Experimental Physics - III
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Lecture - 16
Hall Effect as a Function of Temperature

I will demonstrate the measurement of Hall coefficient as a Function of Temperature. I have already demonstrated how to measure the Hall coefficient as a function of magnetic field or the measurement of Hall voltage as a function of magnetic field. Here basically this we will measure Hall voltage as a function of temperature.

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this is the experimental setup for Hall effect. earlier setup whatever I have shown you; here also same setup only we have provision for changing the temperature of the sample except that one rest of the part here they are same in compared to the earlier setup.

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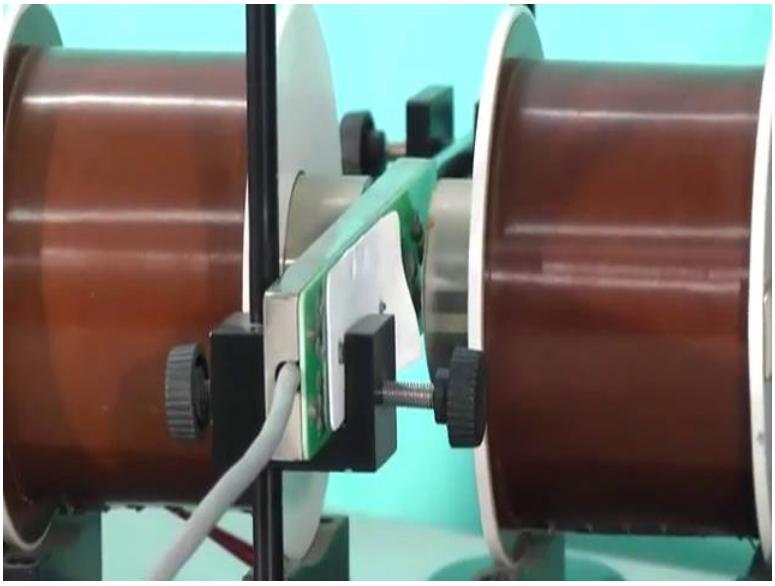

here you can see these we have a sample; we have a sample we have placed the sample between the pole pieces of the electromagnet, because Hall effect magnetic field is compulsory. And, here we have taken sample p type germanium as I mentioned that, if you have p type semiconductor then a Hall coefficient you will get Hall coefficient inversion as a function of temperature means Hall coefficient will have two contributions.

One contribution from the hole and another contribution from the electron. If hole density is greater than hole density is greater than the electron density, then one can see the inversion of the Hall coefficient as a function of temperature. And, that is the important because we will get 0 Hall coefficient at a particular temperature and at that point this mu p square p minus mu n square n will be equal to 0.

from there one can find out the mobility ratio as well as the carrier density ratio. in this Hall for what is there these are it looks very compact system, readymade system. these probe here whatever the sample probe we are using they are basically we have sample on sample there are 4 connections; 2 for the current and 2 for the 2 for current and 2 for this Hall voltage measurement and that probe is placed like this; probe is placed like this. field magnetic field will be perpendicular to these to the surface of the sample.

now, in this probe we have a heater, we have a heater then we can heat the sample and we have to measure the corresponding temperature. we have also arrangement for the measurement of the temperature. basically here we have used thermocouple. thermocouple will give us the temperature of the sample.

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this is the box you are seeing, this box everything giving this power is given from this box to the probe, alit is measuring the temperature as well as the Hall voltage. basically we have here inside, inside the box what we have? Here you can see there is a heater current.

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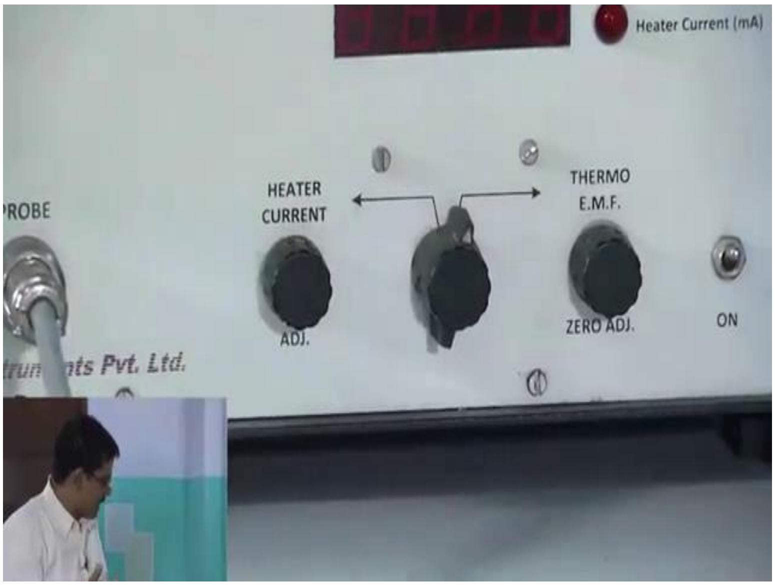

heater means you know this there is a coil of some probably this we use tungsten. if you pass current through this coil, then coil will supply heat and for you have provision to change the heat applying current more current if you apply; heat will be more and temperature will be higher. as I told that we will measure the temperature with thermocouple, I will explain what it is. basically thermocouple gives the E.M.F., it is called thermo E.M.F. and this thermo E.M.F. is the basically voltage.

here we will be able to see the thermo E.M.F. and now this thermocouple one has to calibrate temperature versus these this thermo E.M.F. this calibration, we have calibration chart; company has supplied this calibration chart. I will show you or if it is not supplied one has to calibrate it. this part is for measuring for heating the sample and measuring the temperature of the sample. other part here this half is basically here you can see; now we will set different temperature.

