Experimental Physics - III

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Lecture - 31
Superconductivity

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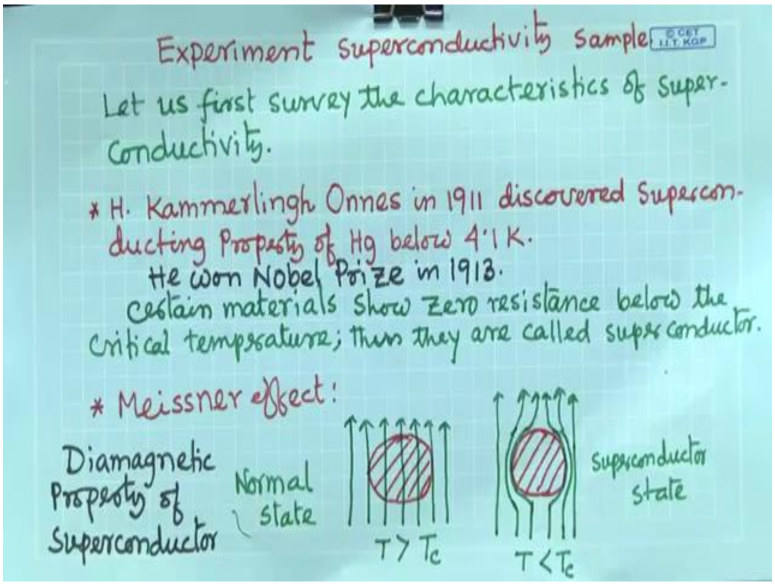

Today I will discuss about Experiment on Superconducting sample. Let us first survey the characteristics of Superconductivity. you are quite familiar with the super conductivity. Let me just tell about it once more.

This H Kammerlingh Onnes in 1911 discovered super conductivity or superconducting property of mercury at 4.2 Kelvin or below 4.2 Kelvin temperature. That was the first observation by Kammerlingh Onnes in 1911 when he was doing experiment, he was measuring i v characteristics of mercury as a function of temperature, as a function of low temperature.

Suddenly he observed that when the temperature reach to 4.1 Kelvin, the resistance of the sample suddenly become zero and for this discovery he own Nobel Prize in 1913. certain materials show zero resistance below the critical temperature. This critical temperature are different for different materials, thus they are called superconductor, since its resistance are zero and current will flow without loss of energy. that is why it is called the super conductor.

Now, superconductor its resistance is zero, this is one criteria, but it is not the only one criteria, there are some other criteria's. one more criteria it should fulfil otherwise we cannot tell even this resistance is zero, we cannot tell we cannot claim that it is a superconductor. That is this diamagnetic property of superconductor; diamagnetic you know this it refill the magnetic field; that Meissner is, it is called Meissner effect. this if you take a material and cool it.

When the temperature is greater than T c Critical Temperature then the magnetic field if you place that material in a magnetic field and you are changing the temperature of that material. above T c magnetic field lines of force passes through the through the material, when the temperature comes below the T c; T is less than T c then magnetic field lines of force it cannot pass through the material. That material repels the magnetic lines of force. here in figures I have shown it. Then this is the property of superconducting state superconductor.

This effect was discovered by the Meissner. that side is called the Meissner effect. These are very famous effect in superconductivity and there are application based on this Meissner effect. Next, you heard that at a high T c superconductor is very popular name high T c superconductor. As you have seen that this first superconductivity was discovered at 4 Kelvin temperature.

This temperature is quite low temperature and it is very difficult to attain this temperature for this. You need helium liquid helium and this is very costly, and it is difficult to handle this liquid helium and this is the barrier of barrier of application device application.

People are trying to get this effect in in room temperature or above room temperature. then this the superconductor discovery of superconductivity could change the world. People are trying hard to get this superconducting property in some materials at or above room temperature. as a result this another type of superconductor discovered the superconductivity was observed at higher temperature.

That we call that high T c superconductor, but what is the reference of that temperature, above which temperature it will be called high T c superconductor.

