Experimental Physics - III
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Lecture – 33
Superconductivity (Contd.)

We are in solid state physics laboratory of Department of Physics IIT, Kharagpur. Today, I will demonstrate experiment on Superconductivity.

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This is the experimental set up for superconductivity. As I mentioned that, we want to measure superconductivity as a function of temperature.

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IT measurement at different temperature, we will do these experiments.

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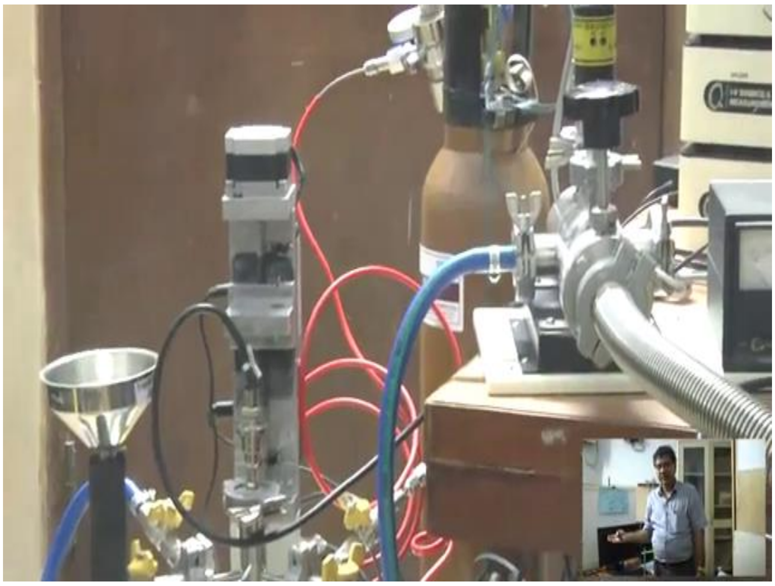

For that this we need temperature variation option.

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In addition, for low temperature liquid nitrogen or liquid helium we have some arrangement we tell that arrangement that is a cryostat to get temperature at lower side of room temperature. This experiment actually takes almost 2 hours to complete it. First, we have to start vacuum. Why we need vacuum, why we need other components that I will explain, but let me start first the vacuum.

Can you please start this vacuum? We have vacuum pump here I will tell you. These a rotary pump it is called rotary pump.

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This pump will use for. You can see this just we have started the vacuum. Let this chamber cryostat chamber come at 10 to the power minus 3 vacuum. In the meantime I will just I will discuss about these components of the experiment. As well as now, I want to show you that levitation I want to demonstrate the levitation.

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As I describe in theory class. this a this is a piece of here just I hanged with thread a piece of superconductor; a piece of super conductor, see its T c, its critical temperature is 90 Kelvin. Now, obviously, it is at room temperature now. It is not superconductor now, it is a normal state.

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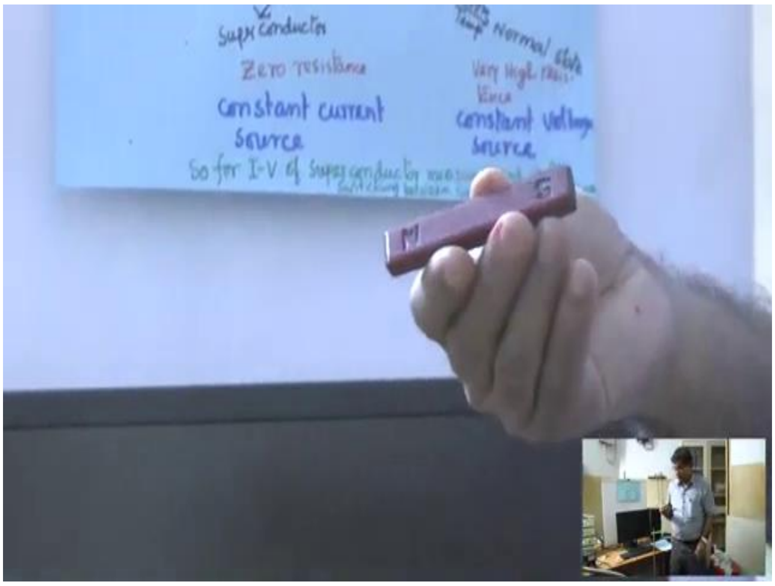

I have a magnet bar magnet. You can see North Pole and South Pole. This is North Pole and South Pole. I have magnet bar magnet permanent magnet it will produce magnetic field ok. Now, if I bring this magnet close to this close to this sample nothing happens you see nothing happens no repulsion. It is not super conductor at the moment. Now, if I cool this sample at lower temperature, liquid nitrogen temperature since it is T c is 90 Kelvin and this liquid nitrogen paper is 77 Kelvin.

If I just drop this sample into this liquid nitrogen and then cool it to liquid nitrogen temperature, then it should show the super conducting property and super conducting property that is it would show the diamagnetic property. Lines of force, it will lines of force will repel by this sample. Now, nothing is happening it is not super conductor. Can we please put liquid nitrogen?

You can see liquid nitrogen we are using. One has to carefully use this one because our room temperature is this is 7 to 273 Kelvin and liquid nitrogen temperature is 77 Kelvin.

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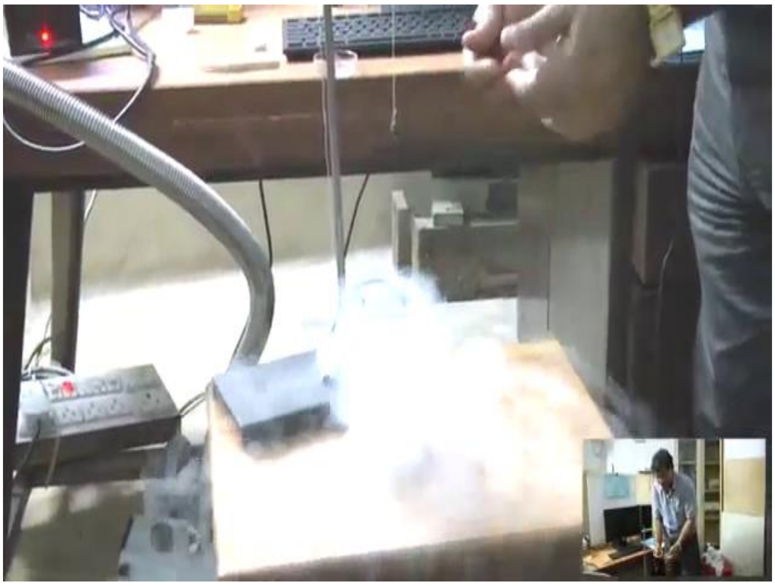

One has to wear glove and one has to wear glove and then handle the liquid nitrogen. It is the boiling you see liquid nitrogen is the boiling now. What I will do, I should do carefully. Now what I will do? I will just anyways. I think it is it should it should been I think I will hold it just I think just no keep it I think it will be inconvenient.

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I will just it is cold, but I can manage. Now I am putting this sample into the liquid nitrogen. Let me just wait for some time. Now, it must be at 77 Kelvin, so it is it will it is superconductor it is in super conducting state.

Now, I am bringing this you see you can see I am not touching, but it is moving. I am not touching it is moving. There is a repulsion; there is a repulsion; there is a repulsion. Now, it has now its temperature has yeah now you can see there is no, there is no repulsion as its temperature is now above 90 Kelvin 90 Kelvin above 90 Kelvin. No repulsion no repulsion.

