peta, giga, mega, kilo, you may have heard of mega, giga, but never heard of exa. Exa is 10^{18}, Peta is 10^{15}, right. So, this scales you never heard of it.

This scales actually at the, but at the bottom side you see milli, micron is 10^{-6}, mm is 10^{-3}, nano is 10^{-9}, pico is 10^{-12}, and femto is 10^{-15}. They have also one, 10^{-18} called atto. So, you understand that.

Now, you can always see, in any building or anything which is real building real road they are in this scale of between 10^{-12} to 10^{-3}, ok roads, 1000s of km correct or 10^{6} km distance from one place to another place.

Then engineering things like a train, train is something like 100m long or you can have a car in the order of 1.5m long or maybe 2m long, right. Household products that is very small, ok, think of a micro-oven, it is less than a meter long, ok. Electronic phone; phone is very small it is about how much distance, maybe something like about 15 cm or 20 cm long right.

Now, if you go down still you have a electronic components that is there inside your mobile phone if you open it up you can see that ICs and other things, by not by naked eyes, but you can try to open and see, but do not ever open. Only when your mobile phone is damaged or suppose accidentally put it in water or water has fallen into it or something happened then you can, it is gone, so you can then open it and see.

And then you can have also thin planes, multi layers, carbon nanotubes, which you cannot see by naked eyes, you have to go to a microscope to see them. So, you understand right, from buildings to nanotubes. But, you know nanotubes can be used to make buildings also, you can strengthen the structures, that is what is the beauty of nanomaterials.

So, this length scale you must keep in mind, ok the when you are talking about something which is nanometric, so how to scale it up, how to understand relative length scale. This is something people sometime forget to correlate. They started thinking that nanometer is something abstract thinking. It is beyond something which cannot be conceived, ok.

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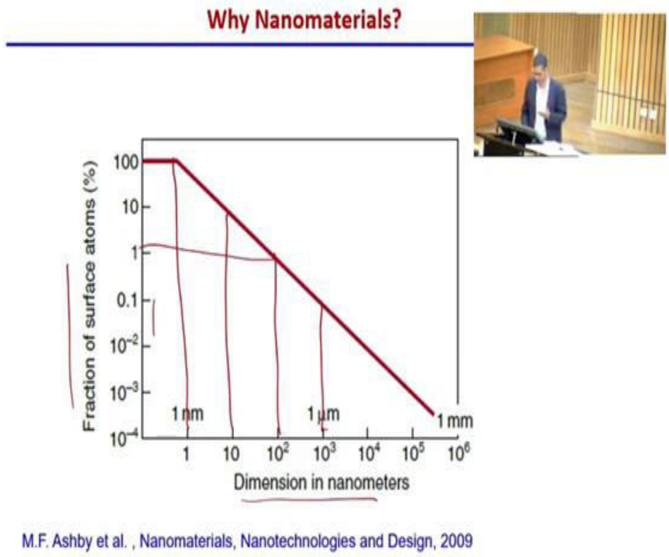

Now, why you study nanomaterials? This is something which I have all discussed already. You know when you make it materially nanometric scale, what is happening? The atom sitting on the surface, number of atoms in the surface becomes very large compared total number of atoms, ok.

So, as you go down the size from let us say micron to nanometric to about even much smaller 1 nm, the number of atom sitting on the surface is keep on increasing, ok. And this one source, this is x axis and dimension nanometers, y axis a fraction of the surface atoms, fraction means percentage.

So, if you look at carefully 1 millimeter size of a pinhead, pinhead with several millimeters only 10^{-3} % of atoms sitting on the surface, we do not care even that because they do not even make any effect on the properties of that correct.

So, now, if you go to 1 micron size, it is pretty small or it is about between 1 micron and 50 micron such a size of a hair, then it is about 0.1 %, between 0.1 to 0.01 % of atoms sitting on the surface. That is not very large. That is why you can you know put oil into your hair put a shampoo or something, you can grow the hairs beautifully right many people do that or you can actually have a different kind of hairstyle because you can surface area is not large, ok.

For hair what is important is its connectivity root of the hair on the scalp that is what actually dictates everything, that is why everybody is interested to remove all kinds of you know things on the scalp by you know using shampoo. So, now if you go down, if you go down to 10 to 100 nm.

So, and between 100 and 10 nm you can clearly see it is about 1 and 10 % of atoms sitting in the surface. But what becomes very rapid between 10 and 1 nanometer? You see that it is approximately about 90 % sitting on the surface of the particle that is why you see you know very interesting change, when you go from millimeter to nanometer.

Millimeter size things will be properties will be dominated by the bulk atoms not the surface atoms because surface atoms are small fractions, they do not actually participate in the whole property determination. You can forget them. You can say get lost, we do not care about you.

But, you know surface atoms become important when you go to nanometric domain that is why nanomaterials are unique because there you cannot ignore you cannot ignore 10 percent, 15 percent surface atoms sitting on the surface. You cannot no longer you know that you have to consider them because these atoms sitting on the surface all bonds are not satisfied.

There are bonds which are unsatisfied and this unsatisfied bonds will increase the energy system, and that is what gives them unique properties. And that is why we are interested to study nanomaterials. And there are many more, ok.