And, at that temperature what is the Hall voltage and if you know the Hall voltage then corresponding Hall coefficient you can calculate. what is the how to measure the Hall voltage? Again this you need this connection this on sample there are 4 probe, 2 probe and this other 2 perpendicular probe. these two probe is will be used for setting constant current and other two probe perpendicular probe will be used for measuring the Hall voltage.

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here you can see this Hall voltage and here it is written probe current. here you have provision for setting probe current mean sample current. we will apply particular probe current or sample current that will be fixed and then we will apply magnetic field that will be fixed. Now, we will vary the temperatures and measure the Hall voltage. then we will have thought Hall voltage or Hall coefficient as a function of temperature. this is the experiment we have to do.

these part is for temperature, these part is for Hall voltage for Hall effect. this part has nothing to do with this Hall effect you know. this part is only for setting the temperature of the sample. now, other part here we have to apply magnetic field.

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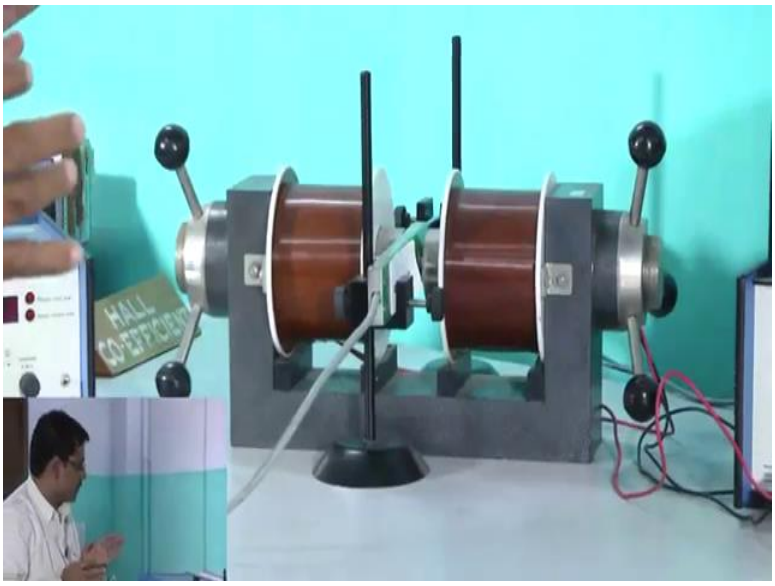

this is the electromagnet; you have seen many times.

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And, this is the constant current power supply for the electromagnet for this coil of electromagnet. And, then we have to; we have to; we have to calibrate the electromagnet for different coil current. we have to for a particular year gap we have to measure the; we have to measure the; we have to measure the magnetic field using the Gauss meters and Hall probe.

this is the Gauss meters and we have Hall probe here, we have Hall probe here; using that one before starting experiment or after experiment we have to removing the sample, we have to measure the magnetic field as a function of coil current. that is the calibration of the electromagnet for the particular air gap and that we will use for calculating the magnetic field for a particular for a particular coil current.

that means, we will set a particular coil current and corresponding magnetic field we will get from the calibration. for that magnetic field and for the sample current, sample current what is the Hall voltage for different temperature that we will measure. now you see this part I think I have shown you many times. basically these two coils, power we are giving through these.

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we can set; we can set magnetic field; we can set magnetic field. say here I am putting some current, I am putting some currents say magnetic field I will use slightly higher magnetic field; let me apply 4 ampere current. 4 ampere current I have set. this is the coil current, now what is the magnetic field I do not know. that we have to; we have to find out from the calibration curve. that after experiment or before the experiment one should do that, since I have already discussed many times; I think it's very clear to all of you how to calibrate the electromagnet using the Hall probe and Gauss meter.

for this I have set this coil current means I have set the magnetic field. magnetic field is applied on the sample which we want to study. Now, you see I will set, I will set here then probe current I will set, probe current I will set; where is this switch on? I will switch on it.

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probe current I will set here; it’s already set. I think probe current it’s very high, I should not go to that high. probe current 0.

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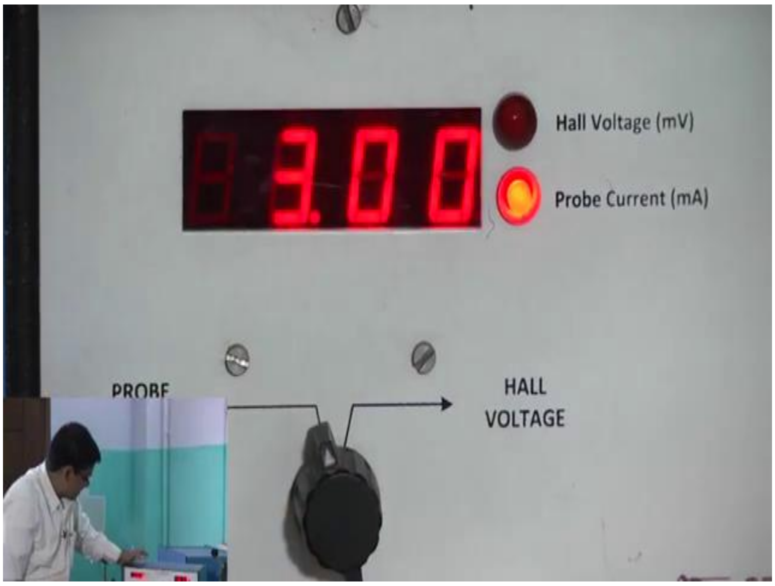

now I am setting say particular current it is in millivolt milliampere, milliampere here you can see. 1 milliampere let me set; let me set 3 milliampere, let me set 3 milliampere current, probe current, sample current that is electromagnet coil current.

