Nano structured Materials-Synthesis, Properties, Self Assembly and Applications
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Module - 4
Lecture - 36
Magnetic Properties – III

Welcome to this course on Nanostructure Materials Synthesis, Properties, Self Assembly and Applications, we are in the Module 4 of this course. And in this Module 4, which has 12 lectures, today we have the 8 th lecture in that series of 12 lectures and we are discussing magnetic properties of nano structured materials. And we looked at the basic magnetic properties of materials in general in the first lecture of these three lecture series, regarding magnetic properties.

And then we looked at what happens to the magnetic properties in nano structured materials that was in the last lecture, which was lecture 7. And we will continue on that we about the applications of these magnetic nano particles in different devices and in biotechnology. And what we learnt, so far are some very important features in the magnetization which change as the size of the particle become small.

So, the most important point was the concept of super paramagnetism, when a particle becomes small if it is a ferromagnetic, you would expect that the magnetization increases as you decrease the temperature. And will suddenly increase to a large extent below a certain temperature, which is called the curie temperature, this should be the behavior of a normal ferromagnet. However, when such a ferromagnet or a magnetic substance we normally refer are ferromagnetic substances.

So, when we say that they in a ferromagnet the basically talking of a something, which normally people call as magnets a permanent magnets. Now, these materials should show a curie temperature below which the magnetization or the magnetic susceptibility should shoot up. That means, it should increase at a much faster rate below that temperature, compared to the rate at which it was increasing above that temperature when it is a paramagnet.

So, the paramagnetic to a ferromagnetic transition occurs at a temperature TC which is called the curie temperature. This should happen in a normal magnetic material, when you decrease the size of the particle in the nano dimensions, what is seen that instead of this large change in the magnetization below TC the magnetization starts to decrease. Now, this is called the blocking temperature and that is the reason we have what is called a super paramagnet, it tries to behave like a super paramagnet instead of a ferromagnet.

So, this we discussed in our previous lecture about super paramagnetism, about blocking temperature and how this difference is the present in the nano particles of different materials. So, today let us talk about some real nano particles, which show different magnetic properties especially in magnetic oxides and their applications.

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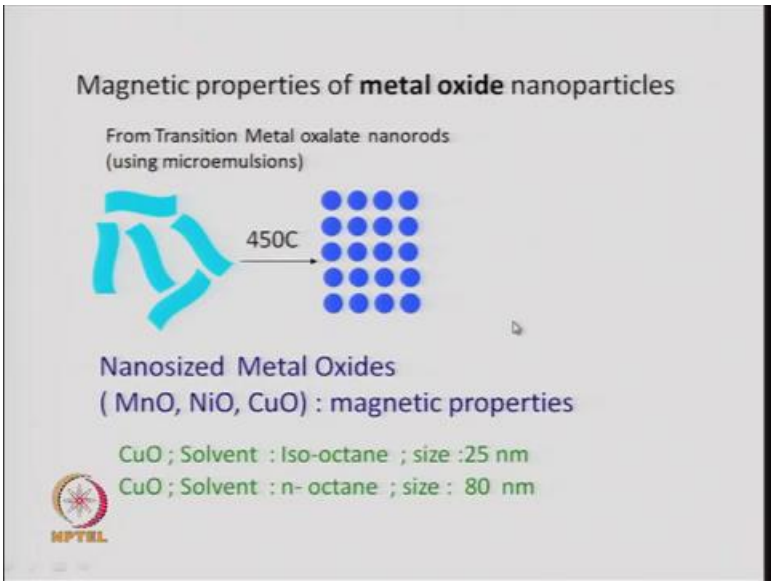

So, this is an example of magnetic properties of metal oxide nano particles, so when we say metal oxide. It can be a binary oxide, say copper oxide or nickel oxide or say cobalt oxide of course, it cannot be zinc oxide, because it should have some magnetism and normally zinc oxide is not a magnetic, because it does not have a an empty d orbital’s. So, normally when we talk of metal oxides we tend to talk about transition metal oxides and transition metal oxides like nickel oxide, cobalt oxide are have very rich magnetic properties.

Now, here we discuss how we are going to make these metal oxide nano particles and one of the methods, which has been used to a large extent is to first make transition metal oxalates and there nanostructures. So, the many reports are there, where nano rods of transition metal oxalates, has been made using micro emulsions, micro emulsion we have discussed earlier. And basically this is a methodology by which a large amount many types of nano materials can be made and their size and shape can be controlled.

So, in this case we are talking of metal oxalate nano structures having anisotropic structures like rods. So, using micro emulsions we can make this kind of rod shaped structures of transition metal oxalates, so say you have copper oxalate and if you use a temperature say 400 to 500 degree centigrade these rods of copper oxalate or nickel oxalate, decompose to give you particles which mainly are spheres. But, sometimes under different conditions you can also get other type of structures like cubes, etcetera.

So, of oxides, so here you have oxalates you decompose at a heat them at a high temperature, say around 400 to 500 degree centigrade and you get oxides and there size of these particles are in nano dimensions. So, they can be 20 nanometer, 50 nanometers, 100 nanometers depending on what was the type of metal oxalate you chose and how was the metal oxalate prepared using which micro emulsion. So, that controls the shape of the starting metal oxide. And that when you decompose controls the shape of the final transition metal oxide nano particles.

So, here you can make M n O, if you start from manganese oxalate you will get manganese oxide, you can get nickel oxide if you start from nickel oxalate, you will get copper oxide if you start from copper oxalate. So, you can get nano sized metal oxides and you can study the magnetic properties of these metal oxide particles and you can control the size of the particles by controlling the micro emulsions. For example, if you use a solvent like, isooctane when you synthesis this copper oxalate to get finally, copper oxide then you get particles of size 25 nanometers.

However, if you make copper oxalate using normal octane instead of isooctane, they are two different isomers. Then in that case the copper oxide, which you get has particles with size of approximately 80 nanometers, so depending on the methodology, whether you take in the micro emulsion, isooctane or normal octane. You can get the resultant oxalates of different size and shape and you will ultimately on decomposition get different size particles of copper oxide, this is an example that we discussed of copper oxide.

But, the same can be discussed about manganese oxide or nickel oxide or a say ruthenium oxide or any other oxide. And how the starting material, starting solvent and surfactant, etcetera will affect the transition metal oxalate and that intern will affect the size and shape of the transition metal oxide. So, this is a big area of research and lot of work has been done and lot is known about how to control the size and shape of the final metal oxide particles, which are magnetic in nature.

