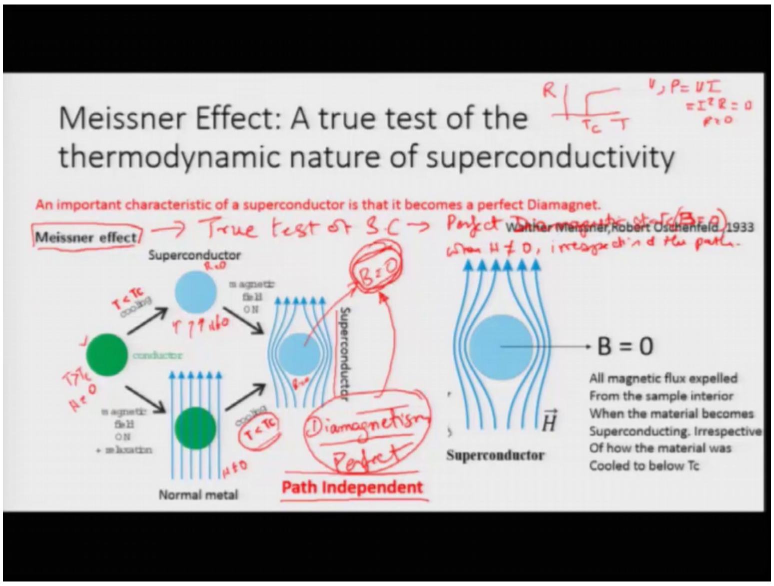
Introduction to solid state physics
Prof. Manoj K. Harbola
Prof. Satyajit Banerjee
Department of Physics
Indian Institute of Technology, Kanpur

Lecture – 82
Introduction to the Meissner state of superconductors and levitation

(Refer Slide Time: 00:19)



We had started taking a look at the phenomenon of super conductivity, which is the phenomenon in which if you measure résistance as a function of temperature; then below a certain temperature which is called as a super conducting critical transition temperature. The resistance goes very low, it goes below measurable values and typically it is considered it goes to the 0 resistance state.

So, the resistance of the material becomes very low, so if you make a magnet by winding a solenoid with this wire and you send a current into the solenoid, the current you send in can be send in 0 voltage. The power you required to send in the current in this which is I square R will be 0 because resistance is 0 voltage is 0 or we power required to send in the current is 0.

So, if you make transmission lines with these wires you actually can send current without any power and and this would make our power very cheap, but of course you need to cool them down and that is the bottle net technological bottle net that how do you transmit powers from a power grid to your home using super conducting wires. And room temperature superconductors as of today are still not available, you have to cool them down to make them super conducting, further more you can; however, make magnets.

If you take a solenoid and you wind up wire or super conducting material and make the solenoid send in a current with 0 voltage you can send in current. And you generate a magnetic field and you take away a power supply, the current will remain in that circuit indefinitely that is the persist in current and there will be a magnetic field which will be maintained in that coil. And these are used typically in MRI magnets which you are all find in hospitals and so on.

So, this is the phenomena of super conductivity, but resistance going to 0 is that the true test of super conductivity. It turns out that there a much more basic way of looking at super conductors a much more basic property of superconductors and that is the following. And that goes by the name of Meissner effect what is the Meissner effect? You can take a normal metal and you can apply a magnetic field to it and you can cool it such that it becomes super conducting.

So, there is the super conducting transition temperature of the metal which you have determined by the measuring the resistance as a function of the temperature. And basically you look at the behaviour of this metal which is super conducting how does it behave in the presence of the presence of a magnetic field? So, you have a normal metal you apply a magnetic field at some high temperature above its T C and cool it below its super conducting transition temperature.

What you will find is that, when the material becomes super conducting it expels all magnetic flucks from within its interior; whatever field was present inside the material is completely thrown out it gets completely expelled from interior of the metal. You can do the experiment in another way you take the normal metal at T greater than T C in a 0 applied field you do not apply any magnetic field which is this. And then you cool it below T C it becomes superconducting, namely as resistance R is equal to 0 this is also R is equal to 0. And then you apply a magnetic field to this you apply a magnetic field to this once it is super conducting.

In this particular case you had applied a magnetic field above T C and then cooled it below T C and here above T C you do not apply any magnetic field. You make it super conducting and then apply a magnetic field here too also it enters into a completely; there is no magnetic field inside the sample all magnetic field is thrown out from within the sample.

