Magnetic Properties

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Lecture No. # 36
Magnetic Properties

Hello, welcome to this the thirty sixth class in our physics of materials lecture series. In this class, we are going to focus on magnetism as we have already is put together lot of theoretical background for the lot of the material properties, and we have a ferry sophisticated model lot of features for the models that we have and we are in a position to use those models has we fine necessary to explain material properties. So, we will look at magnetism today.

We will pull together all the ideas and concepts the related to magnetism and in the end we will see; however, current theory that we have developed helps as understand magnetism or at least some specific forms of magnetism. So, this is what we will do in this class.

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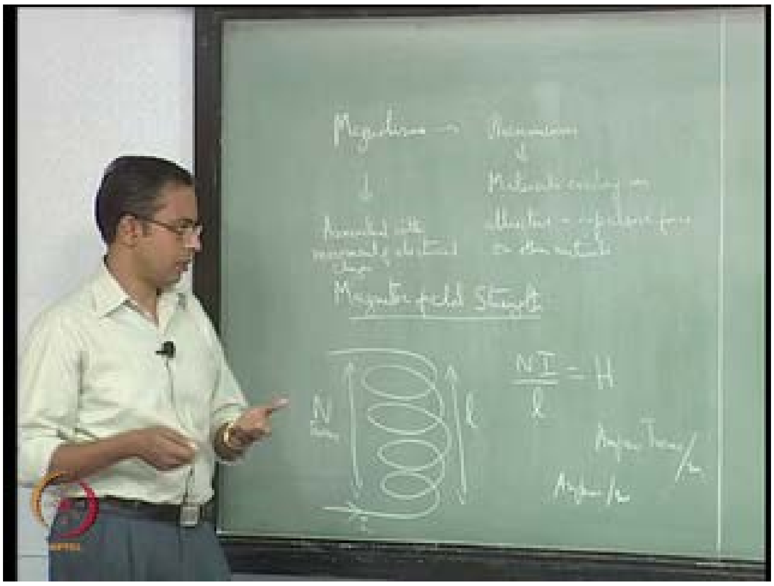

So, if you look at it magnetism is basically an it is an it is a experimentally observed phenomenon right. So, we can experimentally observe this it is a phenomenon was we see materials exerting an attractive or repulsive force on other materials, so this is over and above what you may see from an electrostatic perspective. So, let's assume that they are at least the that sample that we have is electrically neutral and still we find that, the two samples are able to exert some kind of an attractive or repulsive force an each other and in general that phenomenon that we see; which we just quite commonly encountered is a it is called magnetism. It has of course, a lot of industrial and technological uses there are many things that we use which have magnets in them I mean of course, your audio speakers have magnets in them most ah motors have magnets in them and, so on.

So, we see magnets in various places sometimes we are not aware that they are there and of course, sophisticated instruments like NMR and so on also use magnets. So, there are lot of places were magnets are used sometimes we are aware of them, sometimes we are not, but they are definitely they and in principle these are this basic idea is what is true in all those cases. So, in this relationship, in this relation, in this context we will define specific parameters with which we quantify this magnetism the phenomenon of magnetism and then proceed on that bases. So, the first thing that we would like to quantify is something called magnetic field strength and this is this represents the extern this strength of the externally applied magnetic field, so often we are studying what happens to a material as it interacts with a magnetic field to study that we have to actually externally generates this magnetic field impose it on that material or make the material encounter this magnetic field and then study.

What is happening to that material as it encounters this magnetic field? So, we have to generates this magnetic field from somewhere and when we do that the field that we generate is quantified by this things called magnetic field strength incidentally as I mentioned here, this is a phenomenon that we observe experimentally and the way we understand it is that it is associated with moment of electric charge electrical charges. So, anytime there is an electrical electric charge that is moving, so a charge that is moving associated with that moving charge is this magnetic field. So, it is sort of creates this magnetic field around itself as it moves, so and that is how.

We experience it and as so, as such in a static sense you going to see the electro static field, but when it is moving you also see the magnetic field associated with. So, we have this thing called a magnetic field strength and a simple way in which this is this external field is generated is to take is by taking advantage of this moment of electrical charge. So, we simply have a current carrying conductor which goes through a coil and comes out, so we have I goes through this and let us say there are N turns in this coil and we also say the length here is l. So, across a length along a length l we have N turns of this coil and current I is going through that conductor, when you do this we get a magnetic field strength, which is simply N times I by l this is the quantity which we have calling magnetic field strength it is just see denoted by the letter H.

So, H is the externally applied magnetic field and is also called the magnetic field strength and its unit's r as you can see this is a number of turns, this is in meters and this is in amperes. So, this is amperes ampere turns per meter that is what it is, so it is in ampere turns per meter or simply it is in ampere meter, amperes per meter. So, these are the two units in which we represents, so we simply say amperes per meter so that is what ah this magnetic field strength H s. So, now as I said we would like to study what happens to materials when they encounter H field, so H field is there we bring a material make it encounter this field we see how it behaves and on that basics we say something about the material or we understand something about what is going on in that material. So, to do that we have to bring the material in to this system and see what is happening, so say for example, we can keep a block of material with in this coil and then see what is happening.