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Now, for that what is the Hall voltage, what is the Hall voltage? that I can see this in millivolt, it is 48. Now, what is the temperature here? At which temperature this Hall voltage I am getting?

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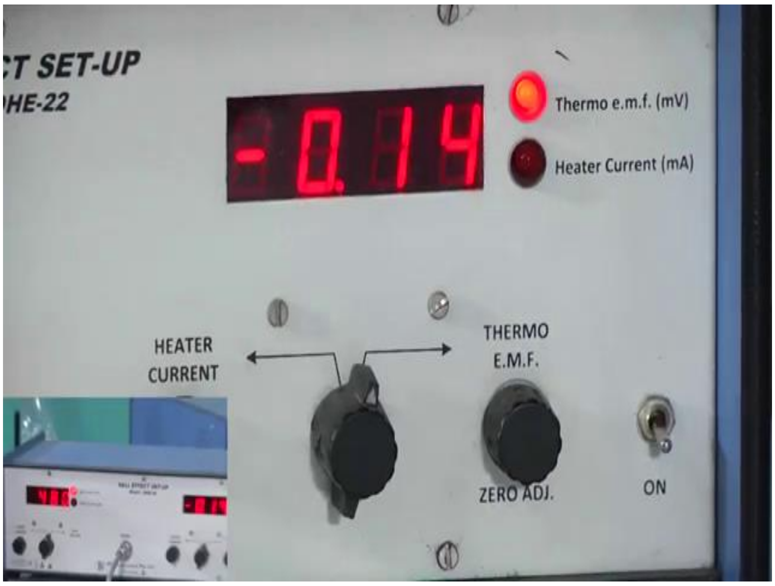

here I would like to show you here it is showing these 0-point minus 0.14 minus 0.14, but I think there is a procedure. Here this thermocouple calibration chart is there, thermocouple calibration chart is there.

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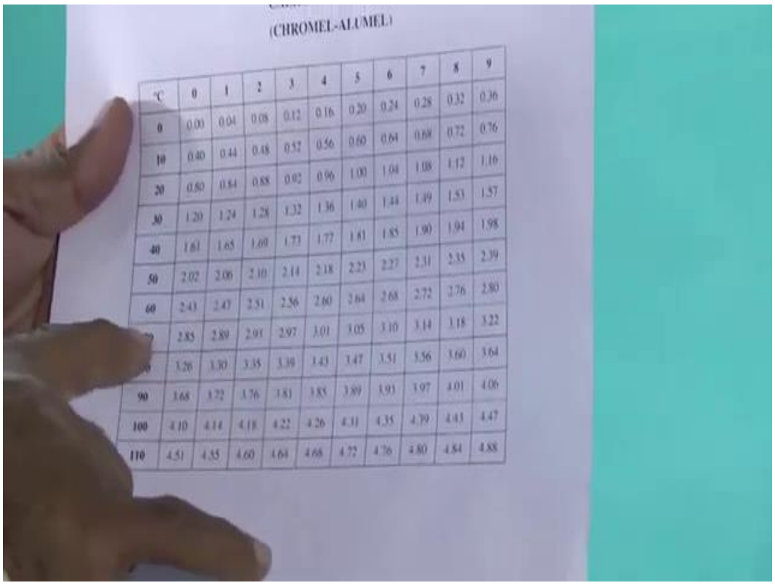
(CHROMEL-ALUMEL)

°C	0	1	2	3	4	5	6	7	8	9
0	0.00	0.04	0.08	0.12	0.16	0.20	0.24	0.28	0.32	0.36
10	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.76
20	0.80	0.84	0.88	0.92	0.96	1.00	1.04	1.08	1.12	1.16
30	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.49	1.53	1.57
40	1.61	1.65	1.69	1.73	1.77	1.81	1.85	1.90	1.94	1.98
50	2.02	2.06	2.10	2.14	2.18	2.23	2.27	2.31	2.35	2.39
60	2.43	2.47	2.51	2.56	2.60	2.64	2.68	2.72	2.76	2.80
[illegible]	2.85	2.89	2.93	2.97	3.01	3.05	3.10	3.14	3.18	3.22
[illegible]	3.26	3.30	3.35	3.39	3.43	3.47	3.51	3.56	3.60	3.64
90	3.68	3.72	3.76	3.81	3.85	3.89	3.93	3.97	4.01	4.06
100	4.10	4.14	4.18	4.22	4.26	4.31	4.35	4.39	4.43	4.47
110	4.51	4.55	4.60	4.64	4.68	4.72	4.76	4.80	4.84	4.88

which thermocouple here? company is telling that chromel-alumel thermocouple. at different temperature is produced different thermo E.M.F. here temperature is given in degree centigrade. 0 degree centigrade this 0 value. 1 degree this is 0.04.

for 2 degree which is up to 9 then 10, 11 up to 19 then 20, 21, 22, 20, 21, 22, 23, up to 100 19 it is given. Now at present the room temperature I have to; you should use some thermometer and check what is the room temperature now.

