Solid State Physics
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Lecture - 75
Superconductivity

So, as I discussed about the Polar Solid.

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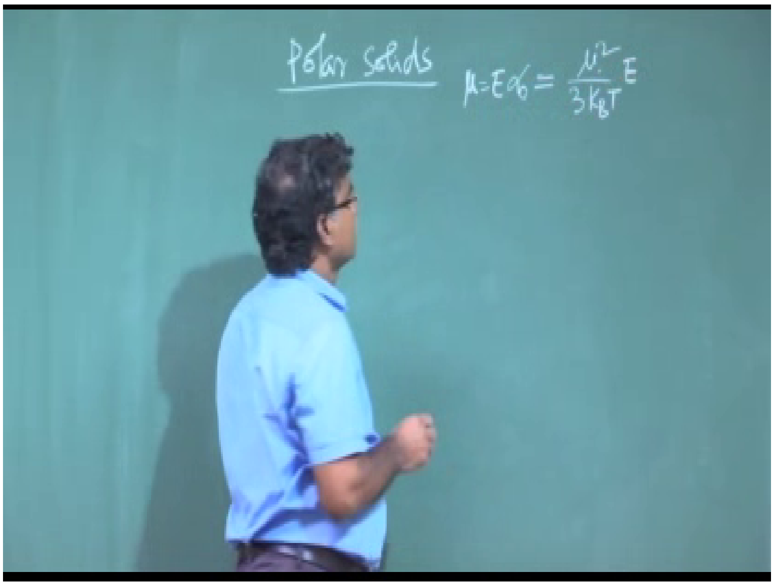

So, it has permanent dipole moment. So, atoms is atoms or ions or molecules of this materials are having permanent dipole moment. Now, that dipole moment we have seen in the dipole moment, this polarizability due to the orientation or dipolar polarizability that depends on temperature that depends on temperature right. So, of. So, what we have seen that polarizability orientation, that is a MU square by 3 KBT, MU square by 3 KBT and MU equal to E into this. So, we have to multiply E. Now, forget this for the time being, this expression of this things just what I want to tell you just qualitatively.

So, this you have material which are having the dipole moment. It just similar to the magnetic material, this polar dielectric material is similar to the magnetic material; it is a paramagnetic or ferromagnetic or anti ferromagnetic right. So, what about the magnetic material having the permanent dipole moment, not induced dipole moment, permanent dipole moment. They are showing this different kind of magnetic property of be different kind of magnetic materials, ferro; ferromagnetic, anti ferromagnetic, etcetera. So, here also that is the way this polar solids are classified. So, it is the paraelectric.

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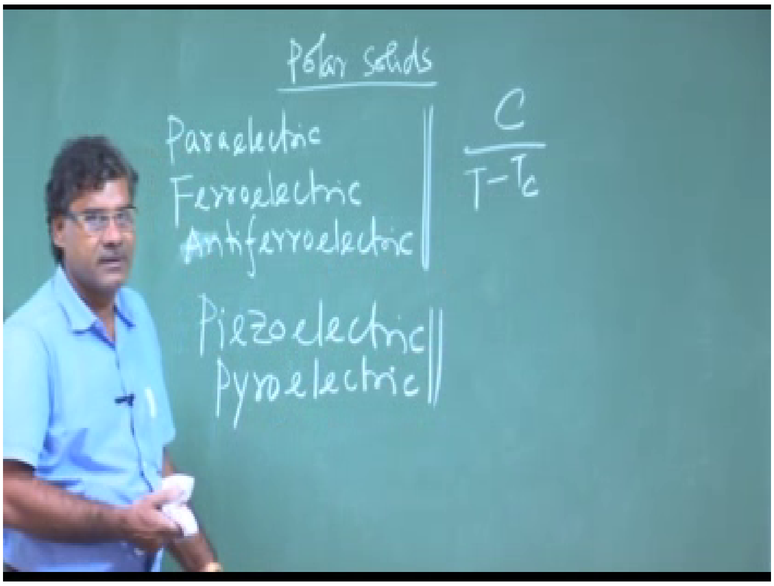

Para electric is the ferroelectric, is the antiferroelectric and there are some more types it is and very useful for device application. So, that is the, is called piezo, electric piezo, Peizo electric and pyro electric.

So, here whatever this para electric ferroelectric antiferroelectric. This all, this 3 are, this just same as that the magnetic material. So, there will be para electric to ferroelectric to para electric phase transition, that is also similar to curie weiss lawok to ex to expand this ferroelectric. So, here we consider in case of para electric as I told earlier, whatever that is physically para electric, there are magnetic gas. So, dielectric gas as I mentioned earlier. So, basically that is where electrical gas there is interaction in the, in the dipoles among the dipoles, in this material. So, just like gas. So, now, when we consider, the interaction. So, again, but this mean field approximation or Weiss field. So, similar interaction, if you put here. So, you will that same way there is no difference, same way one can be able to show C by T minus TC for this ferroelectric material and in ferroelectric material domains are there.

