Solid State Physics
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Lecture - 71
Magnetic Property of Solids (Contd.)

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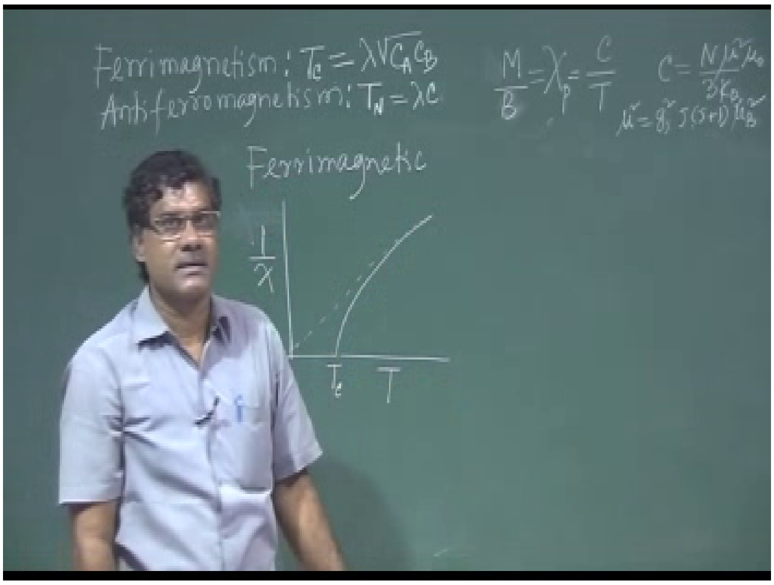

So, this for ferromagnetic: so, as I told this, chi that depends on temper. It is not is very simple form is temperature dependencies is different one. So, that is why if you plot 1 by chi verses temperature. So, in case of ferromagnetic, we have seen this straight line kind of things right. This is TC see in ferromagnetic also this TC is there, but it is concave towards this T axis, if you plot this one that temperature dependence. So, it is become like this curve become like this. And is asymptotic nature it generally cut in the negative axis, in the cut at the in the negative axis.

So it is different; this curve is different than this ferromagnetic anti ferromagnetic and this paramagnetic. They are straight line, but here this curvature in paramagnetic phase is there is a concave towards the temperature axis.

So, that expression I have derived and shown you.

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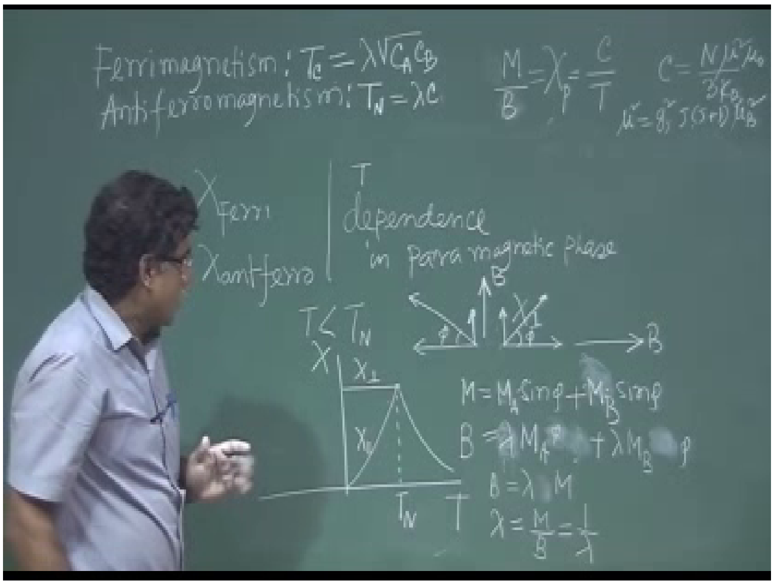

So now, you see this in case of; I think this in case of antiferromagnetic; so I think whatever we have derived chi for ferri, and chi for anti ferri anti Ferro right. These are there mainly temperature dependence, we have seen temperature different dependence temperature dependence, but in paramagnetic phase right. So this behavior of anti-ferromagnetic material at temperature T less than T N; so it is really we take in 2 ways. This in case of anti-ferromagnetic this is your. So, at lower temperatures they are aligned antiferromagnetically, right.

