Nanomaterials and their Properties
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Lecture - 24
Magnetic Properties of Nanomaterials

Of magnetic and electrical properties and this is lecture number 20.

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In the last lecture, we completed our discussion on the Electrical Properties of Materials

Recap:

So, as we know in the last lecture we have discussed about electrical properties of material. In fact, we told lot of interesting things about electrical properties of material, some of these we will recap, but as these concepts, you know are new and these are may not be taught to you, what I mean to say is that you all of you may not be exposed to these concepts.

So, therefore, it is important for you to know this concepts well from the textbooks and you know textbooks means what, textbooks means; obviously, textbooks are magnetism textbooks some electrical properties. But what you will find that those textbooks are pretty big and it is not possible for you to learn in the semester all of these.

So, best is to follow things which I am teaching and then if you do not understand go back to the textbook and study only those aspects which are required by the way. So, Electrical

Conductivity is very important because electrical properties are used extensively in material science by the nanomaterials.

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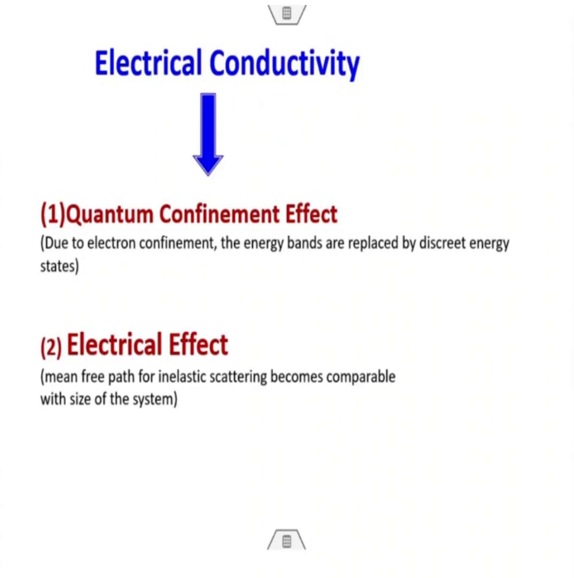

There are two important aspects of electrical conductivity. One is the quantum confinement effects I taught you and this is mainly because of the electronic energy confinement, electronic state confinement and that means, the energy bands will be replaced by the discrete energy states in the nanoscale. That is something which is important in all properties almost like electrical, magnetic, thermal, optical and also acoustic properties of nanomaterials.

Second important thing is the electrical effect which is nothing but the mean free path of the inelastically scatter electrons become comparable size of the system. That means what? If the size of the grains are comparable with the mean free path of the elastic scattering, sorry inelastic scattering electrons or holes then they will not get scatter too much and then you have a increase of conductivity as a result of that.

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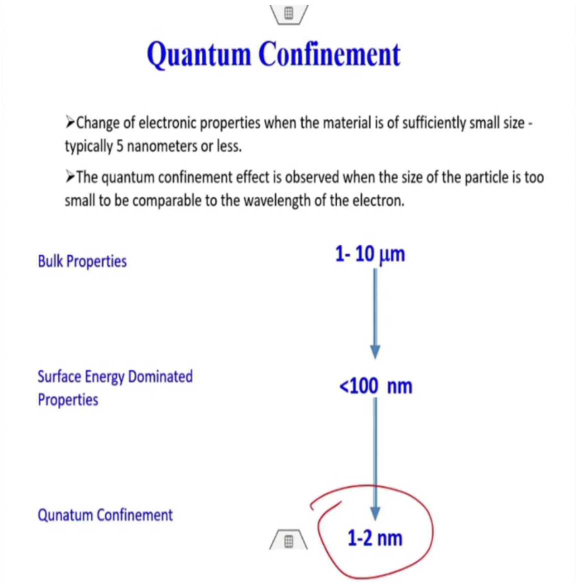

First of all the first one is more important than the second one. First of all, quantum confinement effects are nothing but change of electronic properties when the material is sufficiently small size. Typically 5 nanometer or less and this effect is observed when the size of the nanoparticle is too small to be comparable with the electrons wavelengths of the electrons.

You know I will say you know some of you will have a questions because wavelengths of electrons will be in picometer level right, but that depends on the energy of the system right, energy of the accelerating energy of the electrons, but nonetheless size of nanoparticles which are very less of the order of 1 2 or maybe 5 nanometers that is what happens. So, quantum confinement effects is only observed when particle size is very small. They are of the order of 1 to 2 nanometers ok.

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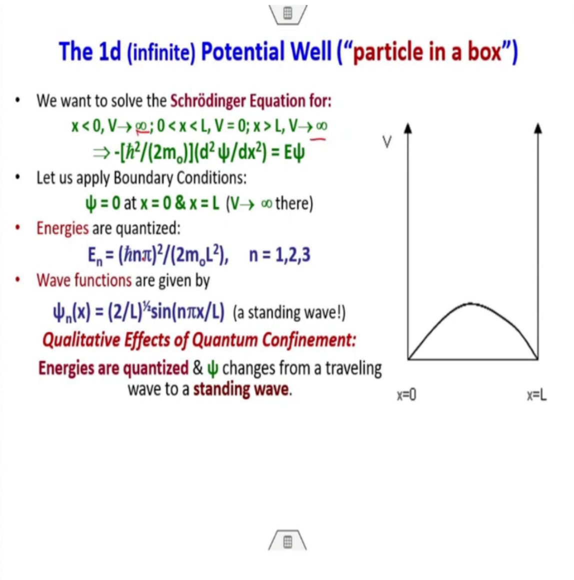

Some materials it may be little bit higher but it is 1 to 2 nanometers normally that is what you see the quantum confinement effects. In order to understand it, I described it the first the problem of particle in a box. It is a one dimensional calculation of energy and the wave function and using the Schrodinger equation and you know that we can consider the electron or a particle basically sitting in a potential well.

Bounded by the two boundaries which has a very high value of voltage, almost like indefinite and that is what is shown as by this normal infinite, you can see and in between it can stay. If you do a complete calculation, you will find energy is proportional to N square; that means the quantum numbers square.

Similarly, wave function will also be a function of n, $\frac{sin n\pi x}{L}$. So, therefore, energy is a quantized electron can only take up those energy levels which are allowed by this calculation and it cannot take any other energy levels that is why it called the quantum confinement. Electron energy levels are confined to certain values.

