Nanomaterials and their Properties
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Lecture - 01
Nanomaterials: An Overview (Part - I)

Dear students, we are going to start the introductory lecture of MSE 694, welcome to this class. You know because of the pandemic COVID-19 we have to resort to video lectures and this is very unfortunate that we cannot have face to face contact with you and hence we I have to resort to recording all my lectures.

So, that you can access it easily from your home or from your place wherever you are and see it whenever you feel it. You can always watch these videos as your at your own time at your own place you do not need to worry about me coming in front of you ok.

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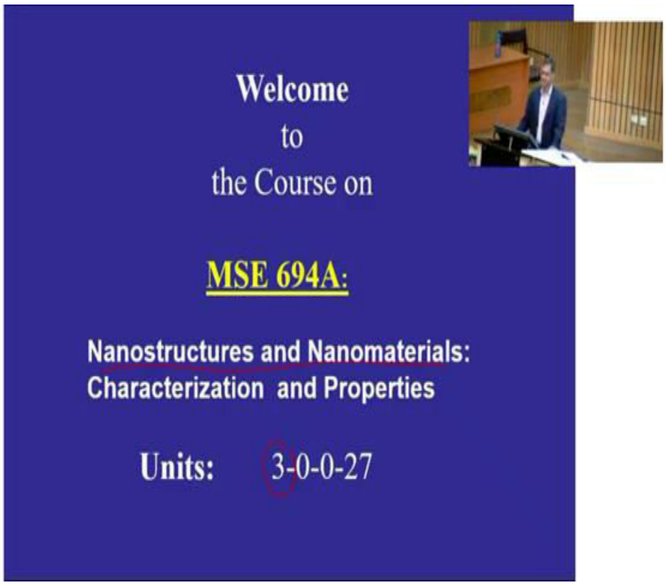

So, let us start this is the course on nanostructure and Nanomaterials characterization and properties. This is a 3 lectures course; that means, we will have 3 contact hours per week having credits of 27.

So, that means, every week we will got you are got to see 3 lectures and because semester is 13 semester 13 week long. So, that means, you will have about 39 to 40 lectures for this course that is makes the course pretty intensive and which you should follow very rigorously. As you understand this is an advanced level course 600 level as well also the matter of the course is very new. So, hence you required to spend time to understand it.

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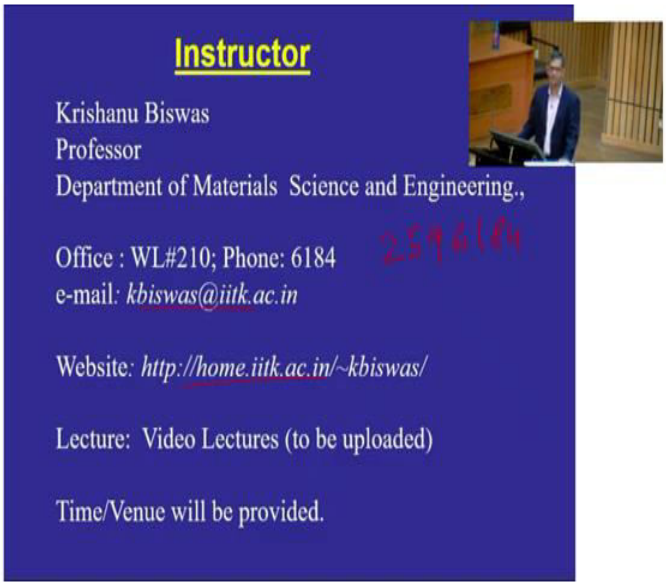

First let me talk about myself, I am a professor at the Department of Materials Science Engineering, my office in Western Lab room number 210, my internal phone number is 6184. But if you want to call me from outside you need to write prefix 2596184. And, to discuss with me the most important mode of communication between you and me will be the email.

So, you can write me email using my email address given here you can also see details of myself in my home page which is given here. So, lectures will be all video and they will be all uploaded one by one obviously. So, that you can see them at your own place, time of the lectures will be given as soon as the semester begins. When you see material for you; because you are going to see it from your home or however, places you are in.

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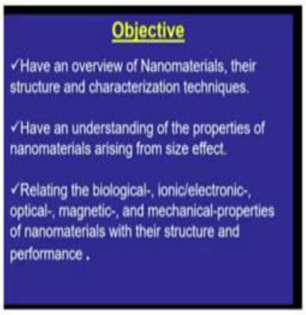

Just like anything in the world happening, there must be an objective or there must have several objectives of this course. So, the basic objective of this course is to have an overview of nanomaterials. And that means, their structure and how to characterize them seeing is believing, but rather than saying also there are many ways of characterizing them.

So, nanomaterials are important hence, at the end of the course you should have an understanding of the properties of nanomaterials because of the small size. And, lastly we must be able to relate the various properties like biological, ionic, electric, magnetic, optical or mechanical properties of these new set of materials with structure and also the performance.

So, in a nutshell as the semester will come to end in 2020 the November or December, you will have an idea of what is a nanomaterial, what are their properties and how to relate this properties with structure. And in this, the characterization will come into a picture because we need to know how to see them, how to characterize them, how to understand their basic structures.

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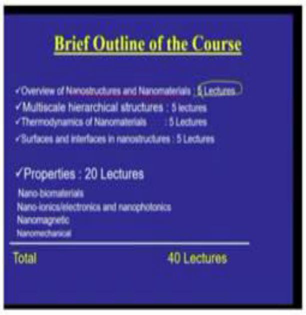

How we are going to go about it? The brief outline of the course is given in this slide, as I said this is a 40 lecture course. So, first 20 lectures will be spent on basic things of nanomaterials. First, I will talk about overview of nanostructures and nanomaterial and this overview is basically related to various things like how nanostructure materials came up ok, historically, as well as you know structurally.

And what are the basic features of nanomaterials, then I will talk about some of the multiscale hierarchical structures of nanomaterials which are available in nature even just think a bone ok. Human bone or any other bone it is has hierarchical structure starting from small atomic level to a macroscopic level.

Similarly, many other things you can think about a cone shell is mostly made up of some calcium carbonate type materials, but the way these calcium carbonate crystals are built in to make a very tough, but strong cone shell is what makes them one of the most important material in the world.

Well, as you know we need to know also some basic things like thermodynamics, surfaces, interfaces of nanostructure materials, nanostructure materials for the surface and interfaces are very important for the infrastructure materials and this can be linked with thermodynamics.

So, I will spend about 10 lectures on that and 10 lectures on the structure and the hierarchical; hierarchical things I will be giving a lot of examples from nature or a man made materials for that. So, that is the almost half of this course, second half of the course will be on properties ok.

Properties means mechanical magnetic you know electric, electronic, photonic many many such properties or even bio properties we will be discussing some of them; obviously, you cannot discuss all of them because of time constant. But I like to maximize this as much as possible. So, that will be our basic outline of the course, but you know as any course we need textbooks or we need to have some material to study with it.

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So, this is what I am showing you here, these are the recommended reading I would say you need to follow them. These are available in our library you can download even or if you do not get you can actually ask me I can send you also via email or something we will try to build even repository of these materials in the course website.