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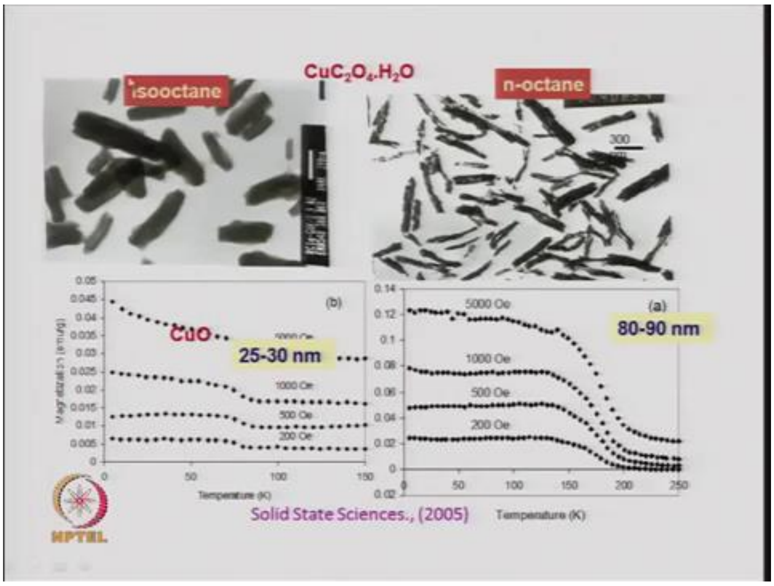

So, now, let us look at their magnetic properties, so this is an example of copper oxalate it crystallizes as hydrate. So, the actual formula is given here, one copper is to one oxalate ion and one mole of water is hydrated and you can find out using x ray diffraction, etcetera the structure. And these says transmission electron micrograph showing you the rod like structures, using isooctane to make the micro emulsion initially and in this case you have used normal octane to make the micro emulsion.

And you see the rods are of different shape size compare to the rods obtained here, so these are both are copper oxalate, both will have the same x ray diffraction pattern. But, both have different morphology because of change in solvent, now when you decompose this rods of copper oxalate to form copper oxide. They give you particles of size 25 to 30 nanometers and when you decompose these rods at around 450 degree centigrade, you get copper oxide which has size of 80 to 90 nanometers.

And when you now study the magnetic properties, because that is the point which we are discussing in this lecture that how does a magnetic properties change with the size of the particles. So, when you look at the magnetic properties, what you see that the magnetization as a function of temperature, in this particular copper oxide there is a slight change around 80 degrees K 80 Kelvin. Where as in this copper oxide both are copper oxide from the x ray you can make out and this copper oxide there is a change in the magnetization.

So, this axis is magnetization, there is an increase in the magnetization at around 200, 210 degree Kelvin. So, both these particles show some kind of a weak ferromagnetism, because whatever was the magnetization earlier, now the magnetization is increasing. So, this sudden increase in magnetization is actually ferromagnetism, if it is very sharp that is most commonly the reason why the magnetization should increase. Since, the increase is not as sharp as a normal ferromagnet, hence we sometimes call this as weak ferromagnetism.

But, more important is the fact that because of different size of particles, here you have 25 to 30 nanometers. And in this copper oxide the size of particles is 80 or 90 nanometers, the two different particles size gives you two different TC's, the weak ferromagnetism, the temperature at which that occurs is called the curie temperature. And that is around 210 Kelvin here and in this case it is around 80 Kelvin, what is of more importance is that if you take bulb copper oxide, where the size of the particles is much larger say around 1 micron or 2 micron and if you measure the magnetization of that copper oxide nano particles. Then you will get a totally different behavior, because copper oxide bulk or large size particles do not show ferromagnetism, it is a weak it is a anti ferromagnet around 230 Kelvin. So, it shows a totally different behavior and hence this is a very important characteristic of nano particles, that it shows magnetic properties very different from particles of larger size, but of the same material.

And this particular thing many times it is called reversal of magnetization, there is something which is anti ferromagnetic, shows weak ferromagnetism. Something, which is ferromagnetic shows something like super paramagnetism or weak anti ferromagnetism. Now, in some cases it is called reversal of magnetization and the reason is this that when a large particle is becoming smaller, then even if the dipoles in the bulk in the large particle can be organized the dipoles on the surface remain disordered.

And, so in the large particle the core of the particle is ordered and contributes to the magnetization. However, when you make small particles, there is hardly any core and everything is on the surface and, so you do not get a net magnetization in that case. And, so a ferromagnetic substance tends to become weakly anti ferromagnetic or behaves as a super paramagnetic. So, there are reasons why this transformation occurs in different cases and one can study them in detail and lot of work has been done in understanding the magnetic properties of bulk materials transforming to nano particles.

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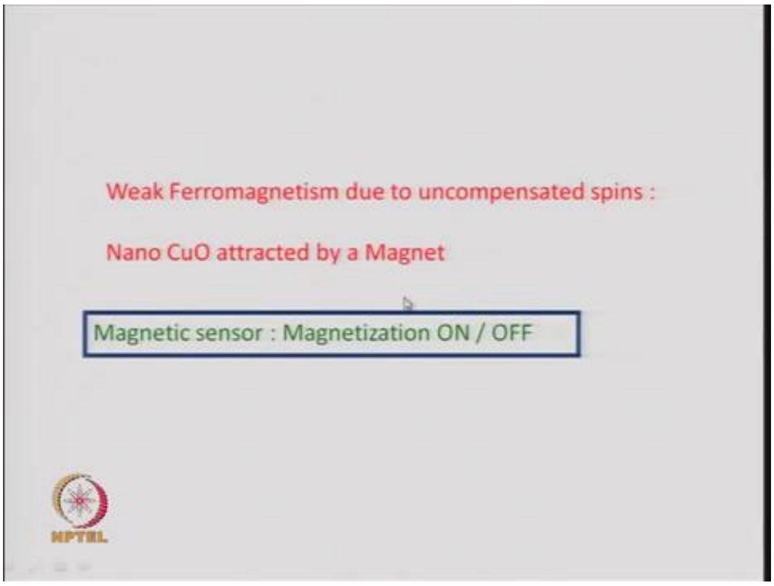

So, this is one of the reasons weak ferromagnetism is seen in copper oxide nano particles, due to uncompensated spins that is the spins which are on the surface in cooper oxide can give rise to weak ferromagnetism. Although ideally on in the bulk copper oxide should have the magnetic movements should be aligned opposite to each other, giving it net anti ferromagnetism for a large size copper oxide particles.

But, in this particular case, since you will have lot of dipoles on the surface that large the magnetic movements, which are suppose to be aligned opposite to each other gets distorted and you have only surface magnetic movements to contribute and there can be weak ferromagnetism due to uncompensated spins on the surface. So, all the spins may not get compensated, which should be in ideal anti ferromagnet, so nano copper oxide particles can get attracted to a magnet.

Whereas, bulk copper oxide will not get attracted to a magnet, because that is a true anti ferromagnet. So, hence such materials can be put into devices as a magnetic sensor and you can switch on and switch off the magnetization depending on this kind of materials, so it can be used as a magnetic sensor.

