Nano structured Materials-Synthesis, Properties, Self Assembly and Applications

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Module - 4
Lecture - 34
Magnetic Properties – I

Welcome back to this course on nanostructured materials, synthesis, properties, self assembly and applications. We are in the module 4 and today's the lecture 6 of module 4. And we will be starting series of 3 lectures on magnetic properties of nanostructured materials. So, today will be the first lecture of the 3 part magnetic properties of nanostructured materials.

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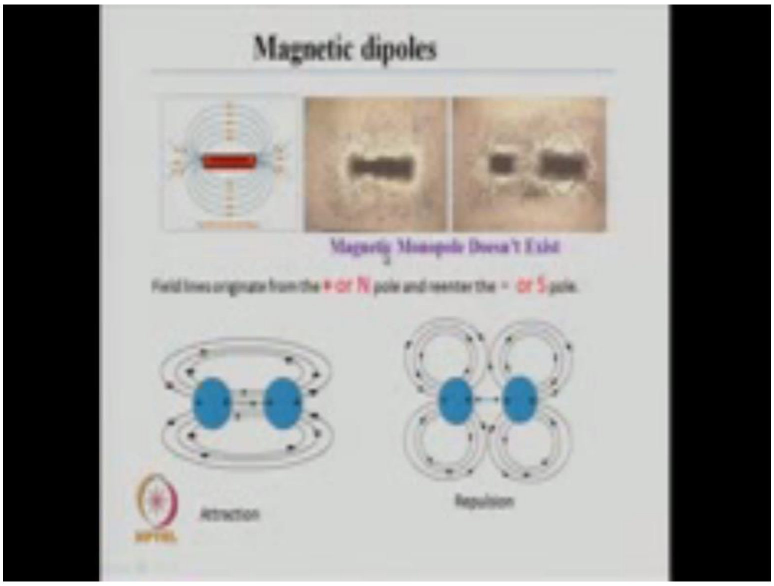

So, what are magnetic properties give to? So, when you apply a magnetic field what happens to the properties of the material? Now, we before we go to the magnetic properties of nanostructured materials we need to know the magnetic dipoles. So, like electric dipoles you have magnetic dipoles and these dipoles normally we represent as north and south sometimes we write plus and minus. But more so in a electric dipoles moment we use plus and minus. Whereas, for magnetic dipole moments we normally use north and south and these lines show you the magnetic lines of forces in the presence of a magnet. Something which is a magnetic dipoles can be represented as a bar magnet where the lines of force move from the north pole to the south pole. And in magnetism there is no magnetic monopole you can have an electric charge as a plus or a minus charge separately.

However in magnetism there is no existence of a magnetic monopole you will always have and north and south together in whichever magnetic system you discuss. So, that is the difference between magnetic dipoles and electric dipoles. And these field lines if they are in this form if you bring in 2 magnetic dipoles close together. That means you have a a magnetic dipoles here with a north and south and you have another magnetic dipoles a north and south. Then they will attract if the north and south face together, because the lines of force can follow in a continuous path. Whereas, if you have that 2 north poles together then that is repulsion between these 2 dipoles and the lines of force will look somewhat like this. So, you can have an attraction or an attractive force between 2 magnetic dipoles or a repulsive force between 2 magnetic dipoles. And these lines of force tell you about the magnetic field around these magnetic dipoles.

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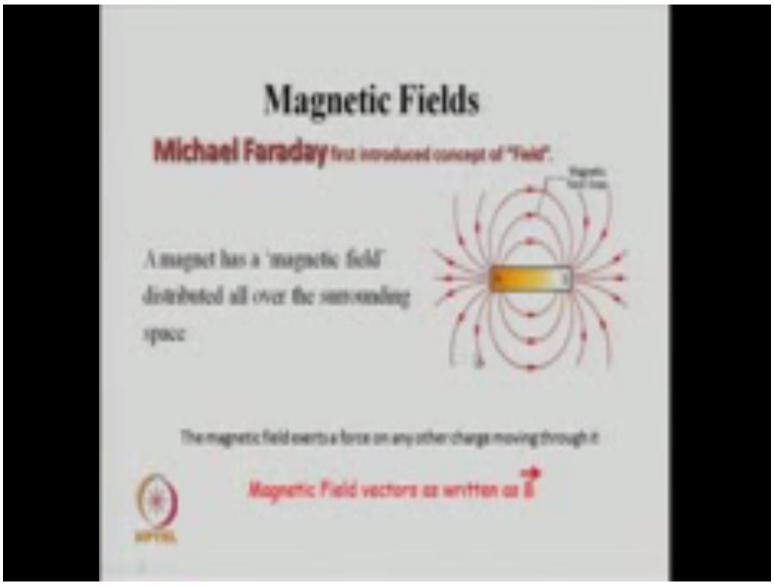

Now, the concept of the magnetic field was first introduced by Michael Faraday. The well known scientist is known for many things including a several things in chemistry in physics and more so for the laws of electromagnetic induction. So, Michael Faraday introduced the concept of field and as shown here any magnet will have a magnetic field as represented by lines distributed all over surrounding space. And these can be experimentally verified and these to force can be seen as well as measured by different experimental tools. Now, if you bring in a charge near a magnetic field then that charge will feel as if an external force is acting on it and that external force is because of the magnetic field. So, a magnetic field will exert a force on any other charge which is moving near it and the magnetic field vector is not really presented as B. And there are several other paper symbols associated with magnetism we will see some of these symbols soon.

