Solid State Physics
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Lecture - 66
Magnetic Property of Solids (Contd.)

So far, we have discussed about the diamagnetism and paramagnetism.

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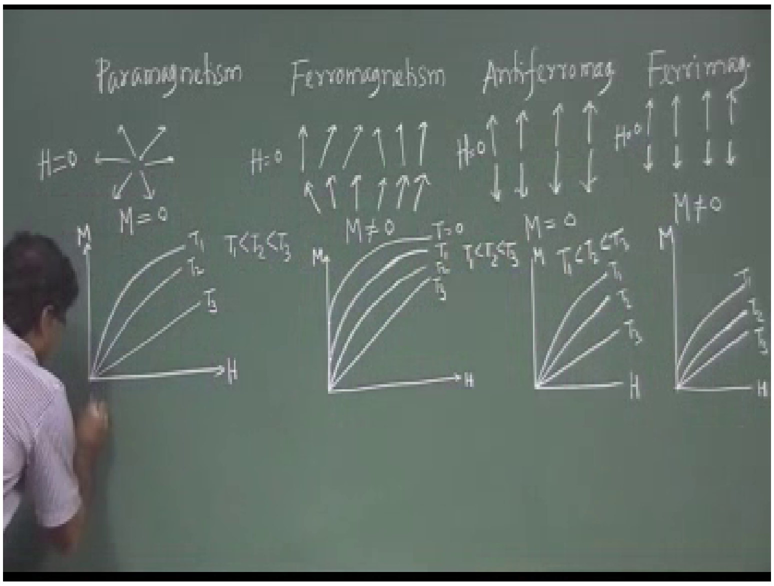

Diamagnetism is due to induced dipole moment, whereas this paramagnetism is because of permanent dipole moment, magnetic dipole moment. And this not only parametric paramagnetism, but other ferromagnetism, then antiferromagnetism and ferrimagnetism.

So, all are due to the permanent dipole moment. So, what are the difference among them? So, basically in this paramagnetic material. So, their dipole moments are there, permanent dipole moments are there. So, all are differentiated based on the ordering of the dipole moment in the materials.

So, in this case if this ordering are like this. Random ordering are random, spin are randomly oriented and without for H equal to 0 for H equal to 0. So, if this dipoles oriented like this.

So, net magnetisation is 0. And if moments are dipole moments are oriented like this, if they are oriented like this so they are pointed in same direction, there may be may not be parallel all are parallel, but they maybe also parallel. So, for H equal to 0, this is the case H equal to 0, and in this case you will get net movement along a along with direction. So, M is not equal 0 M.

So, then this we tell this ferromagnetic material. On the other hand, if the arrangements are anti parallel so number of dipole moments up and number of dipole moments are down. So, then net magnetisation is 0 and this is also for before applying magnetic field.

Now, in case of ferrimagnetic, see if arrangement is anti parallel, but their movements are different. This parallel movements is higher than the; this anti parallel down one. So, moments are smaller.

So, there will be net magnetization, magnetization will not be 0, and this this is again for H is equal to 0, thus again H is equal to 0. So, this way we can differentiate depending on the ordering of the permanent dipole moments in the material we can differentiate the different type of magnetization, right

So, when you apply magnetic field on this so what will happen? And if we vary the magnetic and if we vary the magnetic. So, then then magnetization M, if it varies like this, depending on temperature different temperature if we major magnetization as a function of magnetic field, see it varies like this. This is T 1, this temperature T 2, this temperature T 3.

Where T 1 is less than T 2 is less then T 3. So, in case of paramagnetic material of paramagnetism. So, magnetization varies as a function of magnetic field at different temperature it is; it is like this. In this case this H and this magnetization, if it varies like this, I think one I can take straight line. Then if it is varies like this. So, this T equal to 0 this curve was T equal to 0, this is T 1, T 2, T 3. So, in this case also T 1 is less then T 2 is less then T 3. So, here basically in this case this T 2, so the T 3 temperature here it is variation is similar to the here, similar here, and above if temperature is lower than this temperature is lower than this. Even this T 2 also here similar to T 2 here, T 3 similar here, that above this this T that at T 1 and T 0 which your lower temperature than T 2 and T 3. So, here this we get some it is not from 0, it is from here, it is from here. So, at 0 magnetic field at 0 magnetic field there is a magnetisation.