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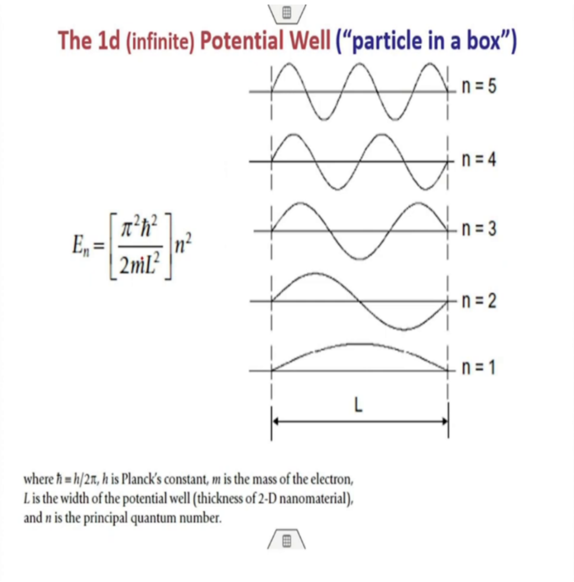

Well, that is this case in a potential well, if a potential well of length l depending the values of n you can have different you know allowable energy levels, like n equal to 1 2 3 4 5 right that is what is important.

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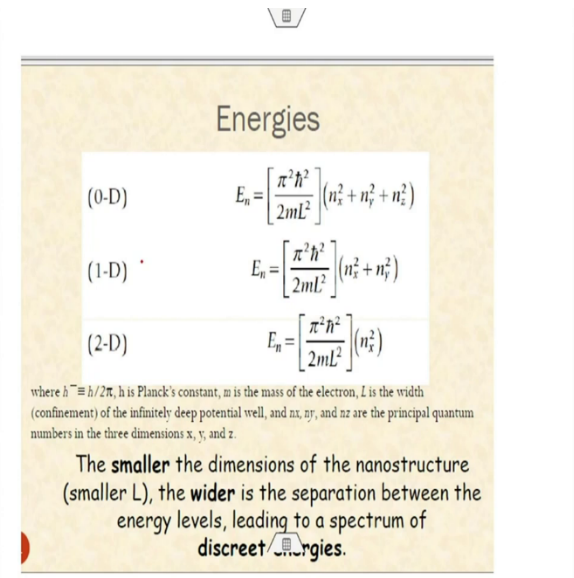

And this can be extended to further 2 D, 3 D ok depending on the size of system. Depending on the type of system as I said its basically 3 dimensional nano particle have a 3 dimensional electronic confinement, 2 dimensional nano particles have a 2 D electronic confinements, sorry 1 electronic confinement and 1 dimensional nanoparticles will have 2 D electronic confinement ok.

So, anyway so, that is the basically aspects you have to understand. So, in one of the dimensions of the nanostructure l that is the potential well dimensions wider will be the separation between the energy levels and that is why it will leads to spectrum of discrete energies.

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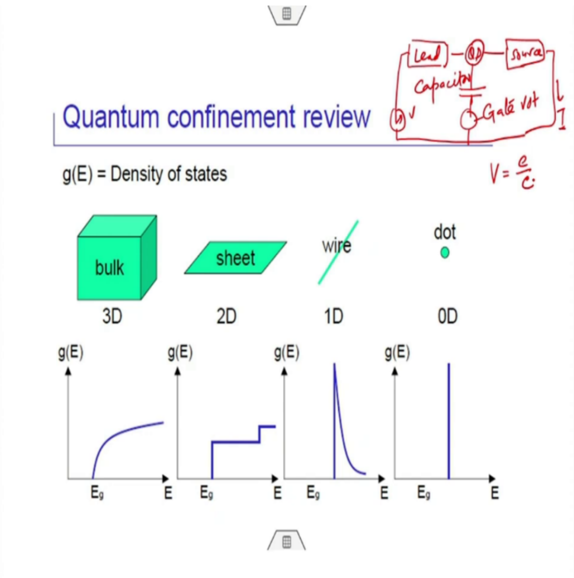

How does it look like? That is what it looks like. If you plot density of states g(E) here versus energy for a 3 D or a bulk nanomaterials, well all the dimensions are more than N nanometers then its looks like this it is a continuous energy band spectrum basically the moment it become a sheet like 2D ok.

Then you can have a discrete and in 1D and 0 D, its basically becomes very very discrete like in 0 D you can have only spikes or basically they are like a delta functions. Well that is dictates ok, let me go by that dictates the you know things happening in the 1D, 0 D, 1D a 2D nanomaterials, the electronic conductions that is the primary thing. Now, you know whenever talking about such a kind of thing, so, what is important is to consider is the what kind of contacts will it will make.

You know for the 3D nano materials or maybe 2D the contacts will be you know ohmic contacts right, but for the 0D and 1D the contacts will be you know basically the conduction from the contact to the material will be given by electron tunneling and that is we have discussed in the last lecture.

Tunneling in the sense of electron can pass through ah basically this is they think of a part what is the meaning of tunneling you know, electron plus magnetic potential energy barrier, a height higher than the kinetic energy of electrons, that is what is used in the electron microscopes.

And many other phenomena in the tunneling electron tunneling microscope or scanning, tunneling microscope also utilize that you can tunnel the electrons from a tip to a surface or to outside by this way. So, I have given you examples of how this can be done. I am not going to discuss about it, what I am going to discuss is the phenomena of electron tunneling. It can also be use this to develop what is known as the Field Effect Transistor ok or FET and they are made from quantum dots as you know right.

So, in this case two electrodes, a source and a drain something like this let me draw it here on the top and show you ok. So, you suppose you have a lead here, and then you have a QD, quantum dots there, another there is a source here. So, you connect it like this way and finally, you put a capacitor here with some gate voltage right.

So, as you see, this is the voltmeter and this is the current I, passing through it ok. So, as you see here in this case whatever we have two electrodes, a source and a drain ok and they coupled by quantum dot, alright that is what is shown in this picture. You can clearly see source and a drain coupled by quantum dot and they are connected to a circuit.

Now, in addition, a gate voltage is provided to the quantum dots correct to control it is resistance and the ultimately a current I, which is passing through this circuit due to the discreteness of electrical charge electrons tunnel from the source to the quantum dots and then to the drain. Because of this gate voltage applied to the quantum dots, electron will tunnel from the source to the quantum dots to the lead what is known as a drain right. So, that is what will happen. Electron tunnel will take place between the lead and the drain.