Once more, I will just show you once more I will show you that is levitation ok. You see repulsion, I am not touching, I am not touching, and I am not touching. There is a repulsion. This is levitation. Repulsion, so there is a repulsive force between this superconductor and the and the magnet. If I wear the shoe of magnet and is the platform is the super conductor if I stand on it there will be, repulsion and I can stand in here ok.

Now you see it has it has come up this temperature above. This a very simple experiment. It is a demonstration of levitation. This principle used in different application as I told this bullet train in Japan this technology is used. Let go to the others other one.

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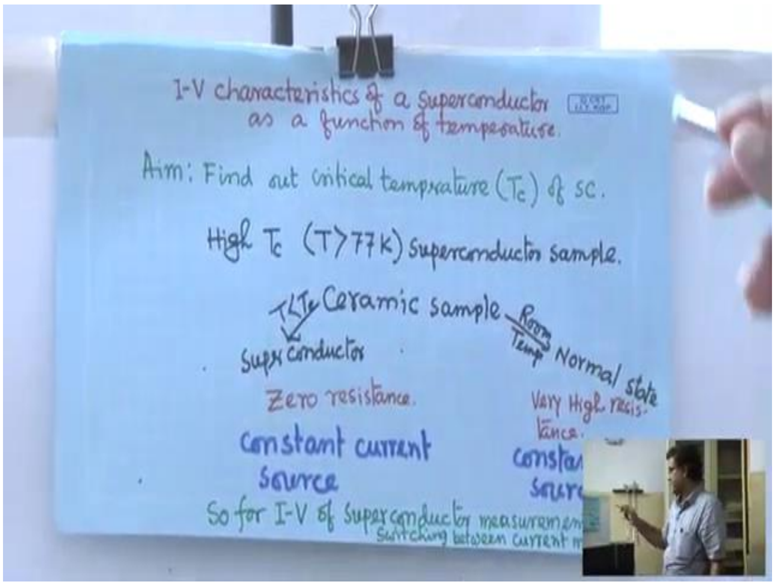

Today here what I want to show you that experiment I-V; I-V here I-V characteristics of a super conductor as a function of temperature. This experiment now I will show you.

In this experiment, our aim is to find out the critical temperature of super conductor as I told that the piece of superconductor these are ceramic. Ceramic sample it is T c is 90

Kelvin. We have to cool down the sample from room temperature to the liquid nitrogen temperature 77 Kelvin. Then if we measure I-V then corresponding resistance change resistance you will see and that how that resistant changes with temperature that we want to measure.

what for that measurement here as I as you know that I was discussing that when one should use constant current source, when one should use constant voltage source. Now, resistance will resistance is high then we should use constant voltage mode and when resistance is very small like superconductor we should use constant current mode. Now, in this experiment with temperature the resistance of the sample when it is not in super conducting state it is ceramic sample; it is ceramic sample. Its resistance is very high, it is like say insulator ok.

for a high resistance when it is in normal state we should use constant voltage source and when temperature is decreasing and then when it is going towards the super conducting state its resistance will drastically change and drop to 0 and that time it is a you are in the region of very low resistance very small resistance. We should use the we should use the constant current source. We need; we need this a power supply intelligent power supply, which can automatically switch from one mode to another mode.

We have we need an intelligent power supply and for this experiment and that we have.

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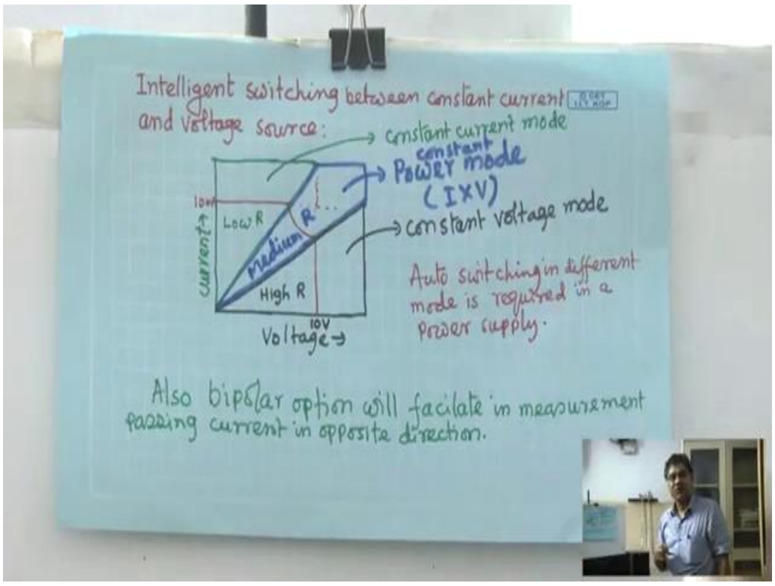

from this diagram you can see that it will that it should work as in voltage mode up to this region; this region and it should it should work in a in a constant current mode in this region and in between in between these two step when resistance is medium it is a I and V both can be changed. there we tell this power constant mode constant power mode, I-V.

In this region I-V when resistance is medium, in this region, these constant power mode. This we have this power supply; we have this power supply here.

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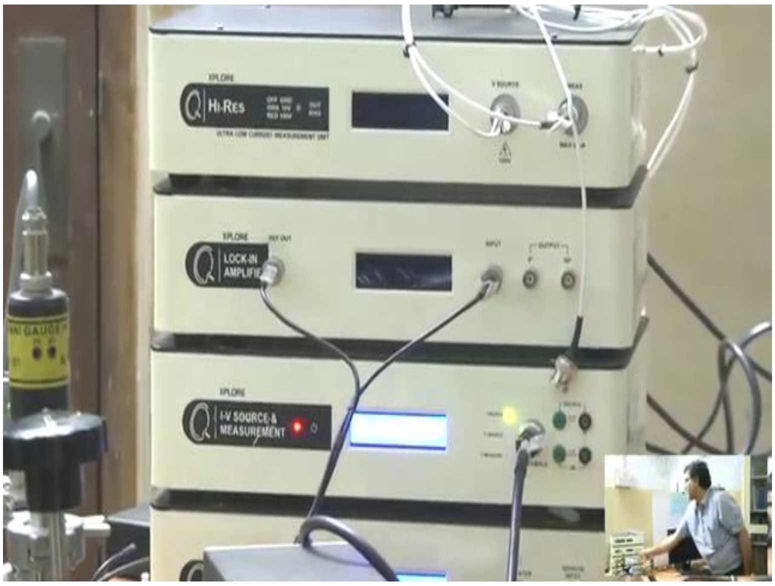

This company supplied this intelligent power supply which will just see the just see the change of resistance with temperature and it will use the automatically it will use the copper mode. Starting from the voltage mode constant voltage mode, then it will go to the power mode, and then it will go to the current mode ok.