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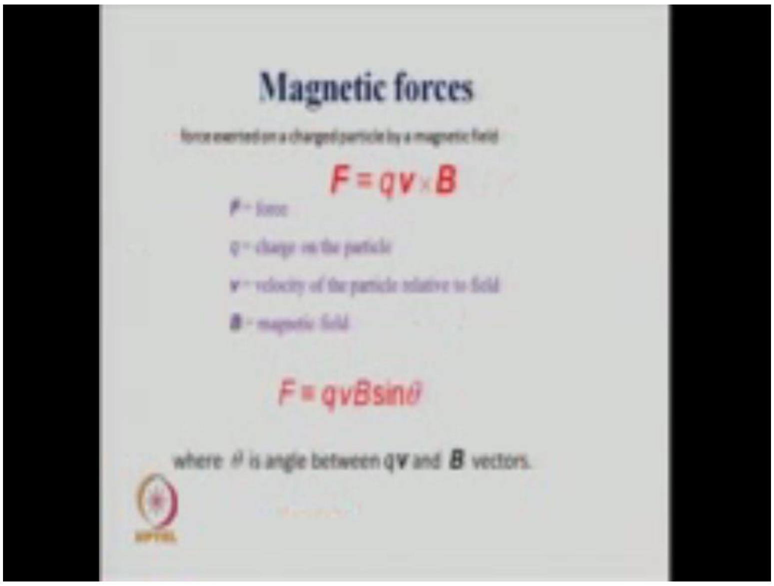

So, the magnetic force felt by a charge which is a charge q which is moving with a velocity v in the presence of a magnetic field B. The force is given by this equation that is the cross product, and if you want to calculate if the direction of the movement of the charge. That is the vector of the velocity and the magnetic field vector if they make an angle theta between them. Then the force will be given by this expression where theta is that angle between the v vector. And the capital B vector that is the vector in which the charge is moving in the direction in which the charge is moving and the direction of the applied magnetic field.

And the cross product will give you this or the vector product will give you this. And you can calculate the force influenced by the a magnetic field or the moving charge. So, what we are doing is kind of recollecting some basic principles of magnetic field. And how particles or charges will particles having charges will be affected by magnetic fields. So, today's lecture more or less will deal with things which are related to the basic concepts of magnetism that is application of magnetic field to different systems.

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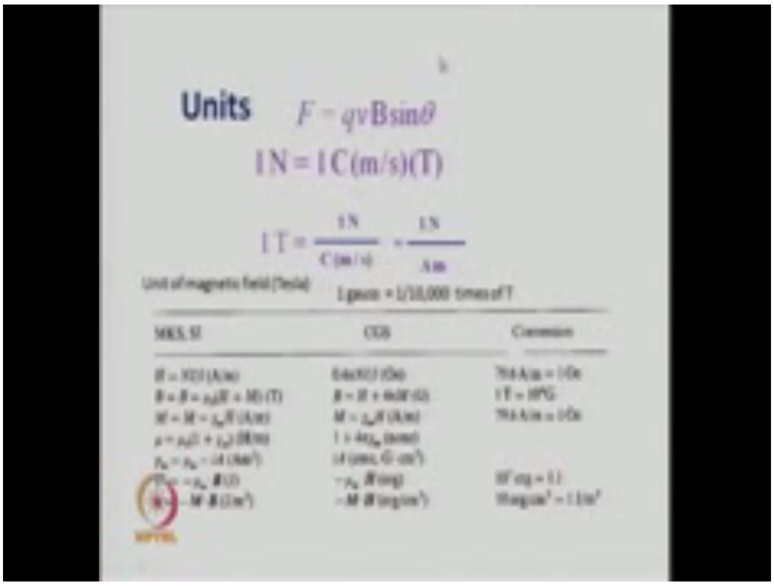

Now as we are looking into the basics of the magnetism and effect of magnetism on different particles. Some units are need to be understood because the units in magnetism create lot of confusion. And so it is good to go over the units which we use in discussing magnetism magnetization magnetic fields etcetera. So, the force is given by this equation and the quantity of force is in Newton’s and if charge is in coulomb's and velocity is in meters per second and B the magnetic field is in Tesla the capital T Tesla named after Nikola Tesla a very famous scientist. And so then 1 Newton becomes equal to 1 coulomb multiplied by meters per second multiplied by Tesla.

And this can be a also represented as 1 Tesla is equal to 1 Newton per coulomb per meter multiplied by second and since coulomb per second. That is charge per time charge per unit time is current hence coulomb per second will give you amperes. So, finally, 1 Tesla of magnetic field is actually equal to 1 Newton per ampere meter. So, this is and in S I units and you can change them CGS units but it is better to use S I units. So, that it is easy to for you to follow the various units. Now, we of course, another very common unit magnetic field other than Tesla is the gauss named after famous mathematician gauss.

And 1 gauss is a very small quantity whereas, 1 Tesla is a very big quantity. So, 1 gauss is 1 by 10000 times of Tesla or 1 Tesla is 10000 cause. So, that is what is written here 1 Tesla is 10000 gauss and many of the the Tesla is actually the S I unit and is given here. So, these are some of the quantities on the left you see the these are quantities of magmatic field magnet field induction B, and then magnetization and magnetic moment. So, these are different quantities given in the S I unit or the M K S unit and it is also given in CGS units and the conversions are sometimes not very simple.

And you need to understand the what are the differences in the 2 systems of unit. Of course, there are tables and books available where these conversions are given. And so for example, let us look at 1 or 2 important conversions here the this is if you look at magnetic field. And that is related to permeability of free space mu naught multiplied by the magnetic field strength and M is the magnetization. And this is given in Tesla now if you convert this in the CGS unit then this becomes H plus 4 pi M. And now, this is given in gauss so hear B will be in gauss and the question is H plus 4 pi M.

However here it is mu naught H plus M so these kind differences will occur when you are using S I unit or CGS units and 1 has to be careful which units 1 is using. Similarly, if you look at another equation where mu that is you are talking of mu here is the magnetic moment is related to 1 plus chi M where chi M is the magnetic susceptibility. And this is related to mu naught into 1 plus chi M can be transformed to a 1 plus 4 pi chi M. So, this kind of differences in the questions can occur and 1 has to be careful. So, there are many other differences between S I units and CGS unit in magnetism and 1 has to be very clear about them.