So, discreetness of electron discharge the electron tunnel from the source to the quantum dots and that the drain, one at a time. So, therefore, the junction which acts as a capacitor, junction which is act as a capacitor here, that is what it is, it is in the capacitor, you can see that there is a capacitor which is acting as a capacitor.

Suppose a raise in voltage which is given by $V = \frac{e}{c}$ when I say (Refer Time: 10:31) electron is added, am I correct? And as a result electrons switch tunnel until a discrete voltage is reached. This effect is known as a Coulombic Blockade. Am I clear? So, in this way you can actually create a FET, a Field Effect Transistors by using quantum dots.

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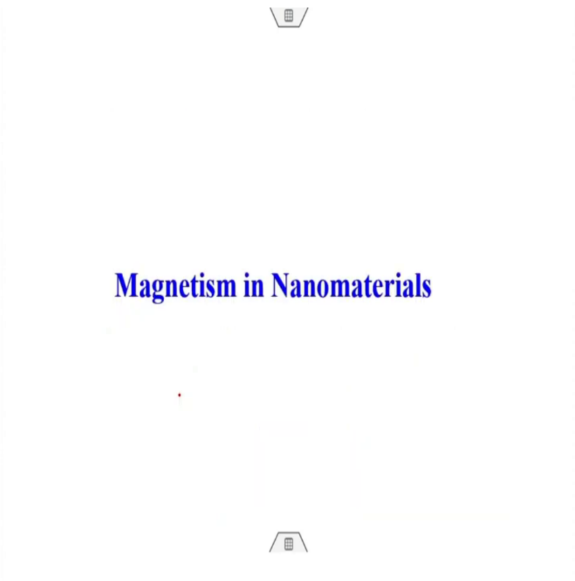

Well, let us go to the next subject, the topics what I am going to teach. That is the magnetism nanomaterials. Well magnetism is very widely known in the literature and we use lot of magnets in daily life in your cars, in your you know machines like computers, hard disks are magnets or your mobile phones or even many household things ok.

So, therefore, like refrigerator, TV, washing machines we are using that. So, how nano will help us to boost the magnetic properties of material, that is what is the purpose of discussions.

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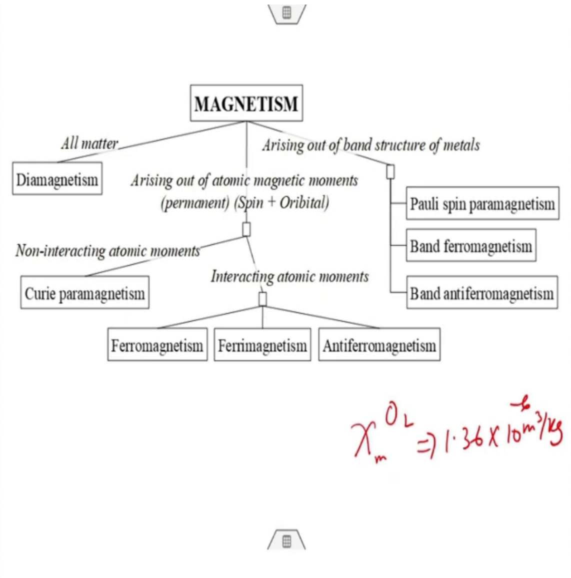

But what I understand is that you know all of you are not from the similar backgrounds therefore, whatever I am going to teach you the effect of size of nanomaterials may not fully percolate to you, all of you.

So, therefore I decided I should give this small you know introduction to the subject and then come back on the discussion of nanomaterials and magnetism. Magnetisms observe in different forms actually, right but you can have diamagnetic material paramagnetic material or ferro or ferri or antiferromagnetic material. So, I have clubbed ferro, ferri and anti-ferromagnetism in one class. Diamagnetism in one class and then paramagnetism is another class.

All the matter in this world are basically diamagnet. What is the meaning of that? Ok. That means, all the material in the world is basically diamagnetic, by the way magnetism is universal you know. It is present in everywhere. It is present in galactic galaxies or cluster of galaxies very small value 1 2 3 micro gauss.

Earth magnetic field is also very important. It has strength of 1 gauss and it reverses. In fact, everyone 10^5 years actually, 2×10^5 years and then you find we have already discussed magnetotactic bacteria where magnetic particles are present in the bacteria to guide them to move from high height to lower height or from one place to other place in the water.

And then you have magnetic nanoparticles you just find in rocks and then can be always used to determine the earth magnetic field both in the directions and do you know that many birds actually have cluster of nanoparticles about 2 to 4 nanometers in their beak area which help them to you know move or you know homing ability, that is to come back to their home right like pigeons they have that kind of things.

So, now magnetism is very important in all class of life correct. So, as I told magnetic materials are different types ok ferro sorry dia, para and ferromagnetism. So, therefore, they need to be first discussed ok. Diamagnetism is what this is the property all material has and you know in response to any applied magnetic field hence you do not require any atoms or have a net with the net magnetic moments.

This is basically very weak negative magnetic effect. Then you will see magneto susceptibility is very small here about 10^{-5} and hence it is always amongst by the presence of stronger effects like ferromagnetism correct. So, simplify so, of understanding this diamagnetic effect is simply based on Lenz's law.

And you know Lenz's law states that change in the magnetic field will induce a current in a loop of electrical conductor which will tend to oppose the applied magnetic field as the electron velocity is a function of energy for the electronic states, diamagnetic susceptibility is essentially independent of temperature and it tends to exclude the lines of force of material. By the way do you know that in a super conductor excludes all the magnetic lines of forces.

So, therefore, this is the perfect and diamagnet that we know. There are many gases like hydrogen, nitrogen and ionic bonding material like sodium chloride, magnesium oxide or even cobalt material like zinc, germanium, silicon, diamond, carbon. They all have diamagnetism right and many organic material also show diamagnetic behavior that is very clear and Lenz's law is tells you know right handed law left handed law you know that it tells you what is the effect of applied magnetic field on diamagnetic materials.

So, I am not going to discuss about that. Paramagnetism which is the next star in the class of material is so stronger than diamagnetic behavior there are two types of distinct paramagnetism observes. What are they; one is arising when the atom molecule has a net magnetic moment other one which comes with band structure like you know Pauli spin, spin or weak spin paramagnetism.