So, this property is called as diamagnetism, you have comes across this that whenever a material if you apply a magnetic field to it, it will actually try to shield the magnetic field from its interior it will not allow the magnetic field to enter into the metal. And you have come across in smaller ways in when you looked at the faraday effect Lenz's law, that if you take the metal ring and if you try to apply a magnetic field and then try to oppose the change in flucks by setting up currents which will apply a field which is opposite to that of the applies field. So, it will prevent the change in flucks by setting up currents ok; however, super conductors are the ultimate limit of diamagnetism.

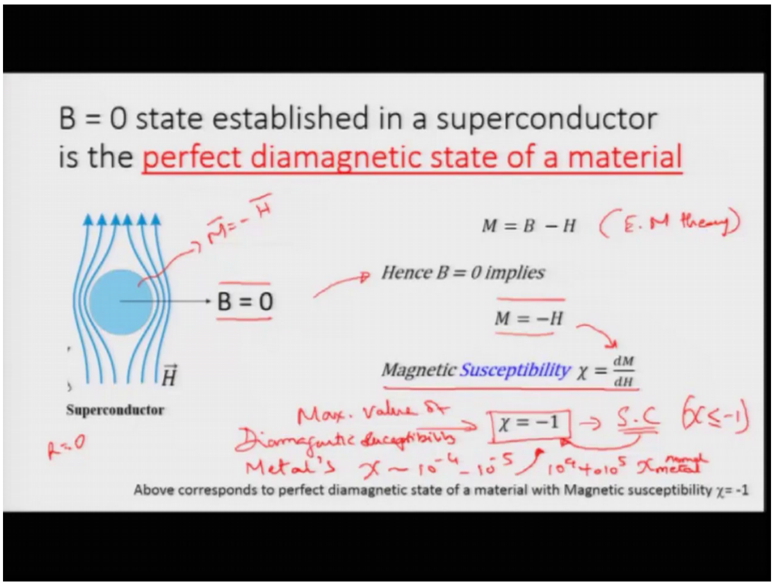
They setup such strong shielding currents that they make the applied field completely 0 and it does not depend on whether you have applied the field above T C and then cooled it down and then apply I mean the field is continuously maintained whether above or below and you just cool it down. Or there was no field applied you cooled it down and then apply the field in either cases irrespective of the path taking, you will enter into this perfect diamagnetic state. Perfect diamagnetism is when the field or the local field magnetic field inside the sample is perfectly 0; irrespective of the applied field the magnetic field which is present inside the sample is completely 0.

And this is the typical characters of super conductors any superconductor will exhibit perfect diamagnetism. Namely, if you apply a magnetic field it will throw away all the magnetic field from within its interior and this is the Meissner effect and as the Meissner effect was shown to the path independent, does not in which way you have applied the magnetic field, whether above T C you have applied the magnetic field and then cooled the sample below T C. Or you cooled the sample first and then applied the magnetic field either ways you will enter the perfect diamagnetic state of the material.

So, you may reach the unique state of the superconductor irrespective of the path and this is the true test of super conductivity, this is taken as the true test of super conductivity. Namely perfect diamagnetic state which is a B is equal to 0 state, the field inside the sample is 0 when applied field is non 0. And this state is reached irrespective of the path and this more than resistance going to 0 as a function of temperature below T C then Meissner effect is taken as the true test of superconductivity.

So, these expelling of magnetic field from interior of a super conductor is the true character of a super conductor. So any super conductor if you apply a magnetic field to the superconductor it will throw out magnetic field from within its interior. So, any super conductor if you want to know it is a super conductor then below T C you should observe the Meissner effect.

(Refer Slide Time: 08:05)



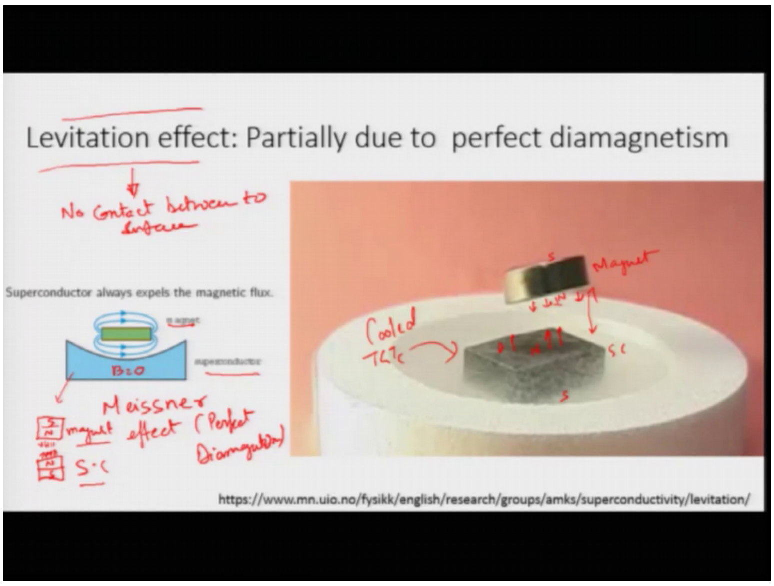
Let us look at this perfect diamagnetic state which is B is equal to 0 state, a little better why is it called as perfect diamagnet magnetisation is B minus H you know this from electromagnetic theory; where the magnetisation is B minus H and getting to a B state implies M is equals to minus H. This is the applied field M is equal to minus of H. The magnetisation in the sample is minus the applied field, it completely opposes the applied field and as a result inside the sample the make magnetic field becomes equal to 0. And the magnetic susceptibility chi is dM by dH. So, if you put that here you will get susceptibility of the superconductor is minus 1.