So, origin of these things just the interaction of this electric dipoles. So, with different kinds of materials are there. So, this A. So, just I will. So, since they are similar. So, I will not described more on that topics. So, same way as we have described in magnetic material, the same way one has to describe. So, I am interested to tell more about this

Peizo electric and pyro electric, just qualitatively. So, what is piezoelectric is dielectric material. So, this Peizo electric, Peizo means pressure you know pressure stress. So, dielectric some dielectric materials are there, if you put pressure on them, then it is polarized this material is polarized. So, this type of materials is called piezoelectric material or just converse, one reverse, one if you stress means in a how to produce stress pressure, then it is materials dimension will change, if you apply pressure. So, basically due to change of dimension, this polarization occurs and that polarization occurs means then basically, you are getting in terms of voltage that polarization that charge, you are getting charge basically so that you can get in terms of voltage in terms of electric field. So, here this type of material, we used to ex to express to get the electrical signal from the stress.

So, stress can be mechanical stress, it can be converted into electrical signal because of the stress, we are getting, it is there material is polarized. So, this. So, just reverse on. So, you are getting say, if electrical signal you are getting voltage. Now, if you apply the voltage in this material then it is dimension changes, if change the dimension then you will get electrical, this material is polarized you will get electrical signal that can be in terms of charge or voltage not current in case of dielectric material. So, getting say voltage. So, now, if you apply; so, pressure is giving voltage. Now, if you apply voltage then, it will give pressure. So, due to it this material will feel pressure. So, due to feel stress, they feel force and due to that it will change the dimension. So, that this, that material is used to measure the displacement you know in nano meter order.

So, we tell generally, we tell is this Peizo; Peizo rive, Peizo; Peizo drive means this using this dielectric piezoelectric. Piezoelectric material one can displace, the displace any object putting on that material; displace this subject in nanometre scale. So, this that is the greater application. We use in our laboratory, generally when we need displacement of this order of nano meters, even a less even, will be angstrom. So, you know this atomic force microscopy magnetic that is STMSTM scanning tunneling microscope.

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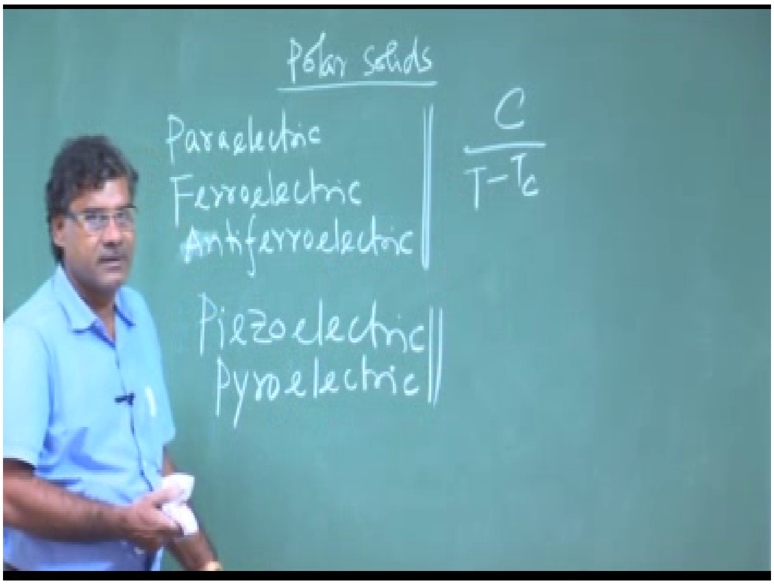

These are the microscope using, this microscope. We basically, image this image of material and this in atomic resolution it is not really atomic resolution, but is resolution is less than nano meter less than one nanometer. So, we can take image on a surface of this material and we can see the arrangement of the atoms on that surface or in this material. So, now, you need something to move, because you are scanning. So, scanner has to move in nano meter scale. So, how to move?

So, there we use this Peizo electric material. So, we apply voltage. So, on this Peizo electric material and then Peizo electric material changes dimension and it is then it moves the scanner moves. So, scanner set of this Peizo electric material are it is taken in shape of cylinder basically, and then it it moves. So, applying voltage on this, on this Peizo electric material. So, our scanner moves and it takes the image of the surface. So, these are very useful for very fine movement in nano scale. So, this is the one type of dielectric material and very useful for device and pyroelectric material, pyro means I think temperature pyro is specifically temperature. So, if you change the temperature of the material, then it is polarized, this material is polarized. So, there are some dielectric material if you change the temperature of this material.