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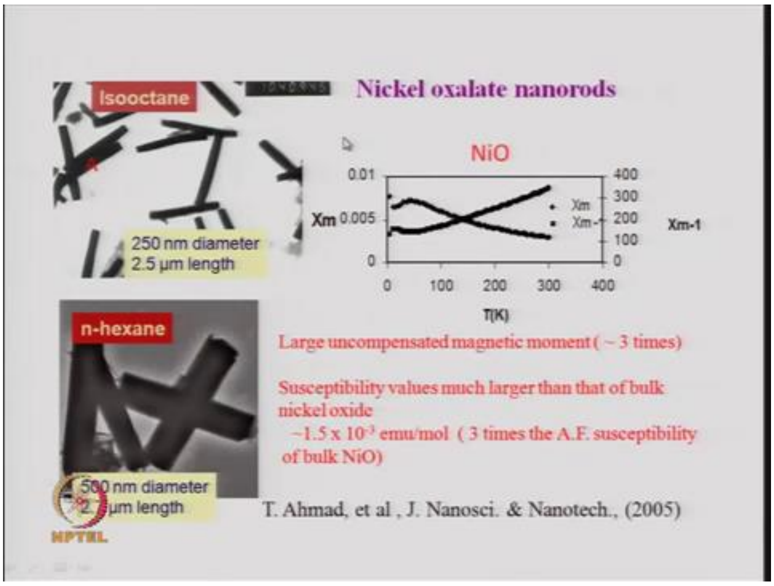

Now, you can look at other materials of similar kind for example, instead of copper oxalate, you can look at nickel oxalate, nano rods, which are shown here. And again the diameter and the length can be change by changing the starting solvent, here it is isooctane and here it is normal hexane. And you see these are much narrower rods, thinner, 250 nanometer diameter, here they are broader 500 nanometer diameter and these rods also decompose at around 450, 500 to give you the oxide, which is nickel oxide.

And when you look at the magnetic property of these nickel oxides, say the magnetic susceptibility as a function of temperature. Then you calculate the magnetic movement, it is three times larger than the magnetic movement of true bulk nickel oxide. Because, nickel oxide is again a anti ferromagnetic and, so the magnetic movement is very low in bulk nickel oxide. That means, nickel oxide having large particles micron sized particles, they have a small movement, because it is anti ferromagnetic.

And when you make it nano particles, the size becomes very small there is uncompensated spin on the surface. And or you can say surface spins dominate and the magnetic movement will become much larger compared to a nickel oxide particle, where all the movements get cancelled, because most of the movements are in the bulk and the bulk movements are get cancelled, because it is an anti ferromagnet. And, so when you measure for a nano particle of nickel oxide, you see that the magnetic movement is three times larger than the particles of a bulk nickel oxide. So, it can be magnetic movement which also means if when you measure susceptibility, the values are much larger than the susceptibility of bulk nickel oxide, so looked at copper oxide, nickel oxide.

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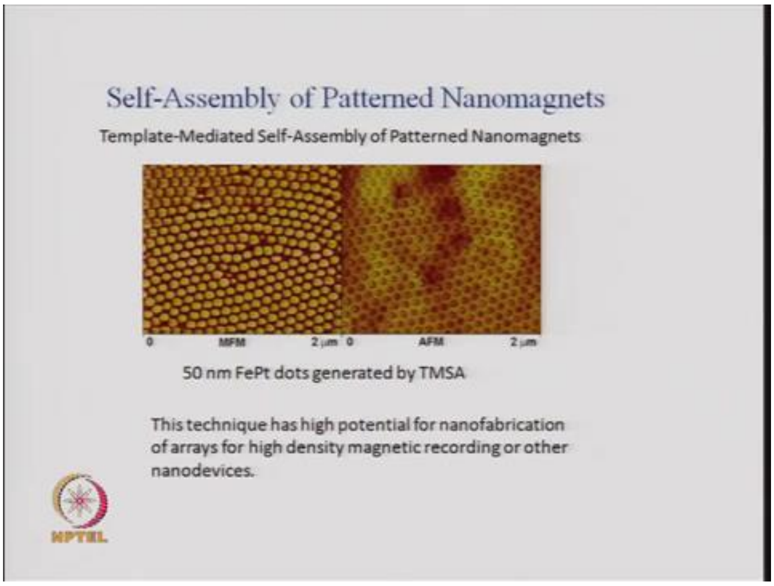

Similarly, you can make many such magnetic materials and many of these nano magnets have applications, if you can order them properly. So, if you can order these nano particles then it will have a tremendous role in application, so self assembly of patterned nano magnets is something one strives to obtain. So, that we can make use of these nano particles, so here is a template mediated self assembly of nano magnets, we are calling these particles as nano magnets.

And you can see that they are organized very, very orderly manner and this is a technique by, which you are observing these particles is called MFM that is Magnetic Force Microscopy. It is a derivative of the atomic force microscopy of course, you can do both atomic microscopy and magnetic force microscopy on the same material using different probes using the same peso on, which you can move the scanner. Now, on the left is MFM, which is a Magnetic Force Microscopy on the right is the AFM, which is the Atomic Force Microscopy.

Be a in the AFM, you see pictures are in image which is generated by the variation of the force, which the cantilever is feeling when the cantilever is moving across the surface of this material. And wherever it has different types of forces, you see this different colors from dark brown, to light brown, etcetera, so is basically maps the force at different points of the sample. And this force is related to the atomic atoms which are present accordingly, you will have a idea of where the atoms are positioned.

However, the MFM maps the magnetic field which is coming out or the magnetic movement from each position or the magnetic force you can call it. So, ultimately what you are measuring is some magnetic property of the material, so if the magnetic property is same everywhere, then you will just get one same shade of color to be imaged. However, if it is varying for example, this point has a different magnetic force compared to the point in between these two a light brown colors there is a dark brown region.

So, the dark brown region has different magnetic force, than these light brown regions and both these light brown regions or yellowish regions has similar kind of magnetic force. So, then when you image the whole thing, you get an idea of where the nano magnets are similar particles having similar magnetization will show you similar type of features. If you are particles which have a larger magnetic force will show up as the different feature.

So, using that you can map the whole surface as a function of the magnetic force, that is why this is called magnetic an image generated by magnetic force microscopy. Now, this particular case the each of these is a iron platinum nano particle or dot we are calling from the term quantum dot, which is normally used in the optical sense, where you have particles which show quantization. And in the optical frequencies they have particular absorption in the visible and here the this can be called as magnetic dots, because each particle has some magnetization.

And hence, we in general these are made up of iron platinum, iron platinum in the bulk is a hard magnet, it is magnetic substance has a high magnetization, a high remnant remanence or remnant magnetization has a high coercive field and that is why it is a strong magnet or hard magnet. And iron platinum small sized iron platinum or nano sized iron platinum, when you make a surface out of it is part small particles of this material, you have a pattern of nano magnets.

So, that is what you are discussing here a self assembly of patterned nano magnets and you have this can be preferred using a template mediated method. And it has high potential for many applications, because these are normally used for magnetic recording etcetera. So, this high density; that means many, many particles over a square unit area are required, then only you will have high density magnetic recording or other nano scale devices use for magnetic recording.

