Nanotechnology Science and Applications
Prof. Prathap Haridoss
Department of Metallurgy and Material Science
Indian Institute of Technology, Madras

Lecture – 02
Nanotechnology: A Walk-through History

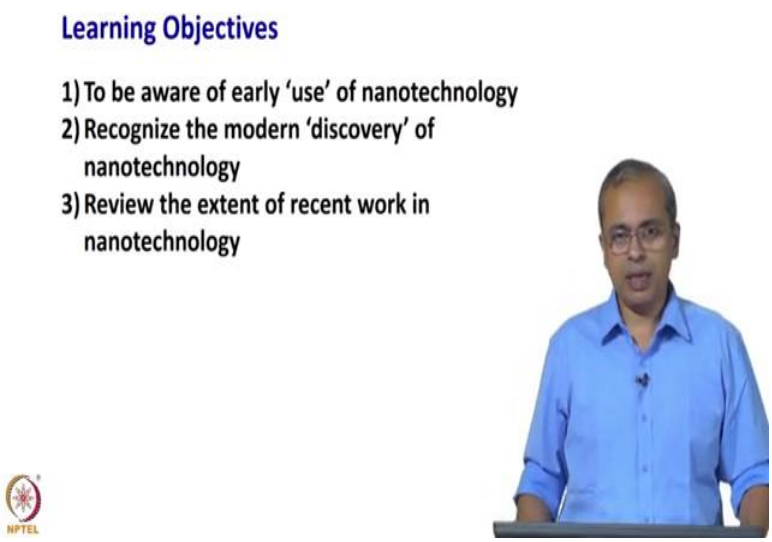
Hello, in this class we will look at Nanotechnology and in specific aspect that we will look at is the historical aspect of nanotechnology. As you are probably aware that in the last say 20 odd years there is been a lot of talk of nanotechnology may be closer to 30 years, I will show you some data in that context. So, if researchers say university professors who have been either students or researchers in the early 80s and then went on to become faculty members now. If you ask them in the 80s there was no in 1980 for example, there was no specific mention of nanotechnology as a significant field or an area that where people were carrying out research that has dramatically changed.

As I mentioned in our previous class today it is almost impossible for you to meet a person who is working in the area of materials who is also not doing some work in the area of nanomaterials. So, that is a dramatic transformation of the state of affairs with respect to research in the space of 30 years and once in a way this happens once in a way like a completely new field opens up and then everybody then sees value in moving to that field.

So, this is what has happened in the last 30 years or so, but at the same time, it is. So, it if you look at popular literature it appears that nanotechnology is then, therefore, restricted to this 30 year period that you hear about, but actually if you look at the history of materials used by human beings you will find that there is a very interesting story which goes back many centuries and nanotechnology has been sort of a hidden aspect in many things that we have done for many centuries .

And today we will try to put this whole story in some sense of perspective. But to begin with, let us first understand why we should have any interest in the field of nanotechnology.

(Refer Slide Time: 02:25)



So, to get started with it our learning objectives for today's class are to become aware of the early use of nanotechnology which is something that may be as I said less of us are familiar with. Then this will also see the modern discovery of nanotechnology and I put discovery within quotes because as I said the field has been around people did not just in consciously realize that it is something that it is very interesting very different and so on and as you see today's class you will get a sense of what I mean.

And so, there was a certain discovery of nanotechnology some years back even though it had been around for a pretty long period of time. We will also find finish this class with a review of the extent of recent work in the field of nanotechnology to give you a sense of the scale to which things have moved in the in this area and the extent to which people are working in this area I think some numbers will bring that out quite dramatically.

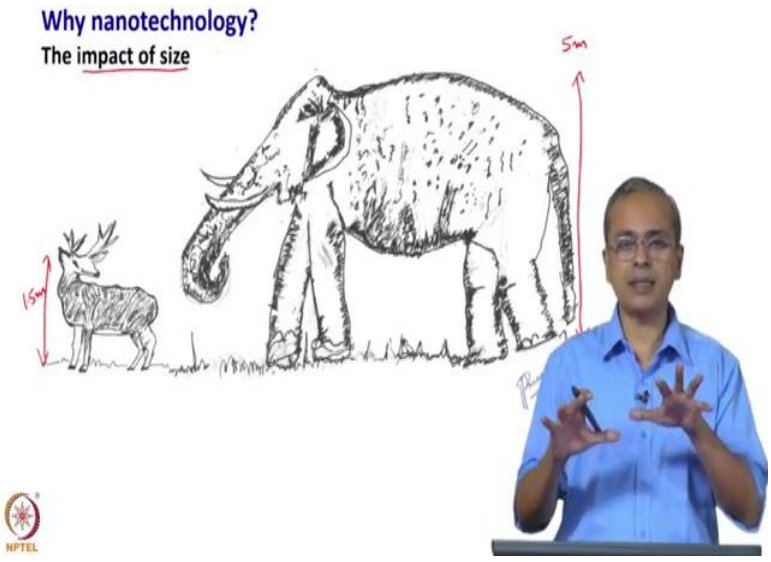
So, this is what we will do in today's class, but as I said we will begin by first trying to understand why people have even bothered about nanotechnology. To do that I will take one particular example as I mentioned in the last class many phenomena that we measure at a macroscopic scale something like conductivity, magnetic properties, mechanical strength many such properties that we measure for a variety of different materials and then we put them for engineering applications. Many of those properties happen at a size scale that is significantly different from the size of that sample.

So, you may have a sample that you are holding in your hand which could have some length and width and height which you can physically hold in your hand, but the property of measuring is happening at a much smaller scale maybe at the atomic level may be at the level of say hundreds of atoms may be at the level of thousands of atoms so, some such thing.

So, and so, there is some phenomenon occurring at that scale which then reflects in the property that you are measuring in this macroscopic sample. So, it turns out that if you start manipulating this material at that scale then you start impacting that property impacting the appearance of that property. So, therefore, suddenly the property itself starts assuming values that it was previously unable to assume and therefore, you see this sort of nano effect so to speak.

But let us use an example to more clearly bring out this idea that scale can have an impact and we will and then get a sense of why this happens for nanotechnology.

(Refer Slide Time: 05:07)



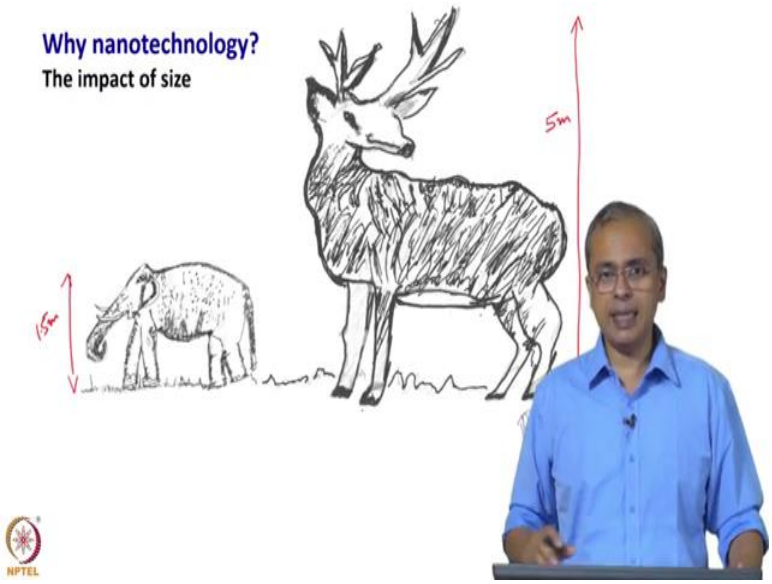
So, we have here an artist's impression of an elephant and a deer. So, this is in this particular case we are going to look at the impact of size and that is something that is one of the aspects of nanotechnology the impact of size on a property. So, normally I am using this example to convey the fact that normally this is what we are used to the relative size of the deer to that of the elephant. So, in our expectation a deer is less tall

than us it is a shorter than us and so, we are typically looking at a deer which is let us say 4 feet tall.