That is the difference of this between these 2, and in this case it is M, and this is H for anti-ferromagnetic. Is it is similar to gally paramagnetic, to similar to paramagnetic. It similar to paramagnetic. In this case also T 1, T 2, T 3. T 1 is T 1 is less then T 2, less then T 3. And this other case H and M. So, it is similar to this ferromagnetic, but magnitude will be different.

So, this T 1, T 2, T 3 same similar to this this one ferromagnetism. So, at even 0 magnetic field, you will get some magnetisation depending on temperature.

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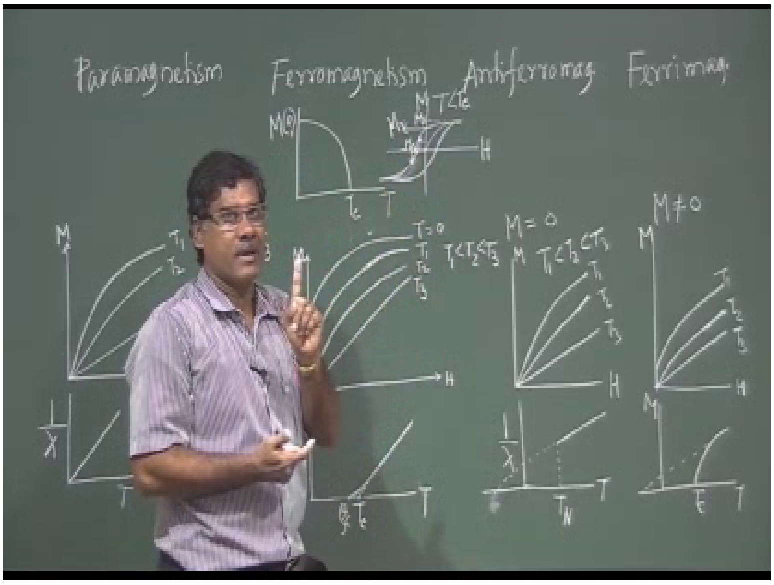

So, these are not good way to differentiate them, but if you plot 1 by kai as a function of temperature, then we will see this variation, I think I can draw one, it is variation is like this, straight line, right.

So, that we have seen earlier also for paramagnetic case. For ferromagnetic case, this is temperature and this 1 by kai. So, you will get basically this kind of curve if you. So, this is T c, it is curie temperatures, above curie temperature. So, it will follow the same paramagnetic behaviour. So, it is started from 0, it will not start from 0. So, it is above is, so sometime this T c this ferromagnetic temperature transition temperature will tell. So, it is exactly not this T c it slightly lower, it is slightly lower, it slightly lower. And then if you draw this I think I should it is slight this. So, if you draw this, extend it this straight line. So, this will T c and this call theta f is called theta f, it is ferromagnetic transition temperature.

But generally this difference between T c and theta f very small. So, thus we treat them as same. And in this case this 1 by kai and this temperature T, if you see. So, it is like this, this is set a T here. So, let my T here and this. So, there is a temperature above that temperature, it is like this, like paramagnetic one. So, this temperature call nill temperature, and below this temperature T n, below the T c their behaviour is different. But so this one if you extend this one.

So, this basically give the negative theta, this is the negative theta. So, it cuts extension of this cuts on this temperature at negative axis. So, for other case it is like this. And if you take the asymptote of this one side generally it cut the negative axis.

So, in anti ferromagnetic, it cuts at negative, but at higher angle, and this for ferrimagnetic, it cuts at negative asymptote it is cuts at negative, but with smaller more smaller temperature. So, these the feature of anti ferromagnetic arrangement in ferromagnetic material, as well as this part of it behave like this.

So, this is telling, this it is it has some ferromagnetic part also. So, this is the combination of ferromagnetic and ferromagnetic and anti ferromagnetic. So, if you combine this 2 so this presence of both are are clearly seen here. So, this type of variation T, and this basically T c with a T c and this is M.

So, these the variation, this the variation of kai 1 by kai inverse of kai as a function of temperature, and if one measure this so one can differentiate this 4 types of material. So now, question is this 2 material ferromagnetic part and this ferrimagnetic part. So, these 2 also shows that this one shows, that at this one shows the; I think I will, additionally this piece one if you apply it shows if you without magnetic field, if you measure the magnetization as a function of temperature as a function of temperature.

So, this we tell this M 0, M 0 without magnetic field. M H magnetization as a function of magnetic field, and magnetic field is 0. So, I have written m 0. So, M 0 it shows this type of variation, this is T c this magnetization. So, without applying magnetic field you will see that that the existence of magnetization up to the curie temperature, where it is saturated one, and then it is shortly fell down at the T c.

