# Solid State Physics
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## Lecture - 52
## Electrical Conduction (Contd.)

So, I will mainly discuss about the experimental procedure to measure the conductivity and Hall voltage.

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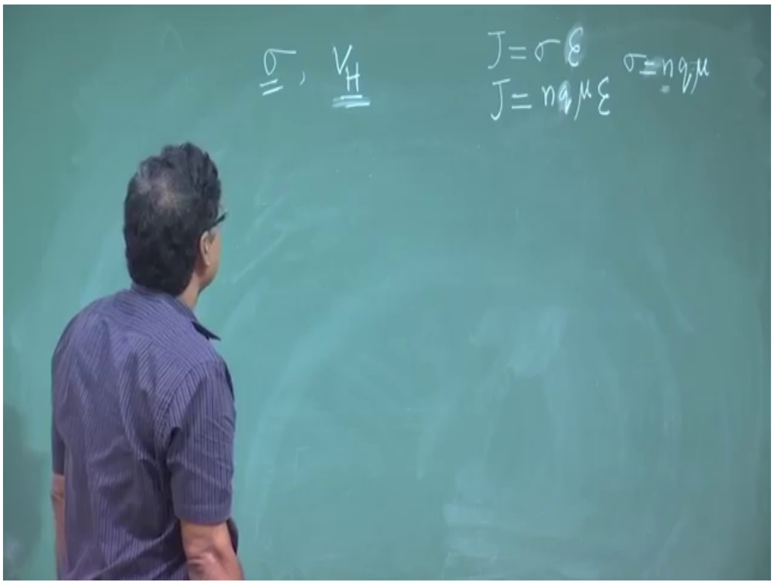


So, as I discuss that if I know these 2 parameters to this these 2 of a sample for a sample then I will get all information about the conduction conducting parameter conduction parameter for conduction right. That we have seen it is; what was the relation J equal to sigma e or I will let me write electric field right and J equal to n e mu. So, I will not bother about the sign.

So, let me write q j equal to nq this is the mobility and yes this is the mobility and here this will be there. So, these is telling me the sigma sigma equal to or let me write here sigma equal to nq mu nq mu. So, this sigma depends on this density of carrier and the mobility of the carrier that is what I was telling and for and this for V H what is this V H V H.

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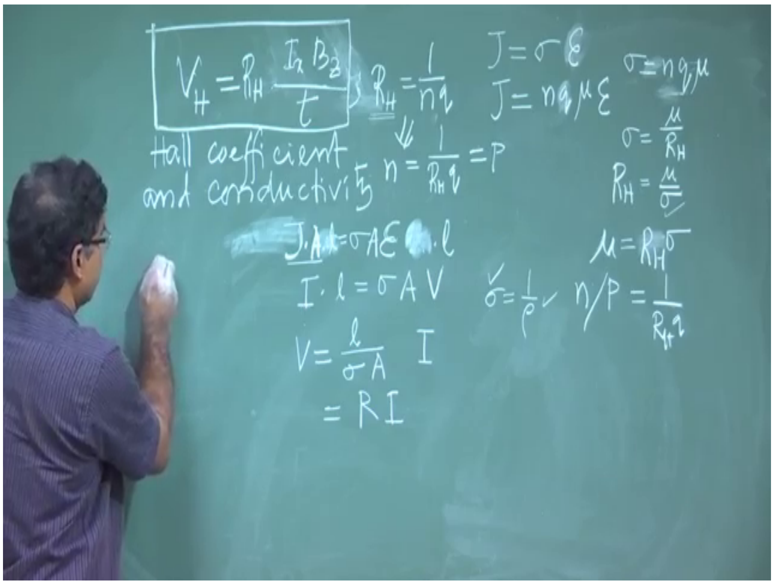


If I remember so V H was equal to R H Ix current Ix and then Bz divide by thickness of the sample t.

So, and R H what is R H; R H basically R H is 1 by nq right. So, if I can measures if I can know the R H then I will know the density this density of states or density of electron. So, from here 1 can tell n equal to n equal to 1 by R H q. So, q this charge is known it is known and this if R H so 1 can get n.

So, one can get n or p right it is can be n or p. So, it is charge carrier it can be n or P whole density and yes. So, that is sort, I will know the carrier density I will know the carrier density and then from the sign of this R H from the sign of the Hall voltage from the sign of the Hall voltage. So, then that I can take the sign of the R H and from there I can I can tell this whether it is it is q is electron e minus e or this it is plus e.