So, some expectation mental expectation we have. So, that is roughly about 4 feet tall and then if you think of an elephant you think of a much larger animal may be at least 3 times our height, so, maybe 15 feet tall. So, something like that we are looking at 15-16 feet tall maybe even more. So, that is our common perception. So, we have this expectation.

So, that this is about 15 feet tall 15-20 feet tall. So, let us say in meters. So, that would be say about 5 meters tall and maybe this is less than that this is maybe about 1.5 meters tall something like that right 1.5 meters tall 5 meters tall. So, this is our sense of what the different animals are. Now, supposing you consider a possibility that we can think of a different world where the 2 animals are suddenly inverted with respect to scale.

(Refer Slide Time: 06:49)



So, for example, I am just showing you here in a sketch. Let us say suddenly we have deer which is about 5 meters tall and the elephant which is now 1.5 meters tall. So, the question we have to ask ourselves is that is there something fundamental in this transformation that creates a problem for this to happen.

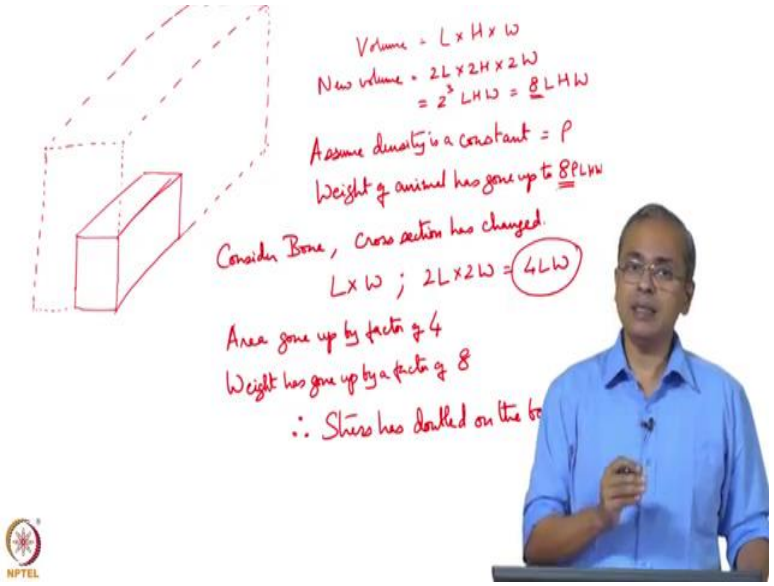
So, in other words, is there a problem if we suddenly bring down the size of an elephant to 1.5 meters. So, about one third it is oriental size or we take a deer and you increase it

is scale proportionally in all dimensions to 3 times it is size a little more than 3 times it is size which is about 5 meters tall. So, we have to understand is there a difficulty and if there is no difficulty, of course, there is nothing much to discuss here but is there a difficulty and if so, what is the source of that difficulty.

So, to understand that let us take a moment to do a small calculation here. I mean this has got nothing to do with the food (Refer Time: 07:52) or any such genetic aspects we will assume that all those things are available that it is both the animals in both the size scales are able to access the food that they can get and so on. So, that is not the aspect that I am looking at not a we are not even looking at what it this represents with respect to predators of these animals in the jungle etcetera this is completely unrelated to all of that. We are simply trying to understand if with respect to size structurally is there an issue with these animals if you simply raise the size of one animal proportionally or decrease the size of another animal proportionally.

So, that is basically all we are trying to look at. So, to understand that let us do a small calculation. So, let us assume that let us simplify the animal to some kind of a cuboid structure.

(Refer Slide Time: 08:41)



So, you have a length, a width, some height and some depth. So, now, let us see if let us consider the possibility that this is being tripled. So, now, so, we make these 3 times or even double it let us just say we are doubling it for the moment, we double everything.

So, I have doubled the length I have doubled the height I have doubled the width of this cuboid. So, what has happened? So, the volume equals length × height × width. So, now, if the original volume was L×H×W the new volume equals 2L×2H×2W that is 2 cubed LHW equals 8 times LHW.

So, the volume of this. So, if you take any animal and you increase it is height you increase it is width and you increase it is length all you double, you double each of these quantities you suddenly find that the volume corresponding to that animal has gone up by a factor of 8. So, volume has gone up by a factor of 8. If you assume density is a constant and it has a value 0 then weight of the animal has gone up to 8ρLHW.

So, weight has gone up by a factor of 8. So, factor of 8 it has gone up. So, now, let us look at the what is the impact of that. So, it has gone up by a factor of eight. So, now, the weight of that animal has to be supported by it is 4 legs. So, 4 legs are there the elephant has 4 legs the deer has 4 legs. So, the weight of the animal needs to be supported by the same 4 legs and since we have proportionally changed the size of the animal the size of the leg has also proportionately changed.

So, if we doubled everything the size of the legs also went up by a factor of 2. So, how is the weight being held? The weight is being held by the cross by the leg and essentially the whole load is being held by the cross-section of the bone; the bones cross-section is what holds the weight it is the one that supports the weight of the animal the bone supports the weight and in particular the stress is being taken by the cross-section of the bone.

So, if you take the bone and if you look at it is cross-section what we see is the cross-section of the bone has changed and how has it changed cross-section is length × W it has now become 2L×2W equals 4×LW. So, therefore, the area has gone up by factor of 4. So, that is what you got here weight has gone up by a factor of 8.

So, area has gone up by a factor of 4, weight has gone up by a factor of 8 therefore, the stress on the leg has doubled therefore, stress has doubled on the bones. You have 8 times the weight being held by 4 times the cross-section therefore, the stress on the bone has gone up by a factor of 2. So, in other words, as you increase the size the rate at which the weight is increasing is faster than the rate at which the cross-section is increasing and therefore, the stress is increasing.

So, why is this important? This is basically important because it conveys to us the fact that when you change the size it is not something that does not have any consequence. So, especially for a deer as you start increasing the size of the deer it is weight is increasing very fast relative to the rate at which the cross-section of it is legs is increasing as long as you maintain the same proportions.

So, if you make the deer very tall you will reach a certain height at which point the bone will no longer be able to support the weight of the deer, therefore, the legs of the deer will buckle. So, they will buckle and the deer will collapse. So, it is not feasible to keep on increasing the size of the deer. On the other hand, when you bring down the size of the elephant actually the legs are in a better position to handle the weight of that elephant because the cross-section is decreasing slowly whereas, the weight is decreasing faster.

So, therefore, bringing down the size of the elephant is not something that gives us a structural problem, but increasing the size of the deer gives us a structural problem therefore, when you go from a reality that looks like this to a hypothetical situation that looks like this we have a problem with the deer being super-sized.

But we do not have a problem with the elephant being decreased in size. So, the point I am trying to convey here is that the size has an impact in ways that we do not we are not that are not apparent immediately. So, there is something internal going on which can have a size-related effect. So, in this case when we are increasing the size of the animal the aspect that is important to us is the stress that is being taken by the bones and that is not something that is immediately apparent to us.