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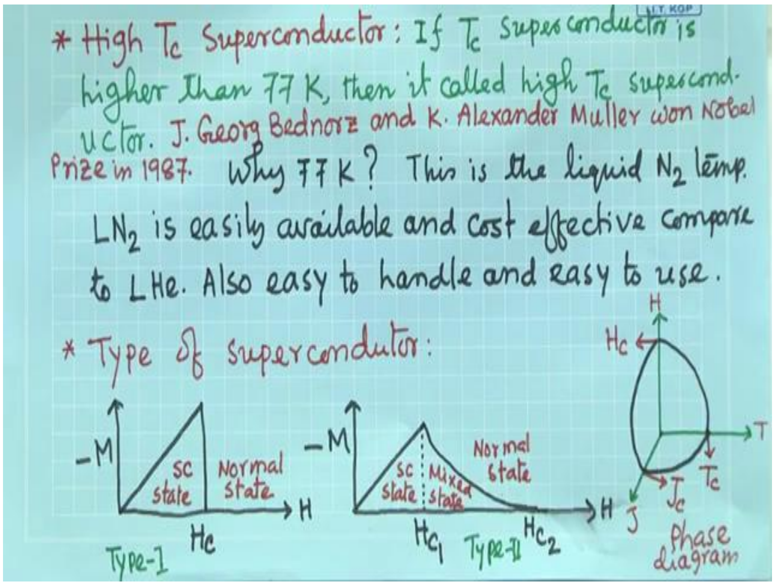

This reference temperature is 77 Kelvin and this first the high T c superconductor was discovered by was observed in some special type of materials ceramic materials and that was discovered by J. George Bednorz and K. Alexander Muller they won Nobel Prize in 1987 for this discovery of high temperatures superconductor. Now, question is why 77 Kelvin is taken as a reference temperature these 77 Kelvin is the boiling temperatures of liquid nitrogen.

Liquid nitrogen is easily available and cost effective compared to the liquid helium, also easy to handle and easy to use. at least one barrier is could overcome if you get the superconducting material above 77 Kelvin above or above liquid nitrogen temperature. That is why this temperature is taken as a reference above this temperature, the superconductors are called high T c superconductor and there are lot of application of this high T c superconductor.

Next type of superconductor; 2 types of superconductor type 1 and type 2 with respect to magnetic field. This the superconductors are divided into 2 category type 1 and type 2. Here I have plotted you see minus M as a function of magnetic field. if you measure the magnetization of superconductor it is diamagnetic. It is magnetization is it is a negative magnetization; I have plotted negative magnetization as a function of magnetic field. You are increasing the temperature it step by step and measuring the magnetization and plotting.

After certain value of magnetic field suddenly the superconducting property or superconducting property are destroyed ok, it come to the normal state from superconducting state to the normal state. keeping temperature at a particular temperature, now you are changing the magnetic field and the magnetic field there is a critical temperature with critical magnetic field. Below of that critical field, the superconductor it will remain in superconducting state and above that magnetic field it will superconductivity will disappear and it will come to the normal state, ok.

That is why here I have shown. here there is a sharp phase change of superconducting state to the normal state. If this type of material we call type 1 superconducting material and type 2 superconducting, material it is magnetization changes with magnetic field like this. initially like type 1 linearly it is varying magnetization and then it is slowly decreasing not suddenly just drop to 0; 0 means, it will must be superpower diamagnetic to paramagnetic. Slowly it is changing and goes to the 0, magnetization goes to the 0.

Initial part is like type 1. here this magnetic field will tell H c 1. This is 1 critical magnetic field; first critical magnetic field and then where it becomes 0. that it is H C 2 that is the second critical magnetic field. Here this I have written SC State, superconducting state. Below H c 1 it is in superconducting state, above H c 2 it is normal state and between H c 1 and H c 2 the state is called mixed state; mixed state means, it is the mixture of superconducting state and normal state, ok.

When from H c 1; when magnetic field is increased it is superconducting states some portion of the materials just transform to the normal state and when magnetic field is increased the transformation of superconducting to the normal state is increased and finally, this whole material become the normal state. if this type of property is absorbing some material. Then these materials is called a type 2 superconductor; type 2 superconductor.

Again it has also application. this phase diagram I have drawn here. One thing is clear that this temperature can destroy the super conductivity, magnetic field can destroy the superconductivity, and current passing through the superconductor can destroy the superconductivity. there are limitation of this temperature magnetic field and current density, superconducting state or superconductivity depends on these three parameters. Here I have done this phase diagram.

This axis is J current density say x-axis, this y-axis is say temperature and z-axis say this is magnetic field. Here inside this loop inside this loop it is super conductive state, outside of this loop is normal state. If you see this T c, T c is defined as that when magnetic field is 0 and current density is 0, ok. then the temperature at which the superconductivity will destroy. That temperature is T c.

Similarly, J c critical current at 0 magnetic field and at 0 temperature what are the maximum current can be passed through the superconductor. That maximum current density is called the critical current density J c; similarly, H c here at 0 this because this is on z axis, H axis. T is 0, J is 0 for this magnetic field that is H c., and maximum magnetic field at 0 temperature and at 0 current density whatever maximum magnetic field we can apply and beyond that magnetic field superconductivity will get destroyed. that amount of magnetic field is critical field H c.