So, if a net magnetic moment do not cancel each other with any molecule or an atom, then you have a paramagnetism present right like oxygen. Oxygen has a net paramagnetism moment of 2.85 Bohr magneton per molecule. So, point we noted here that even if there are many electrons in atom most of the moments are cancel out and then you have a very few Bohr magnetons available. And in the absence of electric and magnetic field is magnetic moments will point up point basically randomly and therefore, magnetization is almost 0.

And when the field is applied then you can have either aligning force of magnetic field or you have disordering tendency of because of temperature these two will also happen and therefore, mostly paramagnetic material will not so, sufficient strength to be detected.

So, you understand that. If there is a net magnetic moment within the molecule or an atom then you have we do not cancel each other then only you can have ferromagnetism a paramagnetic present and a combined effect of these if leads to partial elements of the magnetic moments and the susceptibility paramagnetic material is very small value.

I do not know whether you know it or not for oxygen this susceptibility is at room temperature for oxygen, it is basically $1.36\times10^{-6}\ m^{3}/kg$. This is our susceptibility value very small. But you know this paramagnetic susceptibility is used in our brain for proving the oxygen atoms ok by certainly known as the PET scan by which you know which part of brain is working, which part is not working and it will be used it can be used to detect if there is a defect in the brain for a person which needs to be corrected or not.

So, that is about the paramagnetism. So, from dia to para, it is very clear that there is this increase in the strength of the magnetism, because of the you know net magnetic moment present in the molecule, but it is very small very very small. There is no point in discussing about that. Well, I will not come go back to discussion of the effect of temperature of things temperature will; obviously, has a strong effect on paramagnetic materials because the magnetic alignments can be disordered by the thermal energy field ok.

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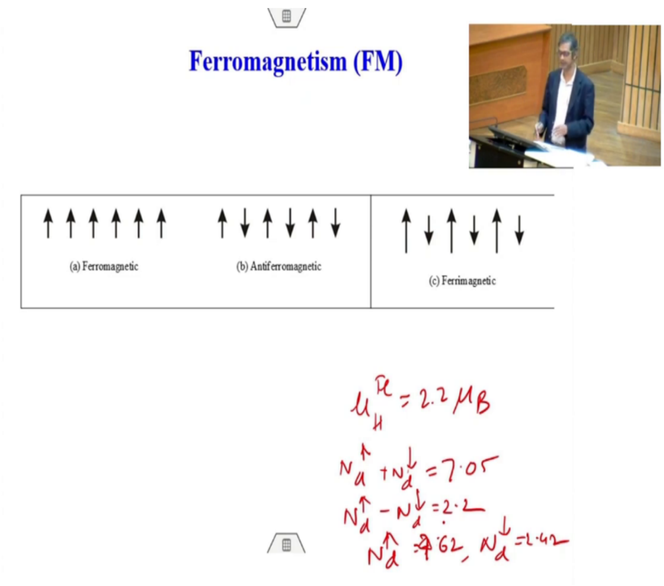

So, then come Ferromagnetism ah the ferromagnetism has different types actually right, like you have a ferromagnetic, antiferromagnetic, ferrimagnetism. Ferromagnetism is what ferromagnetism means you have a spins which are you know isolated or rather not coupled uncoupled spin and they apply magnetic field they align in this direction of field then you can get a magnetic moment, net magnetic moment.

Anti-ferromagnetism is what you have spins which are you know up and down. When you apply a magnetic field they align in such a way that up one is cancelled by the down one and then you have no net magnetic moment that is why it is called antiferromagnetic and ferrimagnetism is again similar to anti ferromagnetism except the strength of the up and down springs are not same.

So, therefore, there is a net magnetic moment, but nonetheless both these two anti ferromagnetism, ferromagnetism or ferrimagnetism strength will be much lower than the ferromagnetism right. The two important ways you understand ferromagnetism in metals is that assembly moments are localized to atoms ok.

Electronics moments are localized to atoms and then you can use band structure giving rise to interaction itinerant electrons and you know first one is conceptually more easier or you can assume molecular field theory and also Heisenberg approach. It should be noted here that the even in metals most of the electrons behave as if they are localized and number of itinerant electrons could be small, although we assume electrons in a metals are delocalized.

Now, if Fe has 8 valence electrons which occupy 3d plus 4 s states 5 3d and 3 you know 2 4s and then 6 3d states out of 8 electrons only 0.95 in the 4 s bands are truly free or itinerant remaining 7.05 are occupied or localized, that is correct. Only the outer shell electrons are delocalized they can move anywhere in a metal like iron, but then your d shell electrons are not outer shell electrons.

So, they are kind of part of the iron atom. Similarly in a nickel as 7 3d plus 4 s is equal to 10. So, it has 0.6 has a 4 s electrons and 9.4 is the 3d electrons. You must be confused that why these fractional numbers are coming this occupancy is because of the strength of the nucleus by which the atoms electrons are bound.

So, therefore, these are the you know moments of the electrons which are important. Now, what about the bands theory? You know I have already discussed about band aspects you know metals has to be will have bands because of the localized electrons are not localized to each atom right.

Electrons in a metal are usually in a gas like free electron gas. So, electrons are non localized to a particular atom. They can move hope around from one place to other place and the band theory is because of that most of the electrons are rather localized and you know a free electron do not contribute to ferromagnetic behavior ok.

That is something which you have to understand very clearly, free electrons are like that. Then band theories you apply able to explain when many non-integral values of that when if iron. The 3d electrons are not fully localized as we discussed, about a 5 to 8 percent have some itinerant characters and those electrons are mediate. They exchange coupling between the localized moments.

So, therefore, we can see that the observed magnetic moment per atom in a iron is about what this is the observed magnetic moment per atom in a iron is 2.2 Bohr magneton right. So, therefore, we can write normally this is what is true N_d is up, N_d up, N_d down is equal to 7.05

and N_d up minus N_d down is 2.2. So, therefore, we can write down N_d up is 4.62 and N_d down is basically 2.42.

These are the number of electrons in a d orbital which are down spin and up spins ok. So, nonetheless; that means, 4 electron, 4.62 electrons are basically 4 and half electrons spins are up and 2.5 time 5 electrons are downspin. And therefore, these two the net magnetic moment of that and spin of that will provide the net magnetic moment ok. So, that is something which you should understand very well ok.