And also if you take the M as a function of H at T equal to less than T c, so then what is c this type of variation, it is look you see if look you see. So, it is it has to be symmetric it is not I have not drawn to the correctly I can put this way, yes.

So, this type of hysteresis loop. You see and in this case also same behaviour you see, because it is basically it has 2 components ferromagnetic and anti ferromagnetic. Here also in this case we will see. So, these the speciality of ferromagnetic material, you can differentiate ferromagnetic material, anti ferromagnetic material immediately right, if you see the hysteresis.

Now, here this called basically at so this called the spontaneous magnetization without applying magnetic field. So, this what magnetisation we are seeing that is the inherent one is spontaneous 1. So, spontaneous magnetisation. So, this after playing field this is called the saturation magnetisation, M s saturation magnetisation. T is called remnant magnetisation M r magnetisation, and; that means, that is H equal to 0 the magnetisation remains.

It is not 0 to make this ribbon in magnetisation 0, we have to apply field in opposite direction, and this much field we need to make it 0 to make it 0. So, this call coercive field this is called, coercive field this called coercive field this is H c another things we can notice that. So, above this that whatever the magnetisation that magnetisation, that is spin up that magnetisation in this direction. And below this magnetisation negative. So, it is down magnetisation reaction is down.

So, above this H c below. So, below this H c it is spin up or magnetisation up direction and when it is just H is higher than H c. So, then it switch to the it switch to down. So, just H c plus minus del h. So, you can takes spin up or magnetisation up, magnetisation down. Magnetisation up, magnetisation down. So, that is why H c called switching field. So, magnetisation is switch from up to down near the AC field. So, that is why it is called also switching field.

So now will discuss the origin of ferromagnetism as we have discussed paramagnetism will discussed about the origin of ferromagnetism. Why this spontaneous magnetisation exist? Why remnant magnetisation is there? Why we need opposite field to make this remnant magnetisation 0? So, that is that is you want to study. So, let us concentrate on the ferromagnetic material. So now, ferromagnetism ferromagnetic material. So, there is a spontaneous magnetization.

That means there must be internal field, there must be some internal field in the ferromagnetic material, right. So, that we have to find out what is the origin of that internal field.

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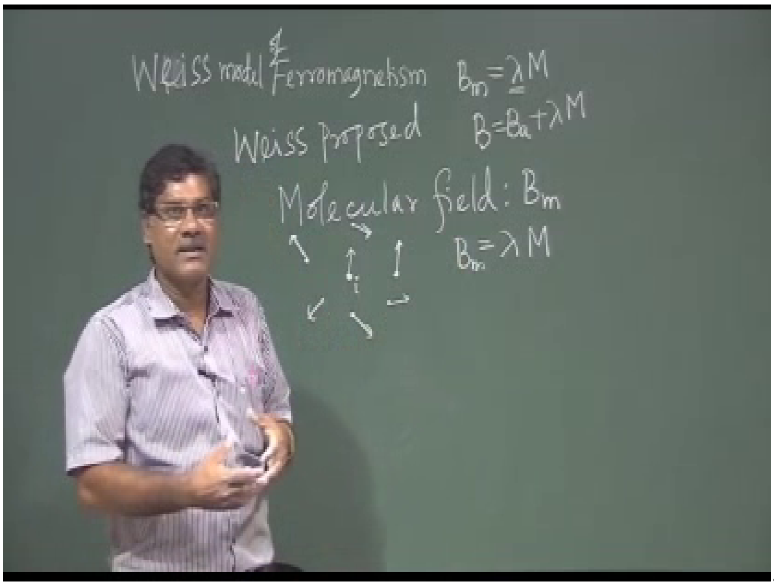

So, Weiss is basically, Weiss proposed that there is a magnetic field, there is internal field in the ferromagnetic crystal, and that field is called molecular field.

Weiss molecular field also we can sometimes we tell. And this this molecular field is because of this molecular field exist in the ferromagnetic crystal, and this field align the dipole moment, permanent dipole moment even there is no external field. So, that is the that is that is called basically Weiss model of ferromagnetism. So, Weiss proposed or assumed that there is a internal field is called molecular field. And because of this field without external magnetic field the permanent dipole moment are oriented. And he so from where this field is coming?