So, superconductor has susceptibility of minus 1 this is the maximum value susceptibility, this is the maximum value of diamagnetic susceptibility. Diamagnetic susceptibility cannot exceed minus 1, they have to be susceptibility has to be less than or equals to minus 1. And superconductors are the only materials which exhibit this maximum value of susceptibility and hence they are said to be in the perfect diamagnetic state, where the material can reach such high values of susceptibility typical metals have susceptibilities which are in the range of 10 raise to minus 4 to 10 raise to minus 5. You can see that the susceptibility of super conductor is orders of magnitude is always 10 raise to 4 to 10 raises to 5 times the susceptibility of a ordinary normal metal.

So, they have huge susceptibilities and they have the ideal value of susceptibility which can be reached and that is why you say that superconductor exhibit perfect diamagnetism. And this is a true character of superconductor, whereas R is equal to 0 can be exhibited by metals; if they become a perfect metal no collations, but of course a metal will not able to exhibit perfect diamagnetism.

Perfect diamagnetism is exhibited only by superconducting state and you can explain this only quantum mechanically, which we will not be able to get into as a part of this course. However, you should remember that for a superconductor perfect diamagnetism is the true character and signature of super conductivity.

(Refer Slide Time: 10:43)



Now, because of this perfect diamagnetism and the large diamagnetism that one has it leads to strange effects; one of the effect is the levitation effect, where you can take a super conductor and you can take magnet on top. So, you have magnet which is placed on top of a super conductor and the super conductor does not allow the magnetic field to enter into the superconductor because of the Meissner effect or perfect diamagnetism. B is equal to 0 inside the material as a result it will expel all the magnetic field from the magnet, which is applied to the superconductor.

And as a result their magnet actual floats on the top of the superconductor, rather than the magnetic field penetrating and passing and magnetising the superconductor the superconductor actually opposes the magnetic field. And as a result you can think of the superconductor if the magnet has a North and South Pole this is the magnet, you can think of the superconductor as having developed an equal pole. So, this magnetic field will be opposed, it will try to oppose whatever is the applied field from this magnet it will oppose it by creating a similar pole.

This is the superconductor. And as a result and you can you know that similar pole magnets repel each other and they can be actually made to float on top of each other and it actually creates the levitation effect. And there is a nice movie on the internet which you can check of levitation associated with superconductor and that movie I show you here. So, this is the super conductor and now you are placing a magnet on top of the superconductor and what you see is that the magnet is floating on the top of the superconductor. You can see that there is no nothing in between this magnet is floating on the superconductor you can think of the this end as the North Pole and this as the south Pole.

It is giving magnetic field from the magnet this is your magnet and this is your superconductor, which has been cooled to T less than T C and this magnet in the presence of this external magnetic field is generating and equal pole of North Pole and South Pole. This is generating an equal field on the other end.

So, this is opposing the externally applied field. So, that these fields are balanced out and because of these two repelling entities, if you adjust it properly you can balance the magnet on top of the superconductor and this is called as the levitation effect. So, you can balance a magnet on top of a superconductor and has no fiction, no contact between the 2 surfaces, no contact between to surfaces.

So, people have thought of trains called the magnet train where you can have a train which have a magnet which is floating on a rail, which is made of super conductors and you can have the train which is never going to touch the railway line; and it can go to a extremely high speeds.

And this has been actually tried out in Japan and they actually breaked the speed of sound and they go extremely fast, but because of safety issues it has not been implemented in they have been remained as an research prototypes and they have not been implemented. But superconductivity leads to perfect diamagnetism and the perfect diamagnetism leads to strange and exhuastic phenomenon of levitation.