So, that also we can find out and I told also that we can find out the mobility of the electrons mobility of the electrons or the whole if I can measure the conductivity if I can measure the conductivity right, from Hall measurement I know this part I know this part from R H. So, basically here this I can sigma this I can write sigma equal to 1 by R H nq is 1 by R H 1 by R H mu by R H. So, R H equal to then R H equal to mu by sigma.

So, Hall coefficient: if I measure the Hall coefficient, if I calculate or determine experimentally the Hall coefficient R H and if I can measure the measure the conductivity of this of this that same sample then I will get the mu. So, I will get the mu value. So, that mu will be mu will be R H R H sigma. So, I want to get mu value I want to get current density here this n or P n or P n or P that I will know if I measure the R H if I measure the R H. So, that is R Hq depending on the sign of this. So, I can I can find out the type of carriers fine

So, here I so I have to I have to set experiment I have to set experiment for measuring this for measuring this for measuring this R H and sigma conductivity. So, ultimately I have to measure Hall coefficient and conductivity of my sample then I will know I will know different parameter for that sample.

So, this form of this you see it was not in that form initially it was not in that form it was just V H Hall field equal to some Jx etcetera, but I have taken this is form suitable form where I can set the experiment and vary these parameters and get the vary this parameter and I can measure them or get the reading from the from the instrument and I can ultimately calculate the R H.

Similarly, for sigma for sigma if what is the form sigma equal to so I have to get suitable form of sigma directly, I have no instrument to measure the conductivity. So, there are instrument resistances we can measure, but it is again it is you need sensitive instrument to measure to measure the conductivity that is not done directly. So, some instrument is giving that value again that based on the principle that instrument is based on some principle and that principle what has to know.

So, that basically from here from our discussion we will know that that principle of that of that type of instrument. So, for here conductivities related with the with the with the electric field, but generally electric field or this current density we do not measure we prefer this we prefer this. So, let us take let us take a. So, if I so this J now if I multiply with some area A in both side area a right.

And if we multiply in both side with some with some this length of your sample along which this you have applied the electric field. So, say electric field is applied along the length and this is the cross section A of this of this sample this the width and the thickness it is related with the width and the thickness. So, then if I multiply with length l so capital L small l whatever so I have to multiply with l also here. So, then I can multiply both side that is know I can multiply divide. So, there is no problem.

So, this I can write I into l equal to this I can write sigma A put a here and this is e l electric field into this length that will give me voltage V, that will give me voltage V. So, the practical this voltage or current for measuring current for measuring voltage we have a meter voltmeter. So, I can design the experiment. So, I need some realistic this parameter which I can measure.

So, this form is suitable form. So, then what I can write V equal to V equal to I V equal to I l by sigma A sigma A. So, sigma 1 can write sigma equal to 1 by R Ho resistivity. So, these conductivity resistivity whatever fine, so this is basically I can write this some constant V equal to some constant I. So, this is nothing, but the resistance right this is nothing, but resistance.

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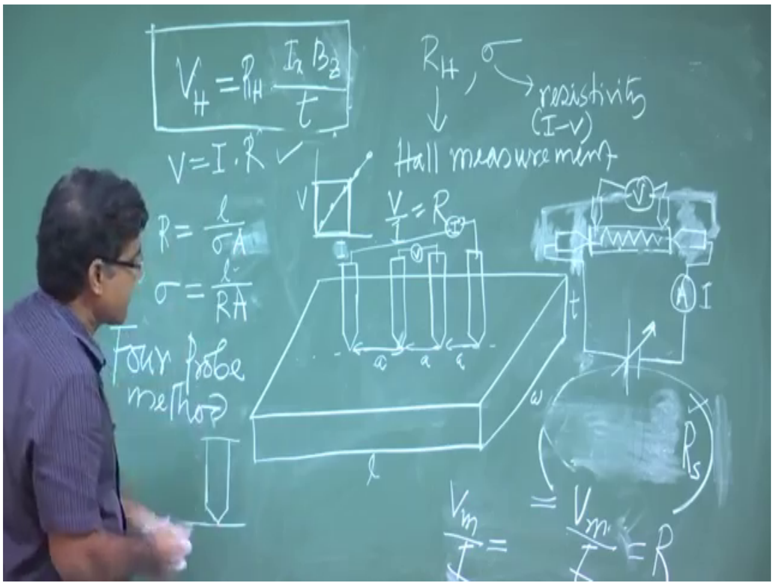


So, I have now formula where I can write that V equal to I have now formula suitable formula suitable formula. So, V equal to I R VR R 1 can write here R Vequal to IR and where R equal to where R equal to l by sigma A. So, sigma equal to sigma equal to l by RA. So, this my the very suitable form for experiment these are very suitable form for my experiment. So, here what I want to measure what I want to get I have to get R H and I have to get sigma for my sample.