So, it is polarized. So, then again here this material, we use that as a temperature sensor to measure the temperature basically, high temperature when you temperature of this say few thousand degree centigrade. So, in that case. So, this type of material is used as a temperature sensor and we measure the temperature. So, this material is temperature sensitive, when temperature changes, then it is polarized means, again it is giving me charge or voltage electrical signal. So, temperature is converted into electrical signal. So, that is a, that is the pyro electric material, it is dielectric, but type again classified as a pyroelectric material. This material is sensitive to the temperature.

So, just I am telling definition, because I am not describe more, because already this course is I have taken lot of classes and I have to finish the otherwise, it will be heavy for you. So, and that is for undergraduate level that is good enough. So, this ferro electric. Now, ferroelectric material is a dielectric material. So, dielectric there are different kinds. So, among polar solids. So, these are the different types. So, ferroelectric material is if this for ferroelectric for Peizo electric for dielectric, for this all this three types of material. So, one condition is required, that is this it is very sensitive to the structure of the material, you know very sensitive to the structure of the material. So, generally, we tell this, it is symmetric material or non symmetric noncentrosymmetric material. So, this symmetric, we express in terms of rotation.

So, this material has to be to be ferroelectric to be Peizo electric to be pyro electric. It has to be noncentrosymmetric. It has to be noncintrosymec symmetric, means a rotational with respect a rotational symmetry. So, there is symmetry. So, noncentrosymmetric. So, I will not explain. So, this the, it is just I want to say this very structure sensitive. So, among. So, so this. So, pyro electric or Peizo electric whether it is ferroelectric or not or oror they are vice versa. So, it just want to clear I.

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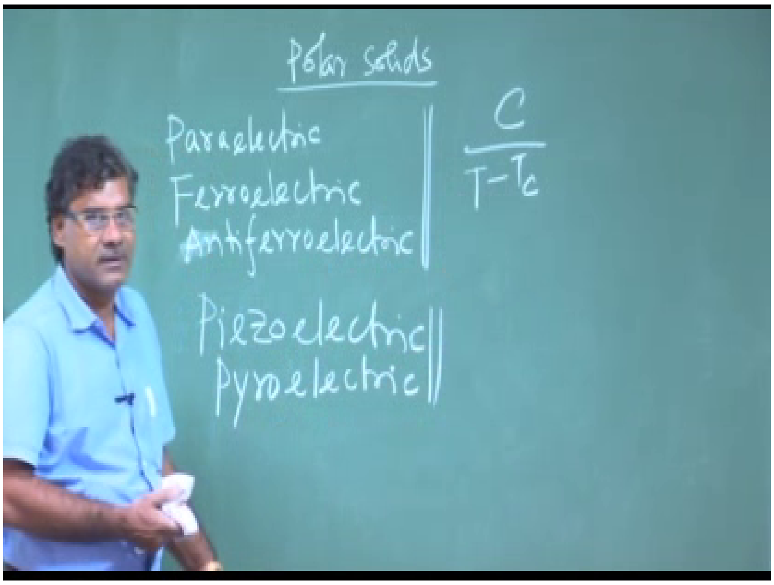

So, generally it is, there are 21 classes of noncentrosymmetric, 21 classes of non symet centrosymmetric material. So, this 21 out of this 21, it is selling 20 class of non symmetric, noncentrosymmetric material or this Peizo electric type or this Peizo electric type and they can, then out of this 20 class of noncentrosymmetric material, only 10 class of noncentrosymmetric material are pyro electric and now, out of this 10 class of noncentrosymmetric materials. All are not ferro electric, some of them are ferroelectric.

So, what is the condition to be ferroelectric. So, noncentrosymmetric, it is not the only condition to be ferroelectric condition, is that this dipole moment permanent dipole moment, whatever this material is having. So, it is change, it is orientation with with respect to magnetic field, electric field. If this polarization, if this dipole moment is changeable applying electric field, if it is direction can be changed applying electric field, then only it is called ferroelectric material. Now, it is ferroelectric it is similar to mag ferromagnetic. So, it has hysteresis loop, right. So, these are called, this P verses, this electric field P versus electric field. So, this remanent polarization, saturation polarization field that electric field. So, this same way, we express.

So, I think, I will not discuss about this things more. So, these are the overall idea, I could give, you about this, dielectric material and this three are very important for application and this seems, these are very similar to the ferromagnetic material. So, one can understand from this same concept and these 2 are very important for any purpose that just I told their definition and this way I just told you that how. So, applying electric field, the dipole moment direction of dipole moment of all materials is not possible to change. So, there are very few materials, dielectric materials are there. So, they are this dipole moment are changeable with the electric field. So, now, I will tell you about the just briefly, I will tell some few statements or few definition of superconducting materials. So, I will just briefly tell about the superconductivity. So, superconducting material.