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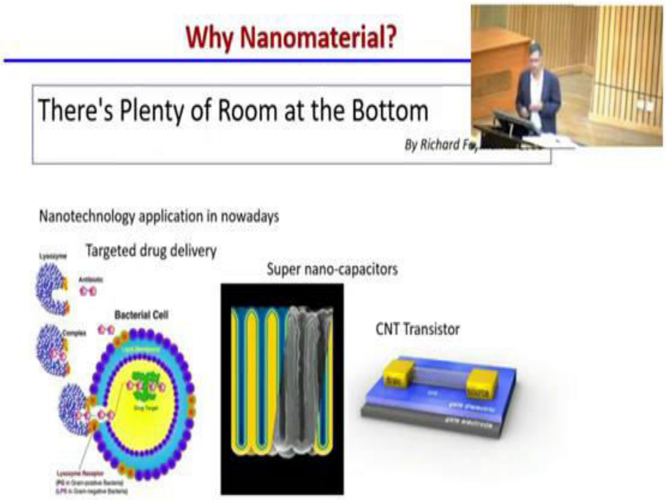

You know I have already told you about Richard Feynman in the last class and he said there is plenty of room at the bottom that is at the small scale. So, you can use transistors using carbon nanotubes, you can use capacitors, you know capacitors they can retain charges. So, you can use super capacitors, you can build lot of charges between interfaces if you create using graphene and nanotubes.

You can use nanotubes to deliver drugs. How do you do that? We will see later, but very simply you can actually change the properties of the material by bringing in nanometric scales, ok. You can this is just a small cartoon which tells you how these you know drugs can be delivered to a particular cell to treat, ok. Nanomaterials has changed a lot.

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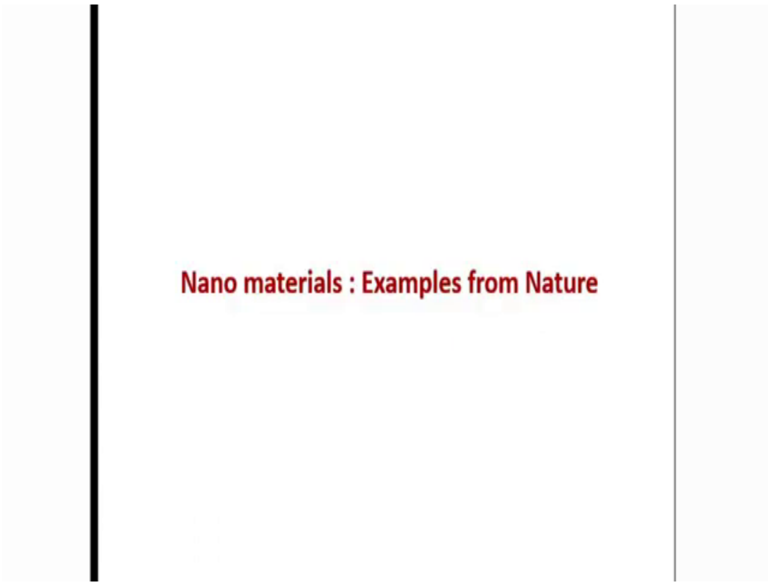

So, now, that is about my first part of lecture, that is about 17 minutes duration, ok. I suited up a little bit. So, now you know very important to come back to you. So, you know these nanomaterials are there everywhere. Think about Corona virus, how many of you seen the picture of corona virus? All of you have seen on the TVs, mobile phones.

What is the size you think? Can you see by naked eyes? Answer is no, you cannot see. Can you see by optical microscope? Answer is no, you cannot see. You have to go to electron microscopes where resolution is pretty high. So, why? Because these viruses very small, think about it a small nanometric level virus of the order diameters of 100 or 200 nanometers is making the whole world going into spin. This is something amazing, ok.

So, humans are nothing, when in terms of the virus. Virus can change the whole world dynamically and also human life, ok. That is what is this viruses. Now, the question is how you know nanomaterials are they new in the world, if you ask me this question I already told it is not new. They always present in this in the earth, always, correct.

These are there they will be there only we are rediscovering it. In fact, if you ask myself everything we do in today’s world nothing but rediscovering from the Mother

Nature. We do not do anything new, ok. All existing in Mother Nature, we are trying of rediscovering it that is what it is.

So, why I am giving these examples to you? You must be worrying that this professor is making us bored, idea of this lecture is not to make you bored. Idea of this lecture is to know that nature is more versatile than human. We always think I am a versatile guy you know I am I can do a lot of things, I can play music, I can do cooking, I can do painting, I can do study, I can do you know repair mobile phones, I am a versatile guy, but we are peanuts in compared to nature.

Nature has everything built in all the things built in for 1000s of years ok, even more, ok lakhs or crores of years. So, you cannot beat that. Human life is only hardly 100 years maximum. So, you cannot beat that. So, that is what it is. That is why we need to know nature more.