So, how to measures? How to how to get them? So, for that I have to set the experiment. So, I will take a sample of some material either semiconductor or metal not insulator please not insulator semiconductor or metal. So, here you see just generally in theory we derive in different way in terms of different parameter, but for the experiment always you have to take that formula that expression in a suitable form. So, that you can set experiment with known or available components; components means you have you have to apply current how to apply current you have to measure voltage how to measure voltage. So, that is known to us. So, these are basic things.

Now, whatever known to us using them I can do experiment I can find out the value of the parameter which for which I am interested. So, that is way always one has to take in suitable form. So, in theory this former in different way that that may not be directly suitable for the experiment like density of states. So, right we always tell density of, but in experiment we talk in terms of density of the carrier and theory we have seen this theory it is related with the density of states. So, that one has to know and it is very important it is very important.

So, this is what I should do. So, this is my sample. So, this thickness is t width is w length is l right. So, this is what I want to measure I want to measures those parameter, but that is that they are related with these. So, that means, I have to this is called Hall measurement one is Hall measurement another is resistivity measurement one is Hall measurement we tell Hall measurement Hall set up for that Hall set up Hall measurement for that Hall set up right and another is from resistivity measurement or conductivity measure resistivity measurement or not resistivity measurement or conductivity resistivity or IV characteristics of your sample IV characteristics of a sample resistivity or IV characteristics of IV characteristic of the sample or measurement of your sample.

So, if I what you know you know if I give you a resistance if I give you a resistance if I give you a resistance a wire if a a wire or a a piece of some strife or piece of rod of some material if I ask you to measure the resistance what you do you just you will take one battery you will take one battery and you connect this battery with this right you connect this battery with this right.

Now, we take really variable battery means you can change the voltage. So, if you are apply voltage across this and current will flow. So, I will I will use ammeter from milliammeter whatever ammeter I will use. So, what is the current flowing through this I can get? So, I will get I for a particular setting of voltage here, but I am not interest for this voltage.

So, for so this voltage will set in my circuit one has to understand correctly. So, we have not interest about this voltage we are having this voltage there are some procedures just. So, voltage divider one can make in different way. So, changing voltage now we are changing voltage to set current in the circuit, now I set a current in this circuit. So, that current is I now for this current this current is passing through this resistance. So, I have to measure voltage drop across this resistance. So, I have to use voltmeter here I have to use voltmeter here.

So, I said in the circuit that I will get this reading from here and voltage drop across this resistance that I will get from this voltmeter. So, this if I set this measurement like this. So, I will get I will get. So, this will be satisfy generally what you do generally what you do you just very set current in different current measure voltage. So, other way either V here I whatever so it is a different current and measured the voltage. So, you will get this type of right. So, experimentally generally we measure many times and plot and take the average value.

So, just from so for this current for this current this is the voltage. So, I know this voltage I know this current. So, V by I will get this R value experimentally I measured and get the R value I know this parameter I know this the geometry of my sample of lA A is omega t wt right, then R I got from my experiment this is from geometry and then I will get cinnamon so these things.

So, this method whatever I told you were familiar with these are not very sensitive if I want to measure the distance of this sample it is not very thin it is not very thin why are you know this resistance is very high. So, for a particular current voltage drop will be high. So, whatever this conventional voltmeter and ammeter are sufficient for this high resistance, but here resistance is very small if I take if you take metal. So, resistors of course, resistivity is very small. So, voltage drop will be very small right if see when it is microampere nano ampere range.

So, you need very sensitive arrangement to measure the current and voltage. So, that is why there is a method it is called 4 probe method. So, probe means generally here instead of we see they here just wire you just connect it or shoulder with it. So, here I have to connect this one and I have to connect this ammeter or this circuit this with this sample if this is my sample if this is my sample. So, from that in that sample what I what I am doing this current is going this way and I am measuring the voltage.