So, you must have heard this, then and it is very important for application, but unfortunately, it is observed only at low temperatures, only observed this super conducting property of materials, at low temperature, how low; what is the as I told in science one has to define the parameter. It is not high small low, it is not very effective. So, basically, this how we get, the, how we can reduce the temperature of a body. So, that basically, we use liquid helium.

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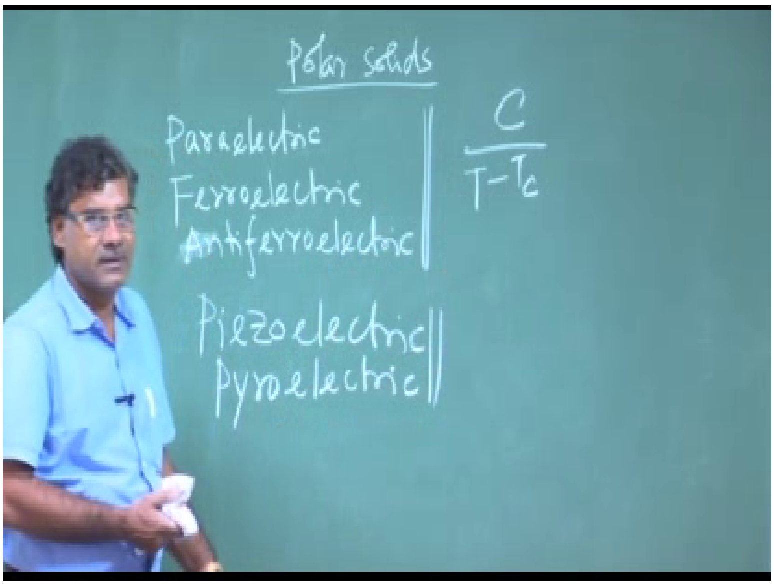

So, liquid helium that temperature is basically four Kelvin probably I told you earlier. So, this the four Kelvin. So, this superconductivity, first it was discovered at 4.2 Kelvin of mercury HG mercury, when the resistivity of this mercury was measured. Resistivity of this mercury was measured as a function of temperature. So, it is behavior was.

So, it is a changing it was changing. So, when temperature is decreased, then it was changing like this and then suddenly jumps, it comes to the 0 resistivity. So, this the the observation, first was made by I think, this what is then this, Kamerlingh Onnes in, I think in 1911, that was first observed in 1911, yes, Kamerlinghonnes. He observed this type of behavior of resistivity as a function of temperature, because we know this for normal metal, if it is pure generally, this temperature varies, if it is pure temperature it is resistivity varies linearly like this. It is not all the time linear.

So, I think it is may be I think lower temperature, it is like this, I think variation like this, but this is the material is impure, then it is variation, variation is like this, because there in that impure material, there is a residual resistivity RHO 0. So, that was the behavior of normal material, normal metal, I can say metal, but suddenly this was observed and this resistivity 0. So, this behavior is basically, is called the superconductivity and this temperature, here where below of this temperature. It is resistivity is ISIS 0 resistance of this material is 0.

So, that temperature is called critical temperature. Below this critical temperature, it is different state than the normal state of metal. So, then we tell this normal state of metal and superconducting state of metal; so, below this temperature, this new state of metal, where resistance is 0 that we tell superconducting state and above this temperature it goes to this normal state. So, there is a phase transition at this temperature from superconducting state to the normal state or normal state to superconducting state so, but it is not the only condition that this will resistance resistivity will be 0, then it is superconducting, most important property of superconductor; it is more useful, more authentic characteristics of superconductor, is the magnetic property of the superconductor is a diamagnetic superconductor is a diamagnetic right.

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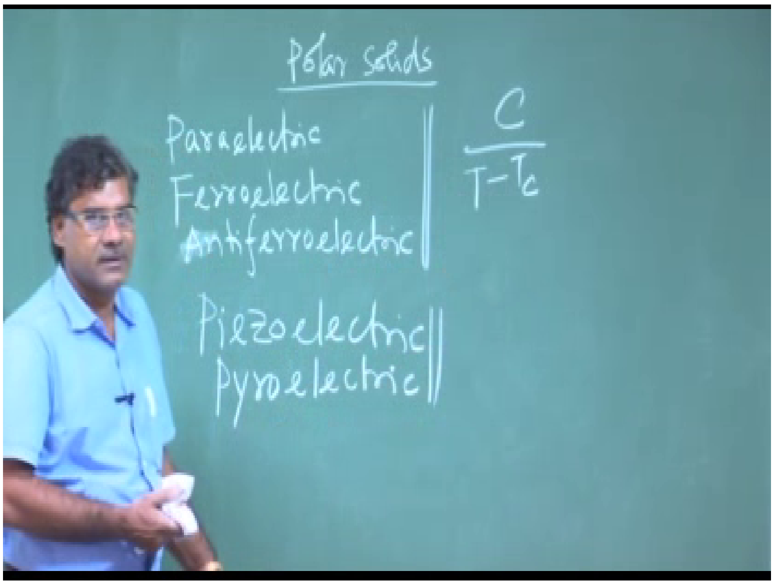