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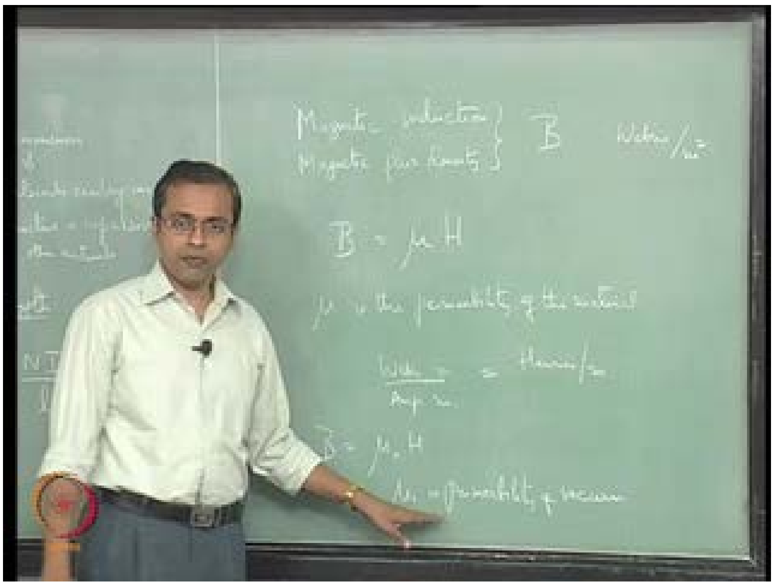

So, when this field interacts with that material it creates a field inside that material and that we call as the magnetic induction we called at as magnetic induction or we also called it as magnetic flux density, these are designated by the letter B capital B. So, magnetic induction or magnetic flux density designated by the letter B and this B is in wafers per meter square and it trill it is related to H, so H is the field that you are imposing based on the current that is going through the coil and B is the field that is getting induced inside the sample as a result of the interaction of that sample with this H field and it is related to the H field by this equation mu H, where mu is the permeability's is called the permeability of the material and it is a constant for a material under certain circumstances. So, you place it under the right same circumstances it will be a constant, so this is the permeability of the material, so this is what we have and you can see the units of mu it is going to be wafers, so this is per ampere meter right. So, this is what you are going to get, wafers per ampere meter this is what you get wafers per ampere meter, so if you substitute that wafers per ampere meter times amperes per meter so wafers per ampere meter this is an amperes per meter you will get wafers per meter square.

So, this is also given as Hendry's per meter. So, the units of that are used in magnetism that way can creates some confusion, but you just have to follow them as they are this is wafers per ampere meter and it is also called Hendry's per meter this is mu, this is the permeability of the material. So, and this is how it relates the magnetic induction what is occurring to the sample as a result of the field that you have impose which is H. Now, supposing if you do not have any sample and you just have vacuum, we can still talk in terms of field that has been induced in that vacuum and in that case we would called B as a B equal to mu naught H, if you did not have a sample and it simply had vacuum in the middle of the coil and this mu naught is then the permeability of vacuum.

Its permeability of vacuum, it is useful for us I mean you may think that you know, that is that is situation that may not particularly useful for us, but. In fact, it is useful for as because it helps as understand how other material is behaving relative to vacuum. So, it sort of sets set some kind of a base line with respect to that you can say what you can sort of gate what the other material is doing and relative to that we can scale the other material, so this is permeability of vacuum, so this is what it is? So, clearly if you have vacuum you going to get mu naught, if you put some material you are going to get mu.

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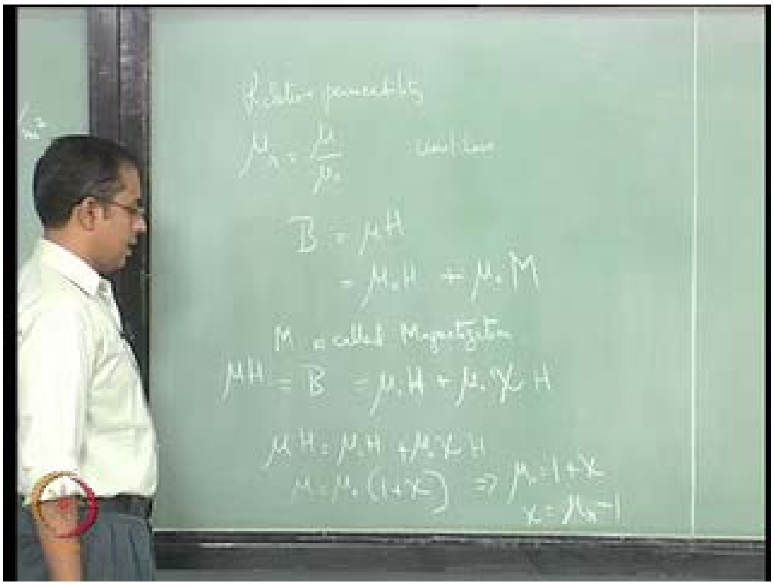

So, we also define something called relative permeability and which is simply the ratio of the two it is mu by mu naught and it is called it is designated as mu r. So, while mu and mu naught both have Hendry’s per meter as their units clearly the ratio is going to be unit less so this is unit less. So, that is what we have now if you look at the material you take the material you place it in the magnetic field. So, it is responding to the magnetic field. So, what normally happens is in some it is there is phenomenon occurring within the material which is either assisting the magnetic field or trying to oppose the magnetic field. So, we can sort of look at the response of the material an in and it is in that sense that we actually compare the material to the response of the vacuum. So, we say the vacuum would respond in a certain way is the material adding to that response or it is subtracting from that response, so that is what.

We can designate it as. So, we called that response the response of just the material as magnetization and it is the manner in which it is adding or subtracting from the system. So, what we basically say is that you know we have originally written B as mu H where we have permeability of that material times the field that we have imposed on that material, we can instead write it as of component given that you already have the field H vacuum in that location would have given you mu naught H right. So, we can separate the component form the vacuum mu naught H times, I meant plus mu naught times some other parameter m. So, we are basically saying that this is the component coming from the vacuum mu naught H, plus this is an additional component over and above this vacuum response which now represents the extent to which the material is assisting or opposing the process. So, this is mu naught m this m is the magnetization m is called magnetization.

This m also we can further relate to we just play will add a one more quantity here and then will write a couple of equation which will simply re-arrange this term, we can write m itself. Now, I have written this as though it were independent of the external field, but actually it is also result of the external field, so in some ways you can related to the external field again you can make this as some constant times the external field in that sense, so we can write the same equation as mu naught plus, mu naught H plus mu naught times chi times H, where this chi H simply telling as that the magnetization that is occurred in the material has not occurred sort of an independent sense, it is occurred as a result of the field that you have applied.