So, basically here I have from this sample I have taken only 2 connection I have taken only 2 connection say at this point and at from this point. Now from this saw this now if I it is a connection. So, now, this is the probe I am telling this whatever probe this just it is not shouldered from just it is it is contact connection you know it is contact connection. So, that is why it is called probe is basically conductive some very highly conductive material this wire is taken this pin kind of pin you know pin right.

So, this is for paper just we use pin to hold it. So, this type of sharp edge so this we put on. So, just put on to this on put pressures like pressure and just this it contact it with the sample. So, these call this contact connection it is not shoulder or this twisted one. So, these just contact this so for that we use the probe kind of thing. So, pin if you take pin to pin. So, I have sample say I have sample and then I put just to probe just with some slight pressure. So, that there will be good contact.

Now, this from that probe I am taking the connection I am adding connecting the voltmeter I am connecting the voltmeter and so as if here if I modify it. So, here this my sample so one probe. So, I can tell this is one probe, this is another probe now from this I am taking this connection from here I am taking this connection from here and other one I am taking other one I am taking connection here I am taking connection here.

So, I am not disturbing my sample except these just to contact now with the contact I am taking. So, this is called basically 2 probe method 2 probe methods. So, 2 probe it is used for supplying current to the sample, then it is used for measuring the voltage drop across the sample right. So, there is the 2 probe. So, we need basically connection for measuring the voltage drop. So, we need 2 connection and also we need 2 connection for supplying current in this sample right.

So, basically we need 4 connection with the sample. So, here if we use 2 probe 2 connection and then I am taking from that connection I am taking this other 2, but with the sample these 2. So, whatever ohms law verification ohms law etcetera whatever you do (Refer Time: 28:36). So, that is basically 2 probe method and in 2 probe method it is it has error, it gives measurement gives error and when specially when this resistance is very small like this type of sample then that error you cannot neglect that error.

So, it is telling that 4 probe method is more accurate than this 2 probe method, but now question is that from where that error is coming. So, let me explain here. So, here you see current is coming current is coming flowing through this right. So, when current is flowing through these. So, there will be small resistance of your probe small resistance of your probe. So, if it is Rp probe resistance. So, current is flowing this way right this way. So, it is flowing through this so that Rp that raises also Rp. So, 2 Rp in your circuit 2 Rp plus there will be some contact resistance there will be some contact resistance you cannot ignore you cannot ignore when your sample resistance is very small.

So, there will be 2 contacts, 2 R Rc contact resistance right and then your sample then your sample resistance Rs your sample resistance. So, from where you are measuring voltage that is why are you are measuring voltage that is important I am measuring voltage here. So, this voltmeter it will give the voltage drop for this resistance this resistance and this resistance and also this contact resistance.

So, whatever this voltmeter is giving me reading that is the current is constant of course, it is flowing current is constant this plane. So, this into I so that will be my voltage whatever, I am measuring measurement voltage are in measurement voltage and then whatever this Vm by so Vm by your I Vm by I. So, here you write Vm by I equal to this is the resistance.

So, it is not your sample resistance it is not your sample resistance. So, if so whatever resistance overall resistance this total resistance is whatever R you are getting and that R you are reading here to find out the conductivity. So, lot of error it is in that it is not your sample resistance it includes the resistance of your probe resistance of your this contact. So, that is why error is more.

So, we have to avoid for small resistance if it is more resistance. So, then it will give high error right. So, I have to avoid this 2. So, I have to try to measure this Rs how to do that how to do that. So, that is why you if we take 4 probe, 2 probe for current and 2 probe for this measuring voltage then it seems you can avoid this error resistance.

So, how this difficult to understand because 2 contact is giving more error and I am taking 4 contact from the sample and it will give less error how it is possible? It is possible just here you think that I am this 2 probe I am using this 2 probe I am using for supplying the current and 2 more probe I am using. So, here say so here to more probe I am using for separate probe I am using. So, this separate probe I am using for measuring the voltage.

So, then it seems I can avoid this one is it. So, let us see. So, here current is flowing. So, current is flowing through this resistance through this resistance this resistance contact resistance fine. I do not have problem, but what about current I am getting from here. So, that is current is it will not this current will not be affected by this resistance.

So, and I will change the voltage I will set a current I will set a current here. So, whatever the resistance I do not bother my. So, these current which is flowing I am sure that this is flowing through my through my sample it is flowing through my sample it is flowing to others also, but through my sample this is the resistance current.

