Experimental Physics - III
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture - 30
Electron Spin Resonance (ESR) Experiment

Now I will demonstrate the ESR experiment in solid [vocalized- noise] solid-state physics laboratory of Department of Physics, IIT Kharagpur.

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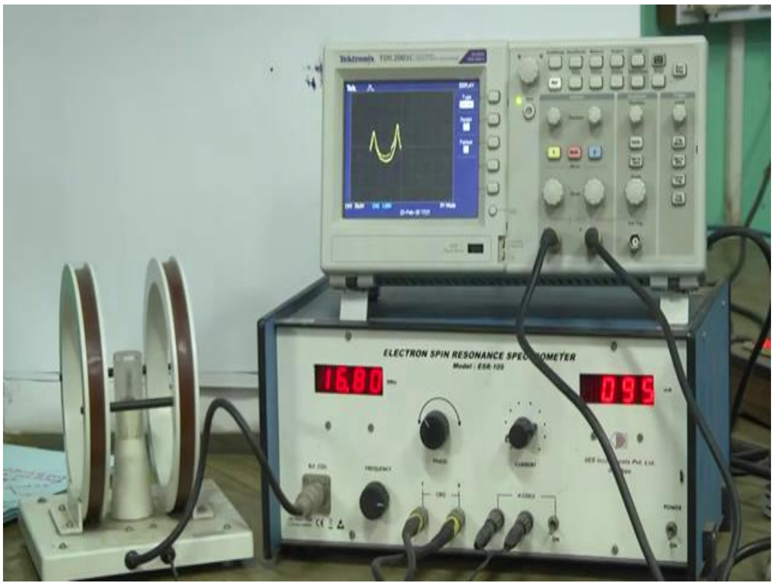

this is an experimental setup or ESR so what do we need; we need a sample as I mentioned in my previous class that we will use DPPH sample in a magnetic field produced by Helmholtz coil.

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This is the Helmholtz coil one pair of Helmholtz coil, I think this way you can see this 2 Helmholtz coil it is separated by this rod. If you see these rod distance it is less than or equal to the [vocalized- noise] the radius of this of this coil.

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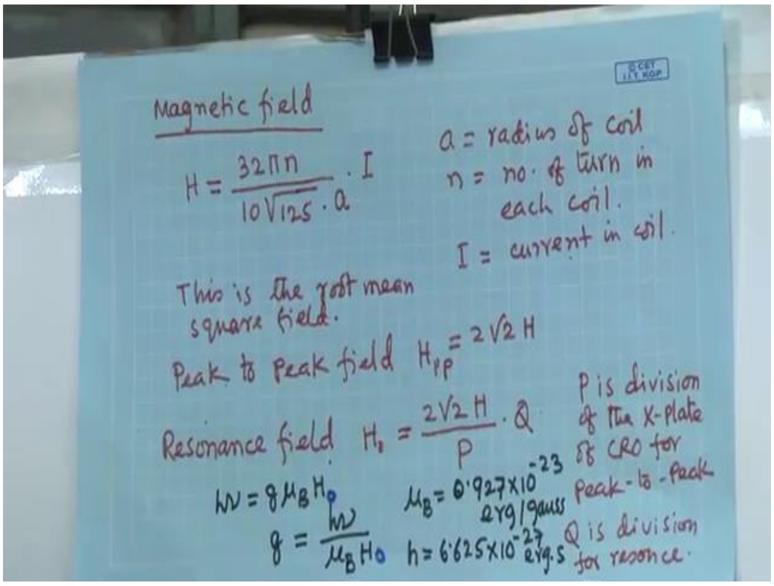

Now, how many turns are there to calculate the magnetic field you need number of turns in you need a radius of coil that will be supplied in manual you will get these values because these value company knows, and they will they will supply us. Now for current so here say I have applied 143 milliampere current; 149 milliampere current. I is 149 milliampere; then you can calculate this H value ok, magnetic field for this current.

now, I will change the current I will change the current for different current you can find out it is a 0 current; it is the 0 current You can find out the for different current you can find out that magnetic field H. Now so in this magnetic field as I told this is the RMS this whatever this this value will get. This value is RMS value root means square value because I so here we are applying.