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here it is showing, it is showing 22.9 degree centigrade, now at present the temperature of this room is 23 degrees centigrade. now, for 23 degree centigrade for 23 degree centigrade; that means, here it should be 23 degree centigrade it should be 0.92. thermo E.M.F. should be 0.92. hopefully there is no current heater current, heater current is 0 so; that means, I have not applied any heat. it is at room temperature. I have put at there and thermo E.M.F. I have to set at 0.9 0.92 here 0.92; 20, 21, 22, 23 0.92.

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I will set at; I have set at 0.92. as per calibration what is the present temperature? that value here thermo E.M.F. we are expecting 0.92. I have set; slight change sometimes it is there, but does not matter much 0.92. Now, I have to note down I have to note down at thermo E.M.F. is 0.92 corresponding temperature from the chart, it is 23 degree centigrade. And, for that this what is the Hall voltage? 47.8. Now I will change the temperature; I will change the temperature.

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what I will do? I will put the heater current maximum. Now, temperature will change slowly-slowly, you will increase and this Hall coefficient will change. here I will get reading of thermo E.M.F. and for that thermo E.M.F. what is the Hall voltage. just I will note down thermo E.M.F. versus the Hall voltage.

And, later on there will should be one column besides of this thermo E.M.F. from the chart I will note down the note down the corresponding temperature. temperature versus the Hall voltage I will get and I will be able to calculate Hall coefficient from the Hall voltage.

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let me now give heater current; generally, how much current I should give? Heater current I am giving now in milliampere; it is let me give some say 600 milliampere; say some 600 milliampere heater current. for this heater current; thermo E.M.F. now I have given arbitrary some higher current. Now, I will it will heat the sample, sample and sample temperature will get through the thermo couple.

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I will put thermocouple here; you see it is from point 0.92 it is changing you see.

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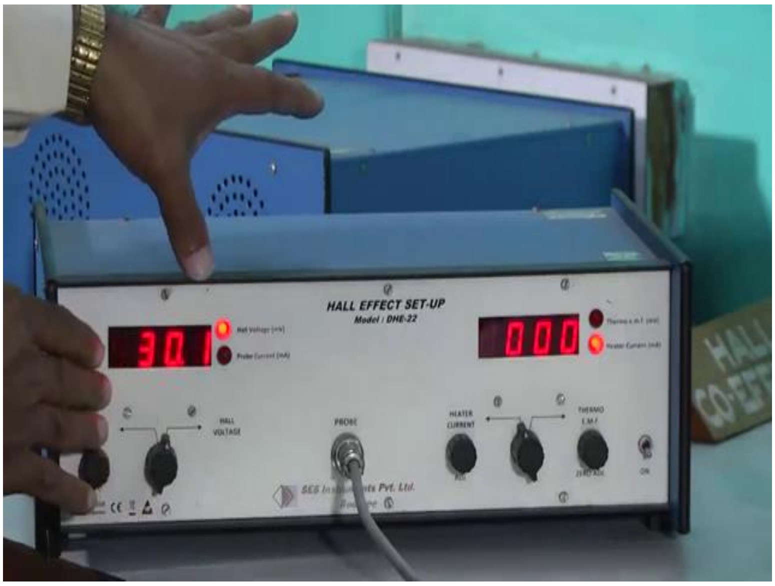

Now, what I have to do? This also changing, it’s not changing much for initial temperature. now I have to note down this two reading you know, I have to note down this two reading. I think here you can see these from initially it was how much? 48. now, it’s the decreasing; it’s the decreasing and this coefficient thermo E.M.F. is increasing, thermo E.M.F. is increasing.

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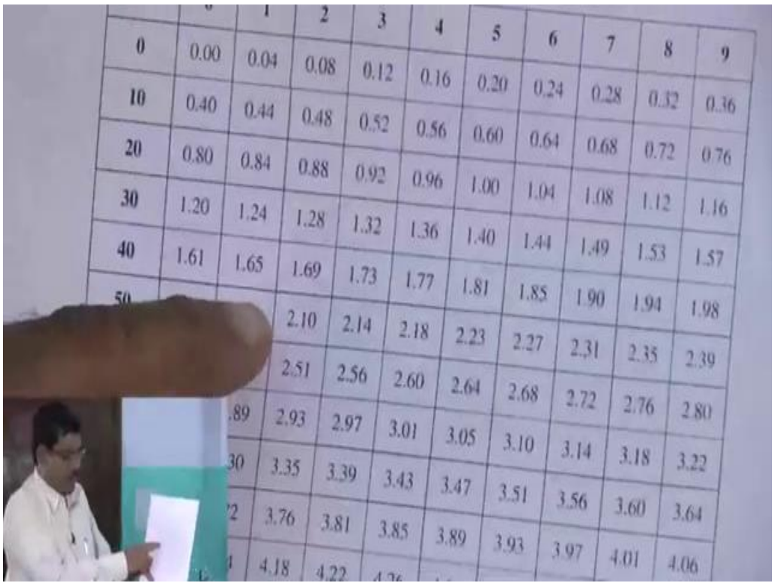