The first one is by Dieter Vollath, name of the book is Nanomaterials and Introduction to Synthesis Properties and Applications this is a very small book, but very important I am going to show you here, this is very very you know useful book also. The next one is by professor Michael Ashby, PJ Ferreira and DL Schodek. This is very important book this book is known as Nanomaterials Nanotechnologies and Design and I am going to follow this book quite a lot.

So, basically; that means, you need to read it thoroughly that is what is it is. This book contains many things well this book has starting from the basic nanomaterials in natural world to how to design make them synthesis techniques and how to understand their properties. Even you can see how the cost and other things are done in this area of materials. So, we will be discussing some of these aspects.

Third one is by Professor KT Ramesh name of the book is Nanomaterials, Mechanics and Mechanism. The book is mostly talked we will discuss about mechanical properties of nanomaterials and hence when I will talk about mechanical properties, I will bring in this book, but some of these aspects are also available in the book by Michael Ashby and lastly, if you are really interested to know about nanomaterials.

You know it is better to look at encyclopedia, encyclopedia of nanoscience and nanotechnology aided by Professor Hari Singh Nalwa is a basically a mammoth it is a more information available which you can refer it for anything you want. But mostly for day to day understanding, the subject you may not need it. But if you really wants to want to know the subject and you know one you are an avid reader. So, I suggest you get this book this is also available online ok.

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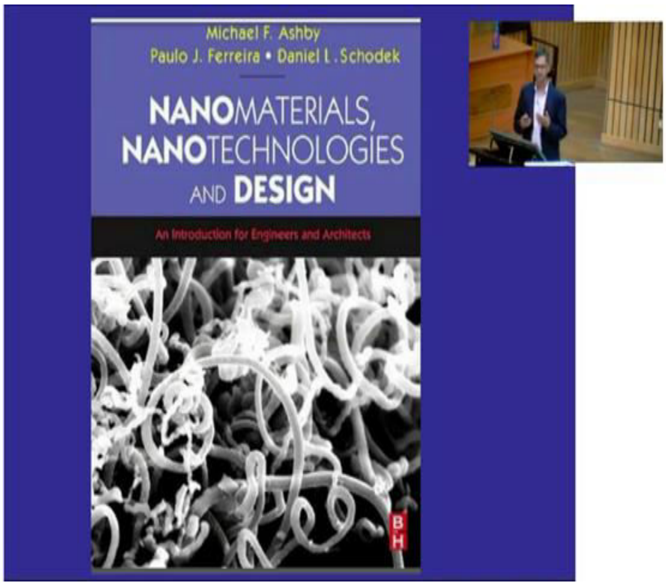

So, let me just show you how the book things. So, these are the 2 books which I will use widely these are marked by yellow color text, this is the first second book rather by Michael Ashby you see here: Nanomaterials Nanotechnologies and Design, An Introduction for the Engineers and Architects very interestingly also for the architects people should know how to use nanomaterials for various applications.

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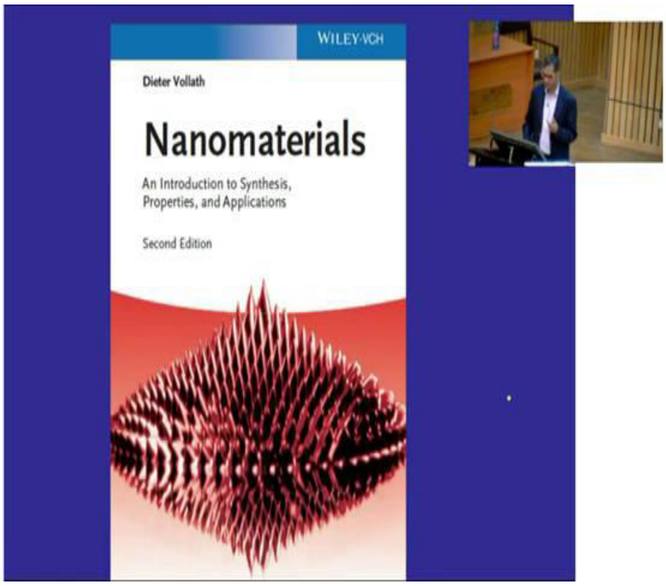

So, this is the second one and this is the first one by professor Dieter Vollath. So, both these 2 books will be the main stay for our course. So, it is better you can get a copy of these books at your disposal. So, that you do not need to you know struggle during the lectures understand your lectures. Although I will try to explain as much as possible, but you know book is always better than anything else.

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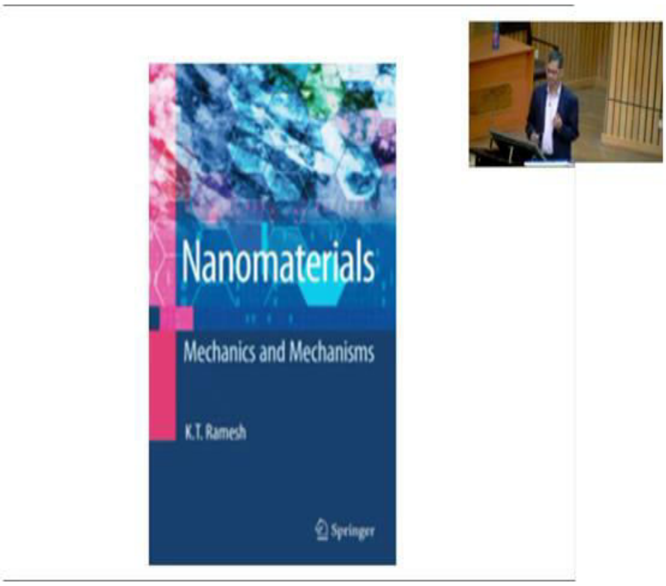

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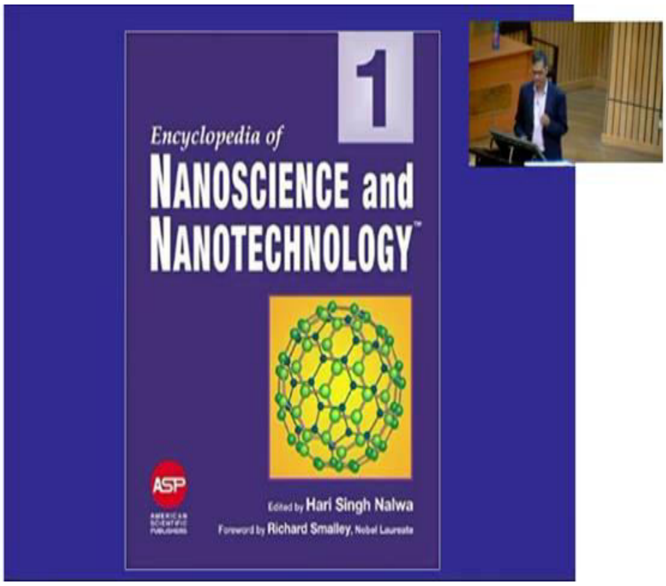

So, this is a third one by K. T. Ramesh Mechanics and Mechanisms of Nanomaterials and the fourth one is the Volume 1 of Encyclopedia, Nanoscience Nanotechnology by Hari Singh Nalwa ok.

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And course website is this it will maintain the lattice site of our department you can get many informations of this. I will try to put these videos also on this course website. Otherwise, we will put it some in some repository, I will send the links for that also.