So, we are we are recognizing that by saying that it is something related to H it is chi times H is, so how we are relating it. So, we have now these 2 equations which are both equal to B and of course, that is itself equal to mu mu times H. So, we originally started with B is mu times H we incorporated we said that consist of a component that would anyway have been there, if vacuum had been there and a component that would exist, if which is simply because that material is adding or doing something over and above vacuum and that again.

We are relating to some with mu naught times something and that something is again related to the field that you have a put. So, given that the we have this equation we can just re-arrange a little bit we have H is a common here. So, we are simply saying mu, so mu H equals mu naught H, plus mu naught chi time H this chi here is called susceptibility magnetic susceptibility. So, chi is magnetic susceptibility mu naught is permeability, so that is permeability of vacuum mu is yes permeability mu naught is permeability of vacuum. So, if you have we have this equation so if you remove H we simply have mu is equal to mu naught into one plus chi and therefore, and mu by mu naught is relative permeability that is how we have defined it implies mu r equals one plus chi or chi equals one minus mu r, mu r minus 1. So, these then are the equations that we have, we have a few equations we have put on here, so we have this susceptibility is also unit less so it is its unit less parameter the relative permeability is also unit less parameter these are both unit less parameter.

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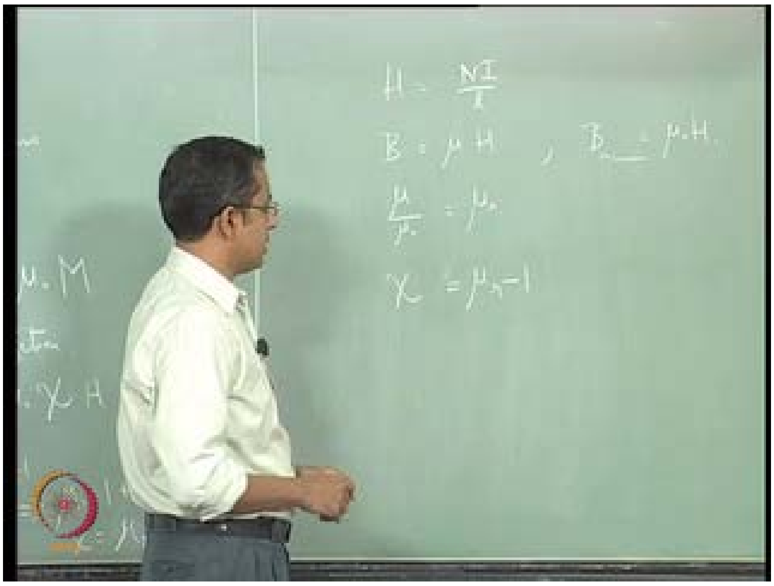

So, we wrote H as N I by l, we wrote B as a mu times H in which the B due to vacuum is mu naught H right and then, we wrote mu by mu naught equals mu r, this is the relative permeability and we also recognize that chi is mu r minus one. So, these are the parameters that relate to magnetism and tell us about various quantities in magnetism they tell us, what are the quantities that we should be watching out for in magnetism, these are the quantities that people have sort of isolated in this magnetism phenomena. So, that if you follow this parameter you can say something about the material, you can compare materials on the basis of the parameter, on the basis of the values of these parameters for those different materials, so this we can do, so these are the equations that we reduce now the magnetism itself

So, we will look at this, so this is what we will use this is the these are the equations that we will pull out as an when we require, now the thing we have to see is we would like to see material and we find that it has a certain response to a magnetic field, we would like to explain why this is having this response? What is occurring in the material that is creating the response? Now, inside the material therefore, we would like to understand what is the charge that is moving, so that we can now say that the magnetic field is related to that charge and therefore, we can now see how that magnetic field response to the field that is being externally applied to it.

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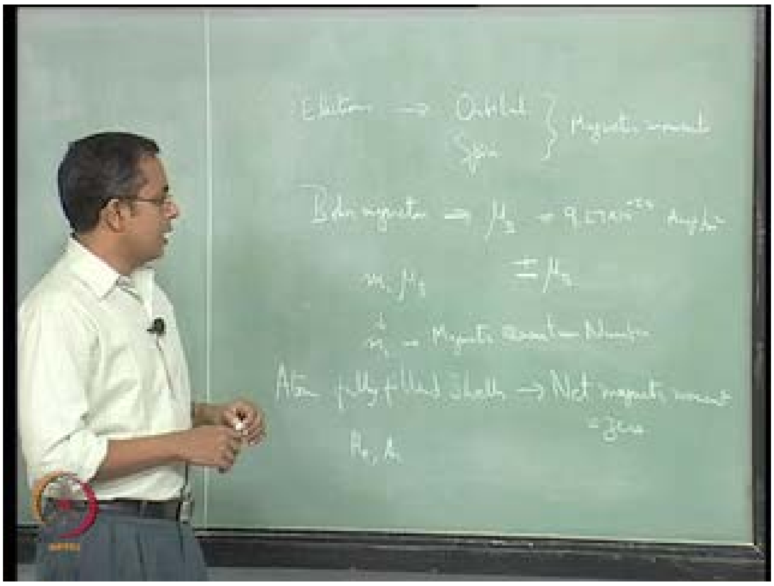

So, inside a material we typically have electrons which are now the charges that are in motion you can have an electron having orbital moment and we can also have it, so it you can sort of thing of it as though it were running around in an orbit all though that is the very simple a way of looking at it and we can also have it.