So, he is proposed he is thinking that you have you have a, you know dipole moment, permanent dipole moment. So, many dipole moments surrounding of this one. So, what happens? This this this one say ith spin or ith dipole moment. So, it feels magnetic field, it fields from field from because of the other neighbours. So, one can tell because of the interaction among the dipole moments. So, this is the origin of the molecular field.

That means so in case of ferromagnetic material, we have considered that this we are considered as a ferromagnetic guest were this, dipole moments formed and dipole moments are there, but they do not interact with each other that we have assumed that we have consider. And based on that we have we are successfully, we have explained all the properties of ferromagnetism. Now to explain this ferromagnetism, Weiss considered that there is a internal field, and this origin of this field basically interaction among the dipole moments in the solids. So, because of this dipole because of this dipole moment there will be it has. So, it has whatever this it will affect this one, it will all will affect this, this one.

So, this affects the degree of affection, degree of effect you can tell, degree the effect it is a Weiss considered assumed that it is proportional to the it will depend on the magnetization of this material. So, it is considered that this molecular field if we write B m, molecular field B m internal field. So, this B m is proportional to magnetisation of this material proportional to the magnetisation this material. So, this proportionality constant, if you write B m is equal to some constant am lambda. So, let me write here just B m, molecular field is equal to lambda M and lambda is called lambda is called this it is constant. It is basically it is; it tells about the strength of the interaction among the dipole moment, strength of the interaction of the dipole moment.

So now what happens? So, this field already exists in the in the system. Now if I apply external field. So, external field B a, applied field B a and already exists field exist lambda M then B m. So, that this moments so now, you can consider as non interacting moments like ferromagnetic gas fill this amount of magnetic field. So, that is that way is that is the Weiss model. So, whatever this for ferromagnetic gas, whatever the let us fall for non interacting dipole moments, and whatever expression formula we have derived. So, all formula will be valid for Weiss model of ferromagnetism only. We have to replace that that magnetic field external magnetic field b by this.

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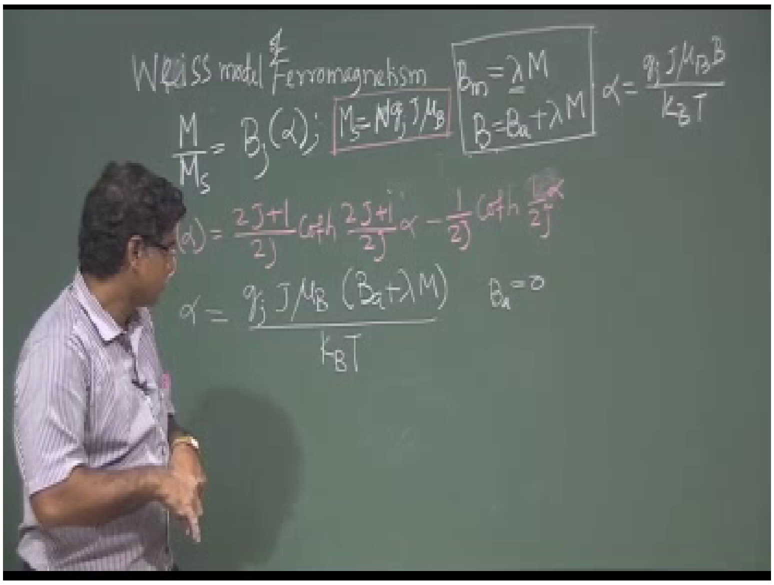

So, what we have got for? So, for ferromagnetic material what we have got? So, this M by M s equal to brillouin function is alpha right. Where alpha equal to g j J mu B B by K B T right. And M s saturation magnetisation, M s is basically N number of atoms per unit volume in g j J mu B.

So, that is the our saturation one, that the saturation one. M there is the saturation, I should write M s. So, this the these was the result for ferromagnetic material. I had B j equal to what was that B j alpha equal to 2 j plus 1 brillouin function by 2 j plus 1 2 j cot hyperbolic 2 j plus 1 by 2 j alpha right, alpha I think this I should right here. Here I will write alpha equal to g j J mu B B by K B T.

So, then this was same minus 1 by 2 j cot hyperbolic, 2 j sorry, 1 by 2 j alpha. So, that is the result for ferromagnetic material. Now if I just this as I mention that this, if I replace this b replace this b, b is here, b is here in case replace this b by this, then it is Weiss model.