So, that is the, that is a marginal effects, this very nice effect or discovery that say if you have taken a material. Now, put in a magnetic field. Now, you are changing the temperature, you are changing the temperatures of this material. So, now, this temperature, here in this case, it is greater than TC; that means, it is a normal state, this metal is it normal state. Now, if you decrease the temperature and come the T is less than TC come T, at less than Tc, then it becomes superconductor, it will tell, it is superconductor, if you find this type of yes. So, if you we find this type of change of of magnetic field, see in this case magnetic field is passing through this, the metal material. When temperature is less than TC and when temperature is less than, sorry here greater than TC, when it is less than TC, then this magnetic material, a magnetic field is not passing through this.

So, this is perfectly diamagnetic. In case of diamagnetic, you know this magnetic field cannot make at this diamagnetic material. So, in case of diamagnetic, what happens. So, you know this B equal to B equal to MU 0 H plus M. Now, here B 0, 0 inside the material. What is the flux density that is 0. So, B this is equal to 0. This is equal to 0 so; obviously, H equal to minus M. So, when you will draw, when you will draw the magnetization as a function of magnetic field, as a function of magnetic field, what you will see here I have taken negative sign. So, if you. So, you will see this type of change. So, keeping this at TEP T at temperature, it is less than TC, but if you keep being this temperature at T equal to 0 is 0 Kelvin, it is not possible to a go to exactly 0 Kelvin, but close to the 0 Kelvin. So, bar, but for definition I have to tell that, when temperature is at 0 Kelvin, then you will see that is, say it is changing, you are changing the magnetic field. So, it is magnetization minus M is changing linearly right. They have linear relation.

So, then suddenly what happens. So, after that it magnetization become 0 it drops. So, this case here, what happens. So, there is a critical field, there is a KI critical field for superconductors, when temperature is T equal to 0 and this is the highest magnetic field HC, critical field. Bellow this critical fields it is diamagnetic and above this critical field, it is not diamagnetic, because it is not following this curve, this straight line, the suddenly it is stop drop.

So, then we tell that this superconducting material is superconductivity is destroyed by magnetic field. So, it goes to for superconducting state to the normal state. So, HC is the critical magnetic field, below of this critical field the material is in superconducting state and above this critical field, it goes to the, it is phase changes and it goes to the normal state. So, not only temperature is important. So, generally we defined in terms of temperature, but is not all the temperature is important, but this magnetic field also important, because magnetic field destroy the destroy the superconductivity.

So, now, interesting, the interesting things is that this superconductors is basically, can produce the highest magnetic field you know. So, far in our laboratory using electromagnet, we get just hardly 2 to 3 maximum 2 to 3 tesla, but using this superconductors in our laboratory. We get 10 to 20 30 tesla so, but this critical field generally most of the materials we see, where it is a very less than 1 tesla, say few milli tesla. So, is less than 1 tesla. So, if you apply magnetic field above 1 tesla of this field. So, it will not be superconductor, it will lose the superconductivity. So, then how this superconductor is producing the maximum like 10, 20, 30 tesla field.

So, that is the question. So, I will answer of it. So, to answer of this question. So, basically, we have to classify it. So, this effect diamagnetic effect whatever observed.

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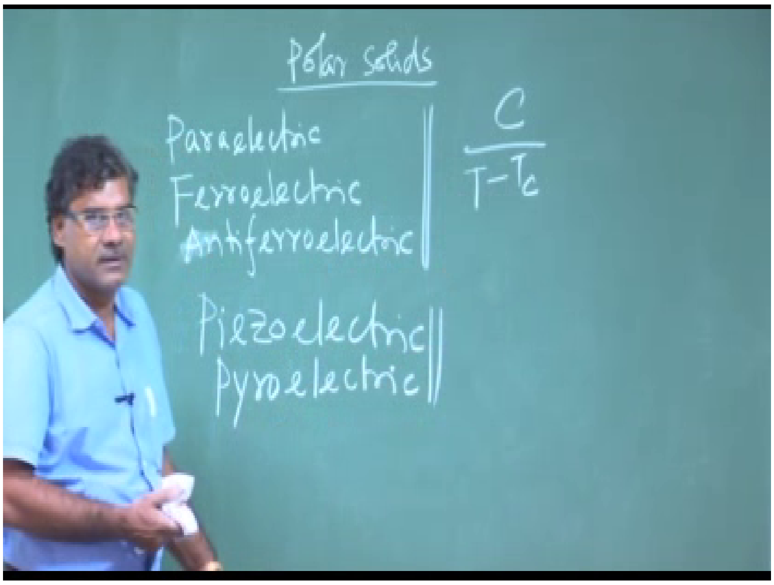