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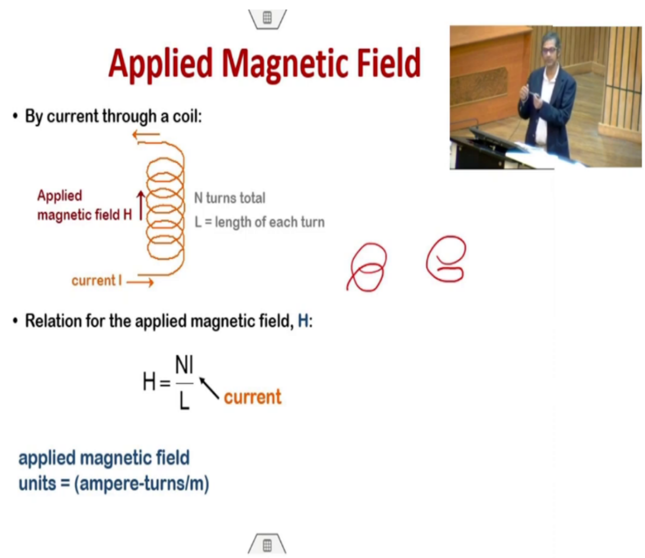

Now, what is the effect of applied magnetic field right. This is the electronic sub structure and all these steps. As you know if I have pass to a pass a current to a coil, we can generate a magnetic field ok. It depends on a number of turns and the length of each turn right. So, the relationship between applied magnetic field and the current is given by this its NI/L, why NI, N is the number of turns, I is the current and L is the length of each turn ok.

Each turn means you can see there are many turns right. So, this is one turn correct. It goes and comes back just like this right. This is one turn. So, you know that then you can calculate what is the applied magnetic field because of this current flow. So, any in fact, faraday according to faradays experimental law, any current carrying coil will have a associated magnetic field with it, that is depends on this a number of coils it presents N, length of each turn as well as the current passing through.

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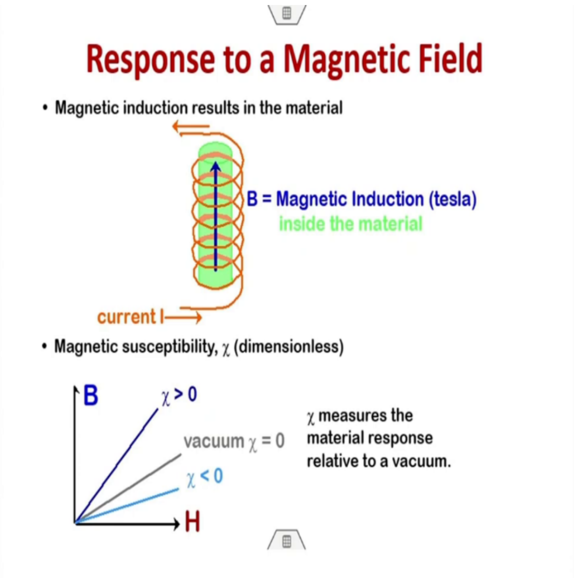

Now, what is the response to a magnetic field magnetic induction result in a magnetism right. So, if you apply if you put a material inside this coil, the field which is generated because of the current flow will induce magnetic field in the material. This we know very well right. You know induction basically is of that whether you using a induction oven or you using a induction heater or you using induction melting unit this is what happens.

If you have a current passing through a coil, heavy current of the frequency is also very large megahertz or kilohertz then you can induce magnetic field in the material, which you are in putting inside the square. So, this induced magnetic field will depends on the susceptibility right, depending on susceptibility you can have you know.

There are different kinds of susceptibility normally vacuum has a susceptibility of 0. And so, therefore, you can plot B versus H, B is the induced field or magnetic induced and H is the applied field and as you see the vacuum is 0 and it increases with at 45 degree angle.

But if this susceptibility is less greater than 0 then increases very steep. Susceptibility less than 0 it increases very slowly. So, measure these susceptibilities measures the material response to the relative to the vacuum ok. Why do you assume vacuum has a susceptibility 0?

Because that is the standard state. So, otherwise you cannot compare. This is this very important thing we should understand.

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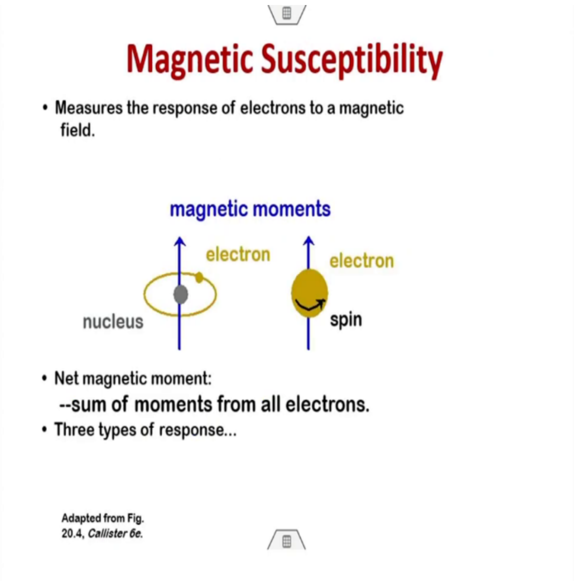

So, now what then how do we understand magnetic susceptibility. It is nothing but a measure the of response of a electron to magnetic field right. So, as you know electrons are moving around nucleus. So, if you apply a magnetic field, electrons will like to align around the in the magnetic field because electrons are rotating right in a circuit. And electron rotating means there is a current associated with it. So, therefore, this is rotating in a loop around the nucleus.

Because of that there isn't net magnetic moment created that is simple like this aspect only coil we can imagine same thing as like a coil in place of a electron moving around a nucleus. So, if you have a magnetic field what will happen? There will be effect on the electronic spin or electronic magnetic properties right.

So, therefore, when such thing happens, electrons may align along the magnetic applied magnetic field or electron may spin down or spin up depending on the magnetic field. So, therefore, there is a net magnetic moment and these are nothing but summation of all the moments of electrons. Based on these things you can have three types of responses possible right.