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So, in a nutshell I should tell you that, you know you should not run away you know this is a very important sign running away from any problem only increases the distance from the solution. We are here engineers to find solutions of the problems humanity is facing just like COVID-19 a lot of scientists, doctors, nurse's even engineers working on to find solutions ok. It is as you can see that I am using a mask, which is engineering product.

So, I need to put it as close as possible on my nose that is it so that means, if you want to solve a problem you cannot make a distance between problem and you, you need to get close to the problem to solve it, but easiest way to escape the problem is to solve it, that is what is it some easiest way to know a subject is to read understand and do that.

So, let us enjoy the nanoworld and I like to see I like to rather recommend you to see this movie: Honey I Shrunk the Kids. This is a very important movie in which the kids will become smaller because of some accident and then they will wander around in the garden of the house.

And finally, they will be facing a lot of struggles because of the small size in our nano size they are not basically nano size. But they are small size than compared to human. So, this movie is available on YouTube ok that is what it is.

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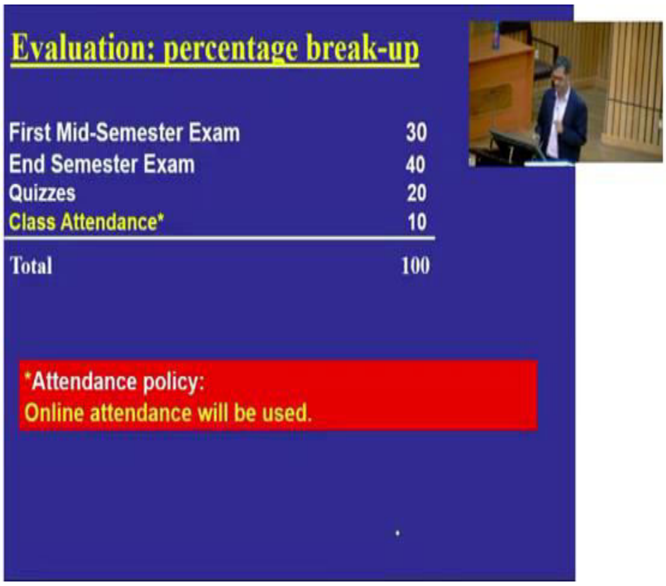

And I do not know whether I should discuss about this slide or not in front of you right now, but this is what I use for evaluation of your performance in the course how to evaluate ok a student.

So, normally we do a mid-semester exam, end semester exam and quizzes I am not sure and we used to use earlier a class attendance as an important percentage of marks. I will discuss it when the semester will begin at the time how to go about it I am still not sure how we can arrange these exams.

So, there is no clarity yet. So, let us not discuss about it ok. So, that is about the introduction of the course which you have got some idea how what is the course, how we can go about it. So, now, I will go to the some part of the course which we are going to teach correct.

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Let us discuss about that you know this course is about nanomaterials, nano is a prefix here the nano word means dwarf ok all of you know meaning of this word ok. So, let me write it out dwarf that is the meaning of word nano in Greek this is the prefix which used for all kinds of things.

But you know it has become so famous in today's world you see nano word is used for many things, like you have iPod nano, this because is basically small machine which can allow you to listen music or you can have you know nano café, you can have a small car known as Tata nano. You can have also Logitech mouse known as a VX nano or you can even have wine named after nano, correct? This is very very widely used word if you search in Google you will find many many such things which, in which nano word is used but you know what is it that is what you should know.

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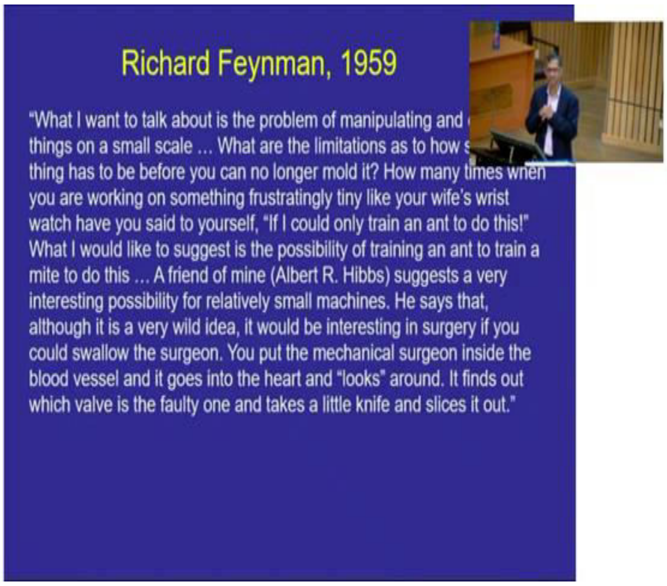

So, in the course of this lecture, hopefully you will understand what is it, but let us start first how it started you know it is very important we know the history, I know many of you do not like. And whenever I give lecture and I started bringing history people started talking about it why to talk about history talk about future. Then the future is born in the womb of past ok. So, whatever happened in the past that actually propelled things to go into the future.

So, it is more important to know that in this connection let me go back to the Nobel Laureate Professor Richard Feynman in 1959 in the annual meeting of American physical society he gave a lecture. And then lecture he talked about something which became a very important, what he talked about is this like this given in the you know inverted commas this is not my words his words I am quoting it.

What I want to talk about is the problem of manipulating and controlling things on a small scale, what are the limitations as to how small a thing has to be before you can no longer mold it. Look at the questions how many times when you are working on something frustratingly tiny like your wife's wristwatch have you said to yourself. If I could train an ant to do this work what I would like to suggest is the possibility of training an ant to train a mine to do that.

A friend of mine is given the name Albert R Hibbs suggest a very interesting possibility of relatively small machines, he says that although it is a very wild idea it would be interesting in surgery if you can swallow the surgeon, you put the mechanical surgeon inside your blood vessel it goes into the heart and looks around it finds out which valve is faulty one and takes a little knife to slice it out, I have changed little bit, but this is how what he said.

So, you understand this is a dream in 1959, 1959 is 70 years ago almost no 60 years ago sorry 60 years ago today is 2020, 60 more than 60 years ago and that is what his dream and the dream actually makes you realize whatever you are thinking today, you can do it tomorrow or not. So, he was talking about a tiny surgeon which can go inside your body and do that.

Those of you, who in a childhood would have seen a character called Doraemon Japanese cartoon character, you could have seen Doraemon can create a small Doraemon if he has a problem inside his robotic machine and that smaller one can go inside and make a repair. So, that was actually dreamt of by Richard Feynman in 1959, but you know nanotechnology came much later only in 1974 by Japanese scientist doctor Norio Taniguchi ok he coined the term nanotechnology.

You know what he referred to? He referred to the precise and accurate tolerances required for machining and finishing of materials. If you want to machine a surface and give a finishing touch you will be dealing with the kind of tolerances which you can accommodate based on the specification of the customer.

Like if you are talking about tolerances of machine tolerances of your watch ok. It will be very very small machine tolerances he was talking about machine tolerances of very small of they are of order of hundreds of nanometers, we will come to it what is nanometer then only we will understand it.