Spinning around it axis. So, in both cases we have a situation where there is a charge that is moving, so associated with both of them you have magnetic moments. So, we have magnetic moments associated with both of them and basically what we say is that we. In fact, we associate what is called a boar magneton, as the most fundamental magnetic moment it is associated with the spin of the electron it is represented as represented by mu B and it is about 9.27 into 10 power minus 24 amperes per meter square. So, that is what it is and so this is the magnetic moment associated with this spin and the orbital magnetic moment is typically m I times mu B, where m I is the magnetic quantum number of that electron. So, for that for a given electron we can identity its magnetic quantum number and therefore, m I times mu B would then be the magnetic, would be the contribution of the orbital moment of the electron and the magnetic moment coming out of it. So, this is the this is the picture of what is happening within the material which then represents and then you have to add this up to get the magnetic moment of the overall material and simply these are all vectors.

You have because of spin and the moment of the charge these this has a quantity, these are all vectors this both have quantities and direction associated with them there are vectors and the net magnetic response of a material is the vectorial sum of the response from all the magnetic moments present within the material. So, you look you have to actually identify all the sources of magnetic moments within the material and you can add them up vectorially, when you add them up vectorially whatever result you end up getting then represents the net magnetic response of that entire material. So, that is how it is going to be, so this is what is existing within the material and, so when you subject it to H field or H field what you see is the response coming from here. Now, again amongst the materials, what is going to happen is based on the orbital moment of electrons.

In fact, the there are there are going to orbital moments of different electrons which should be an opposition to each other as the result the magnetic moments from those electrons its cancel each other out similarly, if you have electrons with in terms of spin they can have a spin up or as spin down. So, the boar magneton contribution from this spin can be in the form of plus or minus mu B, so if you have pair of electrons with one with having the plus mu B contribution, another with minus mu B contribution they will cancel each other out so. In fact, for atoms which have a fully filled cells fully filled electron cells atoms which have fully filled electron cells the net magnetic moment is zero.

So, this is a true for example, for the noble gas ah noble gases, so helium, argon and so on right. So, for these there is no net magnetic moment because the cells are completely full which means all the contributions from the orbital magnetic moments cancel each other out all the contributions from the spin magnetic moment cancel each other out at the end of it you do a vectorial sum you get zero and therefore, there is no net magnetic moment, but there are a variety of materials where either the orbital magnetic moment will not cancel itself out completely or the spin magnetic moment may not cancel itself out completely or both.

So, this can exist in and it is on that basis that you may have a variety of materials where the individual atoms may have a net magnetic moment, still a sample itself may still be neutral because those magnetic moments maybe randomly oriented you the sample consist of a large collection of atoms. So, for the sample again you have to do a vectorial sum of the magnetic moments of all the atoms present within that sample and if there are randomly oriented and their values are the same their again going to cancel each other out and so at the end of it for your sample you may have a net magnetic moment that is zero. So, you have three cases you can have the atom itself having a net magnetic moment is zero you can have atom having net magnetic moment not equal to zero, but the sample having a magnetic moment equal to zero, because they are cancelling out an average and the third case where an either the atom has an net magnetic moment that is zero not does the sample have a net magnetic moment that is zero. So, there is some finally, there is some magnetic moment still left on the sample.

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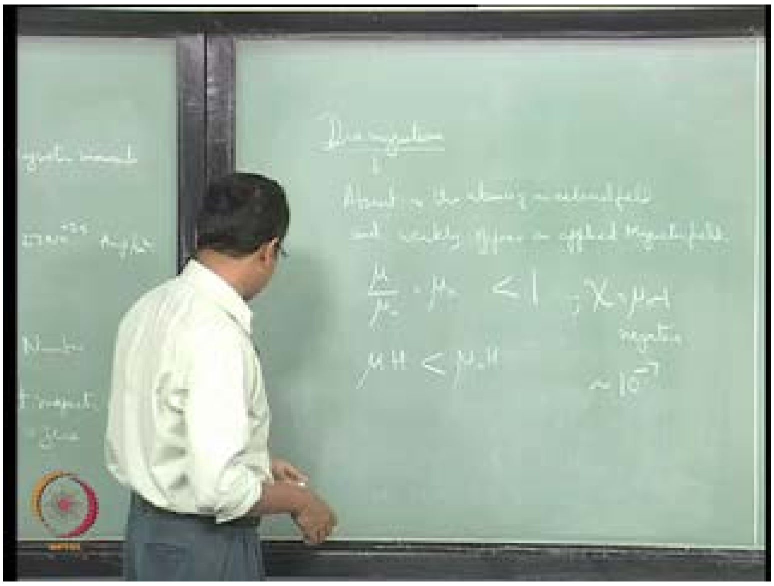

So, we have all this possibilities that exist, so in this context we have a different forms a magnetism which are exhibited by materials one is diamagnetism this is actually in fact, all most all materials show you some level of diamagnetism; the only issue is that it is such a week form of magnetism that in most cases other magnetic phenomena in the material completely swam this contribution. So, you will not see it, so you will not see it in most samples simply because other phenomena or more powerful then this in terms of strength. So, in fact you actually going to see it in cases where you know, you have you have been able to eliminate all other forms of magnetism in it and then therefore, you see the magnetic moment the diamagnetism stand over. So, this is absent in the presents of an external field, the absence of an external field and weekly opposes the field when it opposes and applied field typically the contribution is from the orbital magnetic moment of the electrons they are so if you look a situation where you know all of them are originally cancel they are so the atoms are all neutral.

So, you will have a serious of atoms which are all neutral and then when you apply a magnetic field, it interacts with the orbital magnetic moment of those atoms and they try to oppose this imposed magnetic field. So, they now stand in opposition to this field, but it is a very week interaction, so therefore it tries to oppose the magnetic field and tries to reduce the strength of the magnetic field. So, what we are basically seeing is that relative to vacuum, so if you look at mu by mu naught which is equal to mu r if there were no sample you only see mu naught right. So, that is what vacuum would do now you have put this sample and it is opposing the magnetic field in a very week way.