So, this called meissner effect and this is the very authentic tests for superconductivity, that it has to be diamagnetic it is not only RHO equal to 0. It is not the sufficient condition, it has to be diamagnetic. So, then there is a again critical field now this. So, these 2 types of. So, we classify the superconductor into 2 types. So, one is called type one superconductor, one is called type one superconductor. So, type one superconductor which follows, this say it is critical magnetic field is HC, which allows this. So, HC 1 can write say, generally I prefer to write, yes, BC I prefer to write BC, AC also one can write any way. So, when it follows like this. So, then it is we tell this type one superconductor, but there are some materials where it follows like this.

So, after coming here. So, then from here it starts to decrease, it has start to decrease. So, it does not follow this one. So, does not follow this one. So, then. So, this the one critical field. This is another critical field. So, this we tell if it is BC 1, BC 1 and this BC 2. So, if some materials, if it follows, this type of behavior minus M verses this magnetic field, it follows this type of behavior, then we tell this the material is superconductor type 2 superconductor and basically, type 2 superconductor is responsible for this higher magnetic field from superconductor. So, how that I will explain, how we are getting higher magnetic field, in this in from this type 2 superconductor. So, here you see here you see this. So, this type 2 superconductor I think. So, here what is happening.

So, instead of it a. So, this changes like this, it is following this type one superconductor curve, but here instead of coming to 0, it is decreasing like this. So, it is decreasing slowly. So, this part. So, this one, this we can tell this the purely, we tell this purely, the super purely superconducting state, this purely superconducting state and in this region. We tell between BC 1 and BC 2, in this region say is, it is superconducting state it is decaying so; that means, that is the. So, something is growing. So, normal state is growing. So, then between these 2 this part. So, this part will tell the mixed state. We tell mixed state. So, above BC 2, that is the normal state above BC 2, above BC 2, it is the normal state. So, this the mixed state. So, mixed state means this superconducting state as well as this superconducting state as well as this normal state are there.

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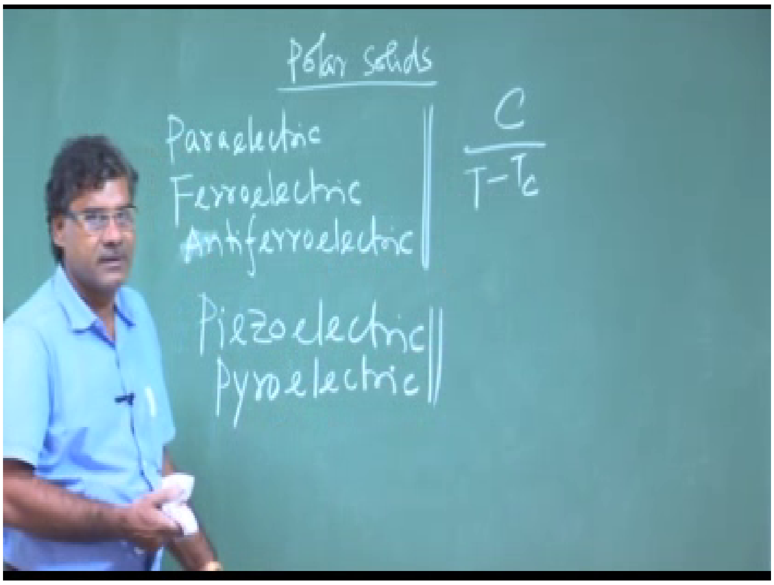

So, now, very interesting event, if you take a type 2 superconductor or if you take a superconductor. So, say in cylindrical form.

Now, put in magnetic field, put in magnetic field and when and apply magnetic put in magnetic field and change varies the magnetic field. So, when it is magnetic field B is less than BC less than BC less than BC. So, if it is type 2 superconductors. So, I can write less than BC 1. So, it is the pure superconduct state. So, you will see the magnetic field change of magnetic field as you have seen like just diamagnetic case. So, as if it repels from this. So, no field will be through this, now if you, if your field is if your field between B is greater than BC 1, but less than BC 2 less than BC 2, then what will happen, then you will see what you will see you will see that as I told this, it has, it is mixed state.