This that that is showing RMS current because AC field is AC current is applied for getting the AC field. Some DC component may be there ok, but in this experiment probably we are not using DC field because we do not where we need higher field For sample you need higher field say then we apply some DC field, and with some AC component in this case we need small fields that is why it can be directly the AC field.

Now, at the center of this of the middle of these 2 coils ok this sample actually center in all respect the sample is put centers. I can open it and show you; one has to be careful because it may damage you can see this tube like thins ok.

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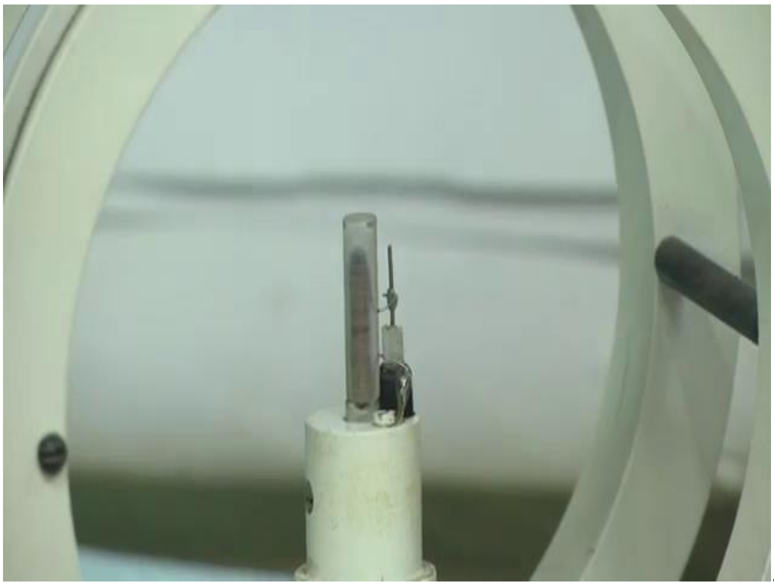
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inside these samples are there and around the samples some coils are there; around the sample some coils are there inside so it is maybe difficult to see, but this is the sample, now this sample is there and this around this one coils are there. As I mentioned this that coil is to produce the so this to apply the radiofrequency radiation or it may be field also radio frequency field.

Here this connection this R F coil. here as I told inside R F these coils are there where radio frequency field are generated in perpendicular this field direction is this. And this coil so it will produce magnetic field in this direction as I told this I showed you if one field is along z direction other field has to be perpendicular to that along the Y axis ok.

This field an R F field this R F field is in this plane here yes. In addition, this this a Helmholtz coil it is giving field in this direction. These 2 fields they are perpendicular to each other. in classical concept whatever I was discussing so if you consider that this is one magnetic; this is another magnetic field weak field. It is coming from this R F coil or you can think that this is one field stronger field and these some R F or microwave radiation ok.

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Whatever the case so sample is in a magnetic field uniform magnetic field of H of H; that H will be calculated from the current and the coil geometry and this radiation whatever I was talking. that will be applied in the sample from this R F coil. the from this connection and this coil current we are taking for Helmholtz coil current; we are taking from here so this current showing here

Now I will close it because otherwise it may be damaged. let me put that cap here so as I mentioned that; as I mentioned that we have to if I we have to say we have set some magnetic field in Helmholtz coil.

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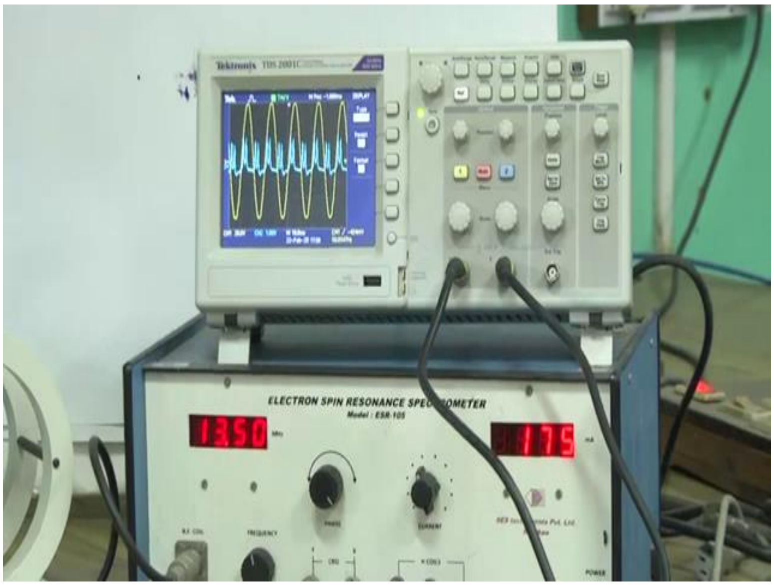