	0	1	2	3	4	5	6	7	8	9
0	0.00	0.04	0.08	0.12	0.16	0.20	0.24	0.28	0.32	0.36
10	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.76
20	0.80	0.84	0.88	0.92	0.96	1.00	1.04	1.08	1.12	1.16
30	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.49	1.53	1.57
40	1.61	1.65	1.69	1.73	1.77	1.81	1.85	1.90	1.94	1.98
50	[illegible]	[illegible]	2.10	2.14	2.18	2.23	2.27	2.31	2.35	2.39
[illegible]	[illegible]	[illegible]	2.51	2.56	2.60	2.64	2.68	2.72	2.76	2.80
[illegible]	[illegible]	.89	2.93	2.97	3.01	3.05	3.10	3.14	3.18	3.22
[illegible]	[illegible]	30	3.35	3.39	3.43	3.47	3.51	3.56	3.60	3.64
[illegible]	[illegible]	2	3.76	3.81	3.85	3.89	3.93	3.97	4.01	4.06
[illegible]	[illegible]	4.18	4.22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Now, it is 1.62, it is around 40 degree centigrade, it is around 40 degree centigrade; see 1.65 it is basically it is basically 41 then 42 then, now 1.73 this 43. this way temperature is increased, now this value is decreasing from 48 it is coming 47.4. we have to; we have to note down with some step we have to note down, I think temperature will be higher and higher this will be decreased faster and faster. from here; Hall coefficient is Hall voltage is decreasing with temperature so; that means, Hall coefficient we will decrease with temperature, here it is positive value.

you will see there is a fluctuation its it happens because yes. here we do not have provision that I think it would be better if we can change the temperature in 5 degree step and then we can wait there. And, we should stabilize this one stabilize the temperature then stabilize the Hall voltage and note down. But, here it is the system is not like this, it's the system is just is continuously heating and there will be temperature slight change when you are taking this reading.

it will not be by any way; one can draw graph temperature versus Hall voltage or corresponding Hall coefficient. it is decreasing with temperature, now what is the temperature? 2.21 2.21 2.21 2.23 2.23 temperature is 55; now this temperature is around 55. it's the decreasing with temperature. you have to note down as long as it is it will be 0 and it will go to the negative. if you note down that one and plot it, note down and then you plot it.

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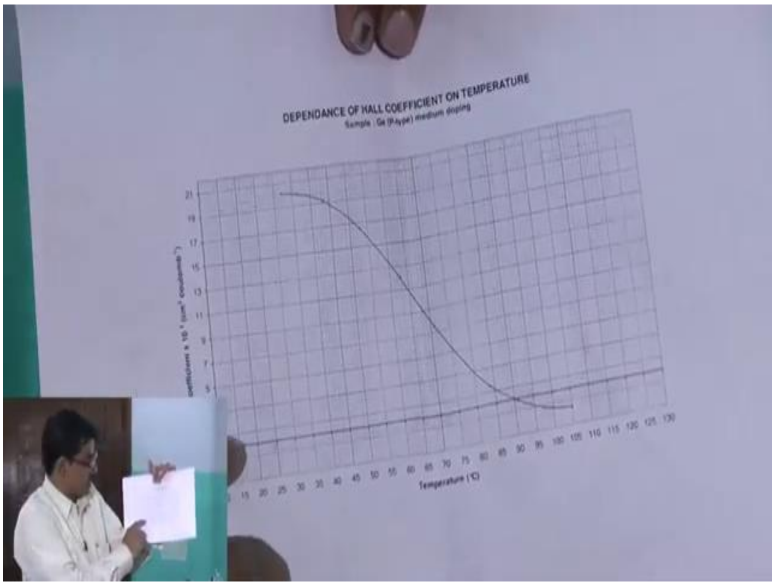

we will expect this type of curve, we will expect this type of this is Hall coefficient; Hall coefficient and this is temperature. initially we have seen this temperature is increasing.

here it is plotted I think during summer they have taken the students have taken this data. it is at 33 degrees centigrade, now it is winter its 23 degrees centigrade. initially you can see that we saw that Hall voltage is not changing with temperature because, is the same value you know; here it will remain same value.

that part we have seen then after that after 55 after 50 or 55 it is decreasing sharply, it is decreasing sharply. Now, what is the temperature? Now, temperature is; now temperature is 2.53 thermo E.M.F. 2.53 thermo E.M.F. here you can check 2.51 temperature is 32 62 and this Hall coefficient it is 40.2. from what is the initial value? It's probably how much? 48; from there it is changing, it is changing this change here I can see it's a Hall coefficient one has to calculate the Hall coefficient.

it is decreasing, it is decreasing; coefficient is the increasing means temperature is increasing and the Hall voltage; that means, the Hall coefficient is decreasing anyway. here important thing as I told it will change like this and then it will cross this 0, you know it will cross the 0. inversion of the Hall coefficient, it will go to the negative, it will go to the negative value. And, as I told that we have to take this value, this is Hall coefficient 0 at which temperature; here it is showing at 90 degrees centigrade. This Hall coefficient is 0.

this curve is same this curve is for this sample. it you will get at 90 degree, we will get at 90 degree this type of inversion. And, then you can find out the ratio of ratio of the Hall coefficient of not Hall coefficient ratio of the mobility of a hole and of hole and electron. this is the experiment; this is the experiment. I will not; I will not complete the experiment to show you this inversion, but one can do it. this is nice; I think I will stop the experiment, but before stopping the experiment before stopping the experiment here as I mentioned here.

this lo black box you know this nothing can be seen, as I told here for heating arrangement this part is there, here this for Hall effect measurement this part is there. Now, one where is going there and what is there I do not know. but these box what it is doing? As I told that it is measuring temperature, it is measuring temperatures of the sample to sample is here and it is measuring temperature. there must be some wire connection for thermocouple and also heater is there. there must be wire connection for heater.