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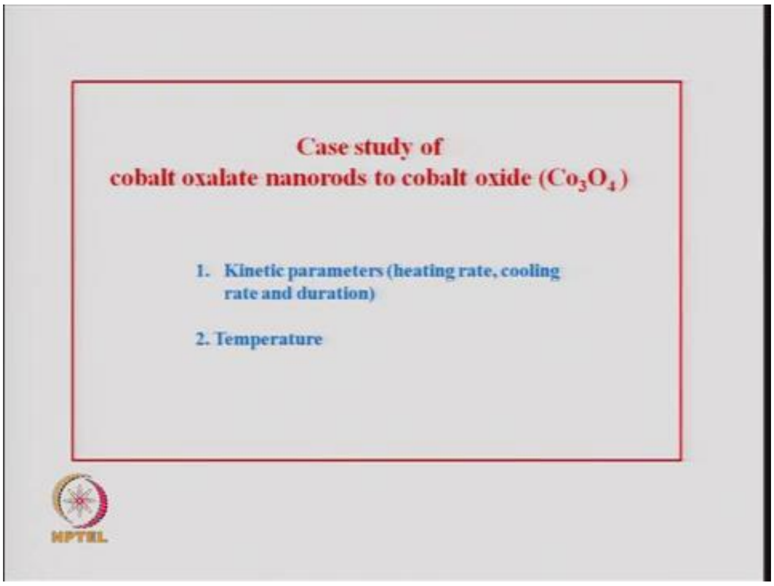

Then let us look at what we discuss, so far is 2, 3 examples of magnetic particles and we mainly discussed the synthesis of magnetic oxide particles, using oxalate and it is decomposition to give you a magnetic oxide, And then look at the magnetic properties of that magnetic oxide nano particles and we see that it is different from the bulk particles of same material and it shows up in the magnetization studies. And typically when you are expecting something to be anti ferromagnetic, in the bulk it tends to become weakly ferromagnetic.

And when something is ferromagnetic can become super paramagnetic act small size, now when you decompose this oxalate to become small sized metal oxide particles. One can study this kinetics that has been done, this is an example of decomposition of cobalt oxalate to cobalt oxide. And now note that this is a formula, which is not like a manganese oxide, which we study amino or a nickel oxide n i o which is C o 3 O 4.

And this is a very important a magnetic material and cobalt oxide can have different formula, you can have cobalt oxide with 1 cobalt and 1 oxygen, you can have cobalt oxide with 2 cobalt and 3 oxygen's. And you can have this cobalt oxide with 3 cobalt's and 4 oxygen's, now you can study the change from oxalate to oxide using different kinetic parameters. And see how the shape of the particles gets affected and you can also see how the length of the rods get affected and instead of spheres can you get some other kind of assemblies.

Because, earlier we showed that you get a rods of the oxalate and particles spherical particles for nickel oxide or copper oxide. Here, we will see that you can get different types of particles for cobalt oxide by varying the temperature, etcetera.

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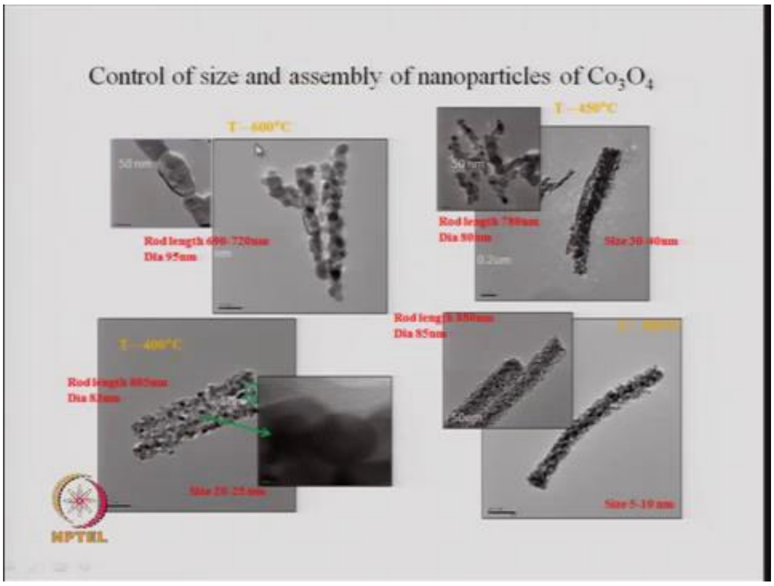

So, you see that when you heat that 600 degrees, cobalt oxalate, you get cobalt oxide of this kind, where you can see this particle small particles are forming a chain. And the dimension of this particles are around you see 95 nanometers is the around diameter and the rod length is around 600 nanometers. So, this is if you decompose at 600, if you decompose at 450, then you get different types the much smaller 80 nanometer is the dia and the rods are around 800 nanometer, each particle in this around 30 to 40 nanometers at 450 degrees.

So, whereas, at 600 degrees the particles appear to be larger, if you decrease this heating temperature to say 300 degrees you still get rods, but these rods are made up of small particles and these small particles around 5 to 10 nanometers. So, what this study shows is that using different a temperatures, etcetera, you can get the same cobalt oxide in different morphology. And the size of the particles which form this anisotropic rod like structure, this size the small size can be varied from 5 nanometers to around 80, 90 nanometers. So, you have a wide variation of size depending on the conditions that you are using to make this particles.

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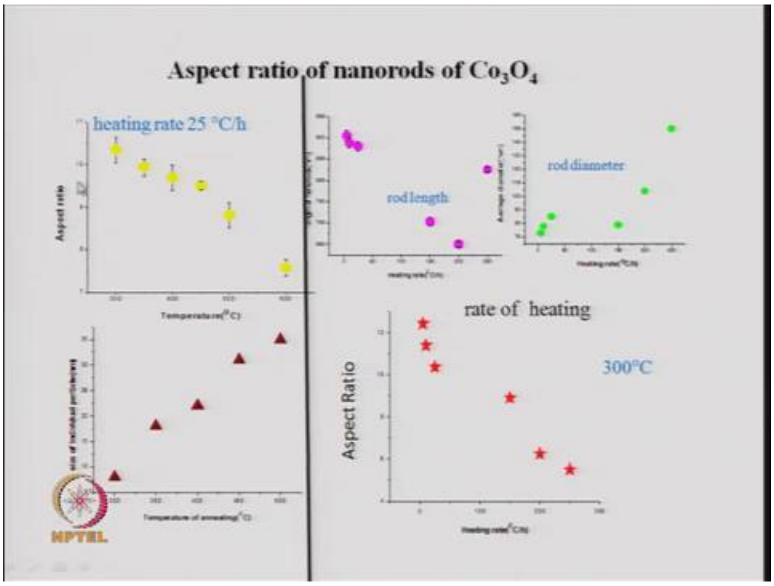

So, this can be plotted here and you can see the aspect ratio goes down with temperature increase in temperature the aspect ratio is the ratio of the length and breadth. And you can see, that if you divide the length by the width it is like 10 when you heat at 300. Whereas, the ratio becomes around 7, when you heat at 600 aspect ratio changes, the rod length changes, rod length is decreasing the rod diameter increases. So, what is happening is the length of the rod decreases, the rod diameter is increasing and the rod length is decreasing that is why the aspect ratio is decreasing, so this effects can be done and vary the cobalt oxide.