Now, here whatever you are seeing actually if I go to the it is in XY format; it is in XY format. If I go out from the XY format; here you can see now channel 1 and channel 2 from here you see channel 1 and this channel 2. It is the scale is 50 volt for channel 1 and this one division is 50 volt and these for channel 2; one division is one division is 1 volt And from color you can see which one is channel 1 and which one is channel 2. This channel 1 is here it is showing the magnetic field. Whatever magnetic field we have applied as in picture I showed; as in picture I showed that, these whatever 50 Hertz sweep unit.

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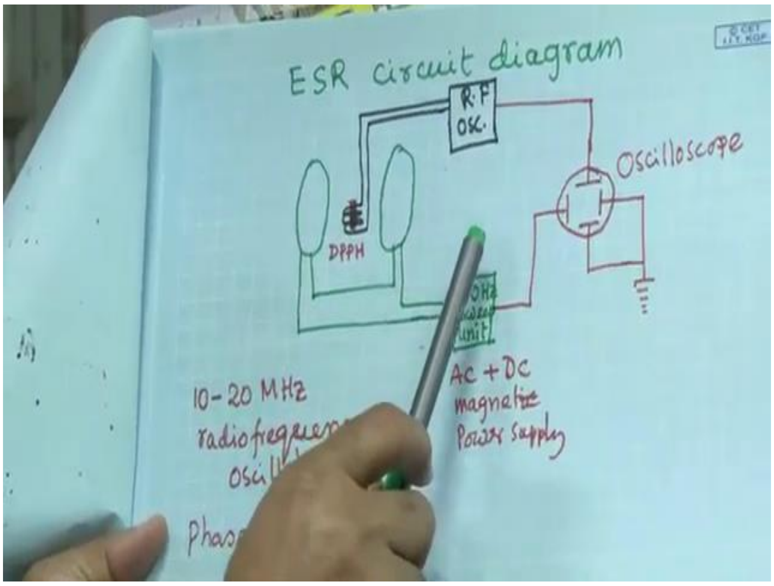

what are magnetic field if it is so these are given to the X axis, X channel X axis And this other array oscillator from there it is going to the Y. XY mode and in in in in normal mode this are this will be one can tell this is the channel 1 and this other one is channel 2. Here channel 1 and channel 2 you can change the amplitude of the using this one; amplitude of the I am changing the division per volt per division ok.

Now it is 50 if I change this one I am changing it is a 5 volt per division, 10 volt per division now it is I can change the position yeah. It is 20 volt per division and this other one is from R F; from R F tank from R F from R F oscillator. Whatever the signal we have put, this is the R F source. In R F oscillator here whatever the this peak we are seen now here you see this this R F coil. This is a what is the frequency; that is R F radiation whatever going or field whatever going so that frequencies this. A frequency I can change this frequency I can change ok.

Yes, this provision is this changing frequency. I can change the frequency here I can change the frequency. Maximum it is 17 around so let me keep at some value so keep it there. you are changing the frequency and here you can you are changing the magnetic field. Now, this norm is for phase shift here written here it is phase written ok.

As I told this, I can change the phase between these phases; I can adjust the phase between these between the channel 1 and channel 2; whatever the 2 signals are there. I can adjust the so one is coming from oscillator another is coming from magnetic field ok;

AC magnetic field. this whatever the signal corresponding signal coming. phase between these 2 can be adjusted using this one, this you see can see it as a moving with respect to the other one if I go now from here I can see this AC magnetic field is applied from this Helmholtz coil ok, at the to the sample and this other one is these mega Hertz here mega Hertz.