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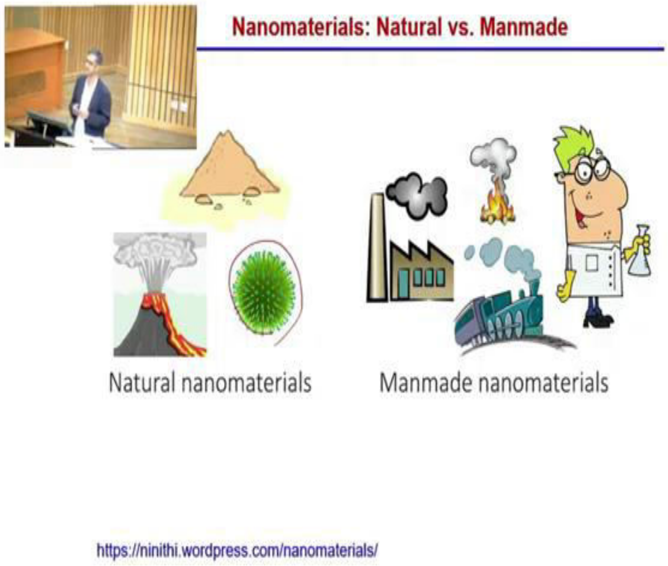

So, let us first see that. You know there are a lot of natural mean nanomaterials, if you see a volcanic eruptions, the you know is the kind of dust and spume come up. Each of these contains fine scale nanoparticles. We never bother, we only bother about the you know damage it creates we only see that, ok.

Then you see this is the virus, this is the Corona virus, right. They exist in nature. Then you can also dust right, dust, sand, they can be that in that there will be also small nanoparticles, but they are not, ok, bad or so bad as compared to human made.

What are these? Factories, big big factories getting lot of you know pollutions. And these pollutions are nothing polluting is nothing, but nanoparticles. They can easily go through your nose and lungs and create various diseases. If you burn a coal or if you burn some kind of a you know pet coke or wood, you create lot of dust, they also contains that.

See, not only that, in the laboratory also you can create you can laboratory can create dangerous nanomaterials, which can be used as a weapon to damage human or society. So, manmade nanomaterials are more than human, no answer is not correct. Man has learned from nature, but they have disturbed the nature that is what it is, ok. You will see that later as I keep on discussing that.

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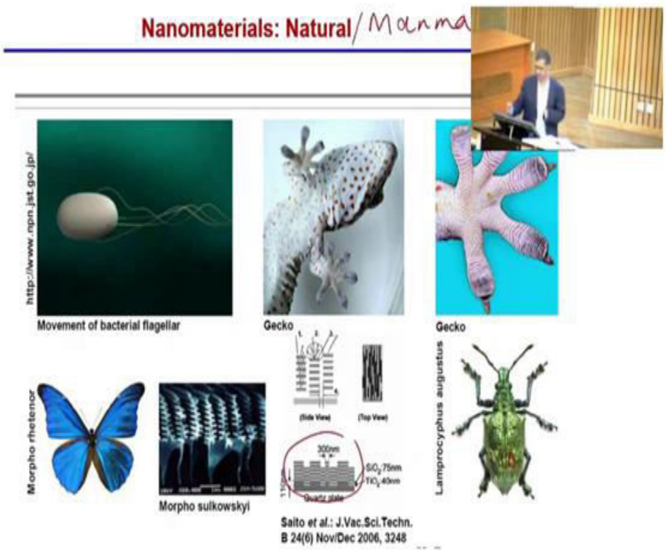

Well, this is the picture taken from website given in Japan. As you see the bacteria, movement of bacterial flagellar, you can see bacterial flagellar these are like a legs of a human with that they can navigate, they can move. Gecko, we will discuss more about it.

It has this you know legs which allow you to jump just like a spider man, right. You have seen spider man movies spider man jumps on the on one from to one place. So, these are also like that, but do the spider works or what is the thing we will see that. Well, you know the color of butterflies also because of nano pigments present in that or you can see these color on the skin ok, Lamprocyphus Augustus very difficult name to remember, correct.

We can also create semiconductor devices which is used in mobile phone or even your laptop in your PCs, there also you have these kind of structures built in ok, or you can create what is known as some kind of morphological structures. So, all these are actually either human made or natural, ok. So, I should put it here also manmade, right.

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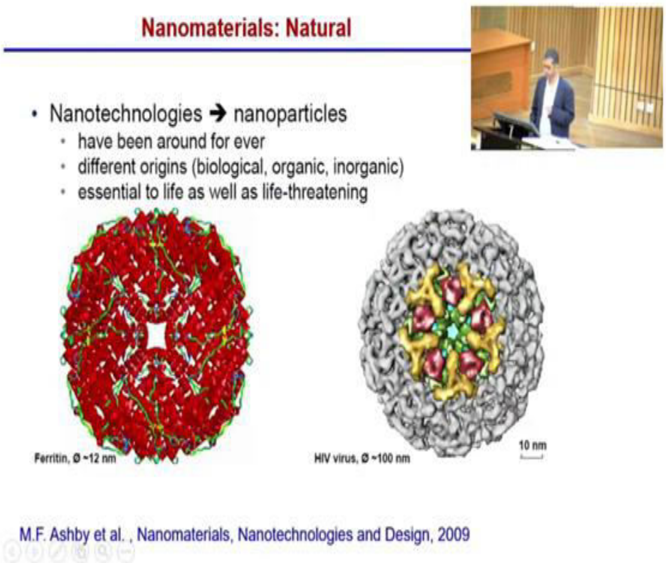

So, now, let us discuss one by one, this is a picture of a HIV virus, very dangerous right, you know that, there is no cure for that. And you know this scale, you should remember this one this is a linear scale length of these thing is about 10 nm. So, what will be the length of that? About 200 nm that is what it is.