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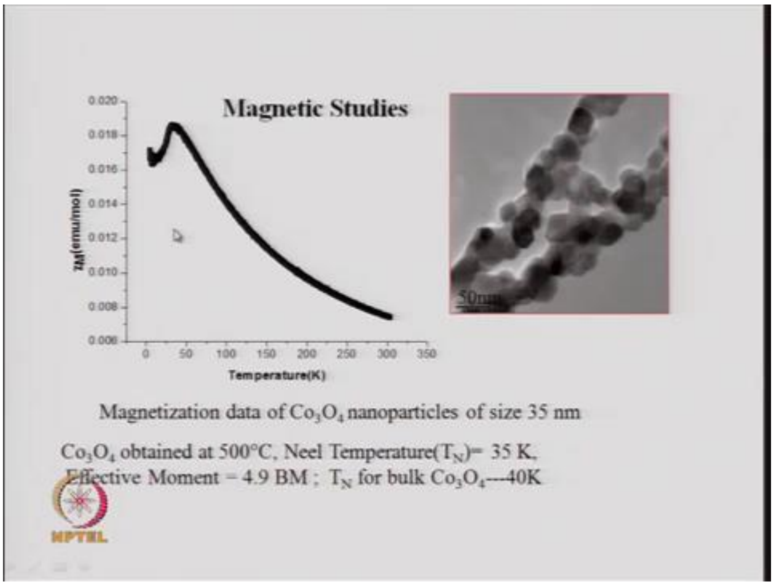

And all these cobalt oxide particles are magnetic, the bulk particles also magnetic the micron sized particle are also magnetic. And these particles which are aligned to form this kind of rod shape structures, if you measure their magnetization or susceptibility this is molar susceptibility on the y axis, you see chi subscript M capital M. So, capital M is for molar susceptibility; that means, what is the magnetic susceptibility for one mole of this substance.

So, it is units are e m u per mole which is electromagnetic units per mole and here you have temperature. And you see that as you cool like any parameter magnet, the susceptibility will increase as you cool with temperature or magnetization will increase as you cool with temperature. But, at a particular temperature which is the Neel temperature you start decrease in the magnetization or the susceptibility and this temperature is called the Neel temperature, because cobalt oxide is known to be an anti ferromagnetic substance.

And in all anti ferromagnetic substances, the transition temperature from the paramagnetic to the anti ferromagnetic state, this temperature is called the Neel temperature. And that is for this 35 nanometer sized particles, this Neel temperature that we get is around 35 Kelvin, so it is around 35 Kelvin that this transition occurs. And the bulk the effective movement is around 34.9 bohr magnetrons, which tells you that it should have around 4 unpaid electrons and if you have bulk C o 3 O 4 then bulk C o 3 O 4 should have Neel temperature of around 40 Kelvin.

So, if you have micron size particles the Neel temperature is higher and when you have smaller size particles the Neel temperature gets lowered. And actually it can change over to weak ferromagnetism like, you saw in copper oxide, in this particular case the anti ferromagnetism of bulk or large particles of cobalt 3 oxygen 4 is seen. But, the temperature at which the anti ferromagnetism is seen is lower then what you will see in the bulk. So, it is 35 Kelvin in this case in the nano particles and it is 40 Kelvin in micron size on particle.

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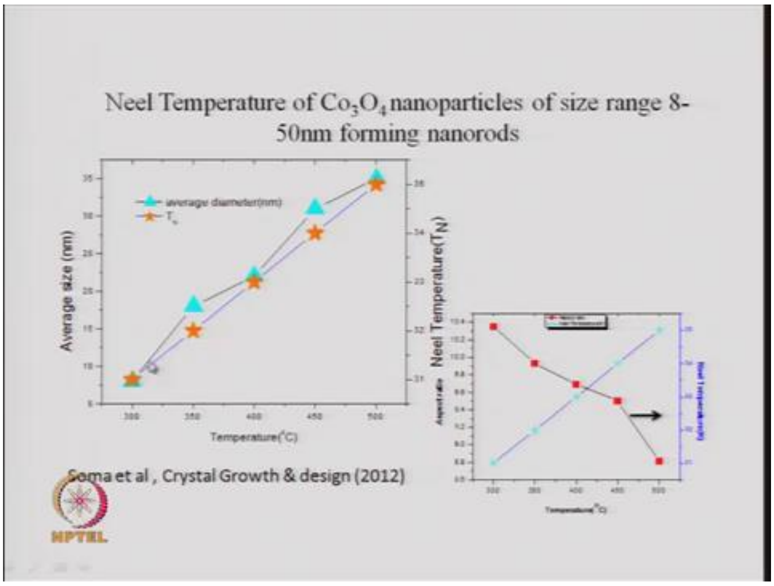

And so if you plot size of the particles, so the average size or diameter of the particle, if you plot along with the decomposition temperature. You will see that as you increase the decomposition temperature from 300 to 600, the average size of the particle is increasing not only that the Neel temperature is also increasing. So, what we showed was 35 nanometer particle, shows a Neel temperature of around 35, this is Neel temperature on this axis.

Whereas, if you decrease the size of the particle to say around 7, 8 nanometers then the Neel temperature goes down to 31 Kelvin, note that the micron size particles have a Neel temperature somewhere up there. So, it is around 40 Kelvin for micron sized particles much larger and for nano particles as you are decreasing size of the particle, the Neel temperature is decreasing. The decrease is gradual, because from 35 Kelvin it goes to 31 Kelvin, when the size of the particle is decreased from 35 nanometers to around 7 nanometers.

So, that is the change in the nil temperature with particle size, so these are very important; that means, you can control the size of the particle and you can control the magnetization of the particle. So, that is the connect that you want, so you have a handle or a material, now no more has a standard Neel temperature, so earlier if you look at book, iron oxide has a Neel temperature of x that is fixed. But, now you cannot say that iron oxide will have a temperature, not Neel temperature it is a curie temperature of some number.

And that number need not be fixed, because it will depend on the size of the particle of iron oxide. So, you will now have many numbers, many curie temperatures for the same material, which is ferromagnetic and many Neel temperatures for the same materials, which is anti ferromagnetic. So, you will not have a fixed number, because the number will change with a change in the size of the particle.