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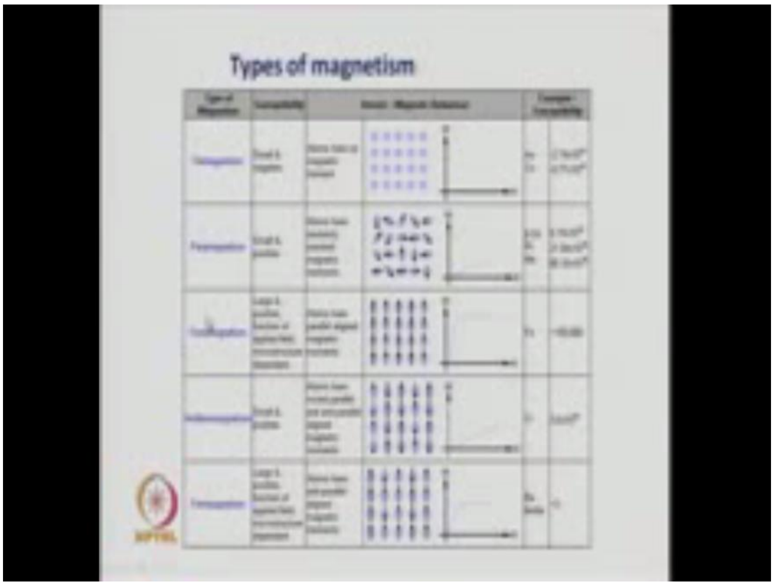

Now, considering different types of magnetism when you have a solid and you have magnetic dipoles. Now, these dipoles can be arranged in a solid in particular manner or they can be in a total disorder. Now, depending on the type of arrangement of these magnetic dipoles or whether they are disordered you will get some net magnetization. So, when you apply a magnetic field to a set of dipoles they will behave differently depending on what kind of strength of the magnetic field is what kind of solid is. Whether the magnetic dipoles are arranged at regular intervals in distance along only 1 axis or along 2 axis or all the 3 axis, because a solid will have 3 dimensions.

So, what are the different directions in which the dipoles are arranged? Now, all these factors give you give rise a variety of a arranged order of magnetization. And hence there are large number of types of magnetization possible in different solids. So, let us look at some of the types of magnetism for example, if you have diamagnetism what does it mean? It means that this susceptibility which we just discussed the susceptibility is nothing. But when you have the magnetization which is divided by the applied magnetic field then you get susceptibility and the quantity is called chi M.

So, a chi M if M is the mass in grams then it is mass susceptibility, but you can also calculate molar susceptibility with then the formula will have chi capital M which is molar for 1 mole, what is the magnetic susceptibility? So, magnetic susceptibility is basically when you have a magnetization and you divide that magnetization with the applied field then you get magnetic susceptibility. So, a more or less magnetic susceptibility is proportional to the magnetization. So, this is what you have to remember and if the magnetic susceptibility or magnetization is very small and slightly negative then we call it diamagnetism.

And normally it is more or less constant with temperature it does not vary much with temperature. And his diamagnetism is actually caused by the electrons in the filled shells of the various atoms formed in the solid. So, in these systems the atoms have no magnetic moment but the diamagnetism is because of the electrons which are in the filled shell and the value of diamagnetism is very small. So, you can see the value of diamagnetism is of the order of 10 to the power minus 6 where for gold and copper. And this is very small compared to other cases where there is ferromagnetism or ferrimagnetism, etcetera.

So, diamagnetism the magnetization hardly changes with magnetic field is very small negative magnetization and there is hardly any there you cannot see any magnetic dipole. So, there is no magnetic moment on the atoms so the this small diamagnetism is due to the electrons in the inner shells and it is negative. And it is very small of the order of 10 to the power minus 6 in paramagnetism it is the other way it is small. But it is positive in this case there are dipoles as you are seeing on the atoms, but they are all arranged in different orders. So, its randomly oriented and hence when you apply a field then they started aligning and so the magnetization increases as a functional magnetic field.

For zero magnetic field they are all disordered as you increase the magnetic field the value will increase. And you can see these values are positive but not very large for these metals now in ferromagnetism what happens the large value and positive is a function applied field. And it is dependent on the microstructure and in this case you see all the atoms are parallel aligned magnetic moments they are all aligned in the presence of a magnetic field. So, when you apply a magnetic field it goes to some value and becomes constant. And that is the maximum you can get when all the moments are aligned in 1 direction.

And so it is a large value and that is ferromagnetism all of them align together and the value as you can see is nearly 10 to the power 5. So, it is 11 orders of magnitude higher than diamagnetism or simple paramagnetism in antiferromagnetism it is small and positive. Because the dipoles are all arranged opposite to each other so it may be close to 0 where its normally small. And it means normally positive and as you apply a magnetic field it tends to increase slightly. So, this value again very small you see 10 to the power minus 6, but it is positive and the moments here are aligned opposite to each other in alternate positions.

In ferromagnetism it is not exactly these moment are not exactly cancelling you can see some are large moments some are small moments. And so they have a positive large number and so it is say a round 3 which is 6 orders of magnitude higher than diamagnetism and paramagnetism. But it is again nearly 5 orders of magnitude smaller than ferromagnetism. So, you can have large number of such magnetic order in different solids and the magnetization is different or the susceptibility is different. And so you can kind of understand the type of solid you have by understanding the plots between magnetization and field which are varying with different type of ordering of the solids.

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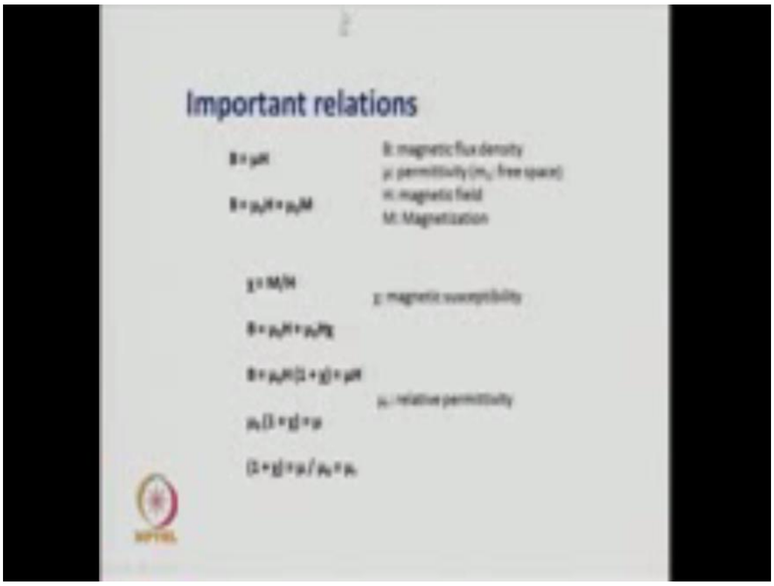

Now, these are some of the important relations one must understand. So, you have this a the magnetic field or which you have applied that is H and B is the magnetic flux which is going in. So, here what we said is that in this case 1 is B and 1 is H so magnetic flux intensity. That is how much magnetic field is going through the sample will depend where its paramagnetic are diamagnetic and H is the applied magnetic field here. So, the same equation is coming here, where you have B is equal to mu H where mu is the permeability. Actually it should be permeability which is normally written as permittivity in dielectrics.