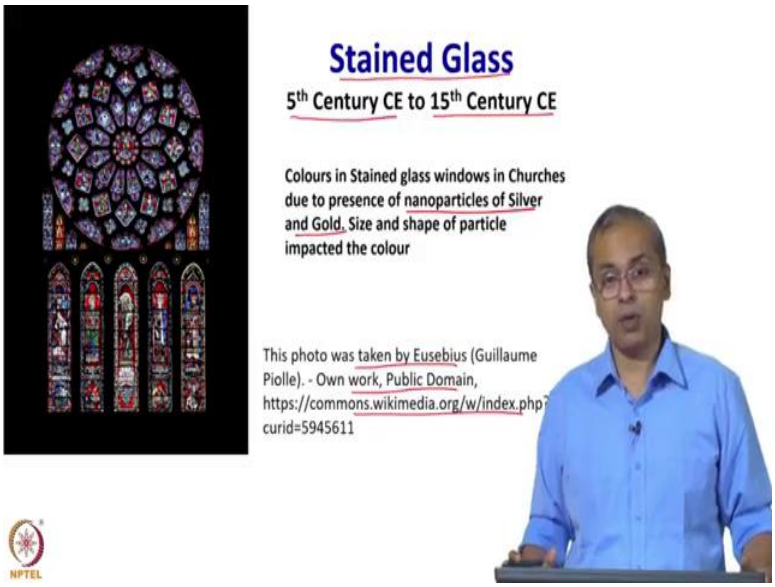
So, you think you can keep raising the size of the animal and it does not actually happen that way there is a limit that you will hit after which the animal will no longer be able to structurally hold itself up and incidentally you are aware of this famous old story of Gulliver's travels. So, he travels to a place where there people way smaller than him the Lilliput's he also travels to another place where there are giants. So, in that story the assumption is that people can have the same built so, to see same proportion.

So, to speak, but can be extremely small in size and also extremely large in size generally this is not something that is going to work effectively. And in fact, even real life if people are extremely tall if you see people who have world record in height

etcetera you look up some literature on them you will find that they are actually having problems with their bones and joints and so on. So, this is the thing.

So, therefore, there is a size effect although this is an example where I am showing you this size effect only in the large scale, but it conveys the idea to you that many other properties also if you go down in size you change sizes dramatically you can have an impact on the property or how it displays itself on the sample or what the sample can do for you in a very different manner. So, and that is why this elephant can do something more the deer can do something less. So, that is something that we want to keep in mind.

(Refer Slide Time: 17:07)



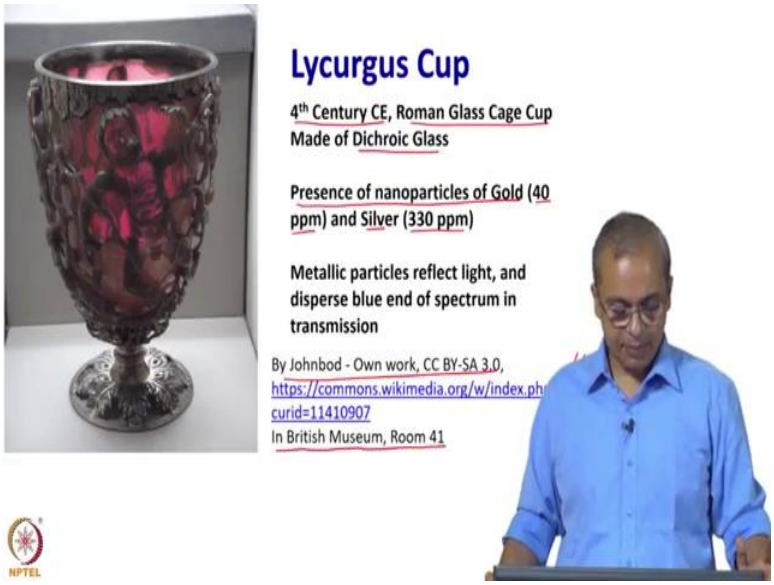
So, now let us look at the history of nanotechnology as I said this is something that we keep hearing about only the last 20 30 years, but if you actually go look at what is around what is still survived as historical artefacts you will find that there is something called stained glass. And please note this is not from 20 years or 30 years ago this is from 5th century CE to 15th century CE. So, 5th century to 15th-century common era. So, this is from quite some time back we are looking at 500 to 1500 years ago in many of the churches you will find this stained glass this particular one is somewhere this is the glass that you see on this slide is based on a photo that has I mean credited here.

So, you can see that this is the place where this photo is available and this is said to be a glass that is from somewhere in the 11th to 12th-century timeframe. So, in those days they would have the stain glasses which were available on church windows and so on

and it turns out that at that point people did not know exactly how they were getting this kind of colouring and so on it turns out that today people have done a lot of research on the stained glass that is available in churches. And they find that there is presence of nanoparticles of silver and gold available in this church glass and that is the reason why the glass has the red colour or other colours that you see there the presence of those nanoparticles decides what colour is there and they are able to use that accordingly.

So, this is very interesting this is 500 to 1500 years ago. I will give you three examples of this nature this is one of them, three historic examples which show the existence and use of nanotechnology from a long time ago and this is one of such example also along similar lines.

(Refer Slide Time: 19:05)



There is this cup called the Lycurgus cup and these are all not some mythical objects these are actually there you can go to many places in Europe and see those stained glasses that I showed you in the previous slide. This particular cup for example, you can actually see in the British Museum a more specifically the information that is available suggests that it is in room 41 of the British Museum again this is a photo for which the credits are out here you can see the original person who took this photo information is out here this is a 4th century cup.

So, again more than 1500 years old it is a Roman glass cage cup and it is made of a particular kind of glass which is referred to as dichroic glass; dichroic glass chroma

etcetera things are those are all associated with colour and the dye suggest two. So, you can get some sense that you are dealing with something that has more than one colour. Again, this particular cup seems to be one of the rare examples of complete cup of this nature actually being present for the most part historically they have only seen broken glass pieces of this nature.

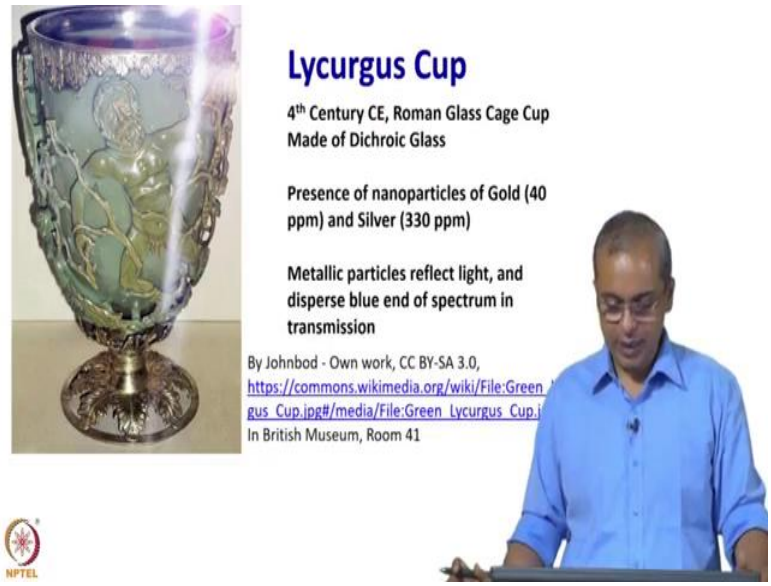
Again, studying this cup, it turns out that they found that the colouring is due to the presence of nanoparticles of gold and the amount of those nanoparticles is just about 40 ppm, similarly it also has nanoparticles of silver and the amount of such silver is about 330 ppm. So, ppm is parts per million.