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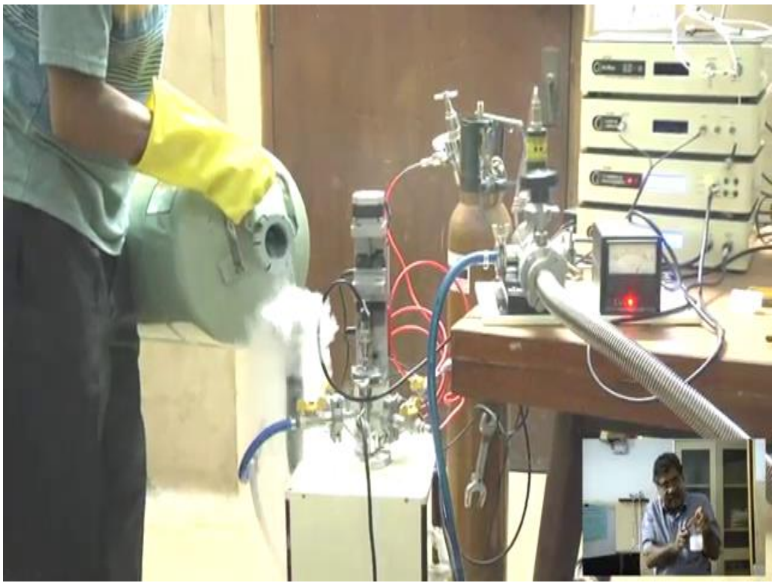

For this experiment, for superconducting this experiment, I-V measurement or to find out the critical temperature, this automatic power supply which can change the mode depending on the resistance of the sample. That intelligence switching between constant current and constant voltage source that power supply one should use and it is there ok.

In addition, this power supply have this bipolar option, which will facilate in measurement passing current in opposite direction also. Just it will change the polarity, automatically it will change the polarity if you do the experiment in reverse direction of the following the reverse direction following the current in reverse direction. You can do also the measurement. This power supply have this option bipolar option.

Generally, in our laboratory normal power supply have unipolar. Manually you can you have to change the terminal positive to negative to positive and then current will get in opposite direction reverse direction ok. However, in this case we tell bipolar when it is automatically change the power as we directed through the programming.

This intelligent power supply we need then that is that we have that arrangement we have. Now, this as I told you this vacuum as I told you this we need vacuum in this experiment we need vacuum now this pump is running there is a sound of pump you can hear. Why we need the vacuum that one can understand.

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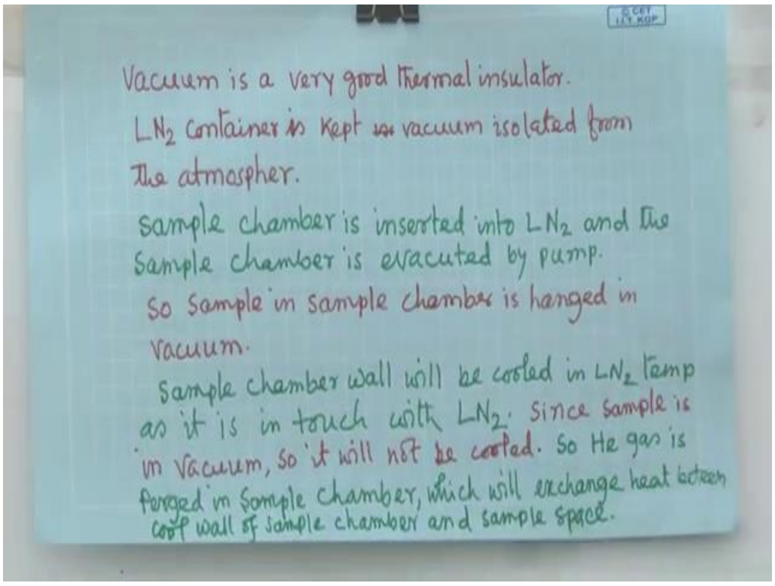

Vacuum is a very good thermal insulator. Liquid nitrogen container is kept vacuum isolated from the atmosphere. Liquid nitrogen as I showed you we have when we are pouring now, there is no liquid nitrogen you see. Just it will evaporate immediately within fraction of time it will evaporate. That is why we have to; we have to close this and if you close what will happen from atmosphere it will take this there will be heat transmission, there will be thermal free energy transmission.

Outside is room temperature inside is 77 Kelvin. Huge temperature difference and because of this temperature difference this liquid helium, liquid nitrogen, liquid helium it will evaporate. If you just close this one inside, it will be pressure because of this evaporation it will blast. That, we cannot do. What we do? This surface outer surface of this container liquid nitrogen container we have to; we have to isolate from the atmosphere.

We use double layer double layer cylinder; double layer cylinder or container. This it will be inside another cylinder. Now, this between two cylinders this part it will be evacuated because air is there. Air through air there will be transmission ok. We have to if we evacuate it then there is no air molecule. There is no molecule to exchange the; exchange the temperature between this atmosphere and the liquid-nitrogen container inner container. That is why we need vacuum ok.

Sample chamber is inserted into liquid nitrogen and the sample chamber is evacuated by pump as here you can see that we are using pump I will shift it here. This is the is the pump rotary pump. There is a valve you can close and open and this this pump is connected this pump he is pouring this liquid nitrogen to cool start cooling this system. You see through this it is connected with this ok.

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This part this two chamber what this two chamber I will tell you; one is sample chamber and another is this that space I explained you that between these liquid nitrogen chamber and the atmosphere. Between these cylinders, the space that is that is this one and this is for sample chamber because that sample chamber is inserted into the liquid nitrogen, but this but it is not.

This is another cylinder sample is in another cylinder. This cylinder itself is put inside the liquid nitrogen ok. Then liquid nitrogen here and then another chamber is there. Between this liquid nitrogen, that container surface and another surface attached to the in contact with the atmosphere in between this space. This sample, this space, as well as this outer space between liquid nitrogen that chamber, and the atmosphere. These two part we evacuate.

One part is for isolating the atmosphere from the liquid nitrogen container surface, thermal isolation and another part we are using this vacuum the sample now this sample chamber it is in inside the liquid nitrogen now the sample is this one. Here I am putting. Now this space is evacuated.

Now, you see now this surface of the sample; this surface of the sample container it is in touch with the liquid nitrogen; it is in touch with the liquid nitrogen right. This surface are cool to the liquid nitrogen temperature. Now, my sample is not touching the is not touching the surface of the sample container. It is just hanging in vacuum then because I have evacuated.

Now, there no. now, it is isolated thermally isolated. Then what we do after evacuation in this sample chamber we purge helium gas we purge helium gas. We take out the atmosphere air we take out the air, make it vacuum and then purge helium gas. This helium gas we tell it is the exchange gas. It will exchange heat from the surface and the sample through this helium.

These that is why this helium we use that is called exchange gas exchange helium gas. That the exchange helium gas will use for that we need helium cylinder. This is the helium cylinders. You can see this is the helium cylinder and it is connected with the sample chamber ok. After vacuum evacuation, we will purge the helium gas inside it ok. Lot of things one needs for this experiment and this that is why this experiment is very costly.

Sample chamber valve will be cooled in liquid nitrogen temperature as it is in touch with the liquid nitrogen since sample is in vacuum. It will not be cooled. Helium gas is purged in sample chamber, which will exchange heat between cool valve of sample and chamber sample chamber and sample space ok. Vacuum we need for this experiment.