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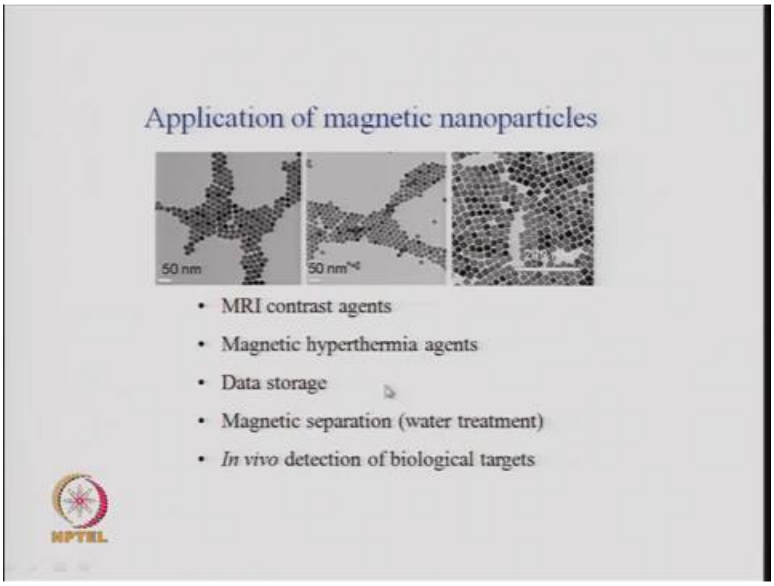

Now, there many applications of magnetic nano particles and these are some of the applications of magnetic nano particles, which are listed here. So, you can use them as MRI contrast agents I think we mentioned yesterday in the last lecture, that you can use for medical imaging. So, MRI stands for Magnetic Resonance Imaging, which is also called medical imaging, because you image a part of the body or the brain using a source of a magnetic field.

And at the same time you have to a do some other aspects, either depending on a whether you are doing stereoscopy or imaging. But, main thing is you are trying to map the magnetic field inside some organ or inside a brain and the magnetic field has to be picked up by some sensor or some detector. Now, this contrast agents when you add them they help you in I identifying demagnetization of a particular place, so if you use a contrast agent and it goes to particular cells in the kidney, then you can see those cells much better against the background of the all other things which are there.

So, MRI contrast agents, help you see the part of the cell or body which organ where you are interested. So, suppose you want to see a tumor very well and you are going to use medical imaging technique, you are MRI contrast agent if it goes to those tumor cells then you can locate them much better. So, that is the use of MRI contrast agents, they are also use for magnetic hyperthermia agents; that means, suppose you put this magnetic materials.

Now, these magnetic materials because of the hysteresis loop, you know if you apply a magnetic field, then you can have a some kind of heating. So, hyperthermia means you can heat the environment with magnetic particles when you apply a magnetic field. So, suppose there are tumor cells and you want to break those tumor cells, so many times you can heat them and destroy them. Now, if you can send these magnetic particles exactly to the cell, which you want to destroy.

Then once these particles go inside those cells and you apply a magnetic field, these particles will then dissipate energy. When it dissipate energy, it will heat up the neighborhood and the cells which are nearby will get destroyed, because you know most of the cells gets destroyed above temperature, whether proteins get denatured. So, around that around 70 to 90 degrees most of the proteins gets denatured expects from very rare proteins which down get denatured, once the proteins get denatured they cannot function and, so the cells will die.

So, what you want is by hyperthermia, magnetic hyperthermia means you are heating through magnetic fields. You apply magnetic field and the magnetic particles, then will dissipate energy in the form of heat, through this hysteresis loop you can calculate how much a heat it can do. Then the third important thing is magnetic data storage, which is a very important part of our day to day life, so other than the magnetic hyperthermia agents, data storage is very important most of the hard disk that you use your CD's, hard disk your pen drives, they are all data storage devices.

And most of them use a up magnetic methods for data storage and in those places, you can enhance the ability of data storage by using magnetic nano particles. Apart from that you can have magnetic separation, especially in water treatment where you can have waste materials tagged to magnetic particles and then you apply a magnet and remove the particles. So, the waste will come along with a magnetic particles and can be removed with the help of a magnet, finally you can do in vivo detection of biological targets using magnetic fields.

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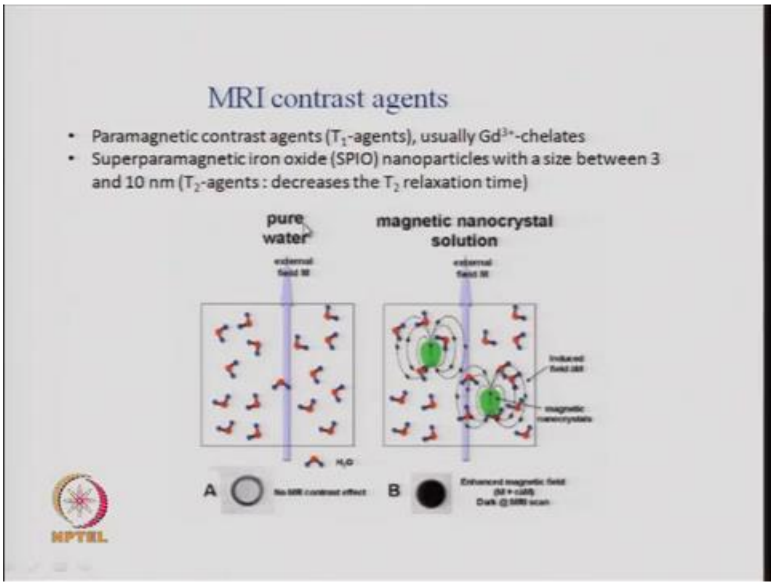

So, the MRI contrast agents as I just mentioned, there can be different types of contrast agents, you can use what are called paramagnetic contrast agents. This paramagnetic contrast agents are also called T 1 type agents, the term T 1 comes from what is called relaxation time it is from a NMR spectroscopy, which has got two type of relaxations, one is the spin lattice relaxation and the other is the spin spin relaxation. So, the T 1 is the spin lattice relaxation and this paramagnetic contrast agents are normally some gadolinium type of compounds chelate compound.

That means, gadolinium complexes and gadolinium has a free electrons in it is f shell and those electrons give it the paramagnetism and these gadolinium compounds are used as paramagnetic contrast agents and are also called the T 1 agents. Because, the spill lattice relaxation time is affected, where as the magnetic nano particles we are taking about or interested are like the super paramagnetic iron oxide, which is called SPIO which means Super Paramagnetism is the property, which we are going to use in this contrast agent.

And these iron oxide nano particles, they are also by a compatible that is why they can be injected in the body are used for MRI contrast agents. And these particles have a size between 3 to 10 nano meters and this small size iron oxide nano particles, which are T 2 agents; that means, they affect spin spin relaxation time, it decrease the relaxation time actually. And that brings about a contrast when the magnetization is being recorded, so like when you take a photograph, you record picture when you do a MRI or any medical imaging you record a picture.

But, the picture is dependent on the magnetization of the object, which it is trying to form an image. So, where ever the magnetization is different, it will have a different contrast and these super paramagnetic iron oxide particles help increase the contrast and, so it help you to see that position much better in the background because of the excess contrast. So, for example, you see on the left side there is a water here and you apply a magnetic field and the water molecules are shown here.