So, that is how dynamically came, but you know it was in 1981 professor K. E. Drexler is at nanotech institution of molecular manufacturing in US, first he talked about bottom up approaches and that is why the nanotechnology came into picture. But only when in 1990s nanomaterials and nanotechnology became a popular topic of research and that is how the major inventions did take place and then last 20 years in the 21st century something more happened.

So, therefore, this subject is relatively new although it is it has been thought about it long before that is new.

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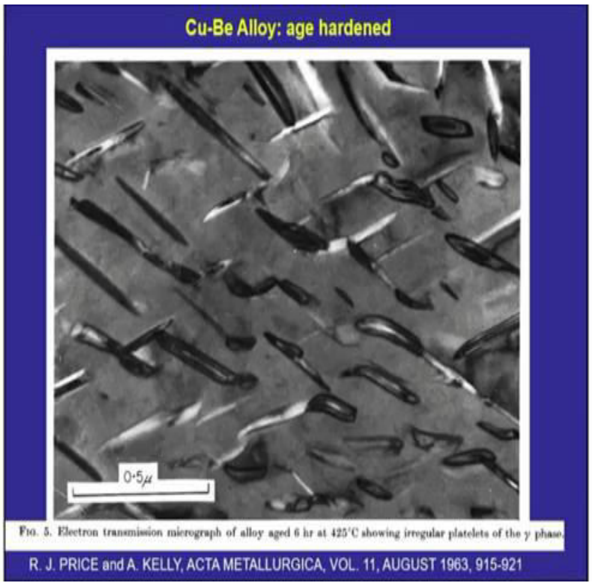

But I would like to show you something else also ok let us talk about, you know we are metallurgist we are dealing with metals and alloys and ceramics and something’s else all these things. We knew about nanomaterials even before that ok how? You may be because you are wondering about it, you know Richard Feynman is a very tall figure in this physics and even in various subjects.

But you know metallurgists were doing silent silently something, what is that? In you know in the beginning of 20th century something on 1910, 1908, 1911 the alloy called beryllium came into picture aluminum copper alloys. And these alloys are now workhorse of the aerospace industry basically plane body and many other things are made of that, why?

Because they have very strong material with light material aluminum is a very low dense, but at the same time it is strong you had only 4.5 percent copper into aluminum to get beryllium and what is. So, interesting about it I will show you that first let us talk about copper beryllium alloys which are similar type, but not used when you do a edge hardening treatment of that when you create is basically this kind of long precipitates.

And this just reported by Price and Kelly in Acta Metallurgica 1963 just 4 years after the lecture by Professor Richard Feynman. You can see these dimension of these precipitates are actually some micron less than a micron $1\mu m = 10^{-6}$m. So, these are actually plates of gamma phase formed in a matrix.

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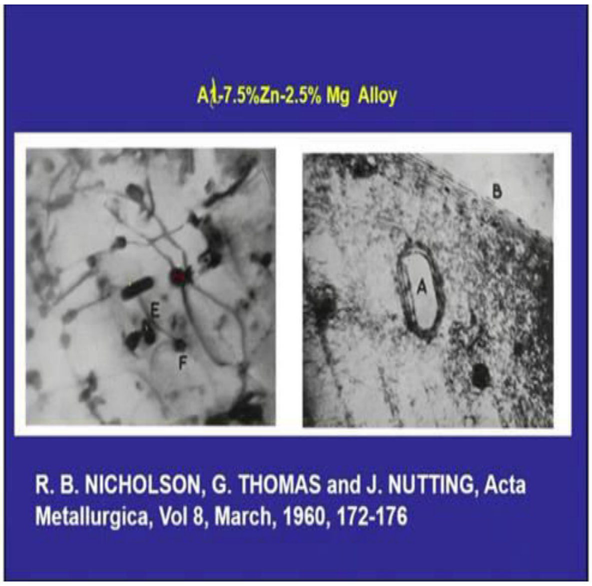

Now, I even go back this was published in March 1960 may be same time similar time scale as professor Richard Feynman's lecture by Nicholson Thomas, Gary Thomas and John Nutting and you know you can see here this picture is taken at 80000 to 100000 times magnification.

There is no micron bar is given, but these are the precipitates which you see here very clearly not only that, you can see these lines which are basically nothing, but a dislocations also if some of you are from metallurgy background you know these dislocations do exist in materials and they interact that is how we give them strength.

So, now this is the precipitates around which dislocations has formed loops. So, dislocations are atomic scale objects, they must be as small as nanometric scale. So, seeing them in a transmission electron microscope in 1960s; obviously, was very very very big achievement and because transmission electron microscope in which these images were obtained came in 1900 after second world war actually in the commercial scale that is in after 1945.

So, these objects you see here basically are precipitates in a matrix of the aluminum, this is aluminum zinc magnesium alloy ok this is Al actually not A1.

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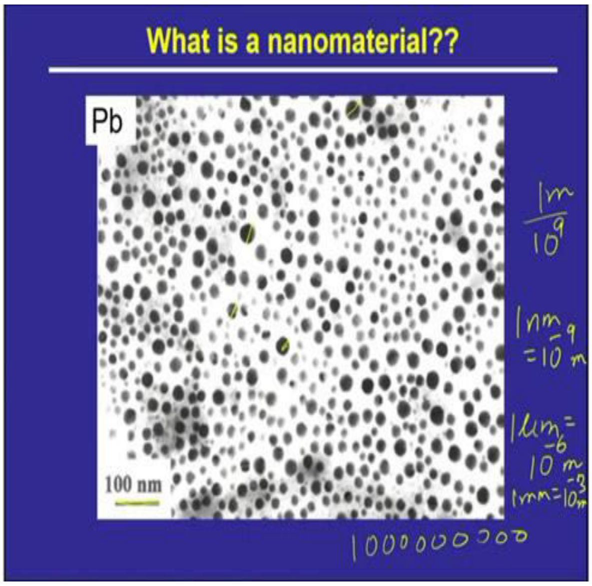

So, what I mean to say is that these were there their subject was there but we never explored it, we never given them as the nano precipitated or nanoscale objects that is what I am trying to say. Well, what is the nanomaterial by the way? I have given you some historical perspectives many people do not like historical perspective.

Let us go back into the subject, what is the nanomaterial? You know this is a picture of lead nanoparticles in on a transmission electron microscope. So, what you see here there is a distance bar this distance here you see here this distance is 100 nm. Now that length is 100 nm.

So, I can use that this is a linear scale I can use that and measure the size of this diameter of each of this particle diameter of this, diameter of this, diameter of this, diameter of that, I can do that and if I measure them I will find all of them will fall below 100 nanometers.

Now, question for you is what is a nanometer? Ok, 1 nanometer is 1 billionth of a meter. So, that means, $1/10^9$ m so, what is then that? So, 10^9 that is 1 billion ok. So, 1 billion if you divide 1 meter into one billion small objects one small object is 1 nm that is a 1nm = 10^{-9}m.

On the other hand micron which you have heard a lot is something like this 1 $\mu m = 10^{-6} m$ and all of you know that $1mm = 10^{-3}$ m. So, that is the relationship. So, 1mm, 1µm, 1nm you are going down the scale and every time you are going down 3 orders in magnitude in scale.

So, any objects has 3 dimension x, y, z and any of these dimensions having a distance less than about say less than about 100 nm is called a nano material, that is what is the definition of nanomaterial. So, this plane also has 3 directions x, y, z and any of this direction if it has the dimension of less than 100 nm, 100 nm means what, 10^{-7}m, right?