So, alpha in case of ferromagnetic material, alpha equal to g j J mu B. So, B will be replaced by B a plus lambda M divided by K B T kb T right. That is the alpha. Now if external field if I put external field B, a equal to 0 means there is no external field is applied. Then alpha will be this lambda M right, when B a equal to 0.

Now, from here I can get M equal to K B T alpha divided by g j J mu B lambda, right.

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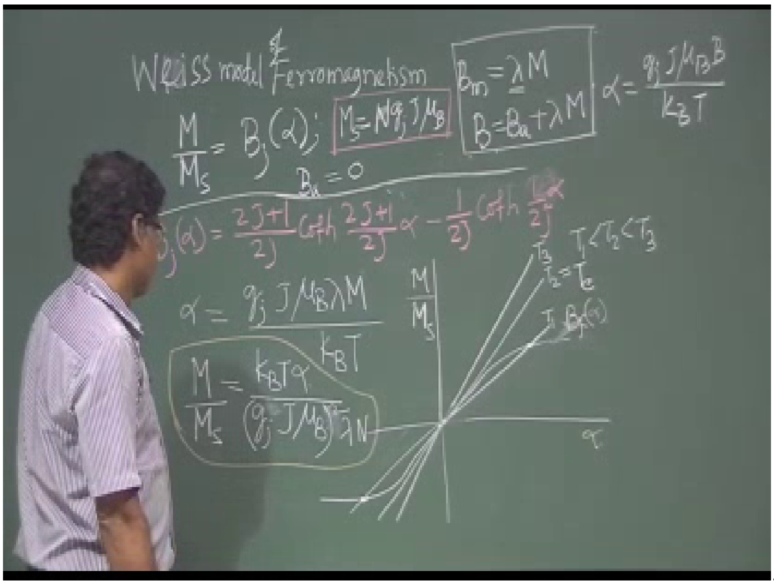

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So, then if I write M by M s just as I reference of M s. So, this what is M s, M s is this. So, I will get divided by M s. So, I will get g square j square. So, I will get basically square of it lambda and then N.

So, this is one expression, we got this is one expression we got. Whereas, B j equal to is this now if I plot. So, this whatever we are doing that is for B a equal to 0. So, this we are doing now for B a equal to 0, for this case under this condition whatever proceed. So, here one thing is so B j what is this? It is equal to basically M by M s. So, here you see M by M s, that is a function of here alpha. And here M by M s it is a function of alpha. So, will get simultaneous solution if I draw both curve both curve, this simultaneous solution will be the intersecting point of this 2 curve. See if I plot this as a function of alpha and this M by M s so for brillouin function, if you plot the brillouin function the curve of the brillouin function is this basically curve of brillouin function is this. So, this is B j of B j of alpha this curve. Now if you draw this one. So, as a. So, this basically for different temperatures, it is for a particular temperature it is straight line.

Now, we will get straight like this, we will get straight line I think I should. So, let me just this ones if I the. So, this will go, basically this way this will go, basically this way this way, and if I draw another flat one. I think this is not the right one. So, these are different temperature. This temperature is say this is T 1, this is T 2, this is T 3.

This is T 1, T 2, T 3. So, here T 1 is less than T 2 is less than T 3. So, T 3 it is not intersecting this this this one this curve it is not intersecting this curve. Except this at alpha equal to 0 where M is 0. So, we do not have interest for this solution. And T 2 it is it is a basically it is a gradient of this B j curve at alpha equal to 0. And this other one is below T 2 temperature. It is intersecting at 3 point this this and this.

So, it will have plus minus value, it will have plus minus value, plus minus value of M by M s and also 0 value. So, we are not interested about this 0 value, alpha equal to M s value. So, here from this curve you can see that below a certain temperature, there is exists of magnetisation, there exist of magnetisation right. Because it has now solution simultaneous solution for which is satisfying this as well as this.

So, gradient is basically T equal to this is the T c critical temperature transition temperature. So, above T c T 3 is above T c. So, it has no solution it is not intersecting. And below T c at T 1 it is intersecting. So, thus this this T c is the transition temperature, above this temperature is paramagnetic and below this temperature it is ferromagnetic. Because there is magnetisation exist even at external field 0.

So, this temperature T c is this basically one can find out this T c. So, that will do. So, this T c at T equal to T c, this gradient of this straight line and this gradient of this B j curve at alpha equal to 0 they will be equal. So, from that condition one can find out the relation between the T c, and the and the this this lambda. So, that I will continue in next class. Let me stop here.

Thank you.