And in magnetization it should be permeability and mu naught is the permeability of free space when there is no material. But something like vacuum then what is the permeability or that is mu naught and it has a constant value and M is the magnetization. Hence chi is the magnetic susceptibility and is given by M by H And then the B the magnetic flux density which is going through the solid is related to these equations. And ultimately you can write mu naught is equal to multiplied by 1 plus chi is equal to mu. And if you take the ratio of a mu and mu naught that is mu is in the presence of the material and mu not is the permeability of free space, if you take that ratio that comes out to be 1 plus chi and that is called relative permeability.

So, these equations are use whenever you want to understand the relations between applied magnetic field and the magnetic field which is induced. So, the magnetic flux density tells you about how easy it is or how permeable the materially is to the applied magnetic field. Now, the 3 different types of materials which are of importance are ferromagnetism ferrimagnetism and antiferromagnetism. So, we already discussed in the table that ferromagnetism has aligned magnetic moments it has a large value of the magnet magnetization and the susceptibility. And this magnetization is the maximum that it cannot reach at some particular field and then it does not change. And that maximum magnetization is attained when all the moments are aligned in the direction of the magnetic field.

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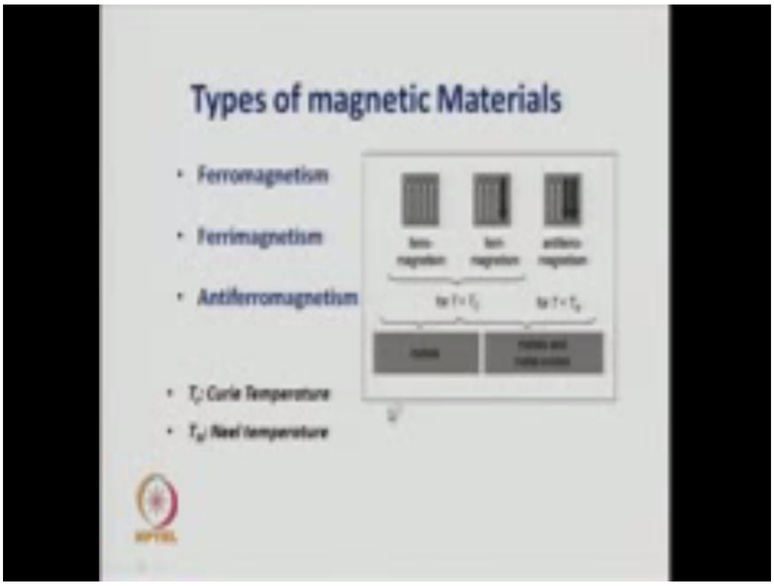

And the antiferromagnetism is when the moments are opposite to each other So, ferromagnetism moments are aligned together antiferromagnetism the moment are opposite to each other in fairy magnetism. It is like antiferromagnetism except that the magnitude of the moment in 1 direction is much more than the magnitude of the moment in the other direction. Hence in this case they nearly cancel their effective moment is nearly 0, but in this case the effective moment can be much larger than this case. So, this is ferrimagnetism this is antiferromagnetisn in ferromagnetism all the moment are aligned and this happens when the material is below a certain temperature.

This alignment of the moment happens below a certain temperature called T c for ferromagnetism and ferry magnetism. This T c is called the curie temperature and for antiferromagnetism where they order antiferromagnetically below a certain temperature. That temperature is called the Neel temperature curie temperature and Neel temperature both named after scientists. And curie temperature is in magnetism is given to ferromagnetism or ferromagnetism at that temperature at which below which this order exists these ordering of the magnetic dipoles and for antiferromagnets.

Then the ordering exists that below all these 3 above their curie temperature are Neel temperature in this case above that temperate they will be paramagnets. And they will have disordered moments like this only below a certain temperature these moments will get aligned like this. So, the behaviour of a paramagnet is as you change the temperature you lower the temperature the moment will increase slightly. Because this moments will start aligning with the field, but when it comes to a temperature where all the moments align then you will see a sudden increase in the magnetization.

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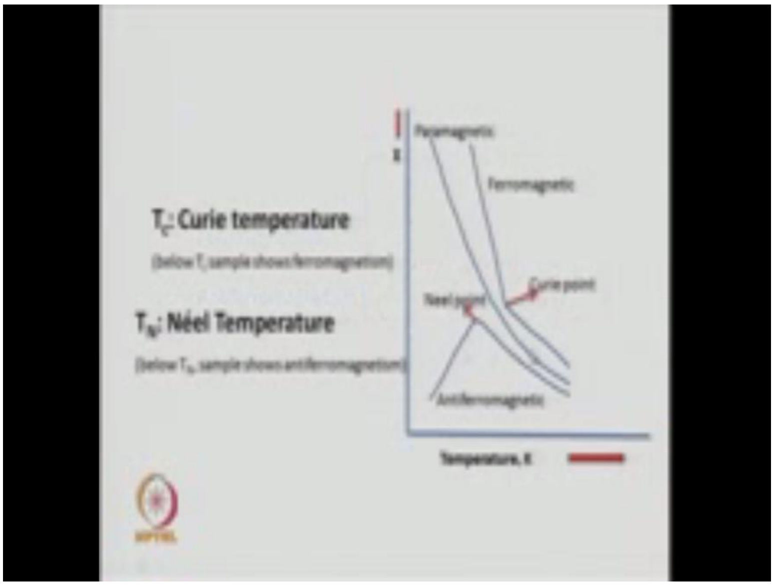

So, that is what you see in a ferromagnetic as you are decreasing the temperature as you are going in this direction the magnetization or the susceptibility is increasing as it should for a paramagnetic, but at the particular point which is called T c. So, this temperature on this axis if you mark then that temperature corresponding to this point is the curie temperature and the temperature a, after below this temperature if you cool the sample further, that means you lower the temperature. Then the magnetization increases much sharply and that is why that compound is ferromagnetic and this is a signature of a ferromagnetic transition. So, here it is paramagnetic this is the Curie point or the T c is the on this access you can find the temperature which corresponds to T c.