So, this virus is tiny, tiny things which you cannot see by eyes, you cannot see even by normal microscope you have to go by go to electron and see that and it can create havoc in your body. This is ferritin molecule, this diameter of the 12 nm.

Why it is important? Because that is what is present in your RBC, and this iron base molecule allows you to allow these RBCs to carry oxygen from lungs to the heart to the various parts of the body, ok. And if you have anemia these cells will be not able to function properly, right. So, you can see this nanomaterials is the essential part of life they are always present everywhere right, ok.

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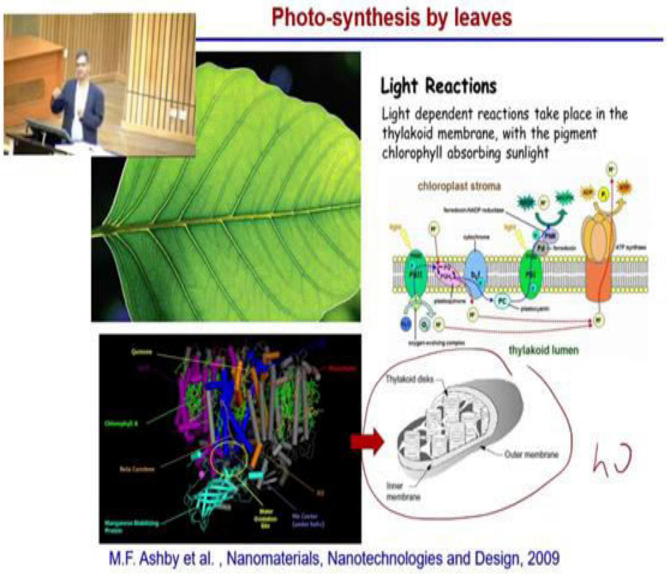

Now, come back to the best part of the natural nanomaterial, ok. You know photosynthesis is something which you shoot you know all of you know that you starting from your school level class 7, 8, 9, 10, 11, ok. So, leaves they look like green and that is where the photosynthesis is happening, correct as you know. This is on the most beautiful example of nanostructure materials. You must understand that.

What is it? Well, you know what is photosynthesis? This tree leaves takes carbon dioxide CO_2 from the air and water, the root sucks water, combine them in presence of sunlight, remember this in presence of sunlight. And produces what? Produces the two most important thing for our life. One is oxygen without which we cannot live in this world; other one is a glucose and that is gives you food.

All the fruits everything you see there are different variations of this product, but most importantly the oxygen is important. Now, why and how does it happen? To look at it you know it contains what is known as a leaves contains chloroplast that is what is the basic unit, ok.

And photosynthesis happens inside this chloroplast. You know these units which are responsible for the green color of your plants ok; they are actually presence in millions of millions, ok. But you know each chloroplast contains very important unit called thylakoids, ok.

You see this is the picture of inside a chloroplast. What are these thylakoid? They actually disc, nanometer size disc. They actually fluid filled sacks ok, sack, ok. So, they are sitting on each other, but this thylakoid takes contains color sensitive pigments and that is very important.

These color sensitive pigments absorb a sunlight and that is responsible for this photosynthesis, ok. And you know efficiency of this process is 95 % which is very very high compared to any other process you see it is a natural process and using nanometric length scale happening inside on the tree leaves, ok.

So, now, this pigments which is present on the thylakoid surface they absorb a sunlight. So, as a sunlight absorbs a photon actually $h\nu$, photon is nothing but $h\nu$, you know that times the Planck's theory. So, that means, once they absorb this light the energy it excite the electrons, then these excited electrons comes on the surface of these thylakoids and dissociate water into oxyl and hydroxyl ions.

And then subsequent reaction happens, right. Subsequent reaction means chain reaction happens. I have showing you here the whole reaction. Let us not discuss about it. It is a quite complex. But remember these thylakoid things they contains lot of different units you see long needle like structure, ok. And all of them contain manganese. Manganese is what is responsible for the things manganese enters.

So, if this is what is the thing then why cannot we mimic it? Well, if you can mimic it you know the plants within the earth produces about 300 millions sorry billions of sugar per year, that is a huge production ok, huge, massive productions. That is the amount of food produced in the world every day, every year.

So, now the question is why cannot you do it? Reason we cannot do is because of this structure, there is 10000 atoms atomic scale structure present in these thylakoids which are so nicely arranged, the electrons once excited they hop from one center to other centers without decaying back to the original that is the key, right.

So, they do not decay back to the original at all. That is what it is. We cannot create a systems, which will not decay back to the original state and keep on doing that. So, that means, electrons are keep on moving from ones and the others reaching the surface. So, in presence of sun it becomes a battery electron on the surface was leaves up in the inside of the thylakoids, and this long battery is keep on running to produce you something.

So, you understand that. That is the beauty of photosynthesis. It is happens because of the nanostructured thylakoid disc which contains the pigments. That pigments allows you to absorb the sunlight in terms of photons, photons excite the electrons in the thylakoids and then electrons jump over from the reaction center one to other centers and leads these whole process.