And the contrast the magnetic resonance should create a contrast, but you do not see a much contrast here. Whereas, the same solution, if you add in the water some magnetic nano crystals, so this is a magnetic nano crystal, this green ones are magnetic nano crystals and, so there will be a magnetic field associated with this magnetic particle, which will give you a net magnetic movement, like shown by this arrow inside the particle. And in the presence of the external magnetic field, it will align in that direction and it will induce this field around this.

So, you had a magnetic field due to the external field, which you applied, which was M in this case, in this case you will have the magnetic field M plus the additional field created by these magnetic nano particles. So, the total field will be M plus some delta M, so the enhanced magnetic field will cause an enhanced contrast and you will see much darker MRI pattern. So, wherever you have these magnetic particles, you will have much more contrast and that is why they are called MRI contrast agents and they are used extensively in medical imaging.

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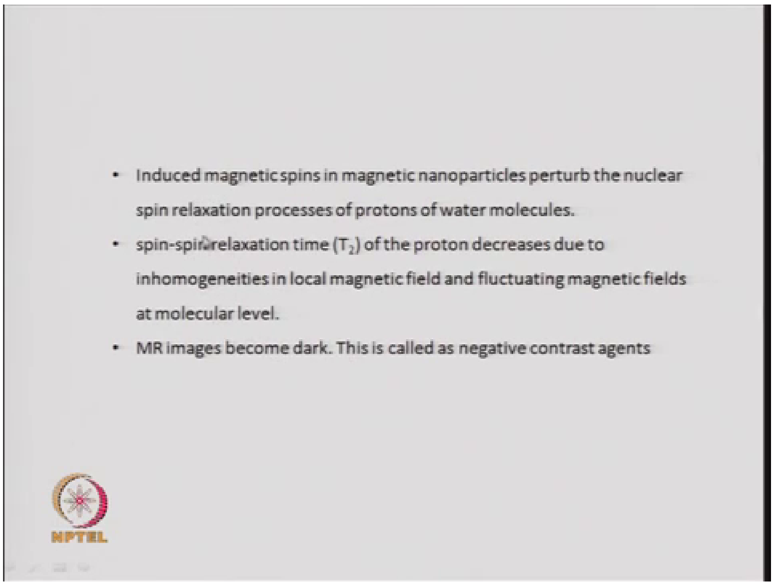

So, this is what we discussed that the particles induced magnetic spin and perturb the nuclear spin relaxation process of the protons of water. And that T 2 the spin spin relaxation time of the proton decreases due to in homogeneity in local magnetic field and the fluctuating magnetic fields at molecule level. And the images become much dark and this is called as negative contrast agent, you can also have positive contrast agent, where this images will become light here the image the wherever the particle is becoming darker.

So, basically what you are doing by adding the particle is ((Refer Time: 45:30)) you are affecting the spin spin relaxation time of the protons of the water molecule, because this is in solution. So, water is there and the protons of the water will always have a magnetic signal and the magnetic field, which is being created by this contrast agent by the nano particles will affect the spin spin relaxation time of the protons of the water molecules. And when it affect that that you can see by an enhanced contrast in the MR images, so this is the role of the nano particles as an MRI contrast agent.

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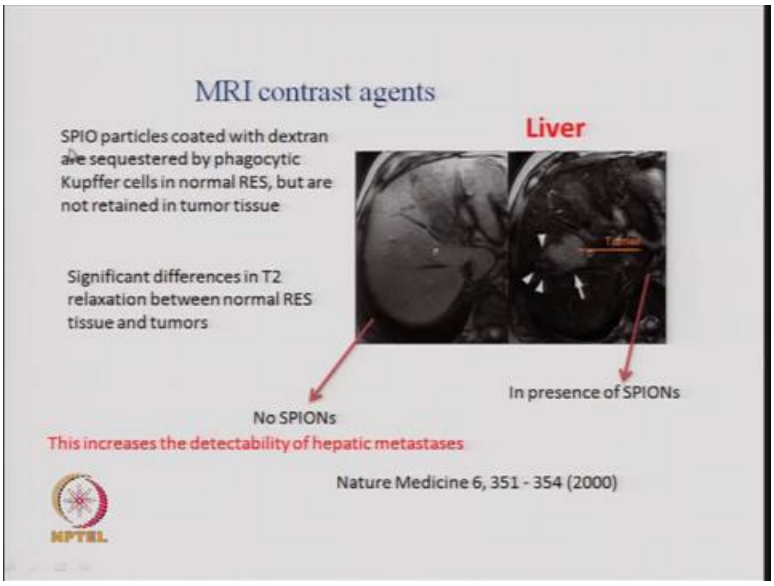

This is an example, where the super paramagnetic iron oxide particles have been coated with some dextran or something you can coat. Because, normally it is not given directly the nano particle inside the body it is coated with something, so that it goes only where you wanted to go, otherwise it will react all places before it reaches the final destination. So, here it is coated with dextran and are sequestered by phagocytic kupffer cells, you see in the liver we want to target this particles to go to the liver, because you want image the liver.

And in this case you see the contrast is weak there are no particles in this case, but when you give the particles in the liver, the contrast is enhanced. And you can see that this particle this is the tumor here, that is what they are trying to say and this is this picture is in presence of the nano particles So, the contrast is much better and the tumor cell is seen easily in this case, the tumor cell is not seen, so the detectablity of the tumor which is here we call the hepatic metastases is much better and you can easily observe this kind of changes in the organs as when you add the MRI contrast agents.

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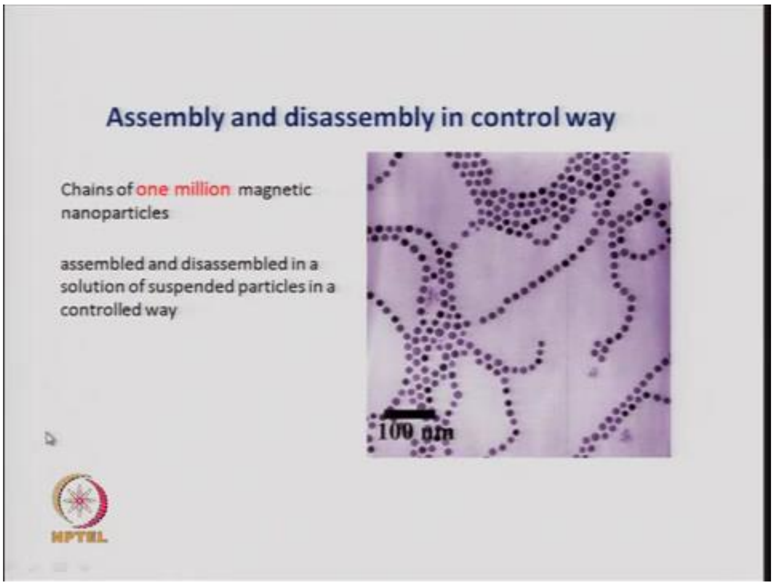

This is another way when you apply you want them to assemble or disassemble in a controlled manner. So, this image where you can see that the particles have been aligned in a certain fashion by using appropriate reagents or appropriate magnetic fields, so they can be assembled or disassembled in a solution in a controlled way. So, if you can do that, then you can use it in real life, you can make it assemble at a part in the body and you can make it disassemble using a trigger. The trigger may be change in a magnetic field or a change in the PAH or something like that, since these are magnetic particles then normally a change in the magnetic field can create the assembly or disassembly in a controlled manner.