That is the meaning of this phase diagram. depending on the temperature, depending on the magnetic field how much current you can pass through these superconductor depending on the current density, depending on the temperature how much magnetic field. You can apply on the superconductor without destroying this superconducting property. That is one can find out from this phase diagram.

This is the very surprising material and it was very difficult to explain this object property. Theory was very important, and this theory was fruitful theory; first fruitful theory which can explain all superconducting property that is BCS theory; BCS theory John Bardeen, Leon Cooper and John Schrieffer.

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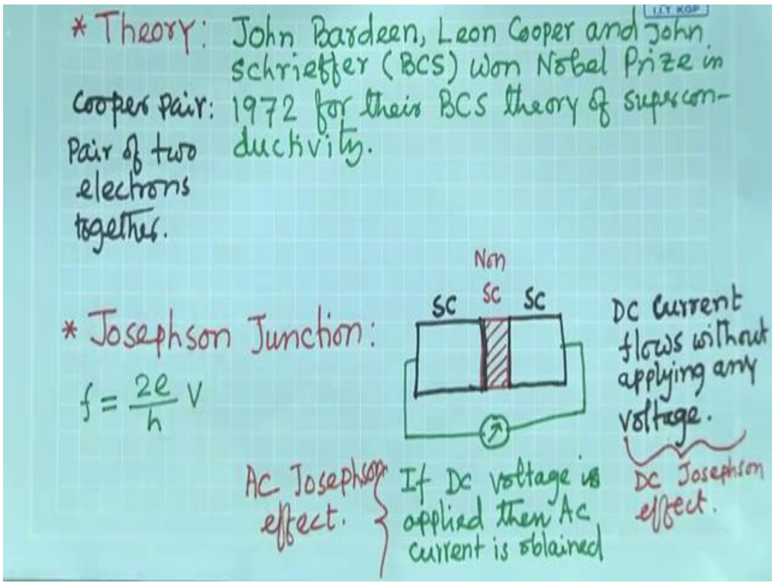

BCS they won Nobel Prize in 1972 for their BCS theory of superconductivity. It was very effective theory, which was able to explain all experimental results observed from superconductivity. In this theory the transport, in transport this cooper pair is considered since cooper pair is a pair of 2 electrodes together, ok. It is not single electron is flowing 2 electrons together they are flowing as if they attracted each other, they should repel each other, but as if they are they stay together, move together. That is called cooper pair.

Based on this cooper pair this theory was developed and it was successful that they got a Nobel Prize in 1972. Another discovery in in superconductivity that is Josephson junction. What is Josephson junction 2 superconductor is separated by a non-superconductor, ok; 2 superconductor layer is separated by a non-superconducting layer. Here I have shown; this is called this is called Josephson junction.

surprisingly without applying any voltage just if you connect a; if you connect a ammeter like this, then 1 can see the current flowing through this through this circuit without applying voltage. we cannot think about the current. What in this case if the structure is like this 2 superconductor is separated by a non-superconductor, then current flows, ok.

This current is DC current without applying voltage. this is called DC Josephson effect. If DC voltage is applied, then current flowing through a junction that is AC current. You are applying DC voltage, but getting AC current that is called AC Josephson effect.

Now, AC current when you are getting then there is a frequency of the current. If frequency is f of that current for when you applied voltage V. relation is like this f equal to 2 e by h V, here you see 2 e double charge it is a cooper pair charge of cooper pair 2 e by h. 2 e by h is the fundamental this constant fundamental universal constant, ok.

Now, this v for a voltage is applied. Corresponding frequency you will get. This nowadays, this frequency because it is easy to measure frequency more accurate accurately. That is why this as a standard voltage to standardize the voltage to calibrate the voltage. nowadays this, this method is that Josephson frequency is used to standardize the voltage.

For a particular frequency what will be the voltage or for a particular voltage what should be the frequency that one can calculate from here and one can standardize the voltage. this this junction is used to standardize the voltage. Next another important observation in superconductivity that is flux quantization; flux quantization, what is flux quantization?