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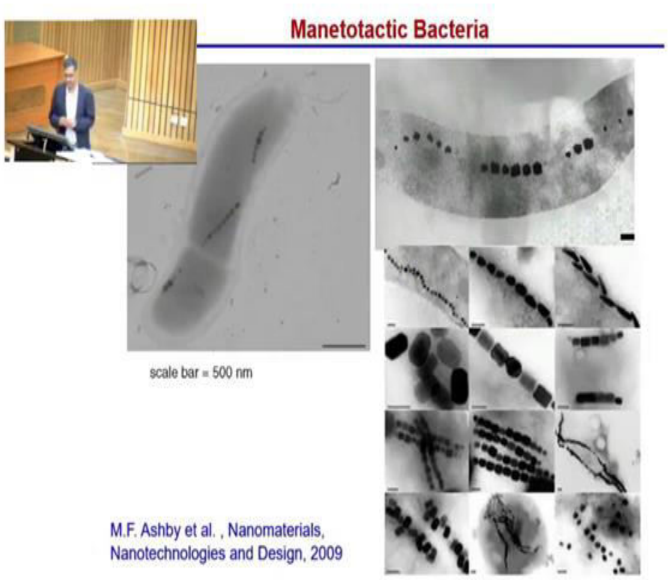

Well, there is another example of nature which I should finish before my another 15 minute slot is that you know bacteria's, ok very very important. And this I am giving you the bacteria's, which are the some magneto tactic bacteria's, magneto, ok a g is missing here, magneto tactic bacteria's.

Magneto means magnet, tactic means which can move. You know there are some bacteria's which live in the swampy waters, ok. Why do they live some swampy waters? They need oxygen, but bacteria's are very funny, unlike viruses, they need food. But you know they need oxygen to create energy also, to burn the food actually, we also need oxygen for many things.

So, now this bacteria should not, if you know the oxygen contents in the water in this in the ocean depends on the depth. Deeper the water lesser the oxygen contents, but oxygen is more on the surface of the water. So, now, if the bacteria's must know what is the optimum level of depth they should be there do you have the oxygen, how do they know that?

They use what this small nanometric magnets ok, to know their depth, correct, to move. We were saying, how it is possible? Well, these magnets are very powerful, they align themselves or they interact with the earth magnetic field. So, now, we knew understand how a earth magnetic field is so important.

It is pretty weak. We cannot feel it, but it is these bacteria's can feel it. Looking at the earth magnetic field they can line themselves. Why? Because see this nanometric size bacteria's are single domains ok, they are single crystals of ferritic nanocrystals. So, each one is very high you know magnetic moments.

So, they can because of that even the earth magnetic field is really small they can still interact with it. And if you look at properly they align in a particular way, they ok serve a particular shape they align a particular way, always. And that is strengthen the magnetic field interactions.

This is really beautiful. And these bacteria store lot of information's, they normally do not die, they get frozen in the you know ice or something. So, if you can get out of them and if you analyze these nano crystals you know what are the concentration of these elements in the water because this is where they make these crystals form on the surface of these bacteria's. They are present there, ok.

So, you have seen the two most beautiful examples of the one is from plant, other one is from bacteria, virus I have already given. So, this is very important that we understand them because from there we can learn a lot of things. So, who knows how they are forming, we can use their analogy to create different structures, right.

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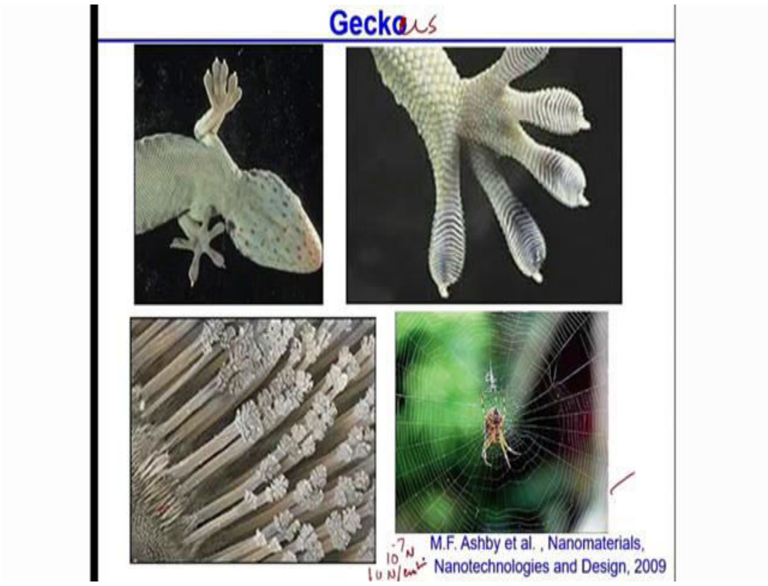

So, now you know, so this is very interesting part of this of this lecture. This is the last part of the lecture. Spider man 1, spider man 2, spider man 3, all these movies many of your watched right and you want to become a spider man, ok. Spider man can solve the whole world’s problem that is what is shown, that is not possible. You know it is impossible.

Is a man cannot solve the all problem of the world. Obviously, it can solve, but that is a dream, ok. That is basically a big dream, correct. So, basically it is a dream. So, these dreams very difficult to realize. But you know spider man’s got the properties from a spider that is what is shown here. How many of you know this spider is also nanomaterials?