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As well as there are 4 connections for the Hall measurement, 2 for current and 2 for measuring Hall voltage. from here there should be 8 connections, 4 for Hall and 4 for heater and thermocouple. I think I will stop. it is decreasing, temperature is increasing. What is the temperature now? 2.98, 2.98 2.98; it's a 2.98 2.97 I can see here; temperature is 73.

at 73 degrees centigrade you have to note down this is the 30.5 Hall voltage 30.5. now, I will stop it, I will stop it first I will reduce the heater current. heater current I will make it 0, I will make it 0, I will make it 0 fine. here let it be there, let it be there. you can see now you should see this it should increase; temperature will decrease again it should increase. But, it's just it is you can just since it is on you can just check it, now it is increasing let us say; temperature is decreasing, it's the it is increasing.

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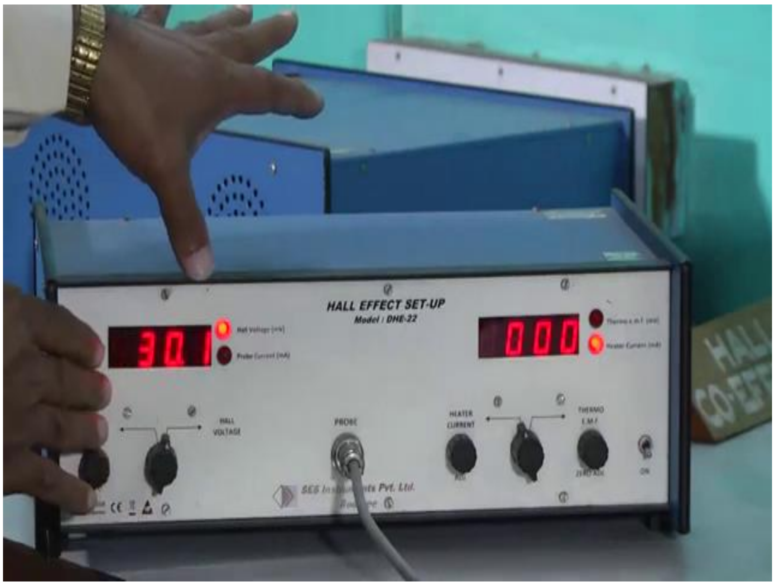

And, this current I will al.

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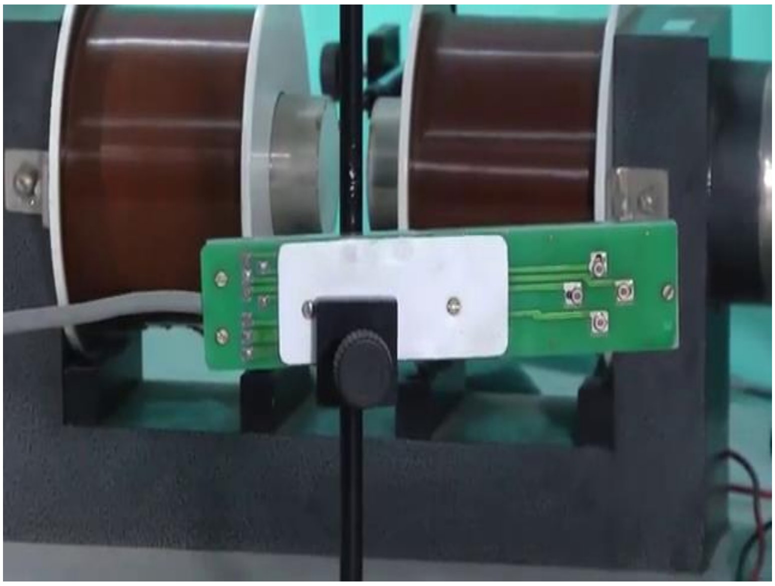

what is there inside of this one everything is there, but nothing you can you cannot see anything. But, here you can see here you can see these this 4, this 4 screw you are seeing basically it is giving 4 connections. that is a 2 for probe current means sample current and 2 for Hall voltage. inside there is a sample and this 4 probe connection are there. and that wire this is PCB; this on PCB this connection 4 connection they are coming and here you can see this 8.

other this is for Hall connection and for heater now I can feel heat, when I am touching it I can feel heat. there should be 2 more connections for heater and 2 more connections for Hall coefficient. here I can see this is 3 1 2 3 4 5 6 7 8. there are 7 8 connections, 8 wire connection is coming through this. 4 for Hall, 2 for heater and 2 for thermocouple.

and these are all separated wire are coming together and we are putting through these I can show you; I think a probe current I will reduce to 0, probe current I will reduce to 0. let me switch up this one. I will open it, I will open it, I will open it. this type of very convenient connector.