Now, to study the behavior of this anti ferromagnetic material as a function of temperature; so this magnetic field is applied in 2 directions: One is parallel to this alignment, anti ferromagnetic alignment of spin of spin up and spin down. So, this magnetic field is applied in this direction and they that he variation of these susceptibility as a function of his parallel field. So, that we tell this chi parallel chi parallel. So, this is one study.

Another one who can apply magnetic field in perpendicular direction, this B perpendicular direction because it does not it is not meter in case of the when T is greater than T N. You know it is paramagnetic. Now it is they are random. Now bellow this nil temperature T N. So, they are already aligned now if you apply magnetic field in any direction one can apply, but this is the 2 generally this is normal practice that we apply magnetic field along the parallel to this alignment or perpendicular to this alignment.

So, parallel to this alignment that is basically is they aligned in a easy direction of the crystal easy direction of the of the crystal or magnetization so that I will come later. So, in this case what happens, this Cp this chi parallel, then this we tell this we tell chi perpendicular chi perpendicular; and if you plot that at T N temperature. So, if it is T N and if you plot chi verses temperature. So, for anti ferromagnetic seen paramagnetic phase this if it is T N in paramagnetic phase is then that will be the hyperbola that will be the hyperbola right and in this case bellows T N.

So, this variation generally it is this is chi perpendicular, if magnetic field is applied perpendicular. So, this variation; so it is independent of temperature, and for this case chi parallel it becomes it generally like this; so at T N this chi parallel equal to chi perpendicular. So, this qualitably I can explain this why it is temperature independent. You see at low temperature T N is less than T is less than T N. So, in that case what happens?

So, both are what about that both are equally they will act equally on this or magnetic field will act equally on this because (Refer Time: 08:46) with this magnetic field they will rotate they will if the align this in this direction. So, they will rotate. So, they will basically rotate with the same angle phi say the same angle phi. So, they are the in this direction because of molecular field. Now this field they are this is my applied magnetic, field it is trying to take them along this direction.

So, there will be balance between this magnetic field and this molecular field and the molecular field. So, when temperature decreases or increases whatever so both will have the same. So, they may call the times it is same angle right. So, they are horizontal component this component will cancel each other, but this component from this component all the time this component will come. And that will be basically that will be a magnetization. So, magnetization is basically MA from this if it is MA sin phi and that will be MA, MB that will be MB.

So, let me write and from here, one will if another will be MB sin phi right. So that will be the magnetization along this direction, magnetization along this direction. And that is one can show that B2 this corresponding this corresponding magnetic this what is call molecular field is basically it is basically lambda MA right and this sin theta phi is there. And this is lambda MB molecular field if you neglect alpha sin phi.

So, that will be balanced with this applied field right; so MA. So, this sin phi for small angle it is sin phi equal to phi one can write phi right. So, one can write phi. So, B equal to lambda phi right. And this M total M MA plus MB this total M then this chi will be. So, chi will be M by B M by B say or yes. So, it will it will be. So, MA phi equal to you see this, this component magnetization is not this, this component, this component. So, MA sin theta sin phi plus MB sin phi. So, MA equal to MB basically MA equal to MB in case of anti ferromagnetic case. So, it is.

So, I can keep sin theta phi I can write phi I can write, but MA phi is this, this component MB phi is this component. So, here this phi will not be there, phi will not be there. So, that will be the magnetization along this direction; so MB. So, that will be basically 1 by lambda. So, chi will be equal to 1 by lambda. So, it is independent of temperature independent of temperature.

So, I will not it is qualitatively I should try to tell because calculation is slightly complicated. So, I want to avoid it. So, qualitatively I want to tell you. So, this other case when it is magnetic field is parallel. So, this is magnetic field is parallel to this. So, it is along this it is direction is along the magnetic field. So, it will remain in this direction right.

So, magnetic field will try to take this one, in it is direction right, so now at temperature 0. Obviously, magnetic field will not be able to take it is. So, that is why this net magnetization will be 0. So, chi will be 0 at T equal to 0. Now if you increase temperature. So, that is there increase temperature, because of thermal energy. So, it is extent direction that is it will be loosened. So, this will this will try to align magnetic field will able to take. So, temperature is increasing.

So, it is trying to align it is trying to going. So, you will get you will get some component in this direction it has. So, it will try to take align, it will try to take align with this align. So, with temperature is increasing the cover because of thermal energy. Now this magnetic field it will try to align along this direction. Thus, it will increase and it will be maximum at this point. So, I will stop discussion on this ferromagnetism.