So, therefore, this mu is going to be less than mu naught, so it is trying to the B that it is creating is less than the B that would exist the induction magnetic induction that would exist in the in when vacuum is present which would be mu naught H, and the magnetic induction which is now present because the sample is present which is mu times H, this mu times H is less than mu naught times H and that and that is how it conveys q that it is opposing that field right. So, that is why you getting a little less field there then there you are getting a little less induction there then you would if you had vacuum. So, mu mu times H is less than mu naught times H in this case, which I mean since H is a constant its simply means mu by mu naught which is this relative permeability is less than one. So, for diamagnetic materials mu by mu naught is less than one mu r is less than one, so similarly if and therefore, chi which is mu r minus one is negative. So, you see that in fact, this gives you an example as we look at other examples you will see mu r therefore, can be less than one equal to one or greater than one and.

Chi can be negative or positive chi can be negative 0 or positive. So, it this is the range that we have available to us, so it is negative, but I also set that this is a very week phenomenon extremely week phenomenon and in a relative sense I mean so the chi value actually works out to of the order of 10 power minus seven, this is unit less it is an a per volume basis, but still we will just its base fundamentally unit less. So, its 10 power minus 7 will just keep that number in mind because that is what we will use for comparison 10 power minus 7 this is for diamagnetic materials. So, originally the atom is neutral that is when this even shows up in any sense as being because that is the only response it has then, so the originally its magnetically, there is no magnetic moment from the for the atom all the other moments have been cancelled out, when you apply the field the orbital moments become apparent, but they oppose the applied field and then.

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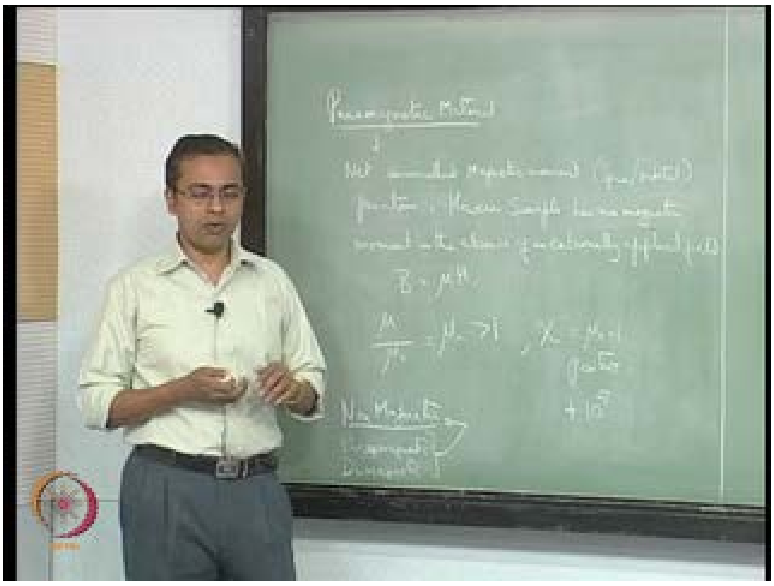

You see the response, so this is what we see for a diamagnetic material. The other material you can consider is a paramagnetic material, this is paramagnetic material or paramagnetic exist in materials where there is in a net uncancelled magnetic moment either of a spin or orbital origin, it does not matter what is the origin spin or orbital net magnetic uncancelled magnetic moment is there and per a atom basis; however, the sample is has no magnetic moment in the absence of an externally applied field of.

So, in the absence of an externally applied field there is no net magnetic moment in this material, but at an atomic level there is a uncompensated or uncancelled magnetic moment either from spin uncancelled spin moment or uncancelled magnetic, I mean orbital moment. So, that is there at an atomic level; however, those atoms are all randomly oriented or the magnetic moment corresponding to those atoms or randomly oriented in that sample. So, as you look at that sample as search there is no magnetic moment in the absence of a field now if you apply a field.

What happens is this uncancelled magnetic moments align with in the direction of the field. So, in some of these materials it is see in that they align in the direction of the field and, so we again we get you know B is mu H and of course, we have mu by mu naught equals mu r in this case, since they are aligning in the direction of the field and the it is adding to the field. So, its strengthening the field in the region where the sample is present because these moments are aligning in the direction of the field therefore, the mu H is going to be greater than mu naught H vacuum would’ve provided you mu naught H when you now that you put that sample the uncompensated or uncancelled magnetic moments present within the sample or aligning in the direction of that magnetic field and adding to that field and therefore, it is the overall magnetic induction in that location is higher than what would’ve been in the case if we had had only vacuum. So, mu is actually greater than mu naught so therefore, mu r is greater than one and chi which is simply mu r minus 1 is positive; however, this is again this phenomenon is still again a very week phenomenon. So, it is a very week phenomenon so in fact, this is chi is a positive value, but it is still of that order it is of the order of 10 power minus 7. So, whereas so it is simply that here it is plus 10 powers minus 7 and in the case of a diamagnetic material it is minus 10 power minus seven. So, of that order we are looking at.

So, it is a negative value for a diamagnetic material of the order of minus 10 power minus 7 and for a paramagnetic material it is plus 10 power minus 7. So, these are small numbers in the relative sense when we look at other systems we will see that there is a difference and a but it is a positive number the other thing the that is common about both paramagnetism and diamagnetism is the fact that both of these are phenomena that are visible only when a field is applied.

So, when there is no field that is applied the material is neutral, so even a paramagnetic material if you stop the field the minute you stop the field they will again go back to a random orientation all the magnetic moments will go back to a random orientation so for the sample you will have no net magnetic moment same thing we diamagnetic materials even though they are opposing the field the moment you stop the field you will actually lose the magnetic moment the orbital moments will disappear and you will any way have nothing in the sample no magnetic response left in the from the sample. So, therefore both paramagnetic materials and diamagnetic materials are in that sense also refer to us non magnetic materials they are both non magnetic materials.