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we can see this hole; this is the female type this is the female type hole. all wire is connected inside female type hole.

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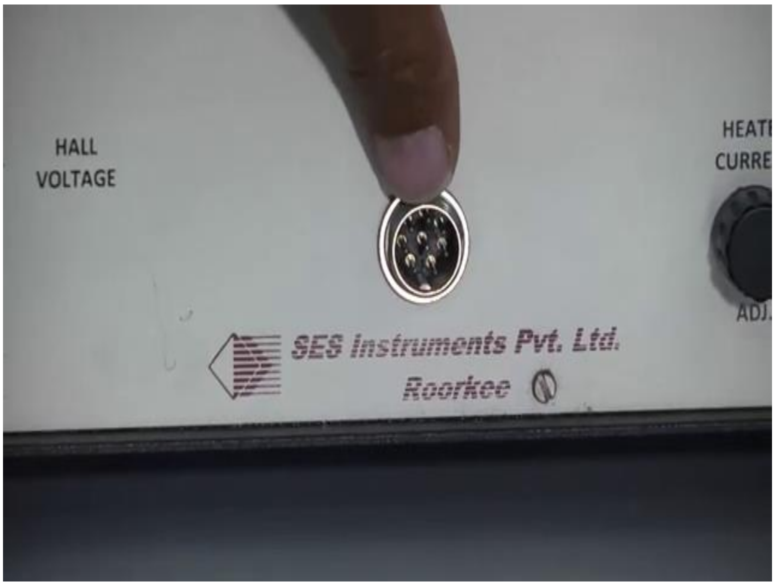

And this is here you see this male type hole, here sorry male type pin. pin to hole connection, pin to hole connection we are making. it is called male female connector. now here let me open it and show you what is inside. I have similar type of same type of you see I have opened it; I have opened it for you. basically I think I will.

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actually what we are seeing; this is like this. some I think I have to take this side, yes say exactly this. this one we are using for just for safety for holding this for clamping here you see. this same probe I have opened one. if you open these what is there what is there?

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these are just simple cover for holding the things and for safety covering the things.

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Now, you see this opposite side, you see the opposite side. since inside heater is there; this is the thermal insulator as well as electrical insulator. I have not opened this one.

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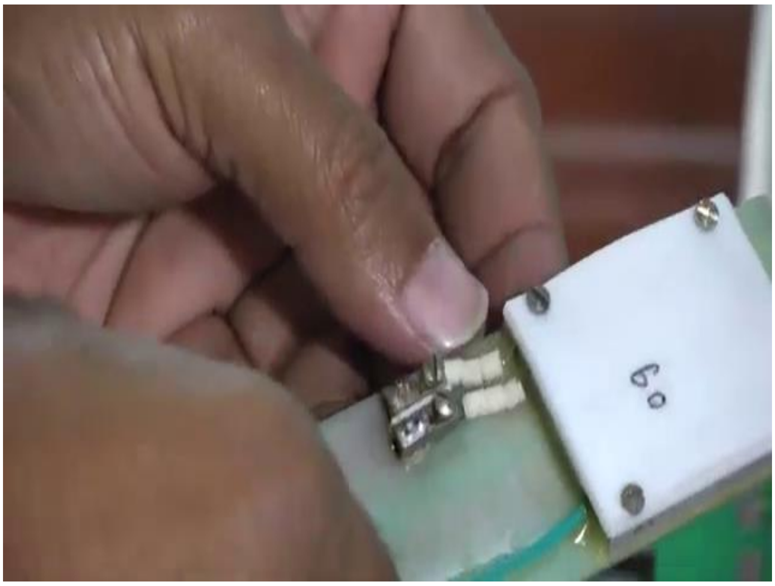

here you can see, here you can see these two are I do not know whether it is thermocouple or for heater; difficult to tell. these are the these two is a looks two means for heaters, inside some coils are there; these two are heater.

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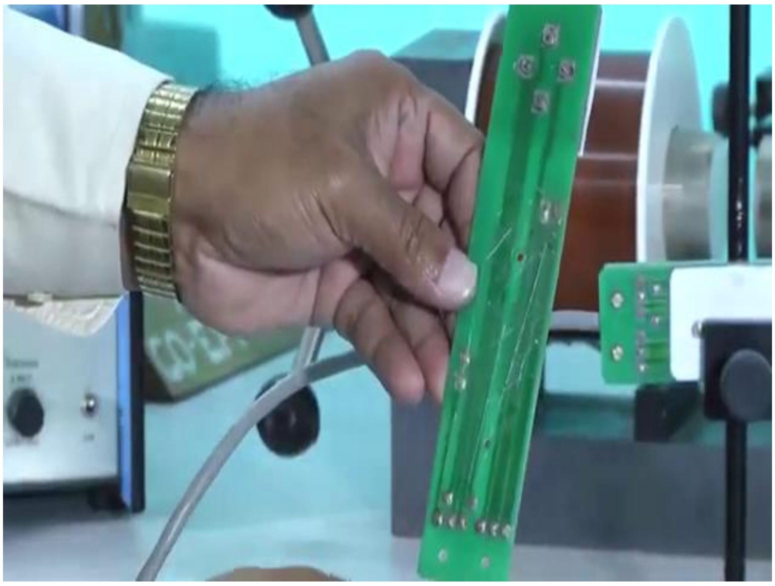

you see from here this connection here is connection PCB. these two connections are coming from the heaters; these two connections are for heater. This last two coming from this two, this is for heater, this is for heater. current is going to the coil it is heating. Now, these two are for the thermocouple; these two are for the thermocouple. here you can see these two are for the thermocouple; these two are for the thermocouple. Here these and these and these for thermocouple.