And this is the magnetization enhancement below the ordering temperature. A typical paramagnet will increase its magnetization or its susceptibility continuously without any sharp change in the chi value. The chi value is a magnetic susceptibility and normally we plot chi E M u per mole that is electromagnetic units per mole. And you can convert it to S I units etcetera and this chi is large indicates magnetization is large. Because chi you obtained by dividing the magnetization with the applied magnetic field H. So, a, this will certainly increase but this sharp point is not there in the paramagnetic substance. In the antiferromagnetic substance the, a behaviour of the paramagnetism is there till this temperature which is this temperature will be called the Neel temperature.

Corresponding to this sudden change in the magnetic susceptibility and this sudden change in a magnetic susceptibility below this temperature is due to the ordering of the dipoles in such a manner the that they are opposing each other. So, when they exactly oppose each other that happens below T n and that that is why this temperature is called the Neel point. Or and this temperature is called the Neel temperature and then the magnetization will go down, because more you lower the temperature more and more magnetic dipoles will start aligning opposite to each other. And that will cause a lowering of the magnetization or a lowering of the magnetic susceptibility. So, this plot more or less explains the 3 different types of a important a magnetic ordering 1 is paramagnetic. Of course, it is a disordered system and the 2 ordering which is ferromagnetism and antiferromagnetism.

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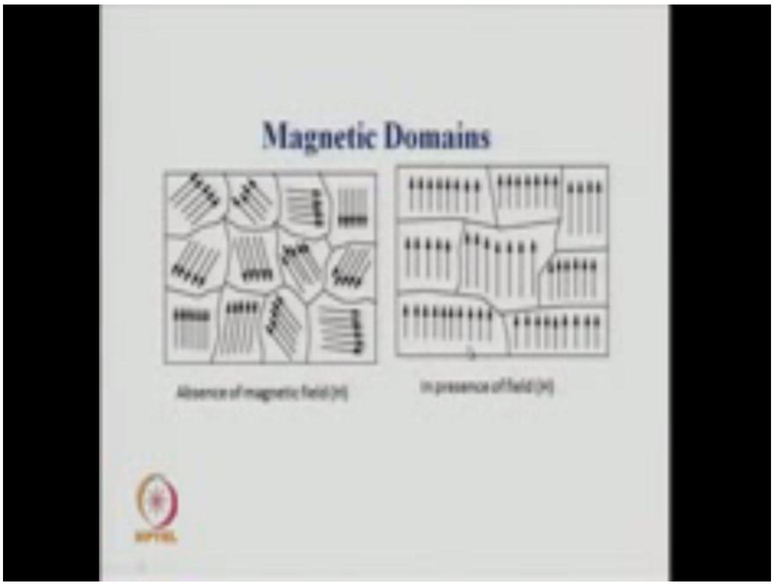

Now, in all these ferromagnets there are magnetic domains, that means if you have particles. They will have small regions within these particles where magnetic the magnetic moments will be aligned within the particle. So, within 1 particle there can be several domains so suppose this is 1 particle. But there are so many different domains in small domains the magnetic vectors are aligned. Because it is a ferromagnetic it should be aligned but they are not aligned in the neighbouring domains. Now, this normally happens in the absence of magnetic field for a ferromagnet in a ferromagnet. Ideally all the vector should be aligned only when you apply a magnetic field which is called magnetic polling. That you first time when you apply a magnetic field to a material which is ferromagnetic. These domains which are having net magnetic moment in different directions will now all get aligned, because of the presence of the magnetic field in this direction.

So, magnetic field is in the direction and all the magnetic moments in different domains get aligned in the different in the direction of the magnetic field. And that is why you see the change in the magnetic moment as a function of magnetic field in even in a ferromagnetic. So, in a ferromagnetic although the definition of ferromagnet is even in the absence of a magnetic field you should see magnetization and sometimes you do not see that because the moments in these in these domains cancel each other. So, although they are aligned among themselves within a domain, but different domains cancel the net magnetization. And in that case the value of the magnetic moment that you will expect for the ferromagnet you will not get that you will get a much lower magnetic moment.

And that the then if you apply the magnetic field then suddenly your magnetization will increase. And you will get that value which you expect for all the magnetic moments aligned in the same direction. And even if you remove the field then also you should get a magnetic moment not like in this case. So, once you apply a magnetic field and you pole the magnate that means all the domains have the dipole the magnetic moment in the same direction. Then even if you remove the magnetic field you will still have this alignment of the various domains unless the domains move and that is called the domain wall movement. So, what you see here are these lines we call them as domain walls, because this is 1 domain and this is another domain. And if you have to go from here to here then these domain walls have to move

So, the entire domain has to move to align in this direction. So, this domain wall movement is done when you apply the magnetic field and once you apply the magnetic field. Then this has a stability and a lower energy and it remains like that unless you apply some other force or give some energy to move these domains. So, magnetic domains are present in ferromagnets. The local magnetic field in each domain is ferromagnetic the local interaction between the magnetic dipoles is ferromagnetic. And that means they are aligned with each other, but that domains neighbouring domains are not aligned with each other. But in the presence of the magnetic field they get aligned and this needs to be done only once. And if you remove the magnetic field you should get back you should retain the magnetization due to this ordered magnetic domains.