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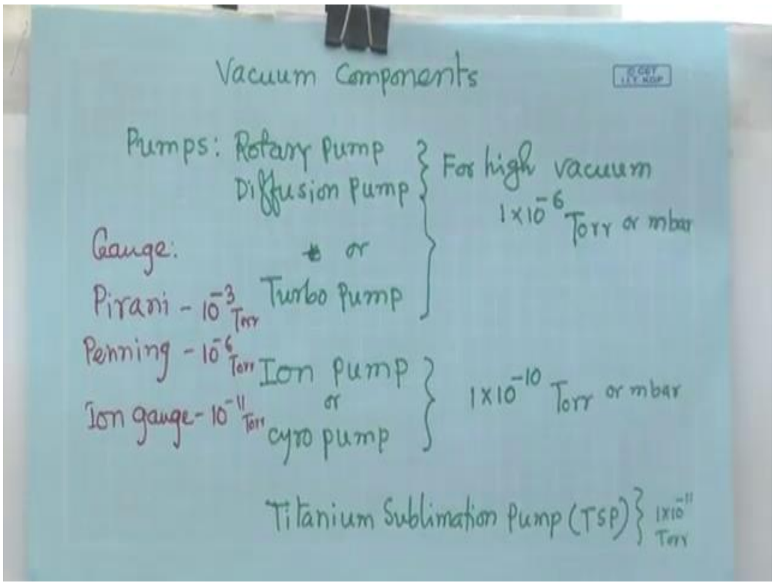

You should know what types of pump are used for vacuum and how we define the vacuum ok. Here I have written some name of the pump. Rotary pump – this is rotary pump here we are only using rotary pump; this is the rotary pump ok. This is the bellow, this is the pump it is connected this through this bellow it is connected with the with through the valve with the chamber ok.

Rotary pump it can initially evacuation it can do it can give 10 to the power minus 2 torr or milli bar vacuum. In this experiment 10 to the power minus 2 torr or milli bar is sufficient for sufficient for our purpose. However, some other experiment like thin film deposition we deposit film and for that we need the high vacuum high vacuum. When this vacuum is 1 to 10 to the power minus 6 torr or milli bar then we tell this is the high vacuum.

High vacuum initially rotary pump will give 10 to the power minus 2 torr or milli bar and then one has to use another pump it is called diffusion pump ok. Diffusion pump without rotary pump it cannot run. That is why this rotary pump is called the backing pump of this diffusion pump. These two pump together or rotary pump and this turbo pump together it can give this vacuum 10 to the power minus 6.

For high vacuum this rotary and diffusion or rotary and turbo pump is required to get high vacuum. If you want to get more vacuum better vacuum then you have to use another pump it is called ion pump or cyro pump. If you use after this if you use this one and this pump. You can get up to 10 to the power minus 10 torr or milli bar and to get even you can get 10 to the power minus 11 torr or milli bar.

For that, another pump we use that is called titanium sublimation pump TSP pump. You can get 1 into 10 to the power minus 11 torr or milli bar ok. torr and milli bar are not equal. There is a relation. Here just I roughly I have written. Now, this pump is giving the vacuum now how to measure the vacuum? For measuring vacuum, we need gauge. Again there are different gauge one have to use for different range of vacuum.

Pirani gauge we use this it can measure up to 10 to the power minus 3 torr if you want to measure higher vacuum better vacuum. Then you have to use penning gauge. That penning gauge it can measure from 10 to the power minus 3 to 10 to the power minus 6 ok. on measuring the up to high vacuum you have to use these both of these gauge and if you want to measure oh better vacuum than the high vacuum say in ultra I vacuum these we tell this ultra I vacuum. If you want to measure ultra I vacuum then one has to use ion gauge.

This vacuum technology itself is a big technology and how these pumps works the working principle of pumps one should learn. I hope that you will learn slowly and slowly. here just I just since I have chance to tell you what are the types of pumps and how to use it but working principle of these pumps I will not discuss. Then I will deviate from the experiment. Now, this pump is used for the vacuum.

Now we can see this temperature variation for that also we need arrangement temperature variation.

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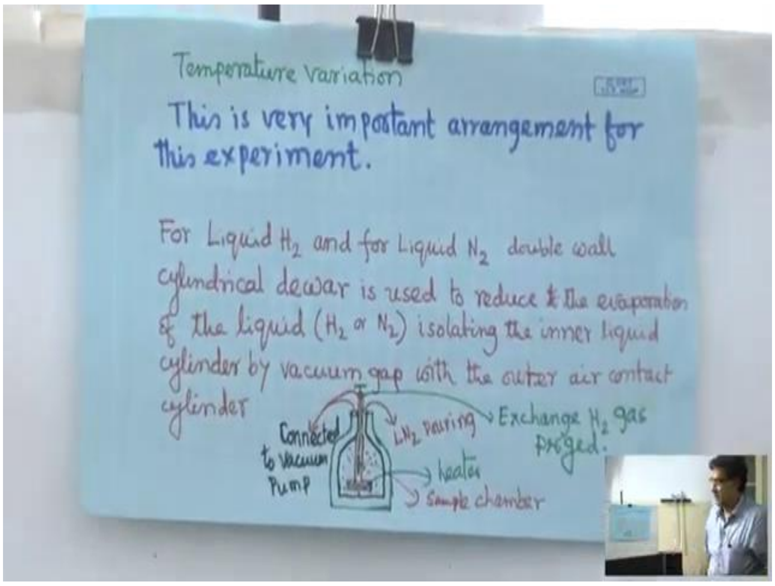

Now we have seen these that I have sample chambers inside the liquid nitrogen. Now, I have use the helium gas I have use the helium gas and that that helium gas will act, as an exchange gas and my sample will be cooled down at the liquid nitrogen temperature. If you give time, it takes almost more than an hour to cool down to the liquid nitrogen temperature.

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Now my sample is the at liquid nitrogen temperature. In between whatever from room temperature liquid nitrogen temperature it will change, it will change continuously. You cannot control the change of temperature but we want the temperature variation in control manner. Not only at liquid nitrogen temperature 77 Kelvin, I want to take this temperature at different at different value and.

I can vary this temperature; I can vary this temperature instead say 5 degree step. This is 77 say it is 80 Kelvin. Then at 80 Kelvin, I want to do I-V measurement, then 85 I want to do I-V measurement, 85 to 90 I-V measurement. In each step, I will change the step getting the temperature in step and stay a constant stable at that temperature and go.

there should be arrangement that I will I will give the temperature range and step in which step 5 degree or 10 degree in step it should change and in each step of temperature it should measure I-V current and voltage at the temperature ok. We need some arrangement. How it is done, what is the principle of this of this constant temperature in step?

Here below the sample this in sample chamber at bottom of the sample chamber there is a coil, heater coil. We give power to this heater coil. It will heat; it will heat the sample space. Then its temperature will change. if I want to do this experiment say from 80 Kelvin to room temperature 270 Kelvin or 280 Kelvin, 73 Kelvin 273 Kelvin is the room temperature not it will 0 temperature. 300 Kelvin is the room temperature. 80 to 300 I want to do want to vary the temperature at 10 degree step or 5 degree step ok.

This heater is there. If we control the heater power, if we are able to control the heater power then we can control the temperature. There is a thermo couple to measure the temperature of the sample place and what temperature I want that set temperature. Now, difference of these actual temperature at the sample and the set temperature, say set temperature is 300 Kelvin 300 Kelvin and this starting temperature is 80 Kelvin ok. this difference of these temperature actual temperature at the sample place and the set temperature if it is say these difference is e some difference e ok, I will show the equation.

Now, this difference depending on the difference see difference is higher heater power we should give the higher heater power and then these temperature gap will decrease with time when the sample actual temperature will increase ok. This difference will decrease and ultimately it should be it should come at zero. When it come close to that, just 2 – 3 degree difference there is lot of fluctuation at that place, but it has to be stabilized.

The process is used for this to control the temperature in steady state in steadily. It is called PID control; PID control, what is PID control? Here that I have shown this is a double wall container inside liquid dotted liquid helium nitrogen is there ok. There should be option to pore the liquid nitrogen. Here you can see here we have option to pore the liquid nitrogen this way.