Now, for this 4 for Hall, this 4 connection you can see these 3 are coming these 3 1 2 3, these 3 and another from here it is coming this. this middle 4, this middle 4 basically for this Hall connection. This probe connection this 4 middle 4 and this side this for heater and this side these 2 are for this side these 2 are for thermocouple, these 2 are for thermocouple. using the PCB basically we are being the four probe as well as thermocouple and heater and heater.

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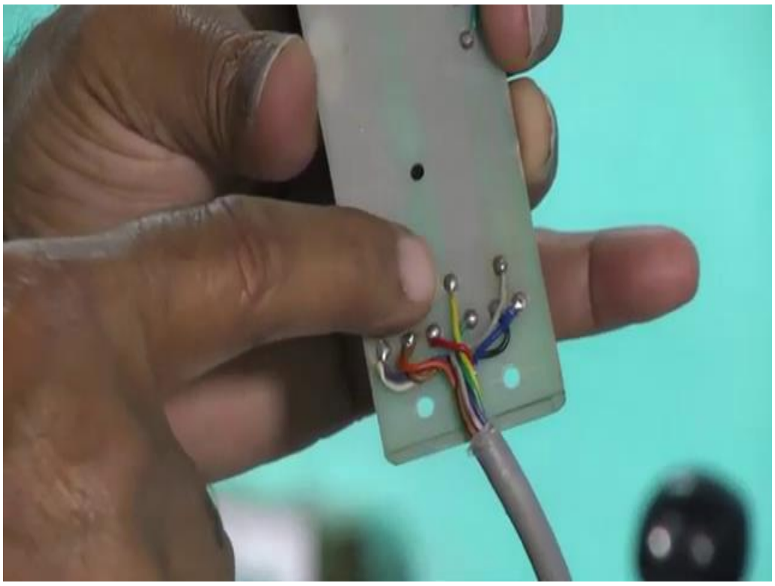

these 8 connection from there you see here 1 2 3 4 5 6 7 8; here 8 wires are there 8 wires are there. these 8 wires are coming through this wire and it’s a connected with this here whatever holes you are seeing. with that hole inside there are metallic part. there it is connected, now this through this we are connecting with this probe here correct. now, here basically what is there here? For heating as I told the sub power supply is there; it is applying passing current through this to the heater.

Some power supplies small power supply is there and for measuring the thermo E.M.F. in volt some millivolt meter is there. nothing else inside 1 millivolt meter is there and 1 power supply is there for giving current to the heater. some power supply battery kind of things are there. And, here already this part you know this again there are some voltmeter for measuring the Hall voltage and there is a constant current power supply inside alit is there.

it is if this all these three voltmeter as well as the current meter means power supply these are kept inside the box. If you open this one can find out. this is the arrangement and generally student work data is ready made system just probe it is somebody put their make the system ready and just rotating the knob and just taking the reading.

But you should understand what are the requirement for the experiment and how you are achieving that parameters from this instrument; that one has to; one has to check and verify. this as I told before the experiment or after the experiment one has to calibrate the electromagnet, one has to calibrate the electromagnet. put the Hall probe and apply the current and this is the Gauss meters, this is the Gauss meters.

At present I have put 0 current adjust 0 make it we have to magnetic field is 0, magnetic field is 0. Now, you apply current; apply current say apply current and take reading. current versus magnetic field you have to calibrate for different current; many times I have done. before experiment you should take this reading that will be the calibration of the electromagnet for this air gap.

Now, in case of electromagnet why company Hall has not supplied the calibration chart at as they have supplied for as they have supplied for calibration chart for the thermocouple, for the thermometer, thermocouple thermometer? reason is that this chart is only depends on this chart these value of this chart only depends on the type of thermocouple, there are different type kind of thermocouple it’s the here it is chromale-alumale. there are others other; two types of material, 2 wires are taken of two materials and make the junction of these two 2 wires.

that junction is put at this at the higher temperature and other two junctions is kept at room temperature. Means, it is coming to these to the other two are coming to this to the voltmeter to the voltmeter which will measure the thermo E.M.F. induced E.M.F. due to thermal temperature difference between the two end between the two end. that is why this chart will not change for this thermocouple. always it will give this, always it will give these values. it will not depend on any other factors.

that is why this company has supplied this one, this one and we can use. But, for electromagnet it does not depend some that we are calibrating magnetic field versus the coil current. But, this coil this calibration or the magnetic field it does not depend only on the current, it depends on another part that is air gap between the air gap between the magnetic poles.

these we cannot keep constant because using this electromagnet various experiment we can do. the sample size will be different; you need different air gap. you have to change the air gap. when you will change the air gap then the for a particular air gap what are whatever the calibration curve that will not be valid. that is why company cannot supply the calibration chart for the electromagnet. One has to student has to or user has to calibrate the electromagnet, keeping the full gap as desired. I think I will stop here.

Thank you for your attention.