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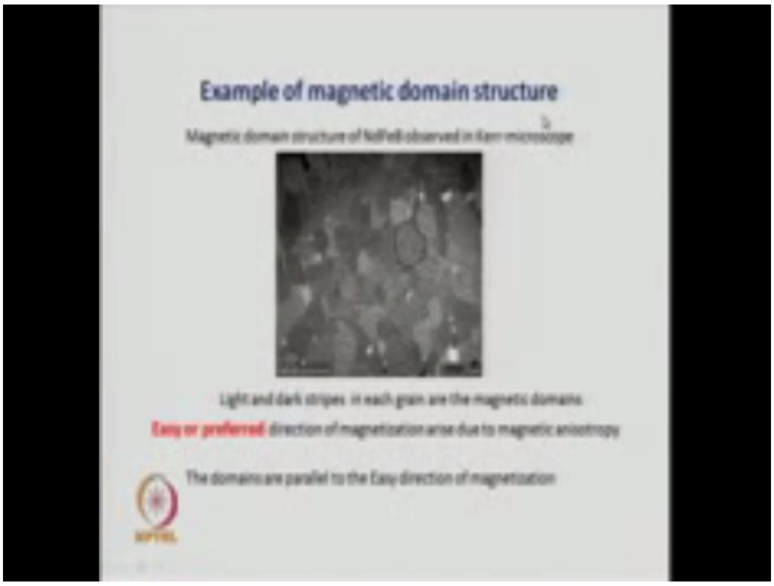

Now, this a example of magnetic domain which is a schematic this we have drawn by ourselves. This is not an experimentally determined structure the way we have drawn these arrows. But experimentally you can see those domains by doing a what we call Kerr microscopy where you apply a field. And the in the presence of a magnetic field the a there is a light which is shunned on the material and the light is rotated the plane of polarization. And the intensity also changes and from those changes of the light being reflected from the magnetic material. You can find out the different domains, because different domains will have different magnetization. And they will rotate the incoming beam which will be reflected differently and so the from that you can identify the different domains.

So, this is a magnetic domain structure of a magnate it is a neodymium iron boride. And it is an important magnet used in several applications where you can see these domains. As if they are different and these light and in these domains these large grains you can see small stripes kind of things and those stripes are actually the domains. So, these are like grains and in these grains you can see these dark and light stripes. And that is because of the difference in the magnetization and the difference in the magnetization is reflected in the rotation of the plane of polarized light by these magnetic surface. And this is called the a Kerr effect in the presence of a magnetic field.

Now, there are different directions subdivisions why these dipoles align along particular directions. That is due to the magnetic anisotropy it is the energy required for the magnetic dipoles to align along certain directions in a crystal in a magnetic solid is different for different directions. So, there are directions which require less energy. So, that will be there easy detection or preferred direction of magnetization. There will be directions in which if the magnetic dipole has to align it has to spend lot of energy then those are difficult regions. So, there are easy directions of magnetization and there are difficult directions where more energy has to be given for the dipole magnetic dipoles to align and hence this is called magnetic anisotropy.

So, the magnetic anisotropy basically tells you about that there are directions in which magnetization can be easily align. And there are directions in which magnetization will not be aligned the magnetic vectors will not be aligned easily. And these domains actually tell you that these domains are parallel to the easy direction of magnetization. So, this Kerr microscopy is very important in understanding magnetic domain structure. And it makes our picture of magnetic domains important and it tells us that what we are drawing here is what is happening in the real solid. And this is a very good technique to understand magnetic domains magnetic domain wall movement. How does a domain wall move if you apply certain energy and these kinds of things are very important.

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So, in a solid for example, suppose you take as a solid here it is like a cuboid. And suppose there is an axis along this axis there it is easy to align the magnetic vector. And this will be the axis of a preferred direction of magnetization. Now, there will be a large magnetostatic energy if you want to a reorient these disciples, because this dipole this magnetic dipole would like to align in this direction. Now sometimes there is random alignment of these dipoles. And the, although they are there are preferred crystallographic axis where the magnetic moment should be present, but there can be random alignment of domains. And the reason the domain structures actually form is to minimize the field of the magnetic material or to minimize the magnetostatic energy.

So, if you have a large magnetic moment you will have a large magnetostatic energy to rotate this if you want but if you break it into domains. So, instead of 1 a entire domain if you break it into 2 domains all 4 domains. Then you see that this magnetic field lines can be easily formed by this circulation of the magnetic field vectors as shown here. So, the domains are basically formed to lower the magneto static energy. If you do not form these kind of domains then you will have a lot of energy. But the magnetic lines of force to be a present that is if you want to turn the magnetic moment in a different direction In this case you see it is easier, because you have 1 magnetic dipole here and you have 1 magnetic dipole here.

However you still do not have any dipole on this site so this is a much better situation where you have got these 4 domains where the magnetic vectors are aligned to form a closed loop. So, this tells us that the formation of domains is necessitated to lower the magnetostatic energy in these magnets. So, the orientation of magnetization each of the domain will be determined by the magnetostatic energy as we mentioned. But it will also be determined by many other factors they are the crystalline anisotropy. That means in some solid the 1 of the directions you may have some energy, because there are certain that comes along this direction. And there are different atoms in this directions that kind of forces between these atoms in the crystal structure may be different from the kinds of forces in this direction.

And this difference in the energy in the crystal lattice will be different along different axis and that is called the crystal anisotropy. That means there are the crystal is not reform its not isotropic in all directions and this will again make it different for the orientation of the magnetization. So, how the a magnetic moments will be oriented will be determined, how easy it will be to get to the minimum crystal anisotropy satisfied. That means according to the crystal structure according to the anisotropy the crystal what makes it minimum energy to align the magnetic moments to lower this a change in the crystal anisotropy is important. So, the magnetostatic energy the crystal anisotropy and domain wall energy. The domain wall energy is suppose you is the energy required for this a domain 1 and domain 2 to move.

So, there will be a difference to move this domain wall which is created by the interface of that to domains which have differently oriented magnetic vectors. So, these here there are 4 domains, because you have 4 different orientation of the net magnetic vectors inside these domains and among each of them there is a interface and that is called the domain wall. So, the domain walls will have some energy a what is this energy between these 2 domains or these 2 domains may be different. And so the domain wall energy is again 1 point of importance. So, the magnetostatic energy the crystal anisotropy the domain wall energy all these 3 things will be of importance ultimately.