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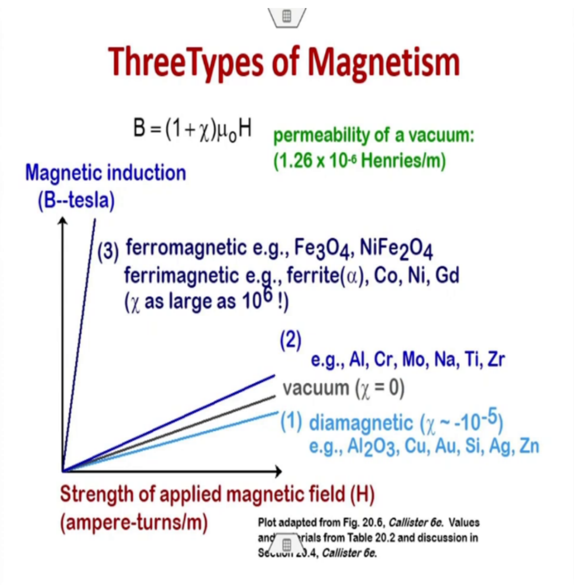

That is what we said the three types of magnetism. You can have a high response that is ferromagnetic material like Fe_2O_3 ok, hematite, magnetite basically not hematite, magnetite or nickel ferrite, Fe, Ni, Fe_2O_3 F_4 ok. They are ferromagnetic. You can have ferrites like alpha iron, cobalt, nickel or gadolinium where this chi value is very high ok.

So, that is what we always write B= $(1 + \chi)\mu_0 H$, μ_0 is the permeability in the vacuum and χ is basically known as the susceptibility. So, you know for this ferromagnetic material chi is very high. It can go 10^6. Then you have a second type of materials like aluminum, chromium, moly, sodium, titanium, zirconium a very low susceptibility almost close to vacuum, right.

So, they so, you know small effect of applied magnetic field, it will not change much. By the way these things are taken from Callister's book on you know material science and you can refer to that. This is available on the internet also free of cost. So, and then you have a third thing is that categorical material is diamagnetic we have already discussed right aluminium oxide, copper, gold, silicon, silver, zinc. They have negative value of them that is χ almost like very small negative value of 10^{-5} or so.

So that means, depending on the applied magnetic field you can differentiate three different types of behavior ferromagnetic, diamagnetic, paramagnetic right. You can see that. So, that is something which is very easy to do using this equation called B= $(1 + \chi)\mu_0 H$, H is the applied magnetic field. Applied magnetic field has lot of effects like that is what we wanted to bring this discussion in front of you.

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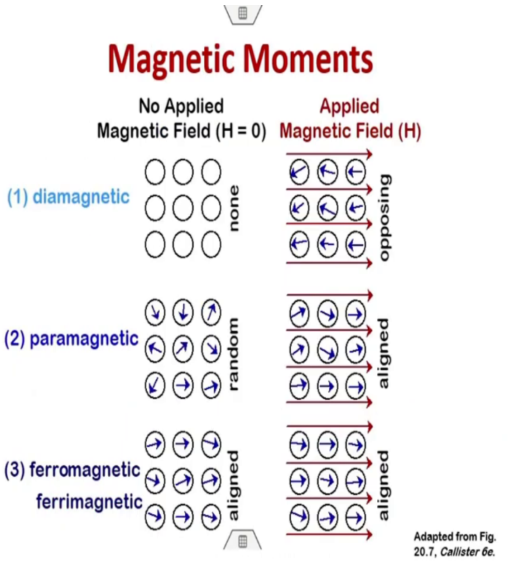

Now, what actually happens atomistically. Your diamagnetic material you have no magnetic field nothing happens. There is no magnetic moment basically present in the atoms or molecules. The moment you applied, magnetic field, magnetic moments will built in very weak magnetic moments will built in, but then they will oppose the applied magnetic field.

That is what happens, superconductor is basically perfect diamagnetic material. It perfectly opposes their paramagnetic field. Lines of forces will be repelled perfectly by the super magnetic super you know so, therefore, superconducting magnetics. So, therefore, diamagnets are like that, they will oppose the applied magnetic lines of forces.

In of against in compare to diamagnetism paramagnetism is little bit different. So, paramagnets will have a weak magnetic moments right as we have discussed. They are very weak magnetism like oxygen, with a very weak magnetic moments and they are randomly aligned. So, you do not apply any magnetic field they are not aligned to any particular directions.

The moment you apply magnetic field, some of these things will try to align to the magnetic field that is what happens in PET scan in brain ok when doctors want to do a PET scan in your brain, you have to know how which part of the brain is basically acting. It is very simple I am talking to the now so; that means, the part of the brain is responsible for talking will be we need lot of energy and energy comes from the oxygen right.

The blood from the heart basically they supplied to the brain. As you know the huge amount of blood is applied to the brain because brain is doing lot of calculations and lot of thinking every time. So, when you are talking then some part of the brain is basically functioning more than the other part and that part requires lot of energy. Energy is provided by oxygen. And so, therefore, if you prove that oxygen then we can understand which part is responsible that you know doctors are very smart ok much smarter than us.

So, they then apply a huge magnetic field to align the oxygen atoms and they can then ebase them. That is what happens, if you apply magnetic field, these weak magnetic moments of the oxygen atoms will allow them to align right, but they will not be perfectly aligned to the magnetic field. They will align at an angle or so.

So, there will be not perfectly alignments, but this will lead to some kind of a increase of the alignments as compared to random in case of absence of an magnetic field. So, then we apply in the case of ferromagnetic ferrimagnetic materials, even in absence of magnetic field there will be alignments of these spins, but then only perfectly aligned.

So, the moment you apply magnetic field they will perfectly aligned and because of that even net magnetic moment which is very high that is what happens in iron, nickel cobalt or in nickel ferrite or in magnetite ok that is what is observed. So, this is what happens in a atomic scale picture. So, you have understood the effect of field then you have understood now the atomic scale structure of diamagnetic, paramagnetic, ferromagnetic materials ok. I hope you getting some idea of that.

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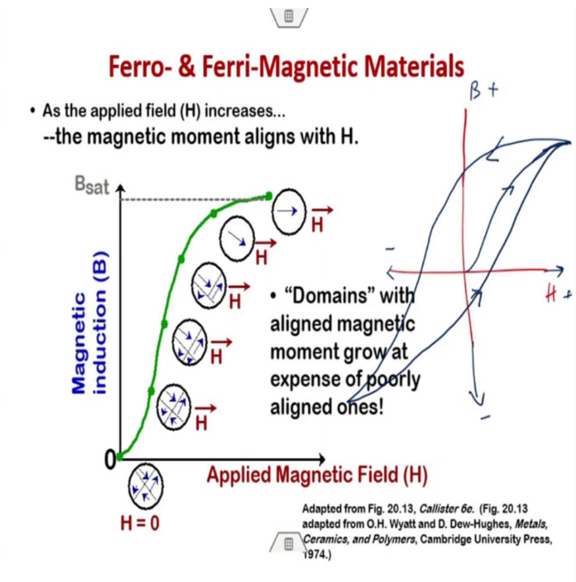

So, let us now focus on ferro and ferrimagnetic materials more. So, it is very clear if you apply magnetic, field there is a huge huge change in the interaction between the spins in the present in the ferromagnetic material and the applied magnetic field and this will lead to magnetization ok. Or this magnetization is measured in terms of magnetic induction ok.