13.50 mega Hertz some radio frequency field are applied or radiation are applied whatever H nu; so nu is this frequency and other side this H we have to find out how to find out H 0. this is the H value, but not H 0. what is the H 0 value, H 0 value is the value at resonance Because in this case we are keeping these radiation field this R F radiation field of constant frequencies is means is the energy H nu is constant.

Now I am varying magnetic field ok, AC magnetic field I am varying; AC magnetic field am varying AC magnetic field this way we will see that there will be absorption for one complete cycle. for a particular where resonance will occur so for a particular H value. That is H 0 at that at that 4 points there will be absorption and that absorption so that absorption from where this coming. that absorption that energy is supplied by this by this coil this R F coil ok.

now, there is a provision here this is an energy absorbed, but then we should see the deep ok, but it is showing the peak it is showing the peak at the absorption point that that mechanism is introduced in the with this array postulator there is a detector and this amplifier. It is a called I think it is an odd amplifier kind of things. It just inverse the object it is that mechanism is introduced in the circuit so absorption whatever instead of deep the signal it is coming here. that is it is a showing the peak so now these 2 we have applied in X plate and Y plate.

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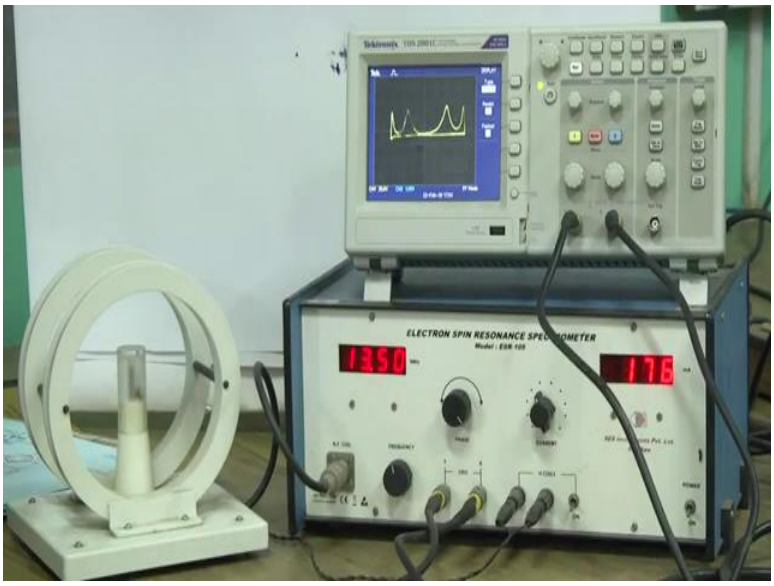

Now, if I go to XY plate mode; XY mode here already it was the XT mode, X YT This is normal time T means time and this Y means it is the amplitude now here you can see here you can see so under this condition at this 30 we have to note down this 13.50 megahertz.

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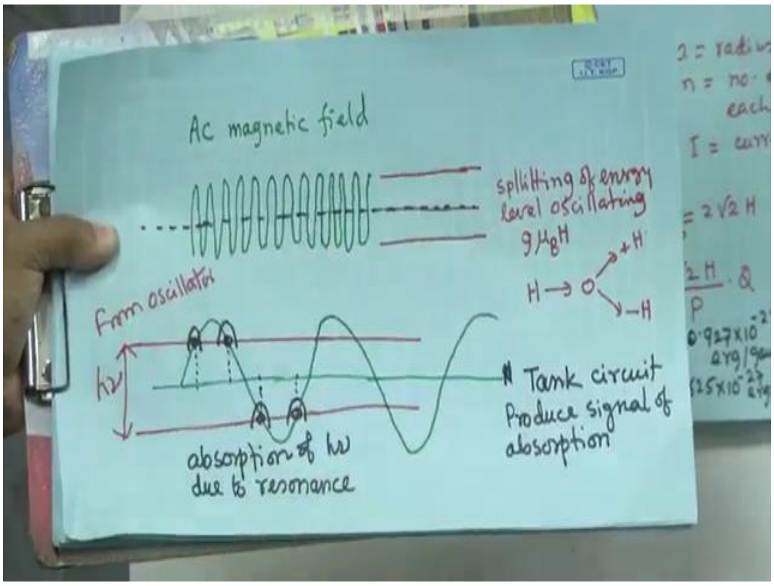