If any of this dimension has that then, we call them nanomaterials, it need not to be that all the dimension x, y, z must have less than 100 nm, but it can be only 1 of the dimensions that is what is important to know.

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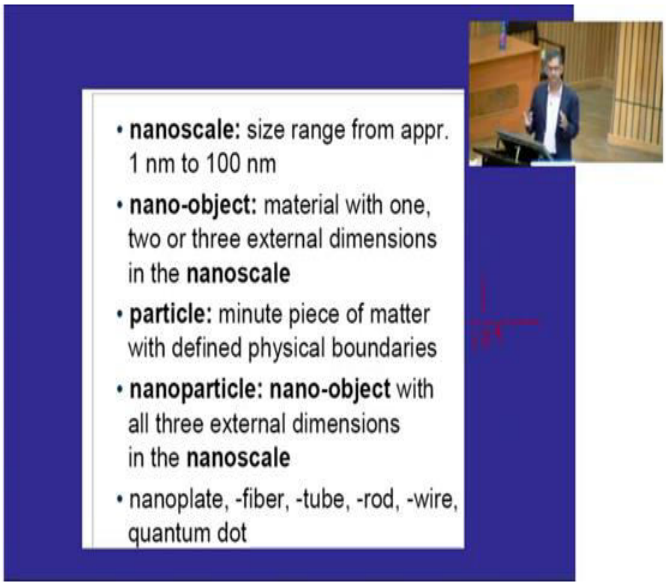

So, nanoscale means size varying from 1 to 100 nm correct. So, nano objects means materials with 1, 3 or 2 external dimension I mean to say x, y, z is in the nanoscale design and it is called nano material and nano objects particle is same thing ok.

So, it can be nano fiber, nano tube, nano rod, nanowire, nano plate, nano quantum dots sorry quantum dot anything you can only you need to write a nano prefix before plate, before fiber, before tube, before rod, before wire that is it, there are thousands of such things are available now. So, that means, you know nanometric size range is important and that any of the dimension in the x, y, z can be the dimension.

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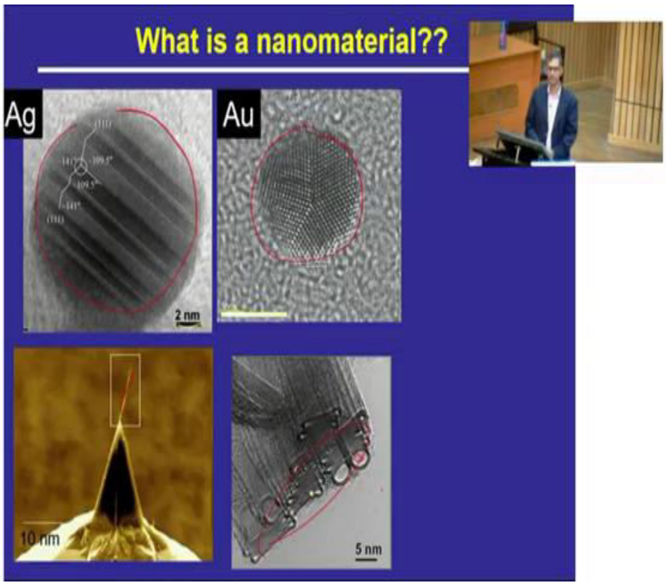

Let us give some examples of that, you know gold, silver are very precious metals, they are liked by the ladies in India. So, much everybody wants to have a gold ring around in their fingers or gold bracelet.

So, gold can you make nanoscale, you see this is a nanometric object this is 5 nm dimension so; that means, this is of the order of 7 nm size silver this is 2 nm dimension. So, this means this is about say about how many 20 nm this is silver nanoparticle, you can see there are lot of things inside and.

In fact, this in the gold each dot cross member column of atoms actually they are taken at such a high resolution. You can also have tip of a atom from microscope or scanning tunneling microscope in a nanometric domain ok.

This is the tip you can see here shown in this white square box, you can also have nanotubes, you can see that these are carbon nanotubes, bunch of carbon nanotubes and this is tube how do you know because you can see there is a hole. So, there is a tube will have only a hole inside it and then something surrounding it. So, that is what is atomic layer surrounding the holes that is what is called nanotubes there are so many nanotubes are present here.

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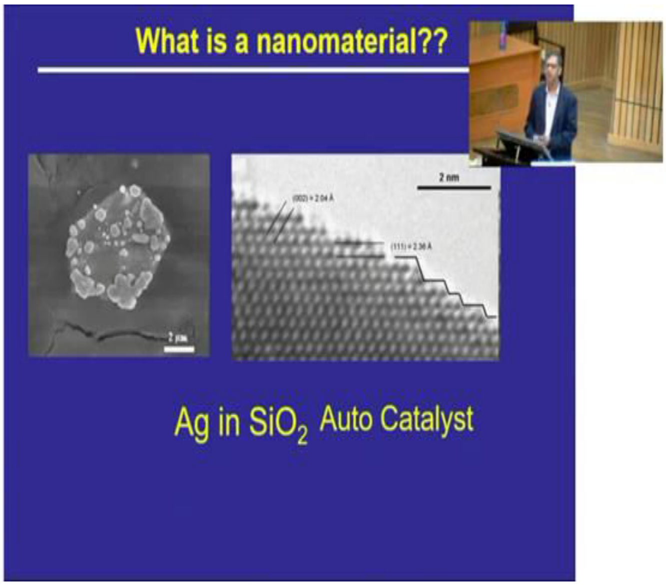

Well, you can also have catalysts you know all the catalysts which are used in the auto industry or so has pernicious metal likes platinum, palladium, silver, gold as a nanoscale, but platinum, platinum, gold is very expensive. So, people use silver. So, you can clearly see that silver atoms are lined up in a present in a matrix this is the steps.

The steps are good because they will act as a site for the reaction which is for which they are made up actually, maybe this is true convert carbon monoxide to carbon dioxide, NOx to nitrogen. So, this is what they are used. So, there and for catalyst all throughout the 100 centuries this is what is used ok.

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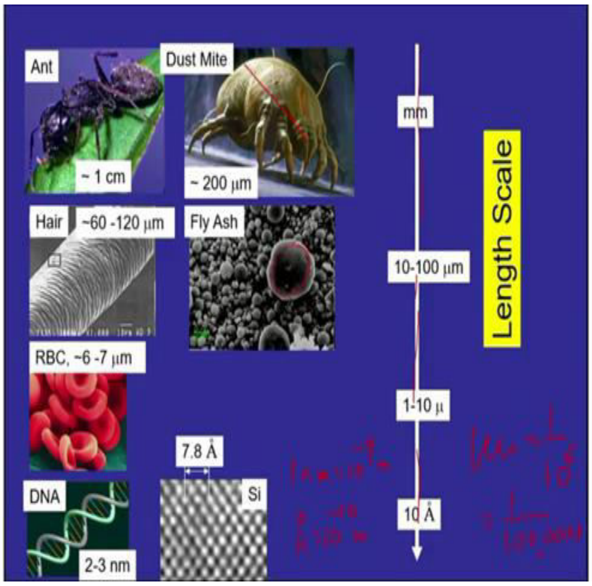

So, let me just talk about the scale as we discuss ant and mites dust mite already in the professor Richard Feynman's statements. So, you know they are centimeter scale ants actually centimeter scale you can see by naked eyes moving around on the floor of your house, right? Dust mites which you may not see it, but if it falls on a screen it makes itching kind of things on your skin there are a couple of 100 nm, 200 nm or 300 nm like that sorry micrometer not nanometers.