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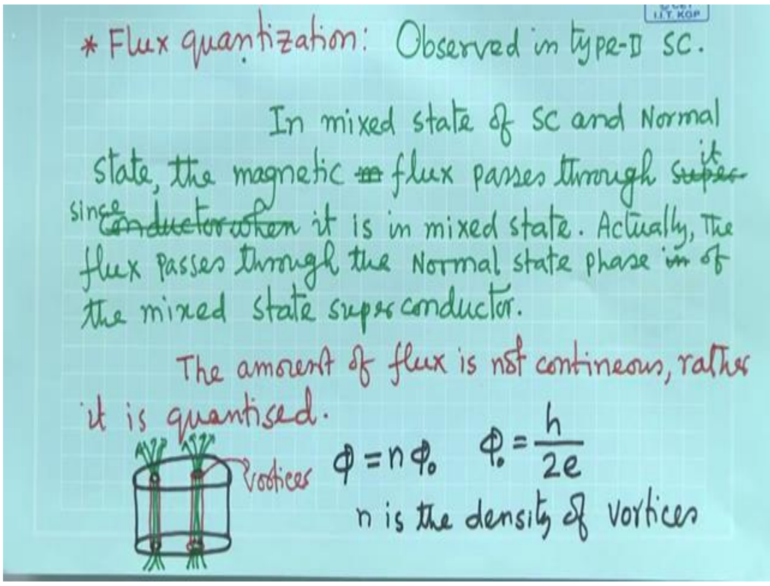

It was observing type 2 superconductor; type 2 superconductor as I told that you are measuring the magnetization as a function of magnetic field. initially linearly magnetization varies up to a it is first critical magnetic field H c 1 and then suddenly does not drop to the normal steps or magnetization does not drop to 0, but it slowly comes to 0 with magnetic field. That is why; that step between the H c 1 and H c 2, this as I told these are mixed state where this some portion of the material are in normal state in this superconductor material,

Now, this type of material if you put in a in a magnetic field. lines of force it will refill from the superconductor. it should not pass through this, it should not pass through the through the superconductor, but surprisingly this material that lines of force, some lines of force passes through these materials passes through this mixed state.

Now, then how this mixed state exists in this material. whether these if you if you take a say spherical ball of these superconductor. Now, these normal state where it is whether it is inside of the superconductor to be concentrated at the center of this sphere, and outside of the outer surface of the sphere is superconductor and inside of the sphere is in normal state or the superconducting state is in the center and outer surface is the is the normal state. It is not like this, it is like here I have drawn you can see the whole things are this metal are superconductor, but you can see this columnar form of the normal columnar form of the normal state.

It is called vertices it is called vertices. These ah; now, it the superconducting state converted into the normal state in such a way that it will form the vertices like this columnar this pillars, ok. that is why the magnetic field lines of force will pass through these vertices, will pass through these vertices; now, this how much magnetic field will pass through that. that will depend on the number of vertices, if 1 vertices is there this amount of field amount of amount of lines of force that is h by 2 e phi 0 equal to h by 2 e; phi 0 equal to h by 2 e this this amount of lines of force we pass through this 1 vertices, ok.

n phi 0; n is the density of the vertices ok, if more vertices are there it will depend on the number of vertices more vertices are there. That; if it is n number; n into phi 0 that amount of flux will pass through it. this is called a flux quantization, ok. these h by 2 e phi 0, it's a value is; I think it is a around it is a 10 to the power minus 15; in the order of 10 to the power minus 15 tesla meter squared since it is flux.

Magnetic field into the area that is the flux. 10 to the power minus 15 tesla meter square. This flux quantization is used to sense the magnetic field. It can as I told that it is of quantized. one can sense the change of this phi 0 amount of lines of force, ok.

That amount is 10 to the power minus 15-tesla meter squared. it is extremely small value and this extremely this small change of magnetic field can be detected using this this phenomena flux quantization. And, in principle, it is used in different devices one device is squeaked a superconducting quantum interference device quit. We use in our research laboratory for measuring the magnetic property. There these phenomena and Josephson junction is used for this quit magnetometer.

What are the applications of this superconductor; what are the application of superconductor, one very great application is levitation.