Now, when I am measuring the voltage here I am measuring the voltage here then there is no voltage drop due to this contact because this is voltmeter it has very high resistance voltmeter have very high resistance. So, no current will flow through this probe no current will flow through this probe right is it can be very negligible current since this resistance is very high comparable compared to this your sample resistance.

So, all current will flow through this and no current is flowing through this. So, there is will not be any voltage drop because of this. So, this contact resistance will not come into the picture. So, there so whatever voltage here are reading I am getting that is purely this voltage drop because of my this sample right because this contract no current is flowing, how this contact resistance. So, it will affect the resistance right.

So, because I R that is the voltage drop so no current is flowing through these. So, there will not be any current any voltage drop across this contact resistance across this probe resistance right, across this probe resistance across this contact resistance only this voltmeter will give me reading that is voltage drop across this purely for my sample. So, I can get rid of this. So, I will get Rs equal to my measurement voltage V divide by I that is basically my sample resistance.

So, this I will. So, the beauty of this 4 probe method hopefully I try to make you understand, but you should think yourself. So, this is very nice method. So, there are 2 ways one is your linear 4 probe method, another is called (Refer Time: 37:13) method.

So, this here whatever I explained. So, here basically in middle of the sample at equal distance we take this probe we take this probe.

So, this outer 2 is used for our current and this inner 2 use for measurement voltage. So, whatever the I explained the same way. So, here these probe distance is very important probe distance is very important and we at equal distance equal distance and this expression is slightly modified. So, I will not discuss that one I will not discuss that 1, but this is the way 1 1 use 4 probe linear 4 probe method.

But for Hall measurement Hall measurement what we do Hall measurement these 2 probe we use for supplying current supplying current supplying current.

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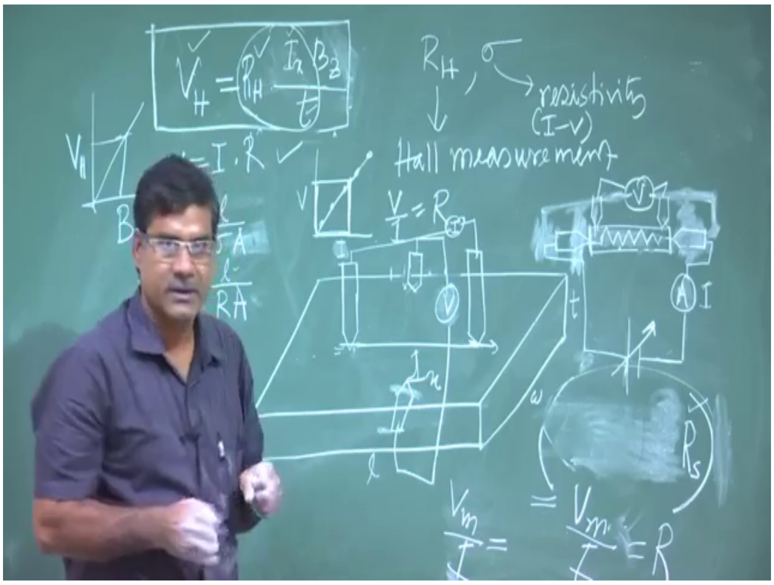

So, this is Jx or Ix and here 1 probe and is along the y direction along the y direction so here to these 2 probe we use for measuring for measuring Hall voltage.

So, this not is not now not linear so probe 2 are using this along the x direction and 2 we are using along the y direction and now this whole sample are put in a in a magnetic field. So, these geometry is called bender geometry. So, I will not just discuss that that part, but here just. So, these the arrangement now this you are setting current Ix you are setting current Ix along the x direction and you are measuring the Hall voltage you are measuring the Hall voltage of their applying different magnetic fields just very magnetic field or and get this Ix get this V H.

And then if you if you if you draw a curve V H. So, you will get I think linear type of curve. So, from there you will get this from the slope you will get this constant from the slope you will get this constant. So, Ix and this is known. So, you get this R H. So, from there what can calculate this all this parameter? So, I will stop here.

So, in next class I will start these thermal properties of solids. So, I think electrical properties of solids. So, it is very I took long time because there are many theories one has to develop free electron theory band theory and then metal how this density of states are arrange and the semiconductor how this density of states are arrange or density of carrier. So, I think I will stop here.

Thank you for your attention.