Very few people, right. Spider is nothing, but a peculiar species, ok. It creates what is nothing, but a silk. And this silk; let me tell you very interestingly even if your plane moving at a speed of 800 km/hr using this spider web you can bring it to halt.

The spider web can so absorb so much of energy, it does that capability nobody ever dreamed of it, ok. Nobody ever thought about it, only when it was discovered. So, that means, spider is wonderful things, that is why the Spiderman movie came into picture. But never try to attempt yourself. You can break your leg or something by jumping, ok.

Let us go back to geckos. Geckos are something which you have seen they are actually lizard. And you have seen in your home, right. You could have seen this lizards can run on the walls, even they can move on the ceiling and they can walk on glassy floors also, glassy floors mean on the ceiling actually. How do they do it? Ok.

They do not fall off. A human trying they will fall off. They are able to do it because of keratin; you know keratin which is present in the hair. These keratin fibers which are present in the gecko, a keratin hairs they have a you know which is shown here you can see that keratin hairs, each of these legs there is lot of lot of keratin hairs. It is between millions of keratin hairs.

This keratin hairs diameter of you can see here 200 nanometers and you know each of this keratin hair when the gecko putting the feet on the surface produces force 10^{-7} N. This is nothing but so small you cannot detect, but with the million or billions of these hairs is become force become very high 10^{-10} N/m, cm^2 very high force.

So, with this large force then this hair can bend and conform to the surface morphology. You understand that, right. Whatever the surface morphology whether it is a glass, there is some roughness, it is not zero roughness. So, that depending on roughness these fibers, keratin hairs actually not fibers they can conform to the surface and then they can get attached. That is the thing they use.

So, you can use this technology to create tapes, the binding tapes, you use in your in home you know to pack something use this kind of tapes, adhesive tapes, right. You can do that. So, these tapes will be very strong then right, obviously. So, you can use microfabrication techniques to create this kind of things which is possible.

Now, what the; what is about the silk? The spider web because spider web is very fascinating, it is a composite. This is not a hair. It contains crystals in a polymeric matrix. You know the spider webs are nothing, but a raw silk which is produced by this spider.

And when the spider this raw silk is passing through these channels inside the body of the spider, they form some of these portions become crystals and these crystals get aligned in particular directions. So, what you have is you align crystals like in the bacteria align crystals like this ok, like this, but they are not inorganic crystals, they are organic crystals in any kind of a matrix.

Crystals and matrix have same structures, so interfacial strength is very high. There is no interfacial tense and not much, and because of that it become very strong material. That is why if you have a spider web and if a plane is moving at a high speed it can stop it. That is the reason it can absorb all the energy. So, that is you know one of the best examples of natural nanomaterials which you can see here.

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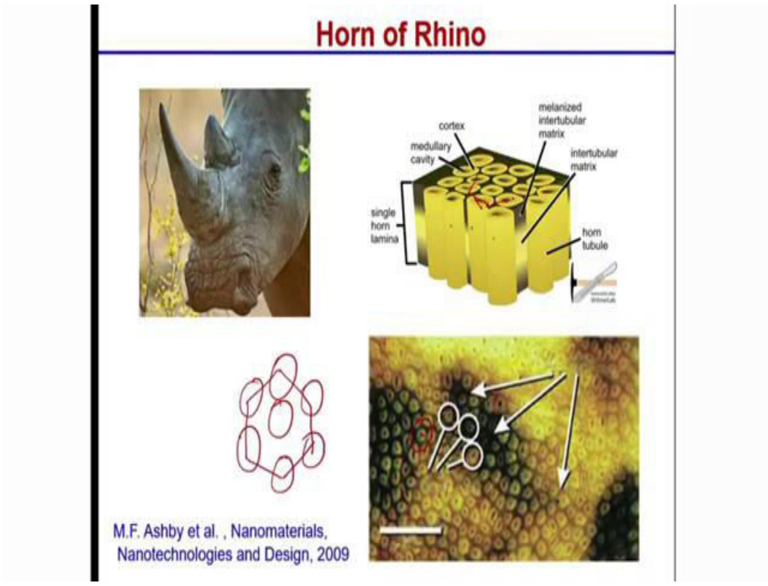

We will see much more here. Yes. Many of you have gone to zoos right, and seen this you know Rhino. Rhino has horns, either one horn or two horns, ok. If you go to Kaziranga you will have one horn rhinos, if you go to Africa you will get two horned rhinos. I know why, but I do not want to discuss it here. You should know it why it is so, ok.

So, now, these are actually pretty strong elements, ok. They are like a what is elephants. They fight each other, but you will never see these horns are getting broken. You can go and check in a national geographic or discovery channels, you will see rarely 1 in 1 lakh cases only these horns will get broken. So, that means, these horns are really strong and tough. How do they make it? Ok.

See, you know these horns are made out of again keratin fibers ok, in terms of microtubules, ok. So, if you look at this, these are the microtubules, densely plaque. You can see here on this picture, each one is a microtubule. Microtubule means there is a hole inside it, that is what you see the black things, ok.