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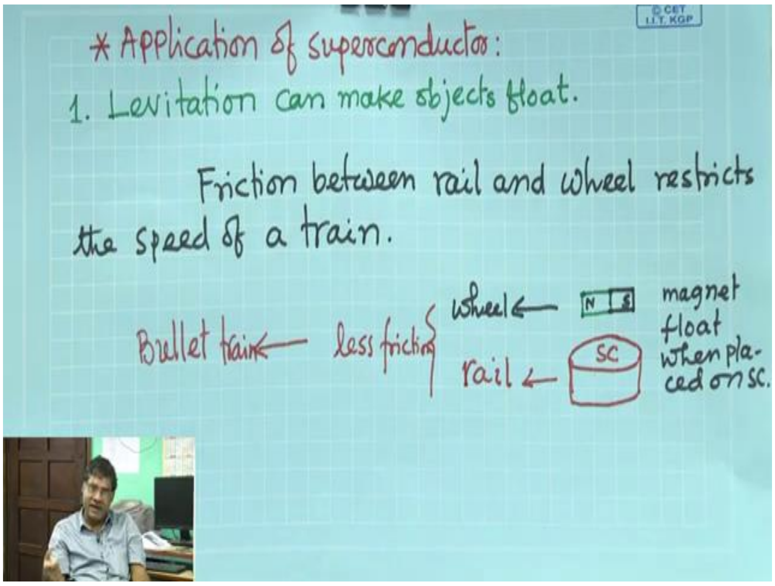

Levitation can make object float, in principle I can just stand in here if I wear a magnetic shoe and stand on a superconductor platform. Magnetic shoe; it will magnet it will produce magnetic field, now if I stand on the superconductive platform. Then the superconductor it will repel the repel the magnet. I will go off and this gravitational force and these magnetic these repulsive force between magnet and the superconducting. there will be balance, there will be equilibrium and in that equilibrium I will stand in here.

That is levitation, but for that, actually we need very powerful magnetic shoe as well as this bigger superconducting platform. Now, have you probably you have heard that that Japan, they have first they have discovered a very high-speed train bullet train, ok. It its velocity is exactly I do not know, but more than 500 kilometer per hour.

How it was possible, because the main restriction main restriction to increase the speed of a train is the friction between the rail and wheel. Rail wheel it rotates on the on the on the rail. This train is a heavy weight heavyweight train and now through this wheel it paste the paste on the rail, ok.

Now this when it will move because of this there will be friction tremendous friction. This friction restrict to the speed of the speed of the train, ok. If by some means if we can just push up the wheel from the rail. it is just in your it is a just it is floating on here or slightly touching the touching the rail, in this way one can reduce the friction and then it is possible to increase the speed of the rail. That is the technology that levitation technology is used by Japanese and they have demonstrated the fastest train in the world, bullet train. that is what I have described here.

These are very get application only restriction still it is not at room temperature superconductor is not available in room temperature. this restrict the application of this superconductor, but still people are trying in one day we may get this superconductor above the room temperature.

Another application there are many applications, but I just showed here the some useful application, which already people can see.

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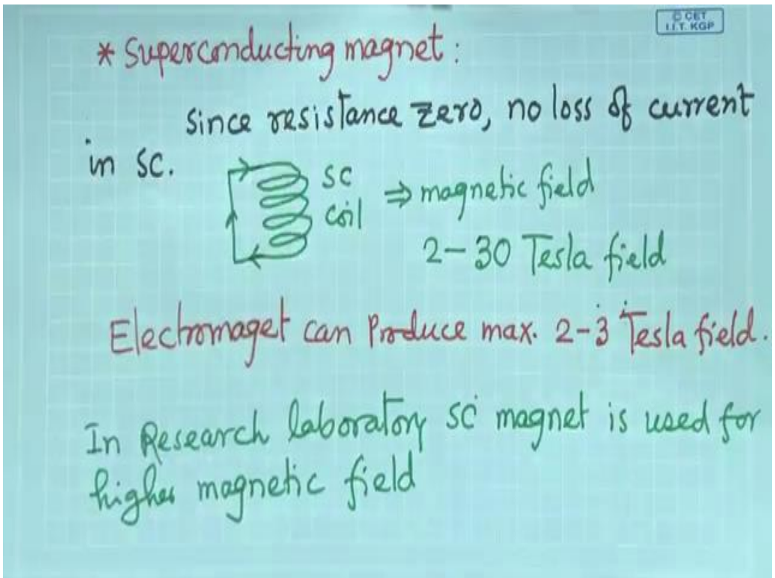

Superconducting magnet, you know electromagnet in laboratory we use. maximum it can produce 2 to 3 tesla field, beyond three tesla it is not possible to produce in laboratory using the electromagnet. for higher magnetic field say 2 to 30 tesla range if we need magnetic field, then we use in our research laboratory we use superconducting magnet, ok. Then superconducting magnet this coil is used made of super conductor and it just set current in this coil.

There will not be any loss of current. It will continue the continue the flow of current in the in the in the solenoid and it will produce magnetic field. as I told it can produce 2 to 30 tesla field easily and this type of superconducting magnet, we are using in our research laboratory. this is another very useful application of superconductors, there are many application, but I just explain this two application interesting application. I will stop here, I will continue next class.

Thank you.