This is something what I discussed about that if you flow current through a coil its produce a magnetic field and then if you put a material inside this coil, this magnetic field will try to induce a magnetic moment ok. That is what is known as the magnetic induction.

So, if I plot magnetic induction versus magnetic field you know that you have already you have seen this kind of plots. This will lead to alignments of the domains ok. Now we are talking from atoms to domains ok. Domains may have many many atoms. So, because of the magnetic field this application of magnetic field applied magnetic field these domains will try to align to the magnetic field and then this domain alignment may grow slowly as we increase the magnetic field.

So, what I mean to say is that when you have zero magnetic field, so, all though in each case spin is aligned, but they are in a not in a net scale they are not aligned to the properly so, that it can give net magnetic moment. You can see these arrows are different directions.

So, they may cancel out completely or they will reduce the magnetic moment right. So, now, you start applying magnetic field you see they will be trying to align properly. So, as you can clearly see that some of these two fields of align more easily more strongly than these two, one the bottom ones. And then slowly if you increase it the strength of the alignment of these two things increases.

And finally, I can see the bottom two has joined together the domains and at a very high magnetic field all the domains actually are aligned to the magnetic field directions and finally, get saturated. That is what happens when you plot B versus x now you can actually you all of you know this is the H this is B. So, this is exactly happens right. So, I think I should try it better way. So, that you understand this picture this is you have studied in your school level books ok.

So, let me just try it in a better way in a different color, right. So, it get saturated, then you reverse the magnetic field, reverse the magnetic field what will happen. This will go like this you know that this is what is the B-H loop looks like. So, we have gone like that then gone like this then come back. So, H was positive in this direction, negative in this direction, B is positive in the top, negative in this ok.

This is something can be correlated with the domain formation domain walls, domain formation alignment of the domains. So, I will go into very big details of these, just to tell you that the concept of single molecule to a domain is very important. So, in a permanent magnet what are the things happens, ok.

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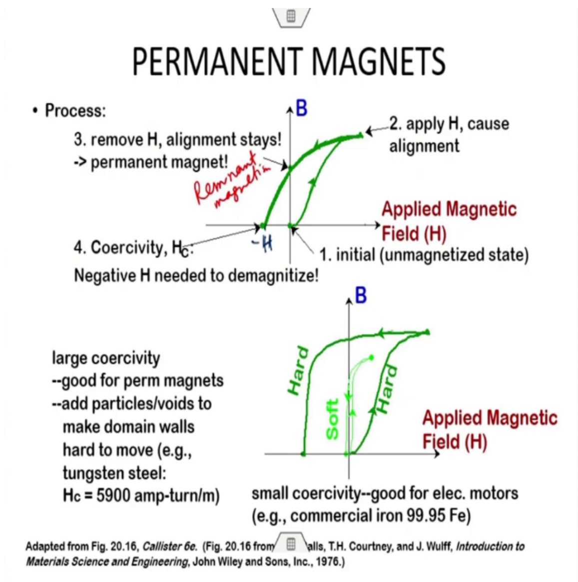

So, if you this is what this is the initial magnetization state and then it causes alignments completely then you removed the H, alignments you started reversing right, you started reducing that you can see you have gone up to this magnetic field this value and slowly you are reducing, ok.

So, as you reduce when you make it 0 the net magnetic moment or induced magnetic moment does not go to 0. It has certain value and that is ok that remains there that is not the feature of magnetic permanent magnetic materials right. And you know still if you keep on going down or decrease the magnetic field further, you will see that at a value close to exactly you know negative value.

There will be some negative H is needed to demagnetize the material. The material will not go to completely demagnetize state unless and until you apply negative value of H ok. This is negative value of H minus H, you are applying then only you can make the B zero correct. So, this is what is known as a coercivity, right.

So, a coercivity is what it is the negative edge needed to be magnetized demagnetize the material correct and what is this? This is known as a remnant magnetism. This value, this is known as a remnant, n a n t sorry remnant magnetic (Refer Time: 38:09) ok moment or basically field.

So, these are the two very important aspect. What is the first one? First one is that if you first you increase the magnetic field, magnetization happened the saturation value saturated value we checked then you decrease it and when you bring it to 0, when H becomes 0 because you are decreasing it, H becomes 0 still you have some remanent magnetic field magnetic induced magnetism remain in the material and that is what is known as the remnant or remnants actually.

But then you keep on decreasing the magnetic field go negative, negative, negative unless and until you reach a negative H value minus H for which the B becomes 0 that is what is known as the coercivity. So, large coercivity is good for permanent magnets; that means, you need to apply that much of negative magnetic field or magnetic applied magnetic field to demagnetize the material. And it now that it add particles or voids to make the domain of walls hard to move ok. You can do that there are many ways to do that, am I clear?

So, based on this curve, we have two types of permanent magnets one is soft and another is hard ok. Soft magnetic (Refer Time: 39:23) will have very small B-H loop, this is B and H right very small the loop ok and hard magnetic material will very big B-H loop right applied magnetic field. As you see for a hard the area under the curve is very very large because that is what is the energy net magnetic energy in the material and for small soft magnetic moments it is area under the curves will be very small.

Think of a switch ok, magnetic switch, every time you switch it on and off if the energy loss is very large. The energy which is getting lost will comes as a function as a form of heat energy. So, that will be heating up the materials and that is what in a transformer core, the magnetic material which is used basically soft magnets, which is a very small surface area or if you want to uses a switch in computers actually zero on and off zero and one you need the soft magnetic material am I clear.

So, there the area under the curve will be very small. On the other hand if you want to use permanent magnet right ok there are many application where we need a permanent magnet like in a motor ok you need to use the permanent magnet. So, there or in a hard disk actually it is a permanent magnet, there you need to know have a very high like surface area or bigger

B-H loop, that is the very important aspects you should very you know understand very clearly.