So; that means, if you have million parts you divide this into a million parts then 330 parts of that happens to be silver. So, it is very tiny quantity 330 parts per million or 40 parts per million. And the manner in which this cup works is that if you take this cup and you view it using transmitted light in other words that the light sources say inside the cup or the it is behind the cup and you are standing in front of the cup.

So, light is going through the cup and then coming to you. So, it is transmitted light that you are seeing what happens is these nanoparticles disperse it turns out that when once they understood what was going on, they could figure out these details it turns out that those nanoparticles are dispersing the blue end of the spectrum.

So, in our visible spectrum, we can go from infrared to ultraviolet. So, the blue end of the spectrum seems to get disrupted by those dispersed by those nanoparticles whereas, the red end of the spectrum seems to go through. And so, when you are sitting on the other side when you are looking at the transmitted light you see the red end of the spectrum coming towards you. And so, you see the colour of the cup is red in colour the same cup exact same cup when seen in reflected light has a greenish colour to it.

(Refer Slide Time: 21:51)



So, this is same cup seen and reflected light in reflected light these small particles metallic particles are able to reflect a sufficient light that you just see the reflected light and it seems to have a greenish hue to it and again basically largely due to what it is dispersing and then no reflecting back at you. So, you see this greenish hue in the reflected condition whereas, if you go to the transmitted condition you see red colour.

So, this is the beauty of this cup. So, and as you can see it is consisting of 40 ppm of gold and 330 ppm of silver. So, now, the question one might ask is we have suddenly sort of discovered nanotechnology in 30 odd years. So, how did these people 1500 years ago actually do this how did they actually make this was there some sort of magic involved in it.

It is not really so; the best understanding of the situation is that to some degree the synthesis process involved a lot of dilution of various constituents that they put together to make the glass. And in the dilution process, there were also some impurities either incidentally or accidentally present in the material in the form of gold and silver which then got diluted vary significantly as they made the glass and in those days much of the activity was some kind of fixed formula activity.

So, many times they would make something and not really know which step in their process was resulting in which property of that material. So, that understanding was still not there they were still evolving that understanding. So, just to be safe they would

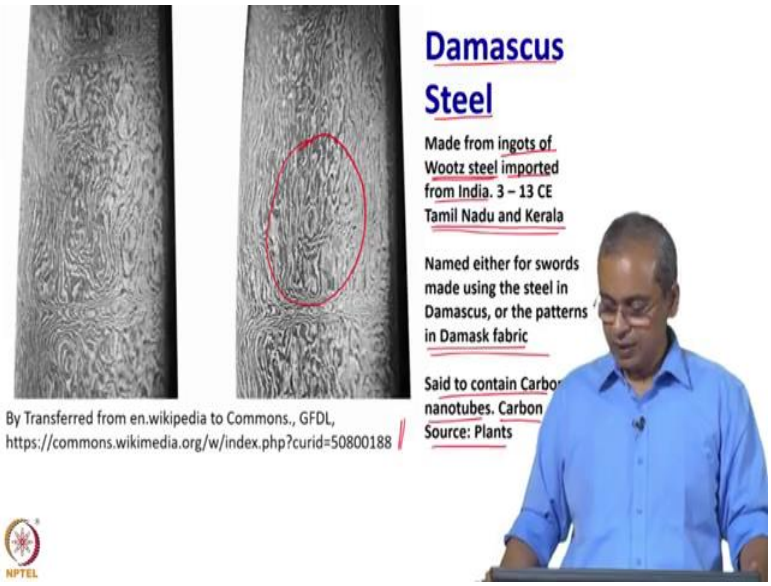
follow the same process like a recipe down to the letter. So, they would get source the ingredients from exactly the same place put it in furnaces that they knew would work and then process the material using machines and people that they knew. So, it was an art and they did not dare change any formula in it because they were not sure exactly which part of that step which step in the process was affecting that property that they were seeing. So, they would just stick to this art and they would pass it on from generation to generation to generation.

So, these used to be secret arts that were held together closely safeguarded by families because their life livelihoods depended on it. And so, often there was no clear understanding of why something was happening, but they knew that they could get that result. So, they would just follow that formula carefully. So, the best guess is that there were gold and silver impurities in the glass that they were working with and the process of making the glass resulted in dilution of those impurities to the values that we are today able to measure which is this 30 I mean 40 ppm and 330 ppm of silver and in the process the glass gave these properties.

Today, for example, people have made copies of this kind of a glass they can make glass of similar nature where they have deliberately included this 40 ppm of gold and 330 ppm of silver and produce glass where you can see red in transmission you can see green reflection.

So, this is again 1500 years old and something that is sort of associated with European influence in to in the progress of science. From Europe let us come to much closer home let us come to India we have done something very interesting and dramatic in the field of nanotechnology also in the same timeframe.

(Refer Slide Time: 25:21)



You can see here something referred to as Damascus steel this is an image of steel referred to as a Damascus steel it was made from ingots of Wootz steel a particular kind of steel called Wootz steel which was imported from India between 3rd and 13th century.

So, all over the world they used to import this steel from us and I mean Europe was the major place at that point in time they would import the steel from us. And in fact, not just anywhere in India it used to be made actually in Tamil Nadu and Kerala. So, it is a very South Indian sort of contribution to the field of nanotechnology and this was important from Tamil Nadu and Kerala and was taken all over the world later I think they also had some versions of this coming from Sri Lanka, but basically this was something that they imported from India and used for making weapons at that time the middle east there were a lot of there was a lot of interest in making weapons.

And so, they used to make swords out of the steel it used to be forged and it used to have the kinds of patterns that you see here it is not there are different opinions as to exactly why it got the name Damascus steel even though it was something that came from India.

The reasons are that the steel was taken from here, but the swords that were made were made in Damascus. So, possibly that is why it was given the name Damascus steel also the patterns that you see here. So, the patterns were similar to patterns in a fabric made in that place called damask fabric and therefore, it was possibly named for that. And these

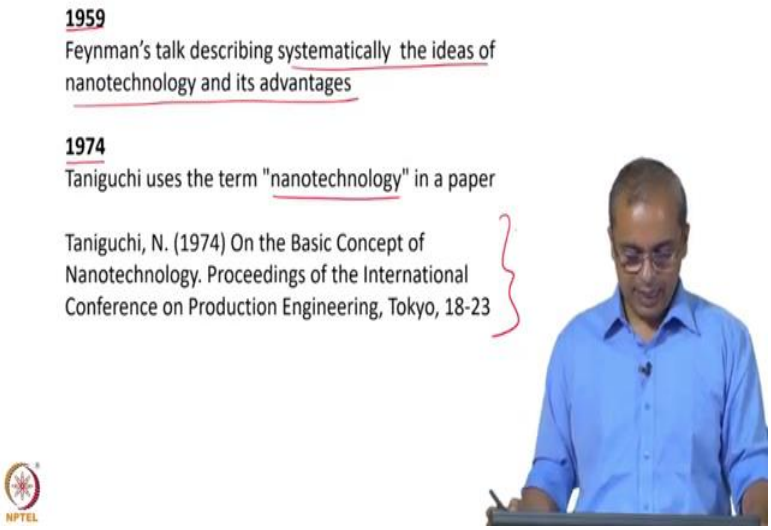
patterns come due to presence of different faces in the steel and the forging process that is done to generate this steel.

Again, this is the source for these images and you can go and look up these images on your own too. Today when they analyze the steel, they find that these steels contain carbon nanotubes and this is something that since 1990 there is a discovery of carbon nanotubes and we have done a lot of research internationally in the area of carbon nanotubes you can see that in India between 1500 to nearly 2000 years ago.