So, from centimeters we have gone to couple of 100 µm. Human hair is very thin you can hold by your hand ok, but its diameter is something around 60 to 120 µm depending on quality of hair you have. If your hair is you know falling rapidly; then your thickness of hair will be small because they are not going much. If you have a good hair that means, hair staying in your head for long then it will be thicker. So, 80 to 120 µm is possible.

You know fly ash like all the coal fire power plants that generate a lot of fly ash this fly ash actually varies small tiny particles. These particles actually can fly long distances because they are mass less almost. So, they are having dimensions of you know micron size, well if you go down a little bit. So, these are actually 100's of microns, right? 60, 120 or maybe some 200 microns.

If you go down 100 magnitude that is 6 to 7 micron these are all red bird cells which carry oxygen's from lungs to the different parts of the body correct? Still if you go down several scale let smaller, the basic structure of our body or any living being it is a DNA deoxyribonucleic acid that is dimension is of the order of 2 to 3 nm, I have already explained. And if you still go down the atomic level what is happening actually levels this is silicon.

Silicon distance between 2 dumbbells actually in silicon dumbbells means 2 atoms is about 7.8 Å. So, 1 Å is 10^{-10} m that is what is written here and 1 nm is 10^{-9} m

So, that means, what 1 nm is 10 Å and Angstrom is used in atomic scale dimensions. So, this is the length scale we are talking about it and you should I think I hope you have now a complete picture. How the length scales actually you know varies and how you can look at it.

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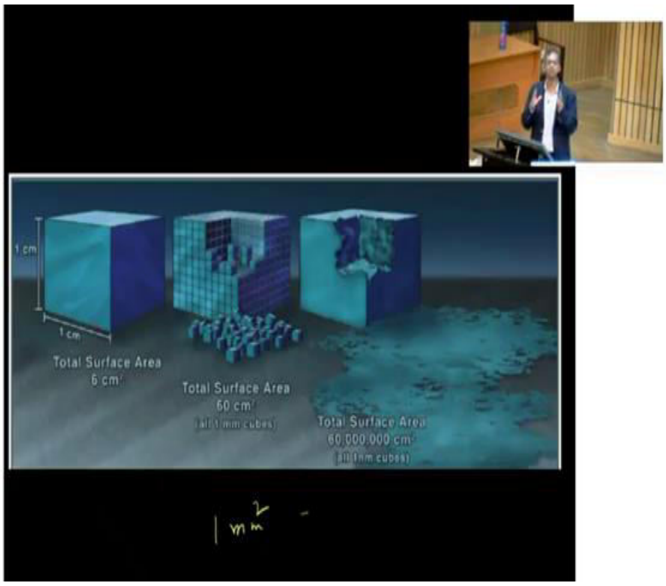

Now, this is also very important concept which you should understand. Well, as you go down the size from centimeter to millimeter to micrometer to nanometers or even an atomic scale the surface area increases, how it happens? Let us do a simple maths ok. Let us take a cube whose side each side is 1cm.

So, that means, cube has 6 sides. So, if each side is 1cm, the area of each face is 1cm^2. So, a total area of the cube is $6\ \text{cm}^2$ because 6 is the total number of surfaces it has. So, now let us do a simple you know geometrical construction, suppose let us break the cube into 1 millimeter cube and there will be many many such cubes possible, correct?

And actually you will have about 60 such cubes and sorry not 60 more than that if it is 1 mm; if it is 1mm ok. So, each 1 mm cube will have 1mm^2 area right and as you know. So, 1 cm is about 100 mm. So, if you do a maths properly, the surface area of these mean this so, many cubes which will produce will have about $60\ \text{cm}^2$.

So, that means, if you reduce this dimension of the cube without changing of the volume for 1cm to be consisting of many many many cubes of 1mm, then your its surface area is increasing by 10 times.

So, what happens if you go down to nanometer scale? Surface area will be decreased by 10^7 times, $6\times 10^7\ \text{cm}^2$ will be the surface area if you make cube each has a dimension of 1nm problem is same.

So, you can imagine that is what happens if you make a material to the nanometric scale. So, in a nanometric scale surface area will increase extensively. So, larger the surface area, larger will be atoms in the surfaces and their characteristics will change ok. So, that is what actually happens when you go down the sides and this gives you many many interesting possibilities.

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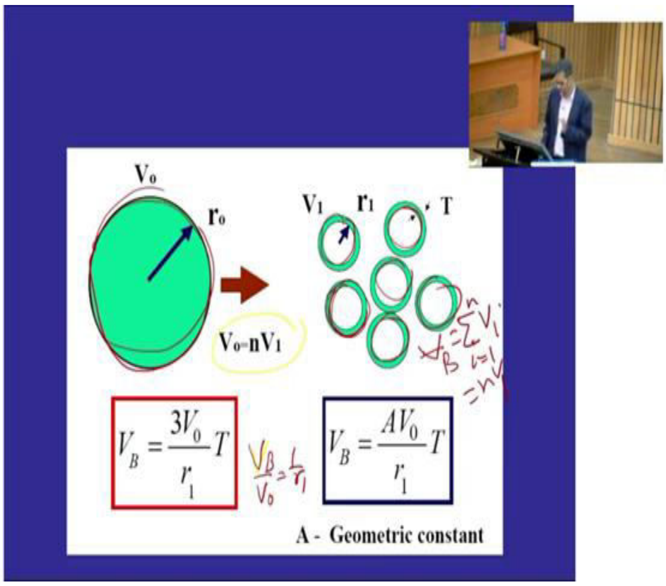

Well, you can do it for a you know sphere same thing I am not going to do it suppose you have a sphere of radius of r_o, a volume is V_0 basically, $V_0 = \frac{4}{3}\pi r_o^3$. Now, if you divide into many many small cubes ok many small cubes of volume V_1, where, $V_1 =$

$\frac{4}{3}\pi r_1^3$. So, you will see this is a relationship volume element constant V_0 = n V_1, correct? Now, if you do a simple math you will find that this relationship that $V_B = \frac{AV_0}{r_1}$ and A is a constant ok, T is basically thickness, thickness will have some mass if you do a proper mathematics that will also going to happen so; that means, what?

A is a geometrical constant whether it is a sphere or cube that will change, but it is basically V_B that what does it tell ok. Let me just change the color of this pen ok tells you $\frac{V_B}{V_0} = \frac{1}{r_1}$. So, as you decrease the r_1, the ratio of surface area of these droplets divide by surface area of this bigger droplets is increasing ok very rapidly. So, if we can think of this way if I consider the atom sitting on the surfaces is given by the volume ok.

So, here V_0 and here V_B all addition of that. So, basically $V_B = \sum_{i=1}^{n} V_i$, right? And here is basically all have same sizes. So, there is nothing, but nV_1. So, you can see that actually that is the simple maths you can do it and understand that by simply breaking into smaller pieces you can create larger surface area.