Then this is the sample this is the sample chamber and at the bottom of this sample chamber, this heater is there; heater is there. Now, inside the sample this with a rod these a sample. Now, this part now this this this outer part as well as the sample chamber ok. These two are connected with pump; these two are connected with pump here you can see this and this; one is this outer chamber outer part of the chamber and another part is the sample chamber. These two are coming through these you see here now it is coming connected with the pump.

That is the vacuum arrangement and why we need vacuum, I explained. In addition, then this sample space is connected with the exchange helium gas cylinder ok. That is the exchange gas cylinder; it is connected through this and to the sample chamber. With diagram, this one can just check that exactly it is working like this. Whatever the working principle I described that is that that is used in the in the setup ok.

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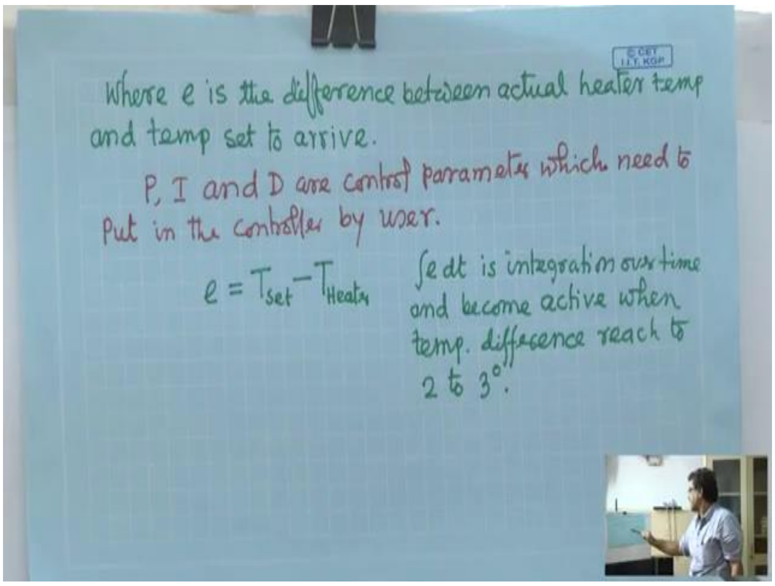

that temperature variation and control as I describe that if e is the difference between the actual heater temperature or sample temperature and temperature set to arrive set temperature we can have if it is e, then if P, I and D are the controlled parameter which needs to put in the controller by users ok. We have to put by trial and error one has to put, but it is a generally component supplied suitable parameter. The difference is this.

Now, we can see here that I think I am missing this I think this oh this part I should show you this part.

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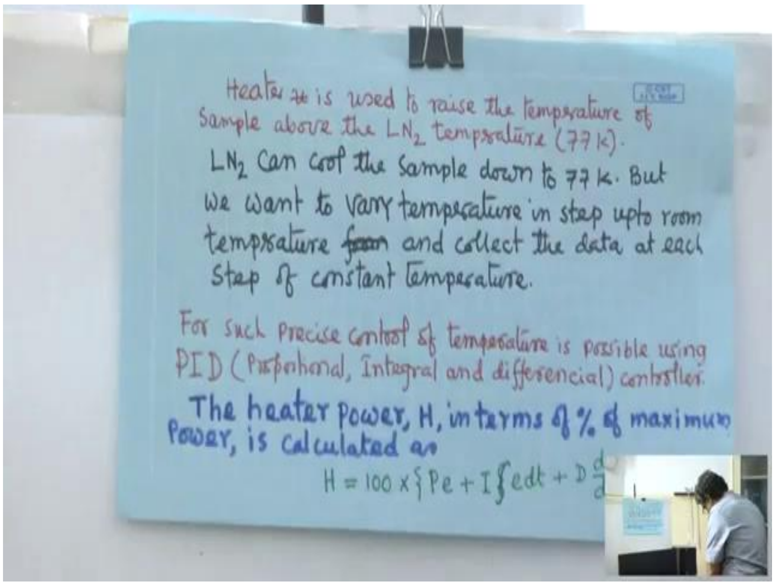

First and that is the second part. heater is used to raise temperature of the sample above the liquid nitrogen temperature as I described liquid nitrogen can cool the sample down to 77 Kelvin, but we want to vary temperature in step up to room temperature and collect the data at each step of constant temperature.

For such precise control of temperature is possible using PID; PID means Proportional, Integral and Differential controller ok. What is that? here you can see the heater power, H, in terms of percentage of maximum power is calculated as like H equal to 100 into multiplied with this whole things. P E proportional to the; proportional to the temperature difference set temperature and sample temperature or heater temperature.

Now, how much you want to give this weightage on this proportional I-V. One has to choose this Pe value of Pe accordingly. then that constant I now integration edt, dt is time t is time and plus this differential de by dt; de by dt is nothing, but temperature difference what will happen with time it will temperature difference will decrease because of this power is given proportionately.

This now de by dt is slope. Temperature difference are decreasing and going to the to be equal to the set temperature. Now, slope are changing; slope are changing and becoming 0. When it will become 0, then set temperature and that temperature, this actual temperature, will be equal. It controls slope of the heating slope of the heating or cooling slope of the heating or cooling. This is the differential part and when temperature range is when these close to these close to the to the actual temperature it is an around 3 degree difference they are fluctuate. In that place what is the fluctuation is it is that the difference integrated over the time ok.

This then when it is close to that temperature. This integral part become active. These three process together proportional integral and differential together it controls the temperature very accurately ok. It is all PID controllers. We have PID controller we have PID controller. Everything is here PID controller I think this company supplied this and here you can see temperature controller ok. It has option of this PID control.

And, this this one it will be used for I-V source; I-V source and the measurement means I-V measurement using the source. Other two units are there for other purpose. For this experiment, we need only these two unit ok. That is what we want to we want to do today.

How to control the temperature for that we need vacuum, we need liquid nitrogen, we need this helium gas ok. This is the big arrangement for variation of temperature and for measuring the super conducting that property. Actually, the change of the resistance as a function of temperature we need this arrangement also we need the arrangement intelligent power supply which will automatically changes the mode from constant current to the constant voltage and then also wherever need this constant power mode all options we need and this set up had that option.

I will continue the now the how we will take data that I will show you. I think I can just continue and here you can see that this we are pouring liquid nitrogen because we will lose liquid nitrogen with time. Why we are losing because this heater is there, it is heating the sample. Initially it is being cooled down, then after that we will also simultaneously we will heat the sample to get at different temperature.

Here now another that gauge I was telling, so it is a here you can see it is a 10 to the power minus 3 up to 10 to the power minus 3 this scale 0.001 ok. It is around 5 into 10 to the power minus 3, this is the vacuum this is the vacuum gauge, and this is the Pirani gauge.

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In addition, and here all connections you can see here this VNC connector here you can see it is written this voltage and voltage source, voltage measurement and temperature sensors and here heater power and this for I-V. For I-V here oh this is I source this is I source this is. Through this connection this current and voltage this I think there are many wires, sensor input.

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This is going to. Here you can see this here there are here pins are there. This 4 probe for wires as well as this for knowing the temperature for the couple. That also is connected here to the sensor input. We are putting all this in the sample chamber through this. You cannot see individually, but it is there so. I have sample the superconductor sample as I showed you. This type of sample we have put there and there the 4 probe connections are there. This wire connections wires are coming and it is connected here ok.

Now sample place I guess this will close a one this pump will closed for temporarily because things are in vacuum and helium gas we have to purge helium gas ok. What is the temperature now? Can I see temperature?