We were making a product which contain carbon nanotubes. Of course, like with the glass we have every reason to believe that people were not aware of exactly what had happened in that material that gave it is incredible properties those swords were known to be remarkably tough and would not break easily and were considered extremely sharp there is a lot of mythology-based on how sharp those swords were. And at that time the carbon source was set of various plants that they used to provide carbon in the steel making process and that is basically what apparently caused this situation where there were nanotubes present in the steel.

Later this art slowly disappeared because as he said this was all very dependent on the source of various raw materials and the process used and so, as the source of some raw materials dried up and they went to other sources potentially some of the ingredients were no longer present. And as a result, the steel did not have exactly the same kind of properties that they were getting earlier even though they were apparently following exactly the same process. So, this is the idea. So, this is what we see.

(Refer Slide Time: 29:05)



So, if you see we have seen some examples from about 1500 years ago where apparently we have had nanomaterials being used in different products and people were actually using them they had phenomenal performance and very interesting performance in one case in the optical end of the utility with the glass and in the other case with respect to mechanical strength from the steel that we looked at.

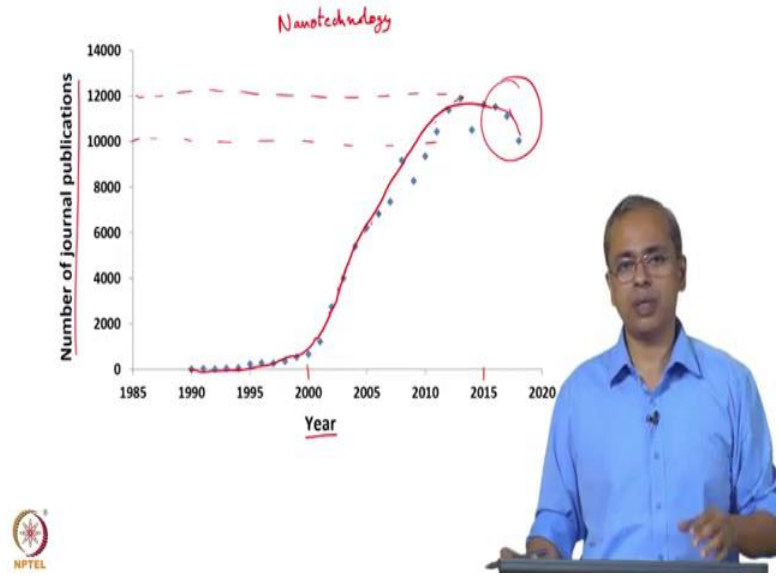
If you look at modern-day our modern-day intersection with the field of nanotechnology. In many ways, it traces itself back to a talk in 1959 given by Richard Feynman famous physicist where he is systematically described the ideas of nanotechnology and various issues associated with those ideas. So, very nice talk, in fact, in our next class we are going to spend time looking at many of the ideas that he had suggested in his talk.

He had a very nice foresight as to what was possible in the field what were likely to be issues in the field what potential advantages, we could get by going into that area etcetera. And there may have been other people who also mentioned nanotechnology or this idea of the scale having an impact on properties might have been mentioned by others, but really his talk put it all together in a very beautiful way and in a very systematic way and covered the ground so to speak

And so, 1959 is very important year in that sense from the idea of making a specific contribution to igniting the field of nanotechnology. Then in 1974 we actually see the first use of the word nanotechnology. So, the references out here again you can go look

up this reference Taniguchi has used this term nanotechnology and that is the first apparently that is the first time that term was actually used in a journal paper of so, of some formal document. So, to speak and since then it has pervaded our scientific parlance.

(Refer Slide Time: 31:11)



If you look from then till now, we saw some historic thing 1500 years ago we saw something say from the 60s. So, you looking at some 60 years ago. So, to speak and from there if you look towards the current day scenario you can see here the number of journal publications and the year in the area of nanotechnology. So, you can go to Scopus and put in a few keywords and do a search.

So, this is one such search for using data that is available in Scopus if you do a search you can get this kind of information. For almost any keyword you can type in some specific keywords and it will tell you how many papers were published in that area with that as one of the keywords as a function of time. You can see that in 1990s we basically had 1,2 papers so to speak.

And till about 1994 that is roughly the same you have just about say 10 papers or so and then from there it picks up and then you see these numbers beginning to climb you can see here it climbs up here and then you are looking at in a more modern times if you see you are looking at numbers of around 10000 papers per year.

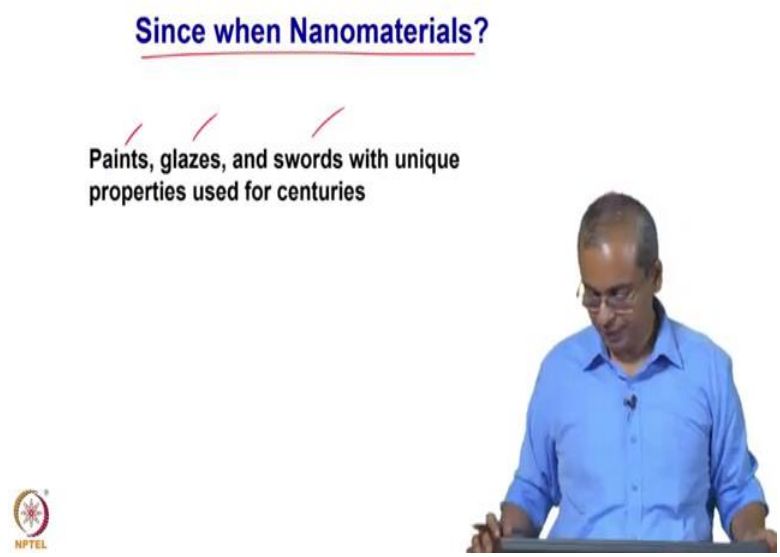
So, this is sort of the graph we have it keeps increasing I am just drawing a trend line. So, to speak and today it is somewhere here and maybe the it is a little bit dropped even a little bit, but this is what we are looking at. So, you can see here that suddenly in the space of let us say 2000 from the year 2000 till about the year say 2010 or 2015.

So, in this 15-year timeframe, we have gone from having a few tens of journal papers in the area of nanotechnology to about 10000 papers or even more that is 12000, so, that is 10000 for you. So, somewhere there. So, maybe about 11000 papers per year which are coming out in journals a variety of journals in the field of nanotechnology that is the extent to which this field has sort of exploded into the scientific community and the interest that people have had in this field. So, this is a huge increase and perhaps it is levelling off you can see some levelling off indicators here and maybe that is where it will level off.

Because naturally there is so many areas of science and technology that people can work in and each of them saturates out at some level. But still this number is large, but it is not surprising because as you will see through the course nanotechnology is not a field in isolation. So, it is not something that is isolated it is something that is possible to know be prevalent in any other area of science and technology. So, be it medicine be it engineering, be it sports be it anything of that nature variety of fields that we as human beings normally interact with use and built. Almost all those fields there seems to be a change in what can be done by introducing nanomaterials, nanoscience and nanotechnology. So, to speak, therefore, researchers even though fundamentally may be working on completely different topics.

one common thread that they might have is this field this idea that they have introduced nanotechnology into their field. That is the reason why you are looking at numbers of the order of 10000 because that is a very large an arena that is very wide in which nanotechnology can be used.