So, this is non magnetic both para as well as diamagnetic, both of them are non magnetic materials so because they do not have any magnetic induction left in them the moment you remove the external applied field. So, that is why, so therefore they are not actually of in terms of technological interest they are not that of great significant from that sense.

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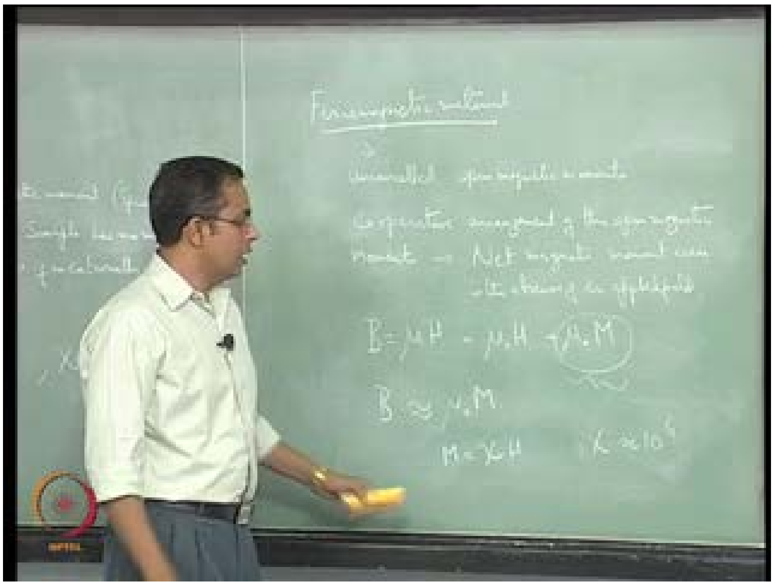

The next type that we are interested in is the ferromagnetic magnetic material this is actually available in a there are couple of other sub classification of it, but we will look at the may main classification of the ferromagnetic material. It is one were you will mostly have uncancelled the magnetic moments of there are each atom has on magnetic moment typically due to uncancelled spin magnetic moments, but the main difference here is that even in the absence of the field; the spin magnetic moments actually interact with each other in the in the neighbor in their neighborhood and several of them begin to align with respect to each other even in the absence of a field.

So, there is and cooperative arrangement of the such that there is a net magnetic field, net magnetic response magnetic moment even in the absence of an applied field. I must qualify this little a bit because you can sort of forces situation where this drops to zero you can force a situation, where this net magnetic moment will drop to zero, but in general it will have a net magnetic moment and if you can always top the magnetic externally applied magnetic field at some point this sample will be left with a the magnetic moments that were that got aligned as a result of the applied field.

So, the co-operative arrangement of this spin magnetic moments occurs at various regions within the sample each region may be randomly oriented, so again we have to do a vectorial sum what we will typically see is that in general for the sample something will remain and that is the ferromagnetic behavior that there talking about. So, in this case when you see when you write B equals mu H I mention that you know you can think of it as a as a contribution due to vacuum mu naught H, plus mu naught m this is the samples contribution to the magnetic behavior that you are seeing in the presence of the magnetic field, applied field what is happening in a typical ferromagnetic material is that this value is very large relative to what vacuum would do, vacuum will give you some response whereas, mu naught m is much, much larger than mu naught h.

So, for a ferromagnetic material this is simply approximately just directly equal to mu naught m and what is m? Its m is itself chi times h. So, simply means that we have a very large value of chi the susceptibility, magnetic susceptibility of ferromagnetic material is a very large positive number and in a relative sense this is of the chi here is of the order of 10 power plus 6. So, for paramagnetic material it was 10 power minus 7 and for a diamagnetic material it was a negative quantity minus 10 power minus 7, so that is what we had for those two, but so they are very small quantities relative to what you are looking at here 10 powers 6, so this is you know thirteen orders of magnitude difference in response right. So, that is what we have here that is how this material differs from paramagnetic or a diamagnetic material.

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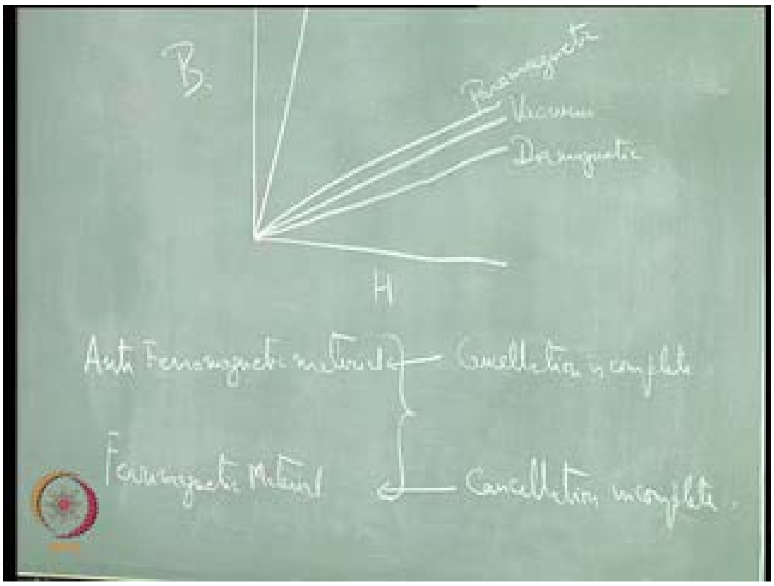

So in fact, if you see if you make a plot of B verses h, so this is the field you are applying, this is the field that is getting induced in the sample if you makes this plot what is see is for vacuum you will see a response here, a diamagnetic material will have a response which is less than that that of vacuum because it is actually opposing the field. So, a diamagnetic material, but it is a very week response will show your response like this, this is a diamagnetic again and when you remove the field this would drop to zero appropriately drop to zero, if suddenly switch of the field here it will this will drop to zero paramagnetic material is slightly better than vacuum because it is assisting the field that is applied, but its again a very week response, so that this is paramagnetic again when you remove the field if you come up to here and H and you switch of the H it will just drop to zero, because there is nothing and it is a that con sense that you know paramagnetic and a diamagnetic material or nonmagnetic. A ferromagnetic material would like this ferromagnetic material would look like this, so this is this means you know for even for a small H you are getting a very large B and that is why it is you know it is much, much larger than the vacuum contribution this is not event really drawn to scale, it is simply drawn as semantic to convey the idea to you in and also in the ferromagnetic material the other important thing is if you bring H up to here and then appropriately switch it off, you appropriately switch it off what you will see is that fair bit of magnetism remains in the material.