corresponding in nrgh thing for that this field is varying for that for a one complete cycle one complete cycle as I told there will be 4 absorption for a for this H 0 value. In addition, corresponding it will produce peak; 4 peak. 4 peaks we are seeing here these 4 peaks we are seeing here. Now these 4 peaks so we will change the phase we will introduce the phase while we will introduce this we are introducing phase this 2 in CRO; in CRO whatever the signal has come. In that these 2 signals is a phase difference we are changing and bringing back bringing this 2, this 2.

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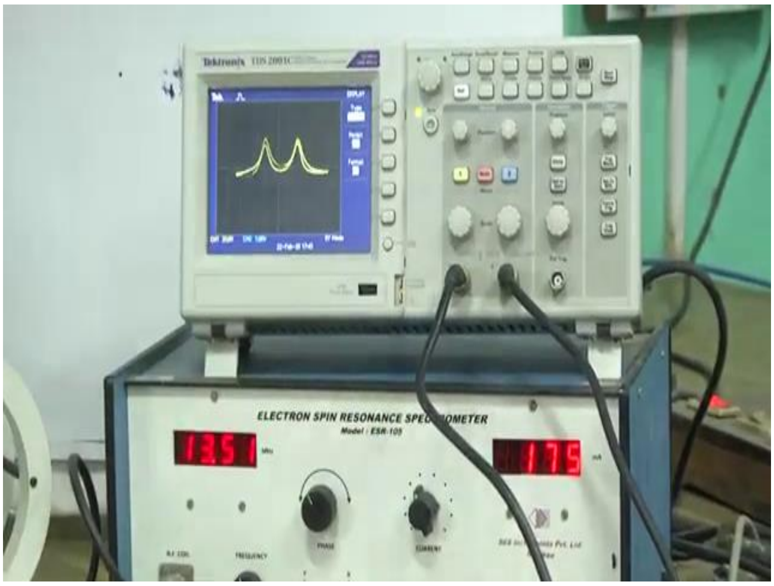

These 2 we will coincide it will give one and these two we will coincide to give another one that I am doing. I will change this phase I will change this phase and you see these 2 are on one side; these 2 peaks now we have 2 peaks now here so for a particular resonance of this mega Hertz R F field. Now this is the current corresponding magnetic field you will know. Now I have to calculate H 0 for that so this value whatever you are calculating for this so this is the RMS value. However, here we will measure peak-to-peak value.

Now, we see resonance is very sensitive. resonance is happening at a particular magnetic field when it is varying; when it is varying this magnetic field it is varying only for a exactly this field it will show the peak there and for other field. It is away from the resonance. This resonant reflect will be minimum; when it is reaching to this peak of this magnetic field ok.

This peak to this peak this peak to this peak this variation here. Minimum effect resonance effect will see when the when it is at the maximum magnetic field minimum resonance effect where you can see this at this place at this side. This end and the last end this end that last end this last these 2 end are for this peak-to-peak value. why here I am taking because this is the place this is the, it is it is maximum magnetic field peak value of this magnetic field and it is away this value is the maximum away from the resonance field.

resonance effect will be minimum there so that is why this minimum whatever we are seeing these 2 H That is P value as I mentioned that P is the division of the X plate of CRO for peak to peak value as I told peak to peak now, I have to here scale we are used 20 volt here you can count this how many divisions are there 1 2 3 4 5 6 7; 7 slightly more than 7 7.2. P value I have to note down it is a 7.2 into division that division and this 20 volt because we will take Q by P ratio.

if you want to take P as a number of division we have to keep this division per volt we have to keep un changed we have to keep unchanged or if you want to change it if you need then you should multiply this P number of division whatever this that will P in terms of voltage this you can tell this number of division 7.2 into 20 volt that is in volt Q also we have taken volt. now, Q is so where these absorption are so where we got this; at which magnetic field this magnetic field we got this absorption of corresponding peak we are seeing here.

here peak to peak we will here peak to peak means of this in the CRO whatever we are seeing here peak to peak value we will take. That peak-to-peak value it is 2 Q not Q why you see this peak value. Now it is coming to 0 then it is going to the other side peak to peak value peak to peak value magnetic field from 0 to H whatever H here we are telling that is 0 to this field ok; that will be H 0. There whatever we are getting that is we are getting difference between these 2; difference between these 2. peak to peak here, peak to peak corresponds to this field and this field ok.