So, there is a black thing. So, 40 layers of these keratin 5 wheels are aligned or putting one by one, one layer, another layer, third layer, fourth layer, like 40 layers and the each of these thing contains 40 layers, so this microtubules of keratin fibers. And these are densely packed.

How you can pack them? By hexagonal array, ok. In hexagonal array if you pack it you can densely pack. That is a highest packing efficiency in the world, ok. So, you can put one here, one there, one there, one there, another there, another there, and center that is what it is.

You know in your crystallography lecture right, densely packed. You can see here, it is done I can draw in hexagon 1, 2, 3, 4, 5, 6, you see that the central atom. That is what it starts to be. So, the here also you can see here on this surface hexagonal array 1, 2, 3, 4, correct, 5, 6 and the central one. So, that is it.

So, now, then these are packed in a matrix also keratin matrix. So, because both are keratin, interfacial energy is very small and they have a huge toughness. You cannot break them at all. And this is the reasons, these horns are extremely costly. In Africa, these you know rhinos are killed for this horn only because people believe this is the strongest toughest material in the world.

So, now, you know why it is. So, these are all, these micro peoples have dimensions of nanometric level, ok. I can give you that. Each of these tubules at about 300 to 500 micron diameter because there are 40 layers of that and each layer is about 3 to 5 nanometers. So, it is basically a hierarchical structures, right.

You see, remember the last lecture, the hierarchical structures are developed one by one other. That is how it is created. So, that is how the horns are tough and strong.

So, if you want to create a tough and strong material which is dream for any material scientist in the world, you have to follow these multi-hierarchical structures, multi-length scales, nanometer, micrometer, millimeter kind of or centimeter kind of structures, and pack it nicely.

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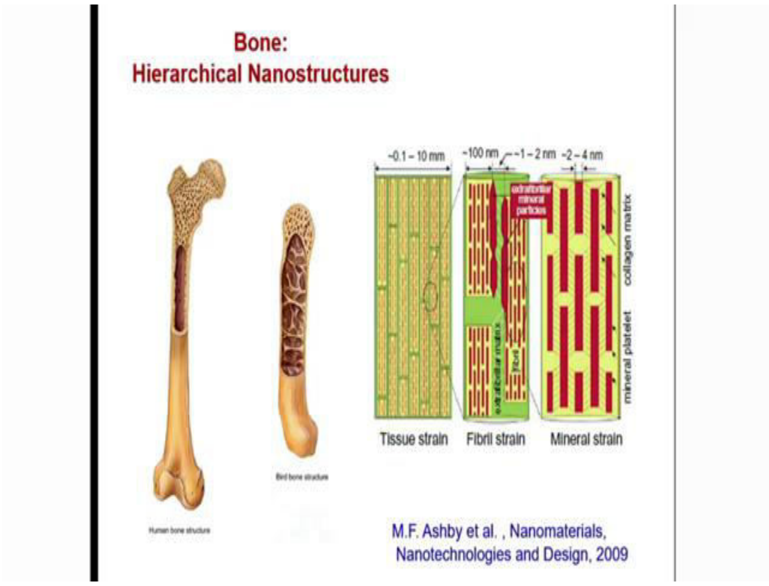

Now, you know natural nanomaterials can repair themselves. Have you ever thought of it? Right. Suppose you play football and one of your friend has you know hit it hard and you have broken your leg, then what doctors will do? They will plaster your leg and they will ask you to sit at home for 1 month that is very painful, right.

Now, this is not painful, you can use mobile phones and watch videos, movies and many things you can do, then come in contact with your friends, right, you can talk to them. So, it is not boring. Earlier when I broke my leg at the age of 8 or 9, I had to sit at home for 21 days. I was reading only books, right, there is no other option, no TVs, nothing. So, nowadays you have so many things to do, but anyway.

Then finally, what happens at the end of 21 to 30 days your bone is repaired that is the beauty of bone. So, bone gets remolded every 12 pairs in your body. That is not something you heard from your doctors may be. Why? Because bones actually have the hierarchical structures, ok, correct.

So, bones are what? They are composites again; inorganic, organic. What is your inorganic? Collagen fibers, ok that is the collagen cells, ok. And what is inorganic part? Hydroxyapatite, apatite crystals, they are nanometric. They are very hard, but brittle.

So, you are putting a hard and brittle materials in a top matrix like collagen. And this collagen matrix is putting into extra, you know what is that called? You know extra outside the matrix some matrix is present which is called something let me see what is extra fiber fibular materials, ok.

Collagen is fibers are separated from each other by extra fibular material is also a basically body cells ok, which consists of extrapolar collagens, ok and apatites are there in the quality I told you. So, you see that this is what it is, correct. This is the extra fibular mineral particles here and this is what is your apatite crystals in a collagen fiber, right.

And this is between these two structures. So, you can see that this is the mineral platelets and this is the collagen matrix, you see these are the plates and this is the collagen matrix. This whole thing is put it here, and then in between then you can put another one here in between these two you can have a extra fibular mineral, ok.

They are separating each other, basically they are binding each other right. That is what it is. Now, this gives them very strong and top things. That is why it does not break. So, easily only when you are hit hard then only you can break your leg or something or your hand, I have broken my leg, I have broken my hand. You know I was very naughty child in my childhood.