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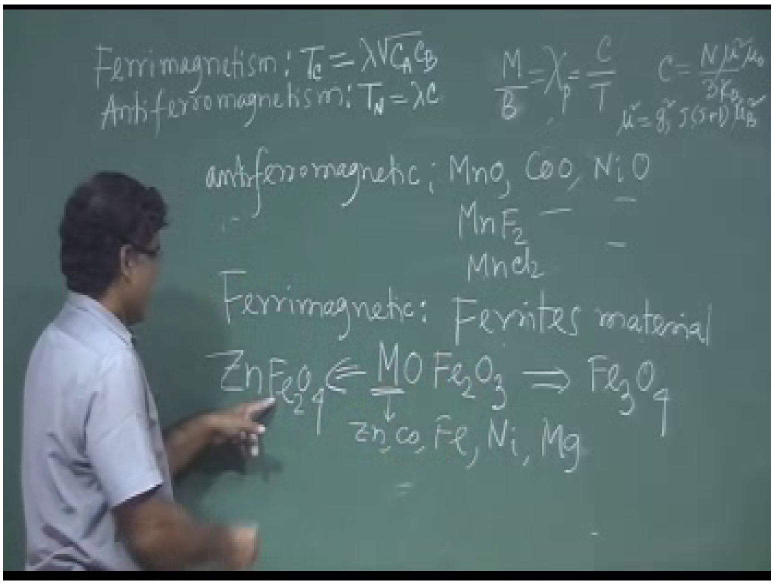

Antiferromagnetic except just I just want to give you some example. This a antiferromagnetic material which are the antiferromagnetic materials as I told this antiferromagnetic material.

So, I can give you some example so this magnesium oxide, right. Magnesium oxide, cobalt oxide, nickel oxide right: their fluoride manganese not magnesium sorry manganese chloride. So, oxide, fluoride, chloride, these are the basically in this case also these are the basically anti ferromagnetic. And ferromagnetic is basically of our this ferrite material. This it was discovered from this ferrite material ferrite material. So, this chemical formula of this ferrite materials is basically MO Fe2O3, MO is basically divalent atom and or divalent cations. So, M can be zinc, cobalt, iron, nickel, magnesium. It can be magnetic or nonmagnetic also. So if you take Fe it is basically becomes Fe 3 O 4. It is also called magnetite. This is oxygen the same. So, if you take zinc, if you take zinc.

So, if they call zinc ferrite, zinc then Fe 2 O 4 right. So, this called zinc ferrite; this called magnetite, nickel ferrite, cobalt ferrite; so ferrite materials. So, basically this ferromagnetic material; they have spinel structure they have spinel structure. I will not discuss about it will be difficult for you to understand now spinel structure. So, it has basically A site and B site. A site is basically called this is called it is a tetra hedral site. It is called tt site or tetra hedral site.

And another B site is it is called this octahedral sites, because this oxygen's because this bonding with this with this ions with oxygen this octahedral in B site and tetra hedral in A site. So, here also A site and B site as we discuss for a sub lattice and B sub lattice. So, here it is there for inspirial structure. So, this I think we can. So, more or less these basic things from magnetism for magnetism, I have taught you there are many other things, but that is that will be difficult for you to understand now.

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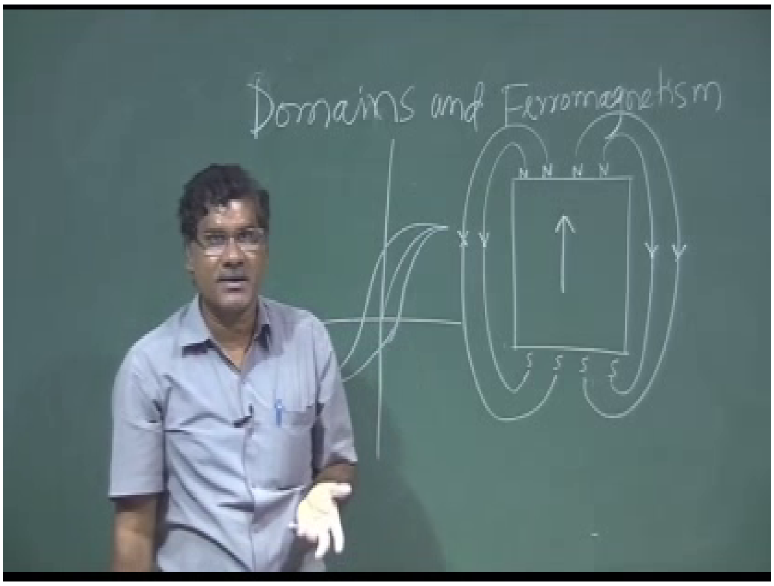