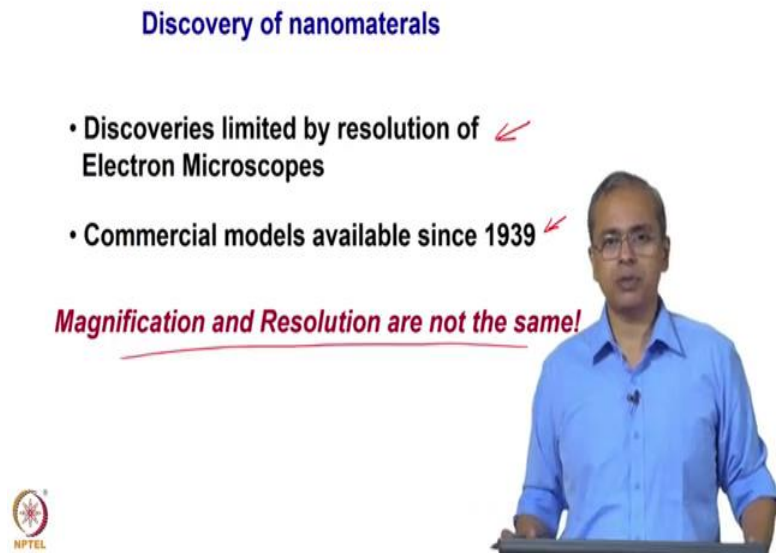
(Refer Slide Time: 34:45)



So, we saw here since when nanomaterials is something that we saw in great detail we have seen that paints glazes and swords with unique properties have been used for centuries and then apparently there was nothing for a very long time and then suddenly 1960s onwards we sort of rediscovered this idea that it could be something 1990s we started moving in that direction and from 2000 we have suddenly started year 2000 we suddenly started doing a lot of work.

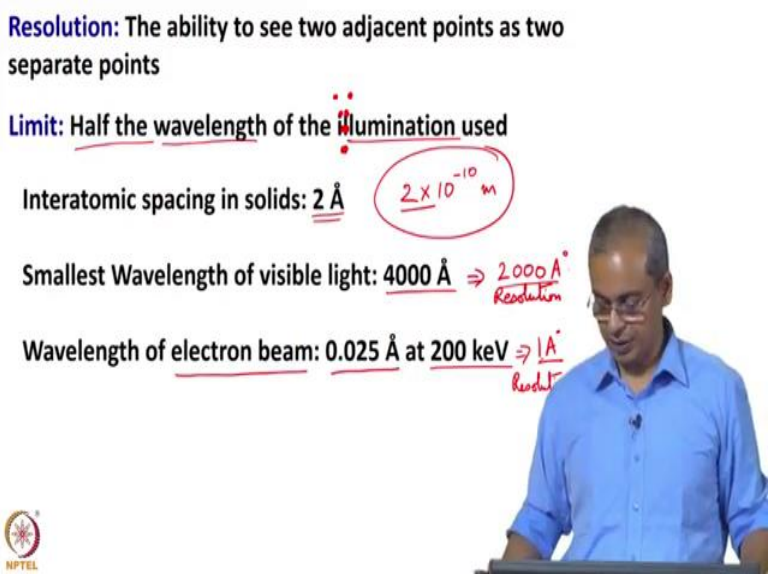
So, what was going on in this intervening period and why do we see this break in the in olden days we did something although we did not know why or how we did it and then apparently nothing was going on in this field for several 100s of years and then suddenly we have discovered it well.

(Refer Slide Time: 35:27)



The discovery of nanomaterials and it is use in nanotechnology has been limited by the resolution of electron microscopes that has been a very significant contributing aspect to the field of nanotechnologies nanotechnology. And commercial where models of electron microscopes have been available since 1939 and particularly magnification and resolution are not the same. This is something that I will show some examples of in another class, but there is a particular aspect of it that I want to alert you to. So, that is what we will see here.

(Refer Slide Time: 35:57)



So, we need to understand what is resolution; magnification we already have an idea we simply say object is of some size if you can make the image 3 times as big magnification is 3x is the way we say. So, what is resolution what and what role does it play in this process of us being able to see something? and as I said it is the resolution that made the difference in our ability to see the nanomaterials. Resolution is basically this idea that if I have a point here and I have an adjacent point here resolution is the ability our ability to see these two points as two separate points and that is what resolution is now supposing the points keep getting closer, I keep it getting it closer. So, they are now getting much closer and then at some point they start overlapping.

So, even now they are two points, but the extent to which they are overlapping is. So, much that I am not able to separate them as two points. So, if we see if our resolution is high then two close nearby points will be seen as two separate points and that is what helps us resolve something and that is what allows us to see detail of a nanomaterial because nanomaterial has very fine detail and that in that fine detail you should be able to distinguish between the left side of the detail from the right side of the detail.

So, you have some small some line that is there or some particle that is there you should be able to see the left side of the particle and you should see able to see the right side of the particle as two separate sides and or there is a particle on the on your left and there is a particle on your right you should be able to see them as two separate particles

Otherwise, it just looks like one big blob and you are not even sure that you have something of very fine structure. So, the point is our ability to resolve something depends on the wavelength of the illumination that we are using. And so, for example, if you take interatomic spacing the distance between atoms in solids is typically about 2 angstroms or 2×10^{-10} meters that is the distance between 2 atoms in a solid. The visible light that we use and typically this is what has been used for all the optical microscopes use visible light has a wavelength of about 4000 angstroms.

So, if you look at half the wavelength of visible light basically this means 2000 angstroms resolution which means what it means that if two points are 2000 angstroms separated from each other I can see them as two separate points, but atoms are not 2000 angstroms apart they are 2 angstroms apart which means I cannot see 2 atoms which are sitting next to each other as two separate atoms. So, in fact, in 2000 angstroms I will

have 1000 atoms together I will see as one particle then the next 2000 atoms I would see as another particle less than this I will not be able to see.

On the other hand, electron microscopes use electron beams they do not use visible light and their wavelength is about 0.025 angstroms based on the operating condition of the electron microscope which in this case I have simply given an example of 200-kilo electron volts.

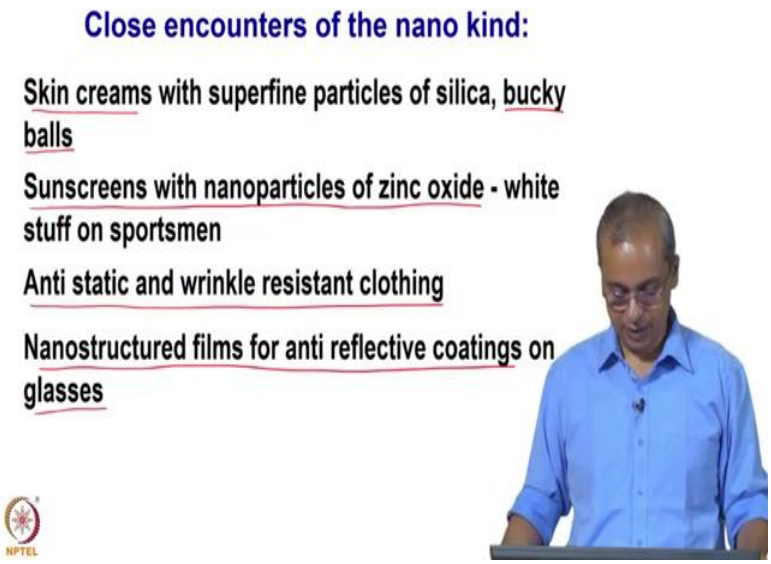
So, now it turns out that with the electron microscope the way the optics of the microscope is set up you do not get half the wavelength of the illumination being the resolution you get actually something little worse than this. So, typically resolution is of the order of 1 angstrom for this operating condition there are electron microscopes with even better resolution normally means a smaller number because; that means, that is the close closest distance you can still separate. So, that number should become as small as possible.