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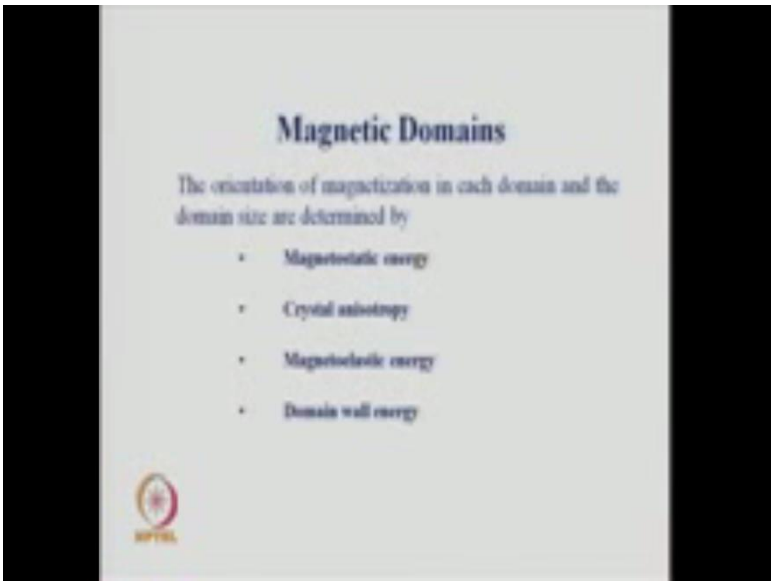

For the magnetic domains to form, so what kind a magnetic domains ultimately result depends on these 3 different factors. And that can be studied as discussed by the Kerr microscopy where you can identify the type of magnetic domains that you have. And it will be different for different materials for example; N D F E B shows this kind of magnetic domains. Some other material will show some other kind of magnetic domain which will have, because it will may it will have a different crystal anisotropy and it may have a different magnetostatic energy. So, that will enable a or because of these factors you may have different types of domain walls and domain wall.

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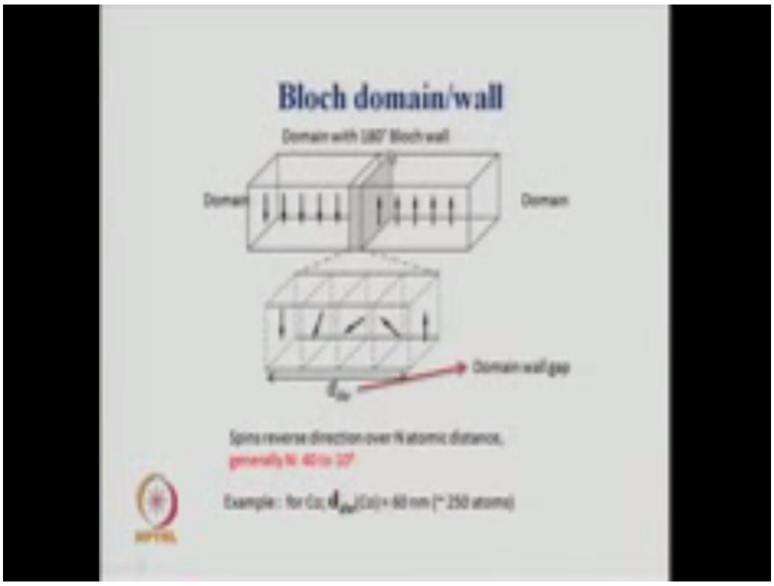

Now, here is an example of a 180 degrees domain wall or we also call the block wall. These are different types of domain walls are there this example we are showing here is called a 180 degree block wall, because on one side of that block wall you have got magnetic vectors along a certain direction. So, in this domain which is domain 1 you have the magnetic vectors along this direction. In the second domain you have the magnetic vectors 180 degrees to this a magnetic vector. So, domain 1 and domain 2 have a magnetic vector which are different by 180 degrees. Hence this wall which separates domain 1 and domain 2 is called a 180 degree block wall or 180 degree domain wall. Now, you can have a orientation of different type of vectors in these domain walls.

So, within this domain wall you will have these a change in the direction of the magnetic vector in this fashion, because on one end of the domain wall you have the magnetic vector in this pointing downwards. On the other side of the domain wall the magnetic vector is pointing upwards. So, in between the domain wall which may have certain thickness. And typically in this case is the example of cobalt metal the domain walls are a 60 nanometre thick. That means this is of 60 nanometre thickness which is approximately equal to 250 atoms. And so within this 60 nanometres or within this 250 atoms the magnetization changes gradually its direction such that it rotates the 180 degrees within this 60 nanometres.

So, you will you will find the vectors undergoing a change in a gradual fashion rotating from this direction to the upside direction throughout through this 60 metre 60 nanometre thickness. So, this d d w is the thickness or the domain wall or the domain wall gap if you may say. And generally this a n this distance can be something like 40 angstroms to 40000 angstrom. So, a so 10000 angstrom so in general for metals like cobalt this d d w a is around 60 nanometers and which is approximately 250 atoms. So, over a 250 atoms the magnetic vector is changing gradually and finally, attains the direction which is present in the second wall a second domain. Now, so this is 1 example of a 180 degree block wall domain but there can be different types of domain walls where these 2 may be aligned at 60 degrees or 90 degrees. So, there can be different types of domain walls or block walls in different systems.

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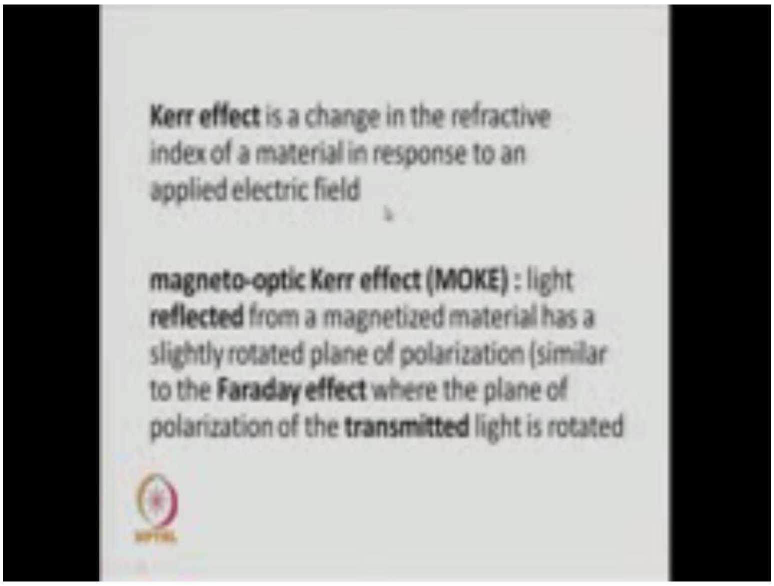