So, that is for higher level things, but domains and ferromagnetic domains and ferromagnetism. So, far we have not discussed about the why ferromagnetic materials show the hysteresis. That we do not know. As well as generally this iron the most of the material I will this magnetic ferromagnetic material at it has it has we have seen this is a saturation magnetization even without applying field is supposed to show this magnetization, but without applying field gel we do not see, but if you apply field and then you we do the field then we see this magnetization.

That is a (Refer Time: 21:39) magnetization also for paramagnetic case to align the magnetization along the magnetic field directions. So, you need very high field where as in case of ferromagnetic material we need very small field to align them. So, these are the things suggest that this before getting the external magnetic field, there are some self arrangement inside the material right; and if it is self alignment if the materials why it is not showing, why it does not show the magnetization of the demagnetized ferromagnetic material.

Demagnetized means if you if this material is not exposed to external magnetic field. So, that material generally does not show the magnetization. So, that is the demagnetized material before exposed to the external magnetic field. So why is generally he is the first interviews the concept of domain concept of domain; so this ferromagnetic material, this ferromagnetic material. So, this if this shows, if it is a single domain or say just there is no domain. So, this is the situation this is the situation. So, in this case what happens?

So, what is the origin why this domain form that is I am trying to say. So, it is the say north pole. It is the North Pole, and then this is the South Pole if it is a piece of ferromagnetic material. So, it has it has magnetization if it like the. So, it acts as a magnet right. So, it will we can get field from it. So, this field direction is this a field direction in this way.

So, now you see this. So, this field direction is opposite is this called demagnetizing field. It is called demagnetizing field as if this field itself. It is generated from this magnetization, but these field will it is opposite to this magnetization. So, as if this field act if acts on this material. So, it will try to take this magnetic movements align to this field. So, as if it is demagnetizing this material. So, that is why it is called demagnetizing field, now this; this wherever this field is going out this going out.

So, it will fill this space and that will cost energy. So, this called this it is called this magneto static energy or demagnetizing energy whatever.

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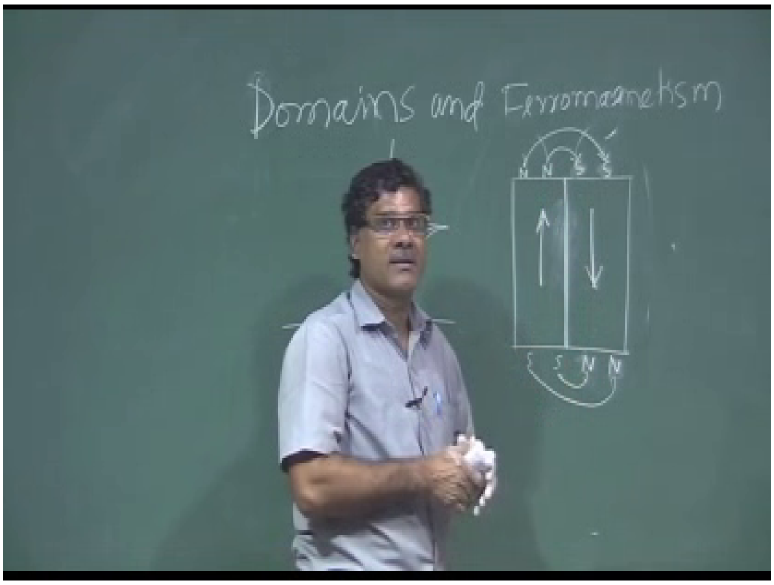

So, it will cost energy. Now if we bakes it, if it is bake from 2 domain like this, 2 domain like this. So, what will happen? So, this now this N, N and this will be opposite direction this south, south. This will be north, north. So, you can see that. So, this will not come here because South Pole near a near to it. So, it will go here. So, this will go here. Now we can see this it reduce this demagnetizing field it reduce the demagnetizing field. So, it will not. So, it will be like this. So, it is reduce this demagnetizing field. So, magneto static energy will be lower from the system, but there will be some there will be this is the call domain boundary domain wall.