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Here it is showing the temperature is 236. In addition, set temper what is the they below set temperature 270.

Student: Sample.

Sample temperature we set at 272 Kelvin sample temperature it is at 272 Kelvin and this one is?

Student: Heater temperature.

Heater temperature; heater temperature one is heater temperature HTR, this is 236 and another is sample temperature SMP so that is 272. This yeah I think I explained. That diagram we do not need. Now, everything we can. Actually, what is happening?

So far, it is just. We can set this I think programming we have to; we have to use the programming I am not much familiar with this programming. Some programming is there.

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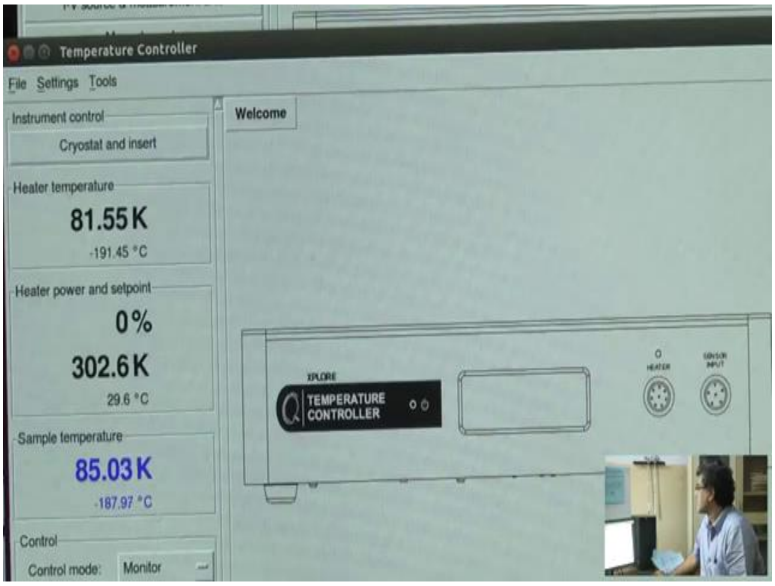

I was waiting for come for temperature. Here you can see now sample temperature is 93.71 Kelvin. This is the heater temperature, but I do not bother about the heater temperature. Since these P, c of this sample is 80 Kelvin 90 Kelvin. At least I have to come down to 85 Kelvin, then when it will reach to 85 Kelvin then I will start heating the sample with PID controller. I will start measurement.

85, 86, 87. Up to me, will take say a 100 degree 100 ok? Then I will see the change of the; change of the resistance with temperature and at that place we should see the we should see the condition. Actually, we have all data; we have all data, let me show you, yes.

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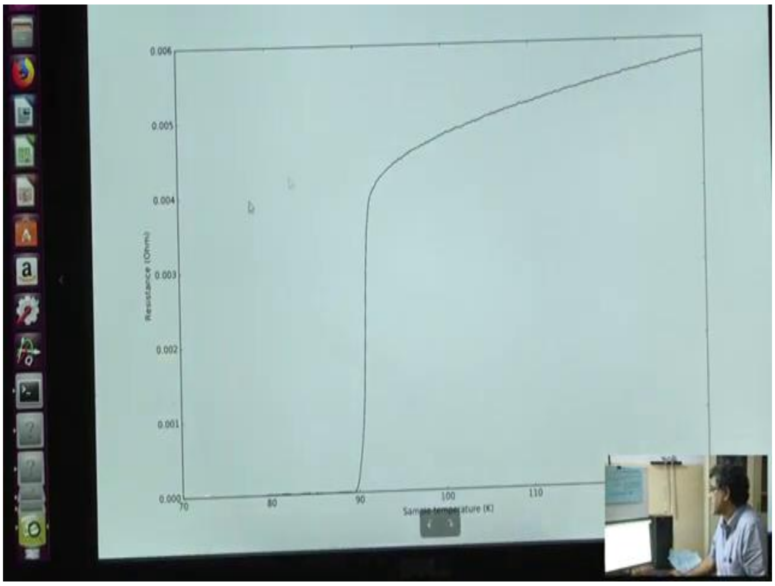

This is the curve you see. Now, actually, we give time to come down this temperature 80, and then we start heating. Then you see that is a 90 at 90. From 0 resistance it has suddenly it has come up this come up this higher resistance and it is changing like this so up to 130. Today just, I will show you from 85 to 95 or a 100 ok. Let me check where that is.

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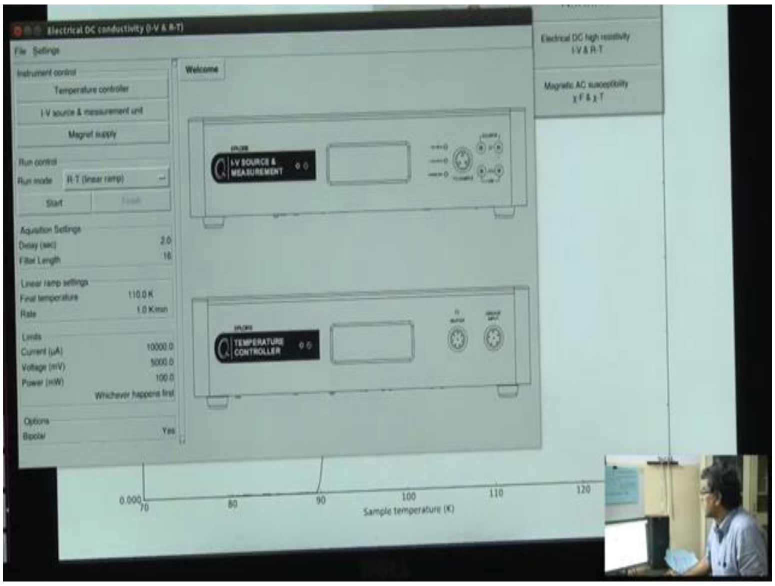

Let me check see in program all data one has to give what is the temperature range you want and what are the. Here I think this temperature final temperature 110 Kelvin we are given, rate of increment of the temperature 1 Kelvin per minute we have given. Then here limit current voltage power limit we have given in program. I think now temperature is where is the temperature let me check I think now it is 88 Kelvin.

Let me just wait slightly more let it come to the 85 and then I will start heating. Yes, it is an it is come 87. At this space, it slightly it will take slightly more time. 87 87. if you wait then I think you have to wait for say a half an hour also to get it at 77 Kelvin or 78 Kelvin, but since our 90 degree transition temperature if you get 85 or 86 then also I think I will start now ok.

It will start to take or I think we have set at 85. That is why let us. It is a minus 186 degree centigrade. Our room temperature and now it is 200 degree centigrade below of room temperature. Yes now it is in the range of 85 I think I will start from 85 and yes. I start means I will stop heating the sample to increase the temperature from 85 in 1 degree step or and take the data I-V and measure the and calculate the resistance and it will plot resistance versus temperature.

Ok. I think I will start the experiment let this one. When I start now something is there, I can start ok.