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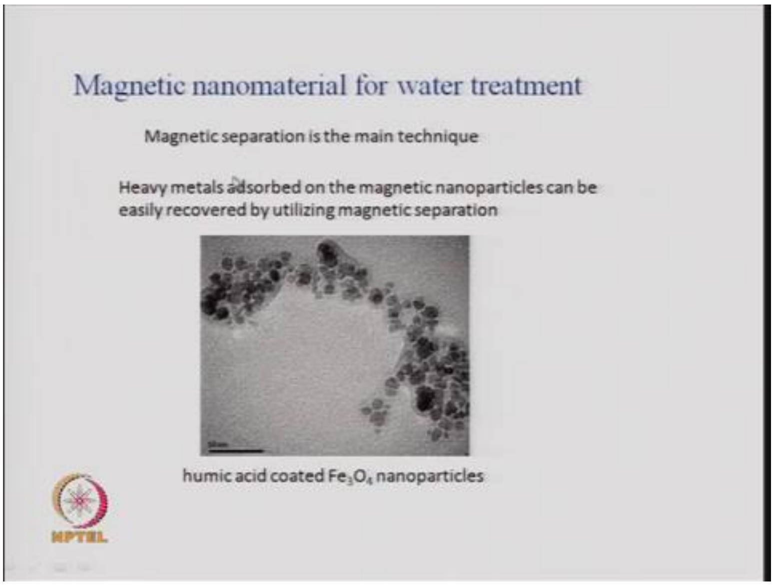

So, here you see magnetic separation is being applied, so that you can remove waste material from water. So, heavy metal are absorbed on the magnetic particles and they can be easily removed, if you apply a magnetic field, so say you use magnetic nano particles like iron oxide and you use humic acid, which can is available from natural sources and humic acid is coated on to iron oxide nano particles. So, you have iron oxide nano particle nano particles and on top of that, you put humic acid and then you put it in a solution which has got some pollutants.

So, here rare earth ions or heavy metals are pollutants, so like lead, bismuth, etcetera are may be lanthanides. And then they get coated adsorbed on the magnetic nano particles, once they get adsorbed on the magnetic nano particle, then you apply a magnetic field all this particle will come to the position close to the applied magnetic field. So, say your applying the a magnate a one wall of the container, then all the particles will go to that part of the container, where the magnate has been is applied. So, you that way you can remove some heavy metals in water using magnetic nano particles and this process is called magnetic separation, so this is the another application of magnetic nano particles.

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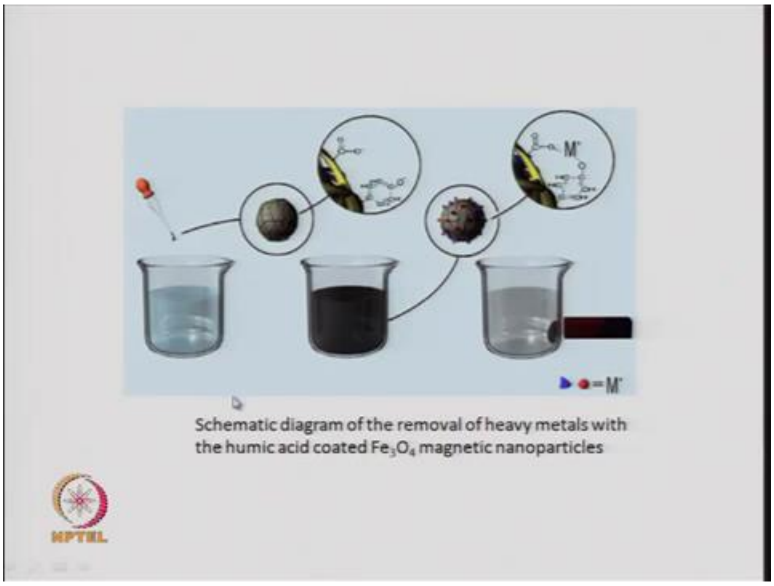

So, this is the scheme, so you can see that you have this solution, which has got heavy metal ions and you want to remove heavy metal ions from that, what you do is add nano particles, which have been functionalized with something. So, this functionalize here can be humic acid which has coated the particles and then you add them and the heavy particles, the heavy metal ions get trapped on the surface of these particles.

Because, it is functionalized with some carboxylate waves or something and that carboxylate group can from chelates with this heavy metals like lanthanum or neodymium or lead etcetera. Once it gets to on trap on the surface of these particles, then you bring a magnet close to that, so once you bring the magnate all this black, which is shown in a black color, they will come and deposit on the wall of this container. So, that the water will be clean, so this is the magnetic separation of this heavy metal ions using functionalized magnetic nano particles.

So, this very important application and with that we come to a close to a today's lecture on magnetic nano particles. And it is also the close of this three lecture series on magnetic nano particles, what are magnetic nano particles, what are their applications and how you make them, how you control their size, etcetera. So, typically we learnt that when you decrease the size of magnetic nano particles, then it has a tendency to reverse its magnetization.

That means what you know in large sized particles to show ferromagnetism, when you make small size particles you will tend to get the opposite of ferromagnetism. That is you will either get super paramagnetism or you will get weak may be ferromagnetism, but and when you have anti ferromagnetism. Then you in a large particle when you decrease the size of the anti ferromagnet you will tend to get either a lower Neel temperature or you will get a weak ferromagnetism in that particle.

And where you can use these particles, the particles which are ferromagnetic, the nano particle which are ferromagnetic can be injected in the body and it can be used to generate energy inside the body locally, because the nano particles are very small. So, they will be in touch with only very few cells and you can apply a magnetic field and heat the local environment around the particles, because during the hysteresis when you increase magnetic field and decrease magnetic field, there will be a hysteresis in the magnetization.

And that will create heating and that will heats the environmental around the magnetic particles and that will destroy the cells around the magnetic particles. Since, the particles will be very small, this heating effect will not be spread to other cells and it will only heat where the particle are lodged. So, there will be a local damaged to the cells around the particles and there will not be a large scale damage of good cells in the remaining part of the organ.

So, you can have very good localized treatment using magnetic you can which we call as hyperthermia magnetic hyperthermia. Now, that is the one thing, the other thing is what we learn that we can do very well what is called face the contrast, like MRI contrast agents they show up in medical imaging there is lot of importance. Because, these magnetic nano particles can enhance the contrast, and so can show up some tissues against the back ground much better or some tumor cells or cancerous cells, against the background. And hence in medical imaging this kind of magnetic nano particles are of great importance and there are many other applications like magnetic separation, etcetera. So, with that we come to an end to a today’s lecture and I hope to meet you the next lecture, where we will start our discussion on the optical properties of nano particles.

Thank you very much.