This is is a double whatever this H field 0 to this H field here 0 to this minus H field. total field here peak to peak is the 2 H ok so 2 H so that when we are taking in terms of Q. here what do how many divisions are there 1 to 2.5 peak to peak here 2.2, 2.5 division. In addition, that in terms of voltages it will be it will be 2.5 into this 20 volt ok.

Now since I have not changed this scale. you can you can just write in terms of in terms of you can write just in terms of number of divisions. here P is 7.2 number of division whereas, that this resonance field it is the that is Q is 2.5 from this formula as I told you;

from this formula so H PP as I told H PP whatever you are getting here H PP peak to peak. that is converted.

The H PP you are getting from where you are getting you are getting these value this this P are there; P are there right. P number of division 7.2; number of division 7.2, P value and Q value is 2.5 we put there now, this is the fraction of the maximum magnetic field is peak to peak value this is H PP it is H PP of that. for H PP we have taken P so it is a for division, this is the magnetic field into how many division we are getting 2.5. These will be the H 0.

From here noting down the I you are getting H you have to calculate that H 2 square root of H that will be H PP H this is the H PP; now you have noted down the P and Q for resonance for this 13.51 mega Hertz R F coil frequency ok, R F field frequency or radiation frequency. You are getting H 0 when you will get H 0. you can nu also is available so from there you will be able to calculate 0. Actually what we will do we will not calculate this way what we will do.

these will remain constant as long as long as I am keeping fix this one but now I will change I will go to the another magnetic field value 1.43. Now you see this resonance when I am changing the magnetic field RMS value will change; RMS value will change. Now here this division is also changing you know it is coming so here division earlier 7.2, 1 2 3 4 5 6 7.2. I should change more than only I will be able to I do not know 1 2 3 4 5 6 7.2 this P value remaining same P value remaining.

This I think I have so if I change the magnetic field magnetic field so amplitude of the magnetic field is increasing as this It is increasing like this, but this red part is remaining the same value ok, red part is remaining same value. H 0 is changing; H 0 is changing and because of that this value or this value you are getting different value peak-to-peak value you are getting different value. higher field this is the maximum field maximum current.

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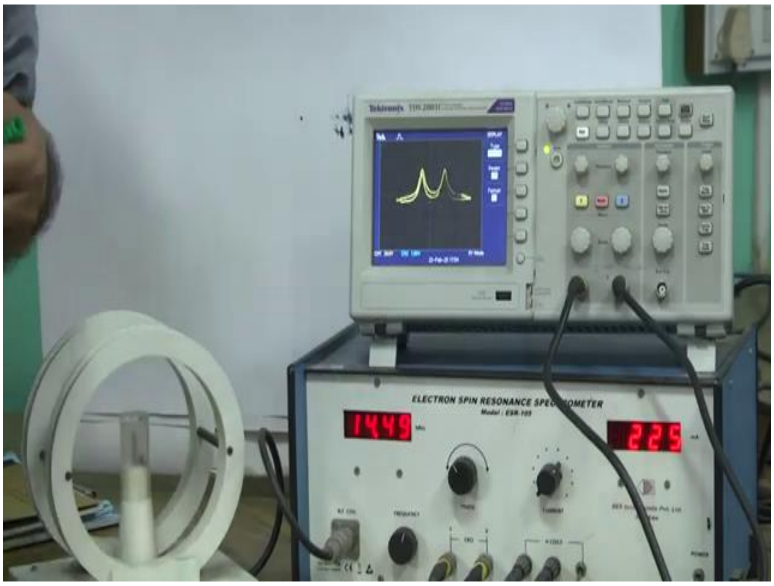

You have to note down this value it is 1.5 now just 2 Q value we are noting down. from 2 Q so this from 2 Q this this value will be 2 Q, say for Q what will half of that will be Q. Q will be here it is 1.5 divided by 2 that will be Q increase I am decreasing field separation increasing; separation increasing and that count you have to take.