Now, the Kerr effect which i just mentioned earlier that you can by Kerr effect you can find out by using the magnetic Kerr effect the domain walls and domain wall motion etcetera. Let us look at what is this Kerr effect? Now, in general Kerr effect is a change in the refractive index of a material when you apply a electric field. This is the simple Kerr effect it is a electro optic effect there is no magnetic effect in that your applying a n electric field and you are looking at the change in the refractive index. So, it is a electro optic effect which is the standard Kerr effect whereas, a magneto optic Kerr effect which is in short form called M O K E or MOKE. In that light reflects from a can be of 2 types actually the magneto optic Kerr effect either you look at the light reflected from magnetized material which is also like called the faraday effect where the plane of polarized light of the transmitted light is rotated.

So, in the magneto optical Kerr effect you look at the light which comes back from the material that is scattered or reflected from the material. And this light is has a different plane of polarization the incoming light which falls on the material has some plane of polarization. And the light reflected by the magnetic material has a different plane of polarization and the intensity can also be different. So, that is the magneto optic Kerr effect or MOKE effect whereas, that faraday effect is when you look at the plane of polarization of transmitted light that is rotated. So, the magneto optical effects is similar to the Faraday effect, but it is different, because we are looking at the reflected light from the magnetized materials. Not the transmitted light when you look at the transmitted light that is called the Faraday Effect when you look at the reflected light in the presence of a magnetic field. Then you look looking at the magneto optical Kerr effect which is the MOKE effect.

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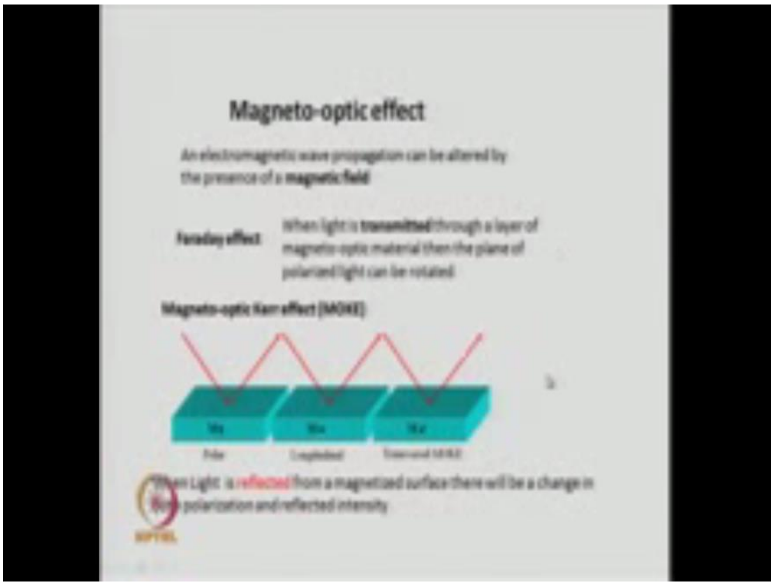

So, you can understand that effect here better in this diagram. So, you have this in the magneto optic Kerr effect you have this incident beam this is magnetized surface and this incident beam then reflects this light. Now, if you look study this reflected light then you will see that the reflected light may have a different intensity and its plane of polarization will be different that the incident beam. So, if you compare with the incident being this reflected beam it may have a different plane of polarization and a different intensity. And that is how you map the domains or domain walls within the a magnetized material. So, this is basically the magneto optic Kerr effects the Faraday effect you will take the beam which process through so that transmitted beam.

And you look at the transmitted beam whether it has undergone any change in the plane of polarization on whether there is any change in the intensity of the light which is being transmitted. That is passing through the material in this case the light is not passing through the material It is being reflected back and you are looking at the reflected light. And looking at its intensity and also looking at its plane of polarization. Once you have information of the plane of polarization of the reflected light from different parts of the magnetic surface. Then you can draw a map and that map is what tells you shows you the magnetic domains. And that is exactly the plot you get as shown you earlier in this picture. And similarly, you can get the magneto optic Kerr effect from any other magnetic domains.

So, this is a very important technique for all kinds of magnetic materials to study especially when they are ferromagnetic or ferrimagnetic that means they have magnetic domains or they have they are antiferromagnetic. So, you must have domains with some order and these domain should not be very easy to a move. That means at room temperature the domain wall should not be moving then you would not get that domain structure unless you cool down the temperature. So, your k t here should not be higher than the domain wall energy that means the movement of the domains should not be possible at the room temperature. So, in that case then you will have to cool the sample and then look whether there is these ordered array of magnetic vectors within these domains. So, magneto optic Kerr effects is very important to look at these kind of materials so this is a picture of a.

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The domain structure using magneto optic Kerr effects, so here it is much more clearer than the other picture as you seen. So, you can see different types of domain structure, so these are some domains here you can see across the interface. And these are some type of domains here these are some different types of domains. So, you can get these kind of patterns using the magneto optical Kerr effect where you can see exactly where the domain magnetic domains are organized. So, today, we have so far looked at all the basics of a magnetization. And what kind of ordering can happen and how these ordering happens even in the absence of magnetic field? Because of the domains being present in this magnetic materials.

And how one can experimentally observe these magnetic domains using magneto optic Kerr effect? And these different type of magnetization, how they will be changing when you reduce the particle to the nanodimension? That will be our interest in the next 2 lectures. How this effects you will one can see in nanostructured materials and what changes will occur to a ferromagnetic material, if you decrease its particle size to the nano dimension? What will happen to the decrease of an antiferromagnetic particle when its size becomes in the nano dimension? So, these are things which we will look into the next 2 lectures in this module 4.

So, thank you very much.