So, do due to domain wall formation of domain wall it will energy of the system will increase. So, there will be balance between the domain wall energy and this demagnetizing energy and this they will try to form domain balancing this 2 energy. So, they will forming such a way that this energy should be minimum for the system; so similarly if you make it more.

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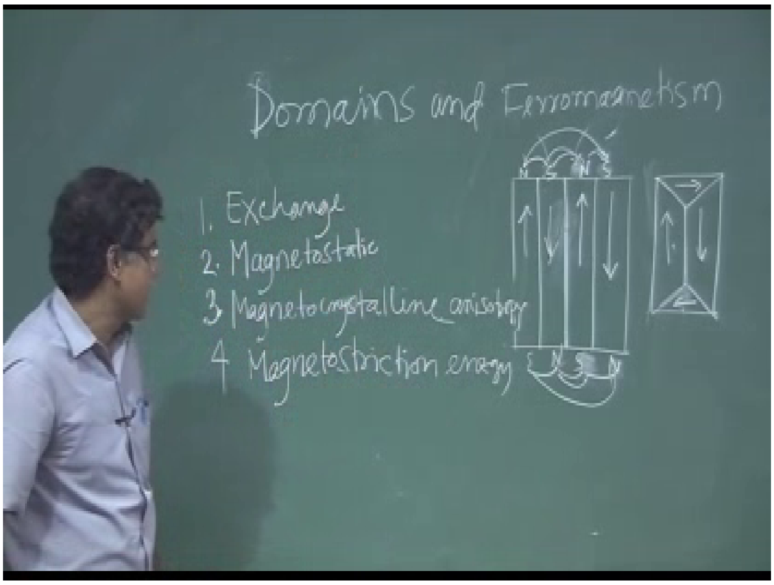

So, then if it is this, then this will be south with this it will be north it will be south. So, it is north it is south. So, this will be south. So, there will be further reduce of this demagnetizing energy right? Demagnetizing energy; so how many domains one can get out of this. So, one will get infinite number of domains. Because if it reduce the one energy, but this is not the case because this number of walls are coming of and thus this energy of the system will increase although this demagnetizing energy is decreased, but as I told this it will it will continue as long as the energy will be minimum. So, this they will the system decide, itself how many domains will be there and what will be the shape. So, it may happen that domain can be like this also.

So, this it can be like this also. This closure domain it is called closure domain. So, in this case you see there will be this a magneto static field energy will be 0 or demagnetizing energy will be 0, because there is no field going out, but here wall will be more wall will be more. So, because of this domain wall this energy will be will increase. So, there will be balance between them. So, now, here you can see this; so because of this energy minimization of different kind. One is exchange energy. Second is demagnetizing energy or magneto static energy. Third is magneto crystalline anisotropy; magneto crystalline anisotropy energy. Third is domain wall domain wall energy is basically compromise with this I think magnetocrystalline anisotropy energy and exchange energy exchange energy and magnetostatic energy. So, other one is a magnetostriction energy magneto striction energy. So, these are the energy different kind of energy involve in this process domain formation. So, this it will. So, it will get the final form in such a way this total energy of this system has to be minimum.

So, one will increase another will decrease. So, that way a systems decide. So, that is the origin of the domain formation. And because of domain this we see this hysteresis loop hysteresis.

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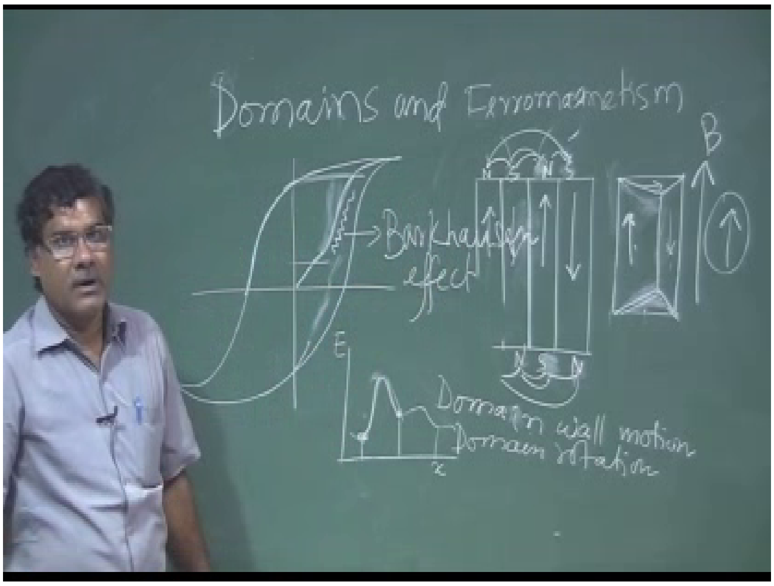