So, we do not actually lose the magnetism its sort of remains in the material that is that is the fundamental way in which ferromagnetic material differs from diamagnetic and a paramagnetic material, even amongst the ferromagnetic materials you can have another two variations an it one is called an anti ferromagnetic material and another one which is called a ferrimagnetic material, the common thing between these two is that it so happens that in these two materials the cooperative alignment of spins occurs in an opposing manner between adjacent atoms. So, the moment from one atom opposes the moment from the next atom which is in a out of a phase with the moment from the third atom, again out of phase with the moment from the fourth atom and so on and.

So, therefore, the even though the atoms have net magnetic moment even in the absence of a field they are actually cancelling each other out so they are in opposition, so they cancel each other out if the atoms are of are of the same kind, they are of the same valance and. So, on they will cancel each other out perfectly in this and that would then be called a anti ferromagnetic cancellation is complete. So, if the atoms are of the same kind and you have the same number of atoms and you have same valance all those things are the same and they where ah aligning themselves in an opposition in a cooperative manner.

You they will all cancel out and you would get an anti ferromagnetic material, which is where the cancellation is complete on the other hand you can also have this kind of a coupling except that the cancellation may not be complete because may be the atoms neighboring atoms or of a different kind or may be or of a different valance and so on and so you will still will left with some net magnetic moment and that is a the ferrimagnetic material cancellation incomplete; however, they are all in the sense that there is a net magnetic moment of associated with atoms even in the absence of a field in that sense and there is a co-operative alignment of a atoms across some distance in that sense they are all subsets of a ferromagnetic materials. So, this is what we understand of ferromagnetic materials. So, will add one more detail about magnetic materials to our picture and then.

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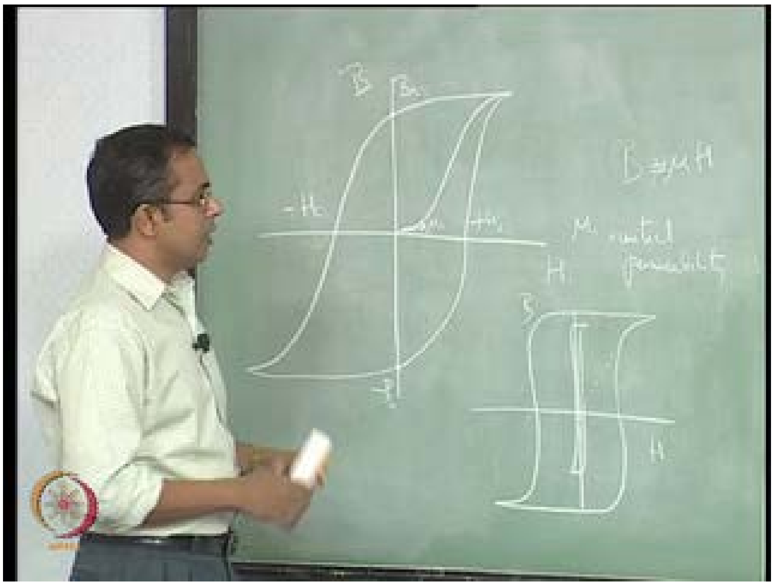

We will look at how the theories helping as understand it of course; this is got to do with how the magnetic materials respond to the field H. So, we can write H draw H verses B plots and what we will see this is for a ferromagnetic material. So, for a ferromagnetic material as you raise H you actually see a response that is looks like this, actually represents the fact that as you initially within the sample already there is the magnetic moments or the atoms are cooperatively align with respect to each other neighboring atoms, but that occurs only over a small region.

So, if you have a large sample several small regions can be oriented in different directions, so the net magnetic moment may be close to zero or zero and then as you put the H field more and more of those regions align with respect to the H field till you reach a point where all the regions have aligned with respect to the H field and therefore, that is that is a saturation you can get an it saturation magnetization if you reverse the field. You will see a behavior that looks like this. So, this is the behavior that you will see and again you can you know you can write permeability here, which is simply if you write B is mu times H right, so clearly at each place them so B verses H if you look at the slope for B verses H that is the that is slope is what the mu is that slope is varying and. So, this is called mu I or the initial permeability and so this is how this behavior is and the it is in these context that the materials this is called remnants, this is called B r remnants; this is in the negative direction minus B r this is coer cvt H c and plus H c this means once you have magnetize it even if you drop the field to zero some amount of induced magnetic field remains in the material that is what the ferromagnetic behavior is all about.

So, that fields remain in the material now to remove that field you have to actually put an opposing remove that induction you have to actually apply an opposite field of this strength before that induction drops to zero that is coer cvt and similarly, when you written again you will have in the opposite direction the induction and the you have to corresponding the raise the field in positive direction before you can cancel it. So, this is what this is how ferromagnetic material responds to changes in field depending on the material you choose you can actually have systems where this is very narrow or this is very wide, very narrow buts steep which means high initial permeability, but very small amount of coer cvt.

So, you can have a situation which looks like this, you can have a situation which looks like this. So, this is the steep claim here so; that means, mu I is very high, high initial permeability, but very small coer cvt you can also have a magnetic materials where you can have this to be the situation. So, here in terms of initial permeability for looking at this direction, it is a lower initial permeability and high coer cvt the inner curve here a is what we would material describing displaying the inner curve is what we would describe as a soft magnetic material describing displaying the outer curve is what we would called as a hot magnetic material.