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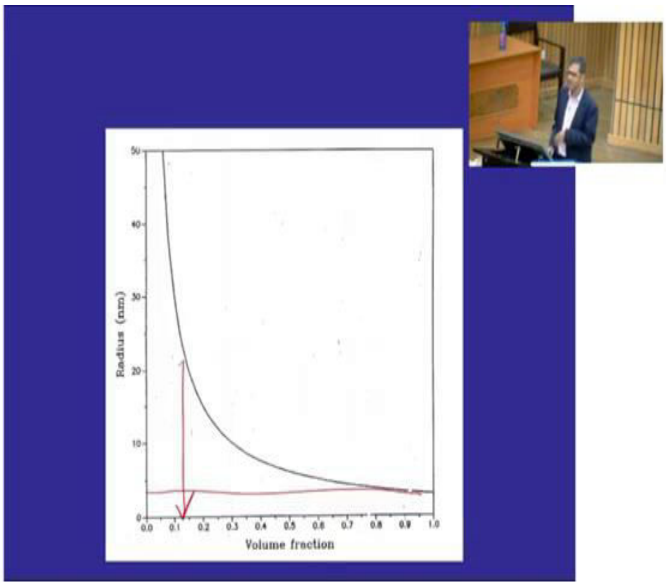

This can be put in a plot. So, as you see here this is the y axis your radius that is our r_1 in nanometric scale 10, 20, 30, 40, 50 and this is why x axis is your volume fraction the atom sitting on the surface.

So, 0.1 is 10 %, 0.4 means 40 %, 0.9 means 90 %. So, you can clearly see whenever size of the order of 5 nm or 4 nm size almost about 90 % atoms are sitting on the surface. So, in the bulk very less amount of atoms are sitting.

So, therefore, when the number of atoms sitting on the surface is increasing rapidly very large fractions the properties are also going to be changed, but if you have a size of about say 20 to 30 nm, only 10 % of them sitting in the surface.

So, there is a drastic change if you go down from 50 to about 4 nm or 5 nm that is very interesting. And you know sorry the atom sitting in the surface will have a lot of dangling bonds, which you will discuss anyway when you are talking about surface interfaces and these dangling bonds are not satisfied. So, their behavior of the atoms will be different. So, if the sitting of the atom sitting inside the surface.

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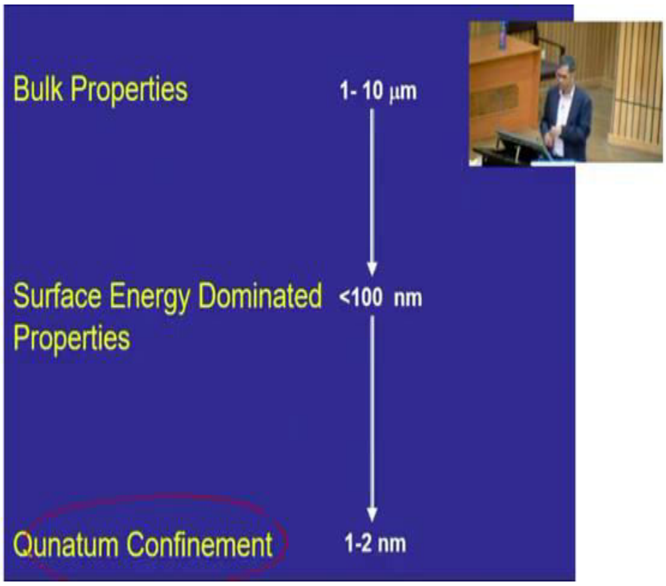

So, you know when your materials dimensions is micron size ok 1-10 μm that is what you see in normal materials ok which you see live steels or cast irons or maybe aluminum or polymers.

They always show the bulk properties because number of atoms sitting in the surface is very very small they do not contribute much of the properties of the material, only atoms since sitting inside the bulk they are dictating the properties, but as I decrease down the size of the particle to 100 nm or lower.

Then you see the surface atoms dominating the properties of the material they are dictating the properties of the material that is why this domain is called as a surface energy dominated properties, but still if you go down to 1 to 2 nm very very small size then it is no longer surface energy is quantum confinement ok.

We will discuss about these, what about electronic properties? Quantum mechanics comes in the picture you can confine the electrons by quantizing the energy levels.

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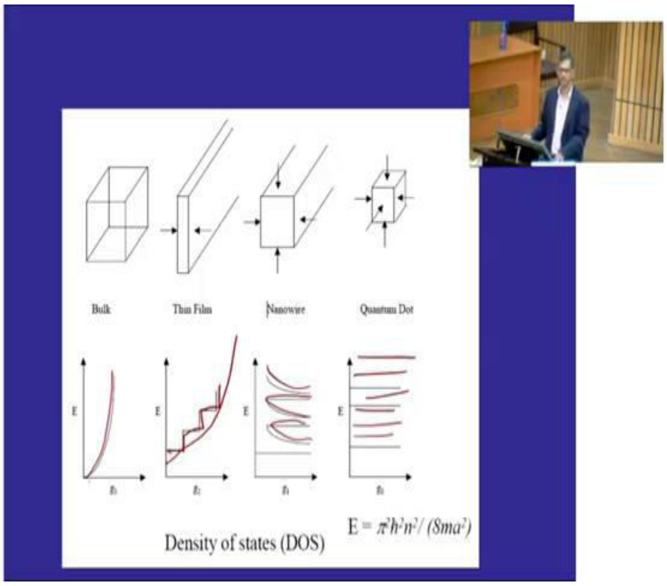

So, this is what is shown here. So, if I have a bulk if I plot energy versus reciprocal lattice vectors you see energy will increase like this ok, that we know square actually g over g 3 square, but if you have thin films very small thin films you have a step function of energy it was initially like this, now it is becoming step, correct? But things will happen that is still different whenever nano dimension of this thin films are like wire or plates.

So, then you see that this kind of energy level discrete energy levels will come and when you have a very small 1 to nm then their discretion is very very large discretion happens. So, that means, at each energy level you will have electrons ok that is nothing, but the concept has come from the particle in box theory which you have studied in your physics in plus 2 or maybe in the first year of engineering or in MSE, correct?

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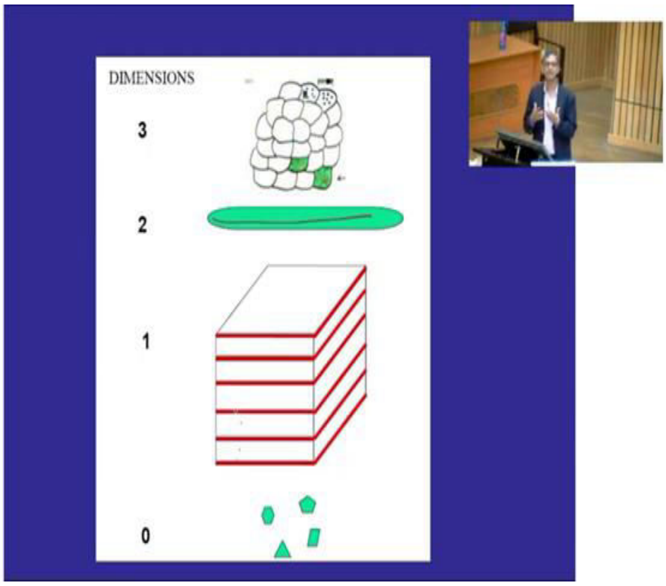

So, now the question is this as I discussed let me just bring this concept also before we stop this lecture today. As I said the physically any object will have 3 dimension x, y, z, but in order to become a nanomaterials all the dimension need not be nanometric scale. If only 1 dimension out of x, y, z is in nanometric scale ok you know only 1 dimension one of these things ok then we call a 3 dimension material correct.