So, 1 angstrom clearly is smaller than 2000 angstroms. So, it is considered better resolution 1 angstrom is better resolution. So, if you have 1-angstrom resolution you can resolve 2 atoms. So, if you have 2 atoms sitting next to each other you can see the atom on the left as a separate data atom on the right as a separate data.

And so, that is the point of having this kind of a resolution. And so, only as the electron microscopes evolved and kept getting better and better and better and their resolution kept improving that we could reach a point where you could actually see the nanomaterials in the microscope. So, not only can you synthesize the material either incidentally or deliberately or accidentally you could actually put it in a microscope and see what you had synthesize and convince the world that.

In fact, you have generated something that is a nanomaterial that the properties that you are seeing are, therefore, a result of that nanomaterial that you have synthesized and therefore, you now have something that is a new version of nanotechnology. So, this is how electron microscopes have dramatically impacted the field of nanotechnology and that is how they have impacted the history of nanotechnology.

(Refer Slide Time: 40:51)



So, now let us close this class by looking at some interesting encounters of the nano kind. So, if you see here even though I said historically many things have happened today nanotechnology has started getting into products that we are using. So, to speak. So, one product that has been that has come to the market in the recent part past is skin creams. So, many cosmetic products actually use very fine particles and they have now started using nanoparticles.

And in fact, there were some that came out that even had Buckyball's in them which is balls of carbon atoms and there were concerns about the safety of this particle because as I mentioned in the previous class, we have a situation where the pores of our skin are about 50 microns in dimension. So, if you have nanoparticles, they can enter the pores of our skin they can go passed our skin and enter into the skin and get into our tissues and maybe even the blood maybe for some medicinal purposes that is very useful.

Because you may want the medicine to penetrate the skin and therefore, it is very nice to have that maybe there are some cosmetics which we do not want penetrating our skin and therefore, this can cause a problem. So, if I am not mistaken some of these cosmetics were then withdrawn because they were there were some questions on the safety of those cosmetics, but those cosmetics did come to the market and possibly some of them are there where they have addressed the safety issues involved.

So, this is skin cream also related to us is the sunscreen with nanoparticles of zinc oxide. So, this is the kind of the white thing that you see many sportspersons wear as they are out there in the sun as they go about playing. So, thus sunscreen consists of I mean it seemed to one some versions of them have these nanoparticles of zinc oxide.

So, again this is something that we are wearing on person so to speak. We also have some versions of cloth that people are working on which consists of anti-static and wrinkle-free wrinkle-resistant clothing; this anti-static feature is very useful in cold countries where it is where you can have dry weather and therefore, charge builds on you.

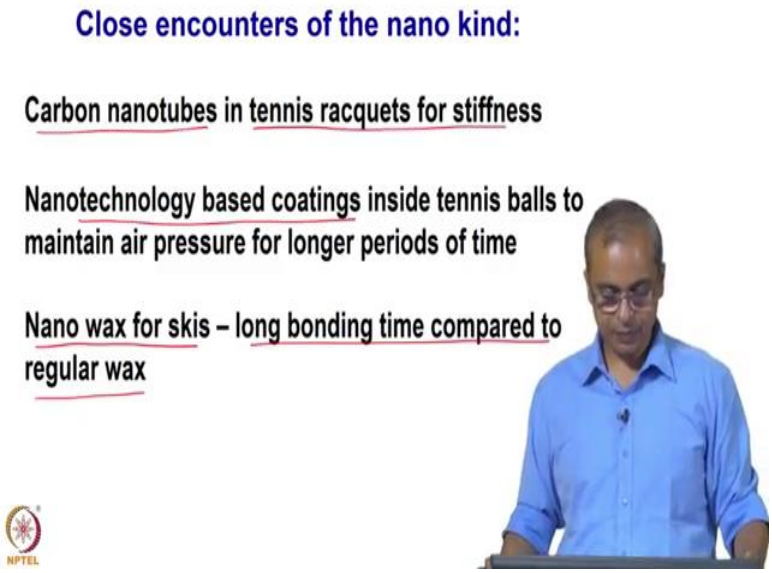
And then when you go touch somebody or may you shake hands with somebody or you touch furniture you will get a spark from your hand it can be quite painful and can surprise you. And having anti-static coating which often contains carbon-based nanoparticles in it helps discharge prevents you from building discharge because it is got a high conductivity and that is, therefore, very useful to have. Also, recently people have started doing nanostructured films for anti-reflective coatings on glasses.

So, eyeglasses that we wear often the quality of the glass as an user experience is significantly impacted by what light is reflected by the surface of the glass. And if you see lot of reflection it affects your ability to see through the glass because not only you are seeing through the glass you are you have to fight the reflections which are also causing glare on your glass. So, nice clear glass means it has got good anti-reflective coatings on it and the main parameter that they are trying to control is the change in refractive index when you go from the glass to air.

So, glass will have a refractive index air will have a refractive index if the difference is significant you see some reflection. So, now, using nanostructured films they make the change very gradual and if they make the change very gradual you do not have reflections. So, you are able to mitigate reflections dramatically and therefore, coatings are coming for glasses even for plastic lenses where they are able to control the reflector, I mean reflections that happen from it.

So, these are all products that we could potentially wear or use in person which have impact from the nanotechnology field.

(Refer Slide Time: 44:37)



So, there are some more products also I will just give a few more here. So, for example, tennis rackets. So, in tennis rackets, one major parameter is the stiffness of the racket. So, as you hit the ball and so on it has to be a stiff racket only then the energy is transferred to the ball very effectively and in recent term recent times there are companies who have looked at improving the stiffness of the racket using carbon nanotubes. So, they do advertise that they have rockets which have carbon nanotubes in them and that has increased the stiffness of the rocket.

So, that is again an example of nanomaterial being used in a product that you and I could actually potentially go and buy. They also related to the sport of tennis there are other companies which have looked at nanotechnology-based coatings which are used inside the tennis ball. So, inside the tennis ball they use this coating the purpose is this. So, in that tennis ball you actually have air at high pressure relative to what is outside and that is why the ball has some shape and that is why you when you hit it you feel a certain reaction from the ball etcetera. So, now, over a period of time the air inside can slowly diffuse out of the ball because you have a driving force there is a driving force because the pressure inside is high pressure outside is low relatively speaking. So, gradually the gas will escape from the ball. So, it is only a question of how long it will last.

So, when you have some special coatings that they have made using nanotechnology they are able to close the pores in the ball even more effectively. So, the expectation or

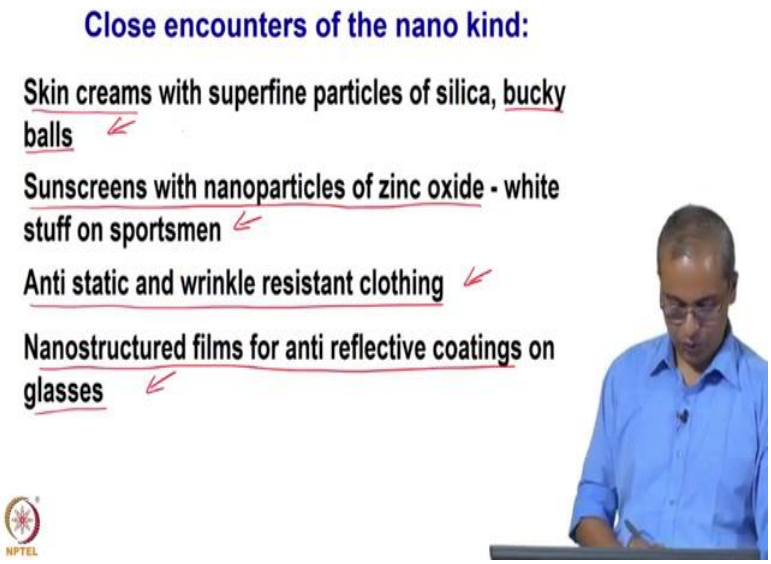
the value that the producer's manufacturers suggest is that those balls which have that kind of a coating are able to hold the air at high pressure inside them for twice as long as tennis balls which do not have that kind of a coating.