So, it has. So, this has superconducting phase as well as that normal state normal met. So, here interestingly. So, this magnetic field. So, if it is the how they arrange normal state and this superconducting state both are how they are arrange here. So, here basically, this normal states, they form a column basically, they form a column, they form column base, column wise, there if it is this is the shape of the material now you now magnetic field these are the i see this column only this normal state column is only normal state. So, now, your magnetic field magnetic field will pass through this magnetic field will pass through this and it will of course, it will pass. So, it pass through this. So, basically. So, now, this these are called vortex these are called vortex these are called vortex and the interesting thing is that this through this vortex through this vortex, the how much magnetic field will pass through it, any amount of magnetic field cannot pass through this.

So, this field is only the amount of magnetic field pass through it the flux pass through, it that is that is phi 0, that is phi 0 and interestingly, it is equal to 2 E phi 0 equal to H by 2 E and they are constant and then this value, if you put 2.067 into 10 to the power minus 15 waber meter, waber. So, this vortex, thus the normal state of the material, they are their size or their arrange in such a way. So, only this amount of flux will pass through that. So, how much flux will pass through this superconductors in case of type 2 in case of in mixed state. So, that depends the density of the vortex the density of the, yes I think that depends on the density of the vortex and if the density of vortex is N density of vortex is N. So, total flux will pass through it equal to N PHI 0, that is nothing, but magnetic flux magnetic induction B, because per unit area, what are the flux that is the magnet. So, that is basically, B passing through this material.

So, now imagine that this superconducting material is type 2 material and in this range, it has this kind of vortex. Now, this material is sensitive, it is selecting, it is selecting, it is allowing that this tiny amount of the flux through it. So, this material is sensitive can sense to this very tiny flux very small change of magnetic field. So, that superconductor is very is in all laboratory. We use to detect the flux and that is the basically, in case of squid, in case of squid that is the on magnetometer superconducting, squid superconducting quantum interference device superconducting quantum interference quantum interference quantum; quantum interference device squid in squid. We can measure, the mag change of magnetization. So, change of magnetizing in terms of flux, you will get the magnetic field of flux and using this superconductor, we can measure the change of the flux they are basically, we use this instead of Josephson junction, probably I will tell you about that one.

So, this is the very interesting phenomena of superconductor type 2 superconductor and this type 2 superconductor is used for producing the magnetic field producing the magnetic field, a very high field, because this BC 1 is very small, but BC 2 of some materials is very high even 100 even 100 tesla BC 2 of some material is equal to 100 tesla. So, because of this high field. So, below of this field, we can use superconductor. So, it will remain superconductor, although you say, it is in mixed state, but is sufficient for our purpose to produce, the magnetic field, if it is purely superconductor state, then if you put current once in this loop, then there will be no no loss all the time current will pass through it and you could get magnetic field from that current in a loop, but since it will be in mixed state.

So, there will be some normal state also there will be some resistance. So, there will be energy loss, but this helps us to get very high field. So, there are many things in superconductor, but I think another part is Josephson junction, the just I will tell how the Josephson junction and this any flux, these basically, called the flux quantization, you know it is just flux quantization is just similar, if you take a ring of superconductor and then passing through this how flux pass through it, through inside the superconductor, if you take this ring of superconductor, how FLA FLUX pass through it, how FLUX pass through it.

So, this FLUX basically, any flux cannot pass through it. So, it is quantized this flux is quantized. So, only this among the FLUX PHI. It has to be N times of PHI 0 and that is the PHI 0 that is the PHI 0. So, this control is in this order you know PHI 0 and this value is this. So, that is why, it is very sensitive to this magnetic field yes. So, then another interesting

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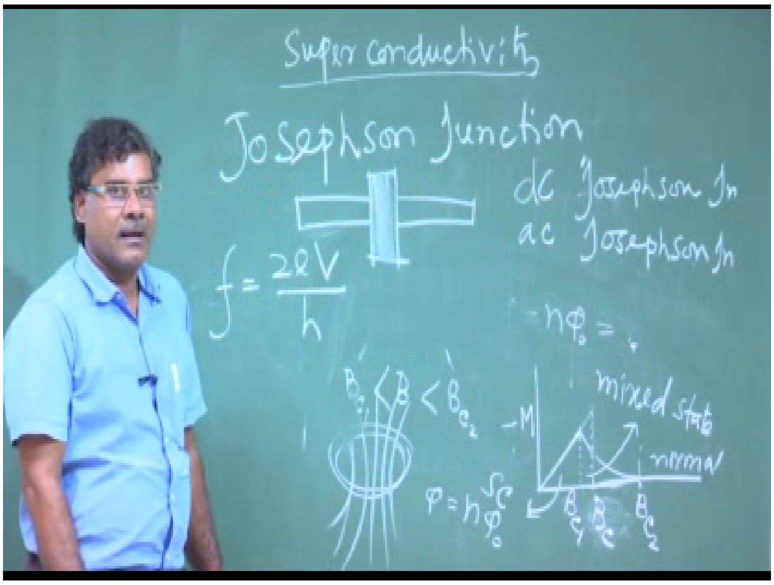