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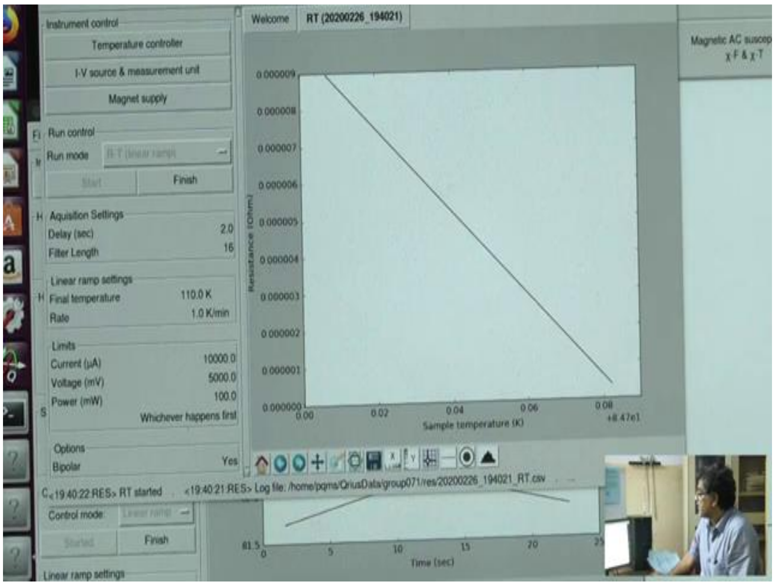

I started the experiment. It will measure the current and voltage in different mode depending on the sample resistance now. Sample resistance is it is in superconducting state. It is in superconducting state. It should be.

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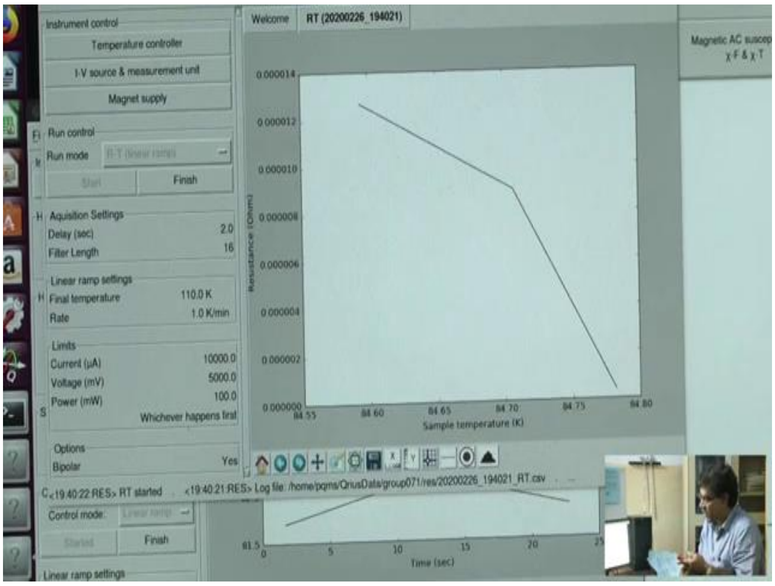

Let us see. It is an it measures I-V and from there it will calculate resistance and then it will it will plot as a function of temperature, it is giving error sum, it is ok.

Student: Yeah.

Heater it is say heating. Now, here it is it is just blinking means heater is on.

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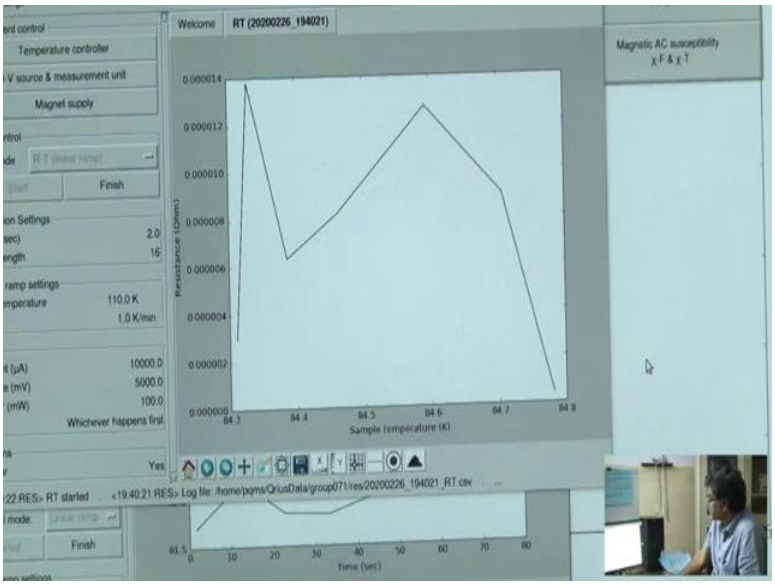

Automatically it is measuring and it will it will do some process you know averaging and this smoothening of the see if we just wait.

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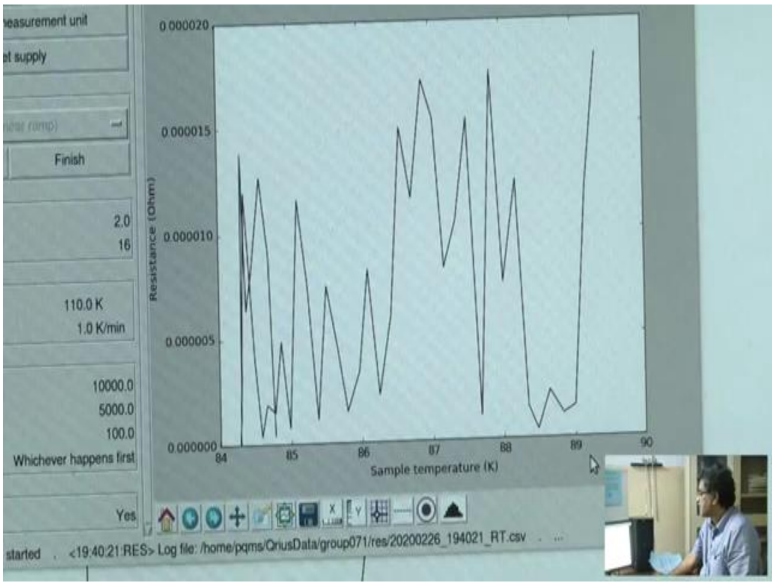

Finally, it will it will give smooth curve like this with temperature. This our student has performed this experiment and this data is like this. This is the old data yes let us see we have given up to 110 Kelvin heating. I think we can give we could give some pastors where, but it would be the 1 Kelvin per minute. Means 1 Kelvin temperature will change. Temperature change the NPC it is a 0.1 degree Kelvin change.

See, it is very difficult to measure at this at this source low temperature it is close to the 0 not temperature resistance. It is almost 0 resistance. And, then if you has to measure this resistance will increase after 85 90 Kelvin. I think it is in this range you see is almost 0. Here also there is lot of fluctuation you are seeing that fluctuation is one can consider it is 0 resistance; it is 0 resistance.

Because here compared to this you can see these are 0 resistance almost, but here you see this scale is one should see. It is the 10 to the power 1 2 3; 1 2 3 4 5 6, 10 to the power 2 into 10 to the power minus 6. 1.2 into 10 to the power minus 6; that means, it is the micro ohm range micro ohm range it is a. in micro ohm range it is a lot of fluctuations say it is the one can say it is the no age kind of pin. It is practically 0 resistance; practically 0 resistance.

Now, here you can see it just it fluctuating, but it is now it is going to be now some finite resistance started to start to come. Now, you see still it is in superconducting state and resistance is very small in less than which are the in the range of noise. Now, it is going it is an 87 is the 87 now started to increase you see resistance started to increase. It is a very good experience that we measure we have we have done a lot of I-V characteristic measurement. They are practically resistant change are not much. Either constant voltage mode or constant current mode we do the experiment.