And therefore, again it is something that impacts the utility of that ball in a sporting situation then there are skis. So, you see again you see a wide range of applications here, we have looked at clothing looking at cosmetic items and so on now we come to skis. So, in skis as they use it for skiing in snow on top of snow and so, the surface of the skis continuously rubbing snow. So, one product that was sold for maintaining the ski as well as to enhance the experience of the skier is a ski wax. So, this max coating is applied to the bottom of that ski.

So, that the experience of the skier as they go through the snow is very good and naturally because of friction whatever max you put will gradually come off the ski and then ever so, often you have to know again do re-waxing of that ski to get back the layer to the extent that you want. Today again there are companies that advertise wax that is based on some nanostructured wax for skis which they believe has much better bonding with the ski and thinner layers and therefore, can last much longer than regular wax on the ski.

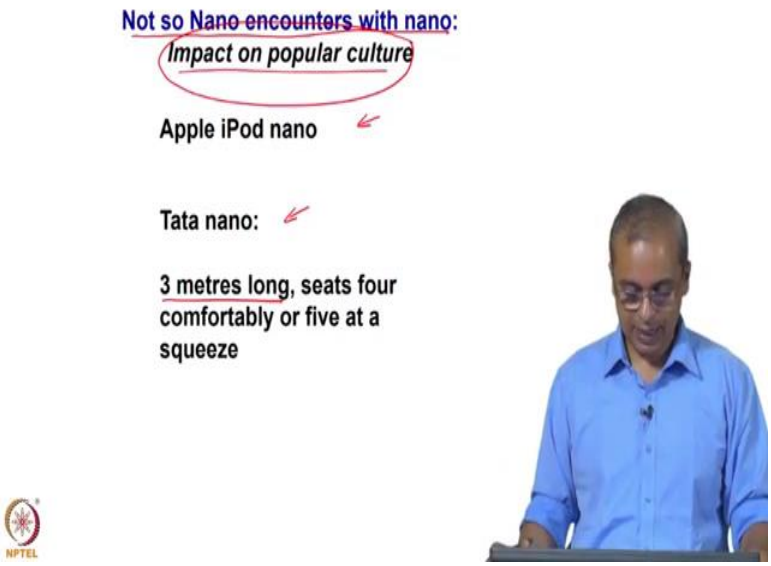
And so, the person has that experience for a much longer period of time and therefore, they can enjoy their skiing for a longer period of time without getting interrupted with having to apply this wax. So, these are some close encounters with the nano kind as I said you can see here.

(Refer Slide Time: 47:59)



Skin creams sunscreen anti-static, wrinkle-resistant clothing, anti-reflective coatings, on glass tennis rackets, tennis balls and skis. So, these are all a wide range of applications where nanotechnology has become prevalent.

(Refer Slide Time: 48:27)

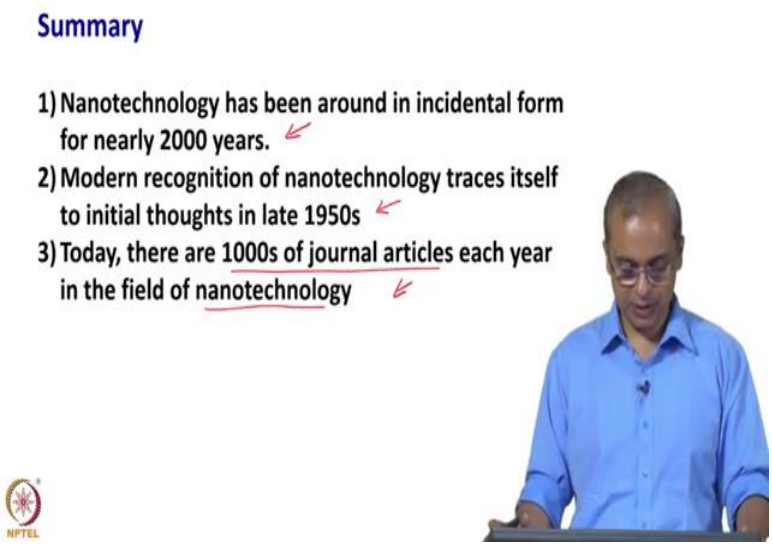


We also see some examples just out of for sake of complete completeness where which I would refer to as not. So, nano encounters with nano because they are not really looking at nanotechnology in sort of the same way that we are perhaps talking about in our course, but it is it shows the impact of this in popular culture and of course, there is the

apple I pod nano and which is for music and so on and there is the car which is a Tata nano which was quite famous in India and as you can see it is 3 meters long it is nothing is in a nanometer-scale there and it comfortably seat four people.

So, it has invaded popular culture and that says something I mean it is not something it means that it is not something that is hidden in labs and only in research facilities and so on the general public who may not even be involved in scientific activity in the formal sense are also using this term. And it means something to them and we have to be aware of it as scientists that it is there and therefore when we explain nanotechnology to the general public we should understand that they may have a different perspective of it and we will have to make a little extra effort to convey this idea to them. So, in summary we find that nanotechnology has been around in some incidental form for nearly 2000 years.

(Refer Slide Time: 49:49)



So, in some incidental form it has been there for 2000 years except that from what we see the people who had that technology and use that technology were not completely sure as to why it was behaving the way it was behaving, but they knew that they could get it to do something for them and therefore, they systematically utilized it. And this is true with science and technology many times there are things that we use where we do not yet know the science of why it is operating that way, but we still use it. This is also true for example, with say combustion there are still aspects of the flame and so on which may require more research, but we use it for cooking all the time.

I mean we do not we did not need to know everything about the flame temperature and which region of the flame had what temperature for us to do cooking we still use it for cooking. So, same thing has been true with nanotechnology yet another field where people utilize nanotechnology long before they understood what it was.

Modern recognition of nanotechnology traces itself to initial thoughts in the late 1950s and since then it has grown in dramatic manner, we saw a wide range of products which we can use in commonplace activity. In fact, I mean you can even extrapolate it more than the products that we saw I mentioned about how they have done this coating to improve the duration for which air stays inside a tennis ball that the same technology can be used for your automobile tires.

So, you can have air inside your tire or of a automobile or of a bicycle for example and if you had the same coating you do not have to fill air that often it would stay in the vehicle much longer and therefore, give you a better owner experience so to speak. So, in a case, modern recognition of nanotechnology comes from early thoughts 1950s and it is really significantly taken over our research processes in recent times in terms of being an area that many of us are working on. And today, therefore, there are 1000s of journals articles 1000s of journal articles every year in the area of nanotechnology.

So, in summary in this class, we have seen the historic flow of nanotechnology from ancient days to periods where there was no real activity and then rediscovery in recent times in a much more formal sense and our present-day activity which is tremendous.

So, this is the background for it, in as we go ahead in our various classes we will take specific examples and explain those examples in greater detail and in our next class for example, we look at Feynman's stocks and some of his Feynman's stock and some of the ideas that he described in great detail in his stock. So, that is the overview of the history of nanotechnology.

Thank you.