phenomena is now basically, the Josephson junction. So, basically, 2 superconductor is separated by a 2 super conductor is separated by is separated by a 2 superconductor. This is 1 sup superconduct, this is 1 sup super conduct separated by insulator, separate by insulator, then this is called Josephson junction and interesting is the without applying, any voltage electric field.

So, there is a current through the junction, there is a current through the junction and. So, that is called the dc Josephson junction, gc dc Joseph Josephson junction. So, without applying any voltage, if you, if we get current through the junction, then it is called the dc Josephson junction. Now, if you apply dc voltage, if you apply dc voltage across this junction, then you will get current ac current, you will get ac current through this junction ac current through this junction and frequency of this frequency of this ac current is 2 ev by h 2 ev by h 2 e v by h. Here, h by 2 e are here 2 e by h times v. So, that will be the frequency very interesting applying dc voltage, but getting ac current through this junction. So, that is called ac Josephson junction ac Josephson junction and this these Josephson junction basically, the 2 Josephson junction is used in this magnetometer squid magnetometer, say if you this 2 squid it is a now, it is the basically, 2. So, 2 junction.

So, here we are putting through this, we are putting just passing current through it and here current is going out. So, current will come here and this one current will flow through this junction. This is a j j 1 and another current will this other part will be through the junction, thickness of these 2 are different. So, when current pass through it. So, that j 1 is basically, j 0 and then yeah. So, depends on the phase, difference phase of current at this side, at the beginning and this phase of the other side. So, there will be phase different between, this both side, between this current of this 2 side. So, this generally it is behavior is like that delta 1 from junction 1. So, this phase, difference is delta 1.

So, j 2 is basically, j 0 sin delta 2. Here, phase difference is delta 2. Now, here total current, your total current is j, you know this total current is j equal to j 1 plus j 2. So, if you add them, if you add them, sorry, now if things are in magnetic field, you know if it is in magnetic field. So, if there is the magnetic field then this is the phase, if it is magnetic field, there is a phase, additional phase is added. So, that is e phi by h plus c e phi by h plus c and this is same, but it is minus this is plus. So, total will be j equal to j 1 plus j 2.

If we add then it is basically, you see, this you have sees, a change of phase, these are and now, if you add then the superposition of this 2 is, if the interference, you know and that interference it is a interference is basically, too light interference, because of the phase difference right. So, here you will get basically, this current whatever total current will get, that is you will get the interference and that interference, that current you can find out, that 2 times of J 0 and this sum sine term and cos term one can just find out. I will not write.

So, that current will depend on this term, you know H cross C, it will depend on this term. So, this current will depend on this flux magnet. So, if you are mirroring magnetization. So, change in magnetization means changing the flux. So, this things is there. So, it can detect it; can detect the change of this flux which is coming from magnetization. So, change of magnetization will get in terms of change of flux, when flux will change, will get this change of this current and that current change one can just from here, one can show this current change like this maximum minimum kind of things. So, that is why we tell this instruments, squid superconducting quantum interference device is this nothing, but this is there and this current their magnetic field is produced, that to this, if you take the solenoid of superconductor type 2 and this or this or this ring and you pass current through it, and you will get current in a ring or in a solenoid.

It will give you magnetic field. So, as thus normal procedure, but. So, here one can, because there is the loss of many, there is no much loss of current. So, you can apply huge current in the, you consider huge current without voltage or with small voltage. You can set huge current in this loop and then you can get huge magnetic field and that has to be less than BC 2, that has to be less than BC 2 otherwise, it will destroy this superconductor. So, this, the way we produce the magnetic field in superconductor, I think this is the, just without telling just qualitatively, I tried to tell you without using any expression and the theory to understand the superconductivity. Superconductivity has gap, [FL] peers say within whatever, I discussed everything is derived from the theory, it is called BCS theory Bardeen Cooper and Schrieffer. So, BCS theory.

So, that I think is you do not need for undergraduate students. So, this just overall, what is superconductive, what are the main properties of super-conduct, just I give you just rough idea about it. So, of, I think, I will stop here and I finish this course, it is already I think 75 lecture or 76 lecture. So, I think this, it is better not to tell more about the things, then this course will be heavy for you, for undergraduate student. So, I think you have to wait for the higher study to learn more about these things.

Thank you for your attention, I will stop here.