However, here this experiment is from transport phase and made this so beautiful. Below 90 Kelvin, resistance is so small it is difficult to measure you suppose to you now after 90 above 90 it is the resistance is huge. These from 0 resistance to huge resistance be change to observe this change from a from an experiment special care has been taken. That is what I told that intelligent power supply is used where automatic switching of this mode is possible.

it is a 88 Kelvin; 88 Kelvin I am showing this one taking time because this is the good experience you know this how this superconducting transition is occurring and we are observing the measurement because this is costly equipment and most of the lab do not have this equipment. But, IIT, Kharagpur in Physics Department in our solid state physics laboratory this I think this explained also new it is a I think it is a 2; 2 years old this experiment, we have brought this one. It is an 89 Kelvin just it is crossing 89 Kelvin.

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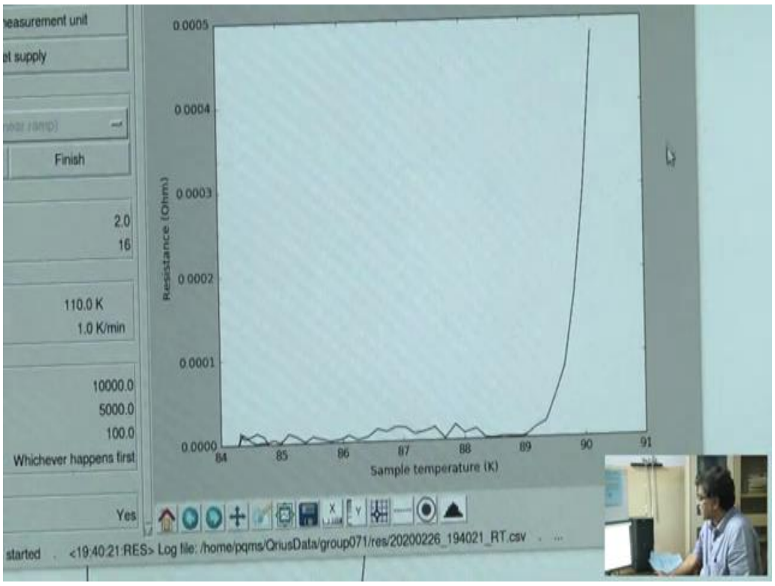

Now, you see just started that is a huge change of resistance from micro ohm or from noise level to just huge and just jumping it is very interesting to see this how sharp the jumping of resistance with temperature at the transition temperature I have not also seen earlier before doing this experiment here. See it is beautiful; it is a good to see this transition. You can see this very sharp change of resistance from micro ohm to now it is milli ohm; it is in milli ohm range. 3 order change of this resistance at this transition point ok.

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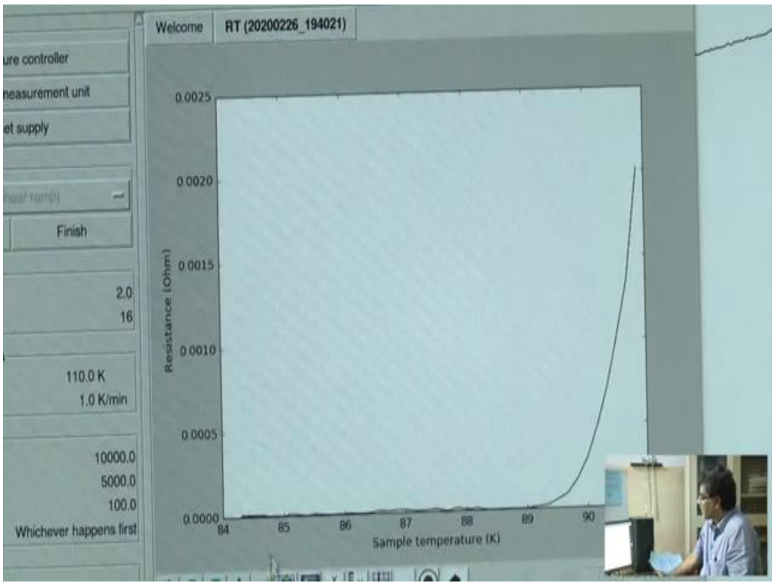

It will just allow to come up to up to 100 degree you can see clearly the phase change. this is the super conducting state it is an almost 0 down in this scale it is 0 you see and then whatever fluctuation we are seeing that is the very small resistance and it is very difficult to measure precisely, but that practically that is 0 resistance and in large scale you can take this really this is the equivalent to 0. Now, this it is the it is the change it started from 89, I think to 91. Within these two.

This curvature you see this curvature is this this is the curvatures and now curvature in other side it is coming. This is the signature of phase transition and middle of this one is taken as a critical temperature. That is it is an around 90 degree or 90.5 degree ok. To find out this transition temperature one has to take a differential from dr by dt. If you plot dr by dt as a function of temperature then here this dr by dt is nothing, but the slope.

This slope change from positive to negative that you can change you can see these you can find out the exact a point where the transition occurred. This inpatient point; inpatient point to get exactly inpatient point one has to one has to do take the derivative of this of this curve. It is an it will be around 90 or 90. 5 also ok. Now, here you can see this nice curve has come this is the phase transition range.

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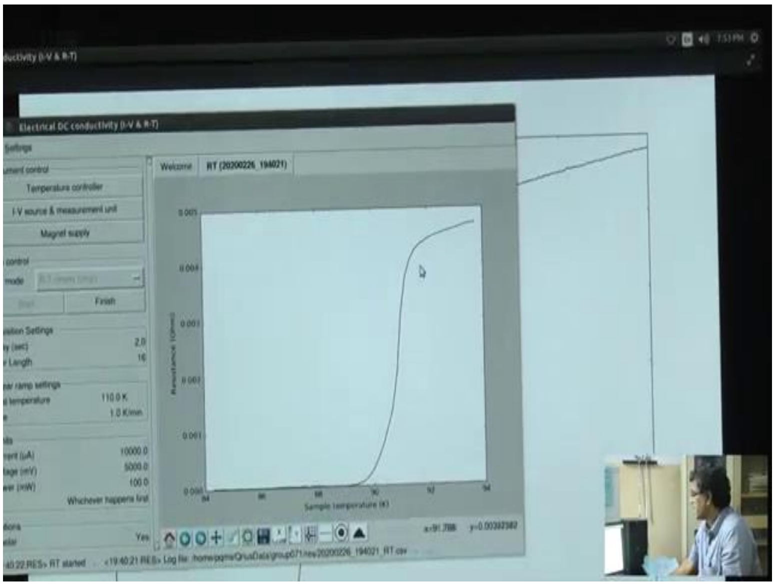

Now, if you just wait it will just it will be like these you know it will be like these as we are at this point now we are at this point now we are at this point now. If you just wait it will it will change like this. I think I will stop here because you are just it is just I was interested to show you this at least this a transition how it is happening in the super conductor. Most of you have not seen such type of experiment earlier.

I have not seen also just 2 years back when this instrument came in our department, then only I saw this this experiment and this very nice experience. Lot of things you could learn from this experiment how to do vacuum, what is the mechanism of this cryostat where you can control the temperature and then how one can measure the from very low resistance to high resistance without breaking the without breaking continuously how one can measure. You need smart or intelligent power supply ok. Lot of things one need to do this experiment ok.

I think that is what I wanted to show you how to find out the typical temperature of a superconductor from the I-V measurement as a function of temperature. From the I-V one can just calculate the resistance and that is what programming is doing and it is plotting. I will stop here.

Thank you very much.