So, here just I think I briefly tell you. So what about 2 things happened here? So, one is domain wall motion. Another is this moment rotation domain that is called domain wall domain rotation domain wall motion movement and another domain rotation. So, you have domain life we apply magnetic fields say if we apply magnetic field in this direction in this direction. So, magnetization will increase right magnetization will increase. So, how it will increase 2 ways it may happen. So, all this magnetization of individual domains, they can align in this direction. So, for that it has to rotate it has to rotate; that means the domain has to. So, then it will be single domain as a whole it will be single domain.

So, by rotation of domain means the direction the magnetization in this domain will rotate. So, that way we can get increase the magnetization. And other way we can get that this. So, already this is in this direction and the direction of this movement of in domain it defends it decided by this because of this. This magneto crystalline anisotropy see in which say that, is a they try to go stay in this easy direction. Then the hard axis easy axis that is because of crystalline environment it is decided. So, that is why it is called magneto crystalline anisotropy. So, they try to stay in easy axis they try to stay in easy axis direction. So, when you are applying magnetic field in this direction.

So, it is preferable already, but this is not preferable. So, what call it. So, this domain can this wall can be shifted this wall can be shifted this wall can be shifted this can be smaller this can be smaller wall can be shifted wall can be shifted like this. So, this can grow bigger and bigger in expense of this unfavorable domain. So, that I it increase and then other as I told this rotation. So in case of this initially if you apply magnetic fields for small field. So, it is domain wall motion because of domain wall motion, but it is reversible it is reversible if you come back reduce from here. So, it will be come back like this it is reversible. Now after that what happens, if you increase this magnetic field more.

So, it is this domain wall motion that this favorable part domain part will increase. So, then it is here getting see in this region it is telling I think this. So, up to this region this is because of this growing up this domain region now. So, up to this it is reversible, but domain wall motion. And up to this also is irreversible and due to domain wall motion and if you increase again higher field. Then they rest of the things they aligned along this magnetic field. So, rotation of this domain this rotation of this domain it is say it is again you reversible not reversible when you will take out this field.

So, it will immediately it will come back it will rotate again come back to initial position. So, I think one has to draw properly. So, this type of so here this part is because of domain motion wall motion domain wall motion. So, this it is irreversible this hysteresis loop is see because of this domain wall motion is not smooth, you know because of defect in the crystal that domain wall when reach in the defect of the crystal it gets stuck there is means it prefer that place is energy become domain or energy become minimum. So say it is energy of the domain wall as a position in the in the position in the crystal. So, it is energy varies like this. It is energy varies like this varies like this.

So, this minimum energy generally it is defect place it is seen. So, domain wall prefer to stay in this in this position, but because of applying higher field it goes then it come here. Then now question is a when you are taking back reducing the magnetic field reduce in the magnetic field. So, it will not come back immediately in this position because if it has to overcome that one.

So, that is why. So, when you will reduce this magnetic field after this rotation will be recovered. And then it will stay here; so to being back this one again at this position this wall position here. So, he need really this energy. So, that is the basically coercive field that is the coercive field one has to apply to being back it to this position. So, this is the reason this because this hysteresis we see because of this defect of the crystal. And if we expand this part, if we expand this part generally one can see this it is like step kind of things it some step kind of things it is not smooth curve. So, these curve Barkhausen effect, ok.

So, this proves this domain wall the smooth (Refer Time: 40:28) it is not smooth. It get pinged by the defect this domain wall pinged by the defect. So, because it is gets the lower energy at this place. So, this experimental it is found also that is the inform qualitatively information of the domains and the ferromagnetism, but it is there are because there are lot of energy involve and for higher study only we can do quantitatively. And it is possible, but for this under graduate students this qualitative explanation is I think good enough.

So, I think I will stop this about the magnetism. So, I will go for next topics in next class.

Thank you.