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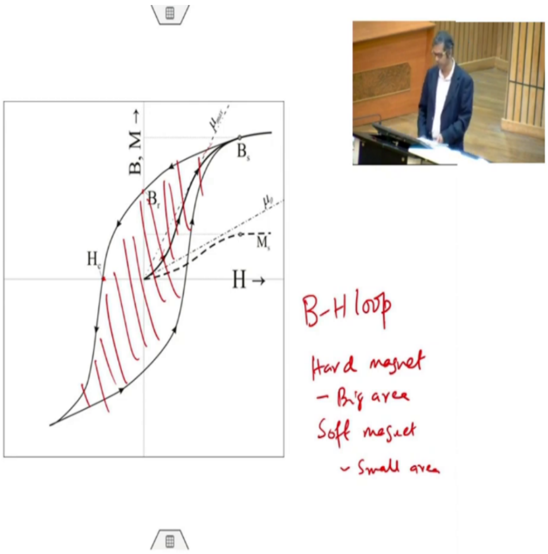

But this is the complete picture of B-H curve ok forget about these things what I am showing here. So, as you can clearly see it increases increases, increases reaches saturation value then you decrease this B-R correspond to remnant magnetism. And then you go to negative valve of H for which the B goes to 0 that is known as the coercivity right, this is the coercivity.

This is the remnant magnetism. Then you can go to the both negative for both the H and B-H as the H becomes more and more negative this is exactly opposite of this curve, this curve is opposite of that ok. So, then you can come back again and then follow this, but this is what is known as the BH loop. So, for a hard magnet, this loop area should be as big as possible, big area I mean to say this whole thing is area under the curve right and for the soft magnet, small as small as possible am I clear. So, this is something which you should not forget correct.

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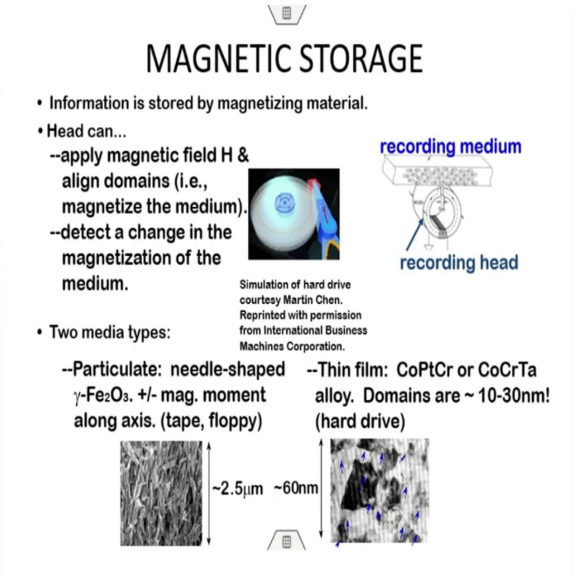

So, now, before I you know close this lecture because as I told I will not discuss about effect of size on the magnetic material in this lecture. I will come back with a new lecture on that but let me just tell you magnetic storage is very important right. You see you know that earlier days maybe your father or grandfather used to use tapes to listen music ok on a tape recorder.

So, in this tape recorder tape, will have magnetic particles present and then you can actually record something using that tape, nothing but alignment of these magnetic moments. So, if you apply you know if you rotate this tape you know with a magnetic magnets between two magnets you can get the sound back right that is what happens. So, head information stored in a magnetic material is pretty that is known something known for long time.

So, information is stored by the magnetizing the materials. So, head can actually apply magnetic field H and align the domains; that means, basically magnetized at magnum medium and detect the change in magnetization of the medium. That is what this heads are done you know. This is the head actually right. That is why it is reading the things. So, now, by in a recording media like this ok.

You have a recording head that is what is called head and in it is basically applying a magnetic field and aligning the aligning these domains and depending on the so, you when you speak you can convert this you know text whatever speaking in terms of magnetic field alternative magnetic field you know that I do not do not need not tell you this is totally done even your speaker is whatever I am speaking it is also same thing with a small magnet which is converting this what I am speaking into a you know some kind of a magnet is driving that conversion.

So, the same thing way something can be done ok. You can have a recording head which can you know align these magnetic particles in the media depending on the how you are speaking and then if you again take this recorded media to a player and apply magnetic field, you can listen the music that is what happens.

So, there are two types of media one is called you know particulate needle separate Fe 2 O 3 plus magnetic moment plus or minus magnetic moment along the axis ok like a floppy disk or a tape right. And thin films like you know hard drive or even CD drives they have this kind of things cobalt platinum chromium or cobalt chrome tantalum alloy. Again you know these concepts comes into back into picture and.

So, therefore, the thickness of these crystals have vary from particulate to a thin film and particulate thickness is micron size they are very big. In thin film they are nanometric size ok why it is so, we will discuss later. So, there is obviously, reason for it why thin films will have smaller you know they will be all grains nano size grains in the thin film deposit on the substrate and then you can actually do this kind of aspects. So, as you can see that magnetic materials are widely used in various applications.

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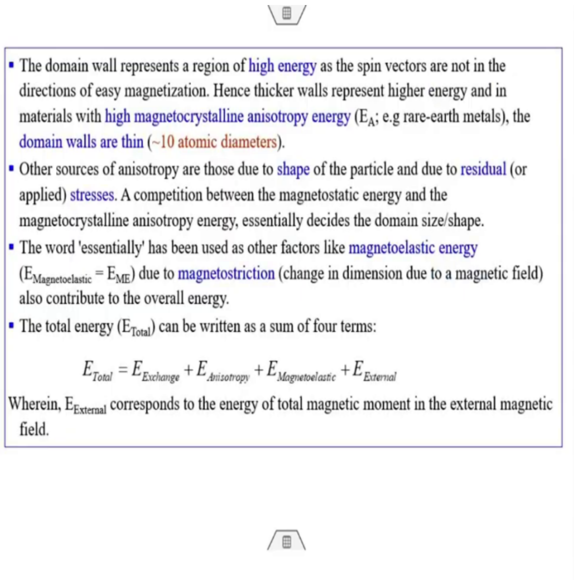

So, now, with these basic informations, I will not talk much today with this basic information's what I mean to believe is that the basic magnetism is something which you need to understand very well ok. Most important magnetic material is ferromagnetic material or ferimagnetic material. They are used a lot in the real life.

So, those aspects you need to read a bit and you know the chapter 5 of the Dieter Vollaths book talks about some of these basic concepts and some of the basic concepts are known very well. And then they talks also about the effect of nanoscience which is the basic purpose of our discussions in the in this in the course. So, with these brief descriptions I stop here and then come back in the next class about the effect of size and these nanoparticles on the magnetic properties.

Thank you.