Like in a grain if one of the dimension is nanometric its called that if you have 1 out of 3 dimensions x, y, z to a nanometric scale like a plate is shown here ok. You see in the plate thickness x, y, z a 3 dimension that x and y a nanometric, but z is z is not ok.

So, because z is not x, y only nanometric scale other than its scale lengths called 2 dimension you can also have lot of laminates stacking each other you can see here 1, 2, 3, 4 white, red, white, red stacks and you see only the thickness of this red color thing is small.

So that means, only one of the dimension thickness not x, y only z of that is nanometric is called 1 dimension ok and you can have 0 dimensional objects when all the directions x, y, z are in nanometric that is a quantum dots. Quantum dots is nothing, but a small size object in which any dimensional nanometer is scale. So, that is the typical way of characterizing dimensional dynamic nanomaterials you understand that. And this is how things are actually dealt in the literature.

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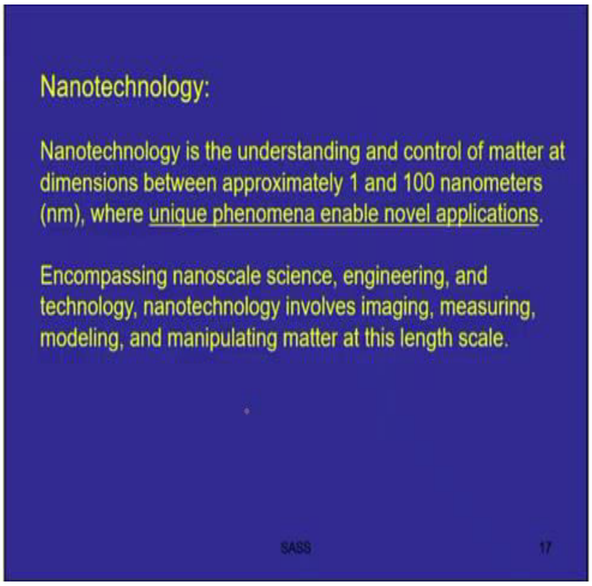

But not only this you can also have many other ways of doing that which we will discuss later. So, what is important is one part is nano material, but what is important is nanotechnology you know what is nanotechnology? You know it is understanding and manipulation or control of the matter in the dimensions 1 to 100 nm ok. And as you have I have only discussed a lot of new things can happen expected to happen in a nanometric scale.

So, it is this aspect the manipulation control at the nanoscale is known as nanotechnology ok. And you know that encompassing nanoscale science engineering technology, nanotechnology it can involve many things it can involve imaging measuring, modeling, manipulating matters and length scales or even creating things ok.

So, that is what is called as all together nanotechnology. So, you can bring this science into a product into a things which are useful a lot of such things available in a real markets ok physically, naturally and also manmade. So, many such products are there I will not discuss about that ok.

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You know I will only discuss one of them you know what is known as the TiO2 nanoparticles ok what is there? Ok.

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Titanium nano dioxide, TiO2 is founds in many products it can be found in spray you can found it even your sunscreen you can find it in your medicines ok. This is nothing, but a very useful material in the real world.

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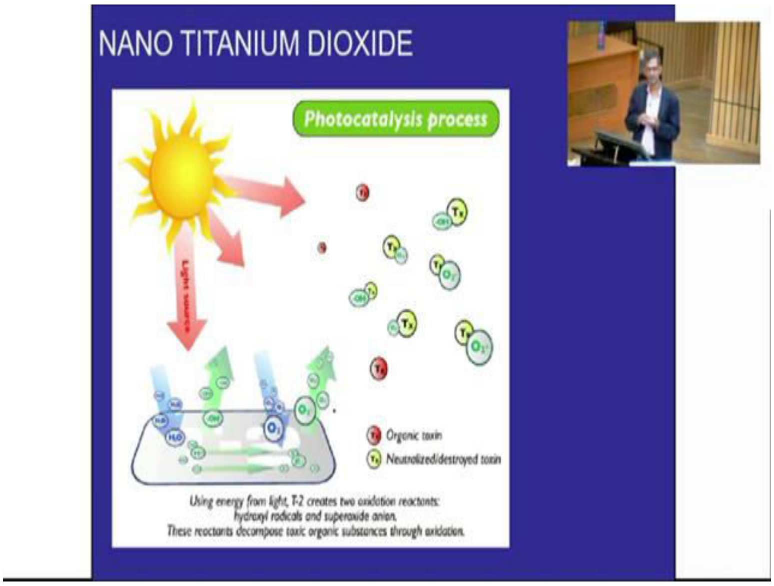

But you know to give you perspectives if you move on the road you will see there are white markers on the roads ok they are sometimes used to you know make different road signs. But if you use simple chalk to make a white mark on the road and because of the pollution, auto exhaust or various exhausts from various plants nearby they can create various polluting agents, suits or carbon monoxide, carbon dioxide, NOx.

They can actually fall on the surfaces of these and cover it and even discolor these white marks correct. So, again you have to mark it and roads are thousands of kilometers long it is not easy to do that it is very expensive.

So, instead of that if we can use a material to print on the roads and that material itself can have a self-healing property, what is the meaning of that? That means, it can take care of itself, when there is a damage. So, when titanium dioxide nanoscale actually does the same way. So, if you look at it if I put white titanium dioxide on a road as a marker and in presence of sunlight it can actually oxidize these carbonaceous materials.

So, that they can become gas and go ahead. So, that is exactly what is used correct. So, light in presence of light they can act as a catalyst that is why they are called photocatalyst, photo means light. So, they can catalyze in presence of light and oxidize these carbonaceous materials into the air.

So, this is just one example, you know to take it out you could have heard a lot of advertisements in the TV and in the news media or even internet, that if you quote your house with some pens it does not get discolored, it does not get you know bad as the time goes off.

So, that you do you do not you need to repaint them, repaint means you have to paint again ok, but if you use this 10 nano titanium dioxide on the outside the wall of the house same thing will happen pollution will not change the color of the or the whatever you are using on the outside walls of your house, correct?

So, that is why these paints are very famous. So, you can use that same thing you can do it in your what is sunscreen, sunscreens protects you from sun right. So, you apply a sunscreen on skin sunlight should not damage your skin correct.

So, these objects if you apply on it can actually create a layer that layer can oxidizes many of these harmful things and not only that it can also protect you from UV lights by various means that is why it is used widely this is one such examples.

So, that means, from scientific concept to technology to the product it is very important to sustain a growth of any field and this is exactly will be taught to you in this course. So, with this let me stop it here I spoken about 45 minutes or so, the last 5 minutes I have kept it open to know about you in the first lecture. So, that we can discuss with each other and know each other.

Thank you.