So, for magnetic storage something so the a hot magnetic material would retain once it once it is subject to a magnetic field, it would retain a certain state much better even with some changes in the its environment it will retain that state you have to make significant changes to its an environment before it loses the its loses its magnetization whereas, the soft magnetic material even with small changes in the field around it the induced magnetization will, induced magnetic field will drop to zero quickly. So, this is for a soft magnetic material, this is a hard magnetic material this is preferred for a things like materials which have been used for applications such as transformers, where you have to keep changing the field applied it through it several times and you do not want to lose energy this represents energy being lose to the system the outer curve would then represent places where you want the magnetic behavior to stay much after you removed the field. So, for magnetic storage this would be much more appropriate, so this is what we have now in terms of what.

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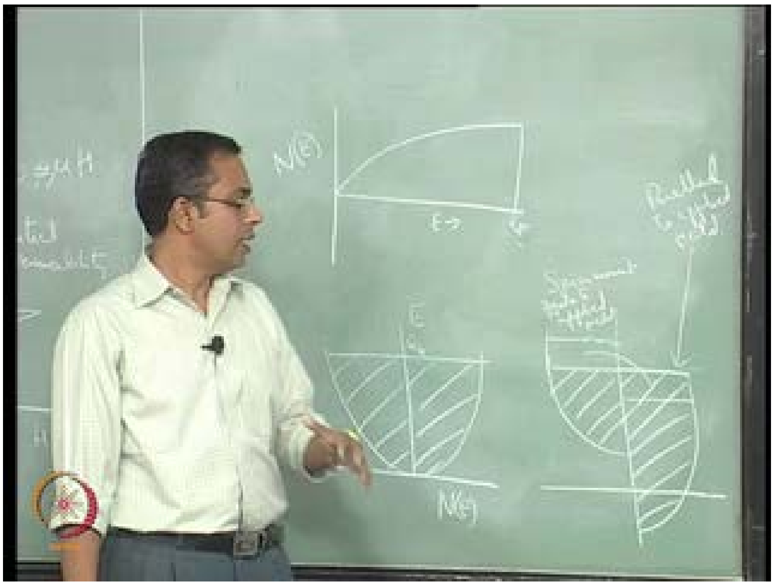

We have already discussed, we do for our systems density of occupied states as a function of energy and we saw this curve and that some ferme energy E equal to F, so this is energy and this is E equal to E F. So, this is the density of occupied states this is what we drew and this represents the states of the electrons now I also said that, this is if you put we included spin in its. So, we actually get a two times this number of electrons actually, so this is the density of occupied state actual number of electrons is twice this and that this because you have spin up and spin down.

So, pictorially we can, we can we will do two things pictorial will just first of all flip this picture around, so we will have picture that looks like this with E on the y axis and N of E on the x axis and additionally what we will do instead, of simply saying that there are two electrons per state we will represented like this. So, these are with spin up, these are all electrons with spin up and these are all the electrons with spin down with the simply a representation as a function of energy density of states where simply a representing this as spin up electrons, these are spin down electrons let us say that is how we are representing half of it is spin aligned in one direction, half of it spin aligned in the opposite direction and we still have the ferme energy.

I will just alert to you to the fact that you know this sort of looks like a E verses k curve, this is not an e verses k I mean this is not that curve that we are talking of this is e verses N of e curve, now when you apply a magnetic moment in terms of the theory that we have developed. So, for the way the material this responding is something like this, what is happening is the states that are aligned with respect to the magnetic field or going down in energy. So, they become more stable with respect to the field that you applying these states that are having a spin opposite to the direction which you applied the magnetic field goes up in energy, so they become less stable with respect to the with respect to energy they become less desirable and, but at the same time I mention that the ferme energy is something like a chemical potential, if chemical potential of two regions goes up then material will move, so that the chemical potential once second equalizes. So, what will happen is electrons from the higher energy level will shift towards the lower energy level till the energy is minimized.

So, our picture after we applied the field look like this and let’s say this was our original E f, so what will happen is we have shifted of by this much? So, actually if we had not done any changes if we are not done any changes the electrons; so, this is spin opposite so spin moments opposite applied field and this is N direction of applied field parallel to since this is parallel this is now going down in energy this is opposite the spin is opposite to the applied field it is going up in energy, if we just maintain their the entire set of electrons to be the same. So, what was a fermi energy here now just moves up here and, what was a ferme energy there moves down here. So, now, we have this set of electrons which are having, so this is now sort of the ferme energy of the electrons which are in opposite the applied field, this is the ferme energy of the electrons which are along the ferme in parallel to the ferme, parallel to the applied field and this situation cannot be sustained, which because it means within the system we have two different ferme levels that cannot be sustained these electrons will move such that the ferme level becomes the same because that is the chemical potential of the electrons and it cannot have a difference, difference will enable them to move.

So, these electrons will simply move here, so you will again come back to some level that looks like this because these electrons would've moved here and so this is what you will have a sure final state within the material, your original state as like this temporarily you got a state where this went up and that went down, but then electrons moves. So, that your final state is like this, so you now have more electrons in the in the occupying the states which are parallel to the applied field and therefore, this explains to you how alignment of the spins are with the applied magnetic moment occurs so you see now.

How our theory that we have developed and the diagram that we developed and so on help as understand what is happening in the system. So, the we will conclude today's class by just summarizing that we have now looked at magnetism as a phenomenon, we have looked at all the major parameters associated with magnetism and the various phenomena of magnetism how it manifest itself and various circumstances and what happens when you take different materials and subject them to variations and magnetic fields ands and search and we have also seen how we can understand it in sort of in some ways from a classical sense and some ways based on the theory that we have developed so far and so we kept a some sense of a how to understand magnetism as a phenomenon and the science behind magnetism. So, with that we will halt today and we will pick it up in the next class thank you. .