So, the question is this is a hierarchical structure once the bone is broken between the two parts there are sensors actually, they can see that something is wrong. There is no connectivity. So, the moment they can sense the sensors they remove all this blood cross everything from that part, then the sensors calm and meet.

So, by the way then they can send the distance how much required to build the bone, then they bring all the materials they bring blood, they bring everything and then they slowly, slowly the bone is repaired. So, can you imagine that? At the nanometric scale you are remolding the bone ok, that is the beauty of this. So, bone is also hierarchical structures. Scales from nanometric to centimeter, milli or meter. Your human bone is something like half a meter, right. It is pretty long depending on the height of you, the human bone is pretty long, ok.

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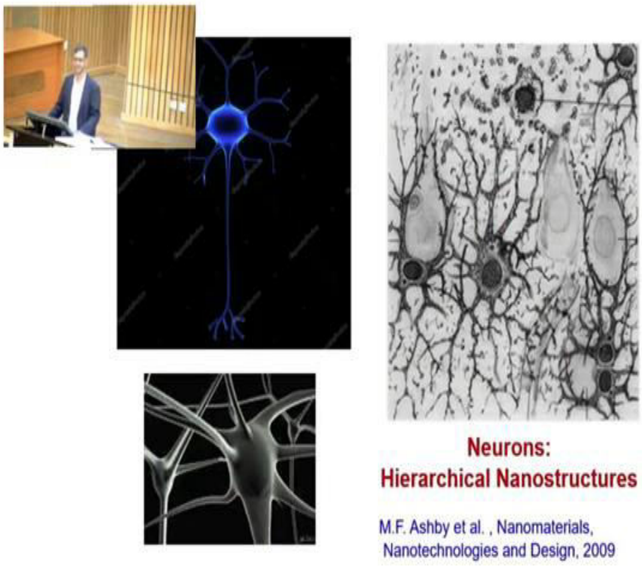

Another important thing is a human brain. Remember, we have not understood human brain, right. But if you understand human brain you can understand your computer, you can actually produce better computers, right. So, what is the basic unit of human brain? It is nothing but a nerve cell, a normal action and dendrite, this is the action and this is the dendrite, right, I am sorry. This is the dendrite; this is the action, correct.

So, they are also hierarchical nanostructures. And they are connected to each other, right. That is what it is. You know a human actually requires to spend only 10^{-15} Joules per operation I am speaking each of my sentences, what I am speaking in 10^{-15} Joules which is very small.

On the other end, a computer requires 10^{-7}Joules per operation. It is almost double I mean not double, 20 % its 8 orders of magnitude high. That is the difference between a natural brain and artificial brain. So, we are long long away to mimic on brain. We do not even understand how the brain works, but again these are all nanostructures. There are very small-scale structures present inside your brain that is what makes you intelligent human being, ok.

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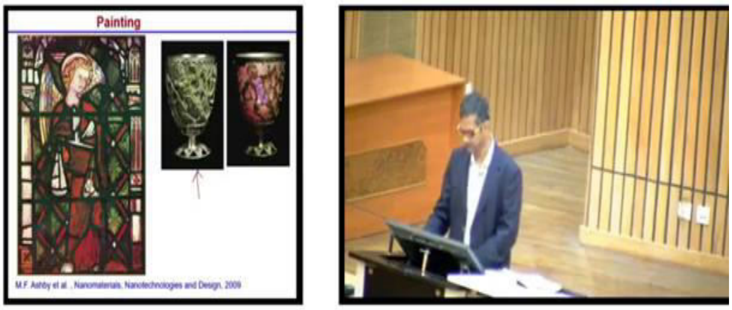

Now, in the last couple of minutes I will not discuss much, but I will tell you, you know these paintings you see in various churches and you know glass work everything, especially in the western world you can see that. And how many of you see this glass? This glass is a very typical one which is donated to Byzantine when she, once see you know what is the why he won a war against Constantine, ok.

Constantine in Rome, he won against Licinius in Trash in 324 AD. This glass if you sign light from outside, they look like this, the left hand side. But, if you sign like from inside it looks like that. It is a killing of that king is shown there, you can see that actually. So, it is basically because of gold particles, nanoparticles present in a glassy matrix distributed properly, very small fraction of that. That is what gives you this life. Same thing valid the hair also in the paintings, ok.

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So, this is a painting for Mayan Civilization in Mexico ok, long back. When you can see there is an animal or some kind of a very careful species encrypted here, ok. Mayan civilization is very interesting you should see some of the movies in the Hollywood movies where things are shown, right.

So, once the analyzer seen the gold nanoparticles present there. So, this is how the colors are built up. So, you must be thinking where from they got into whole nanoparticles. They have got it from colloids or maybe some minds actually it is present there.

So, that is really available. In those days, you know Mayan civilization is you know about 1000 or 1500, before birth of Christ in those days there is no chemistry root to prepare nanoparticles, but they are utilizing it to make it beautify these paintings, ok. Let me stop here.

So, I have given you 3 sets of things in 3 duration. I will divide the lecture also 3 durations, so that you can understand. So, these are the examples of nanomaterials which are used in the real life naturally and manmade to create different structures. So, the next lecture we will move one step further and discuss about how we can classify nanomaterials. How you can you know differentiate between one from the other nanomaterials, ok.

So, let us take a break and we will come back ok.