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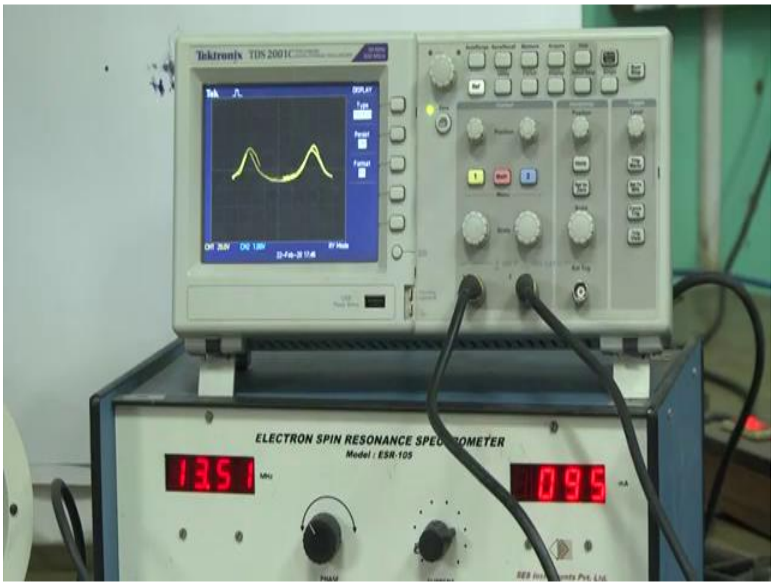

Here what we are doing for different current I am varying I different current am varying I and getting different Q value. Half of it will be Q value number of division whatever here divided by 2 this half of it will be Q value if I plot if I plot Q by Q as a function of I then in manual I can show you that in manual I can show you that.

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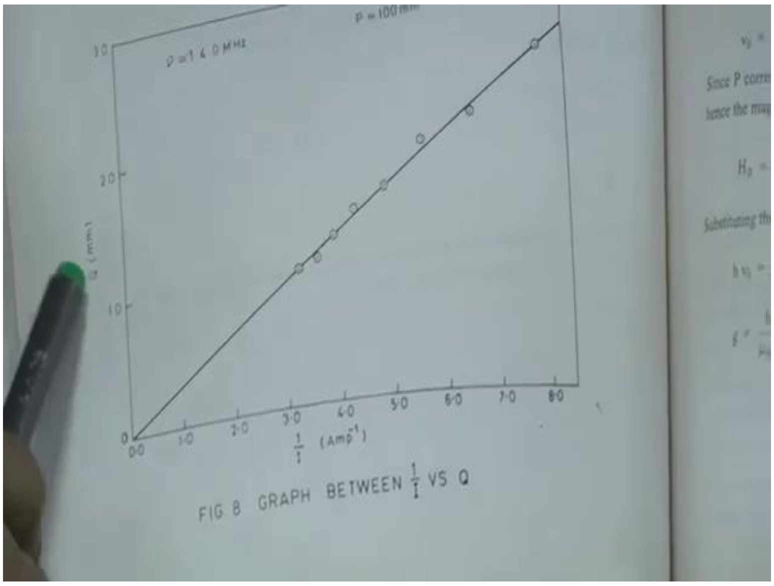

This is the manual where you see this plot is 1 by here 1 by I; 1 by I amperes inverse and this is the Q value this is the Q value. so from here and this is for the particular nu value nu equal to 14.0 megahertz; 14.0 mega Hertz in our case 13.5 mega Hertz And P value is in our case 7.2; 7.2 number of division 7.2 here it is a millimeter then in our case it will be 72 millimeter. 7.2 These are is a centimeter 7.2 centimeter. 72 millimeter so for this P value and this nu value I am varying Q, I am varying Q. Therefore, as I told if I vary current and then 0 currently is flat no resonance now resonance peak value are changing Q value are changing ok.

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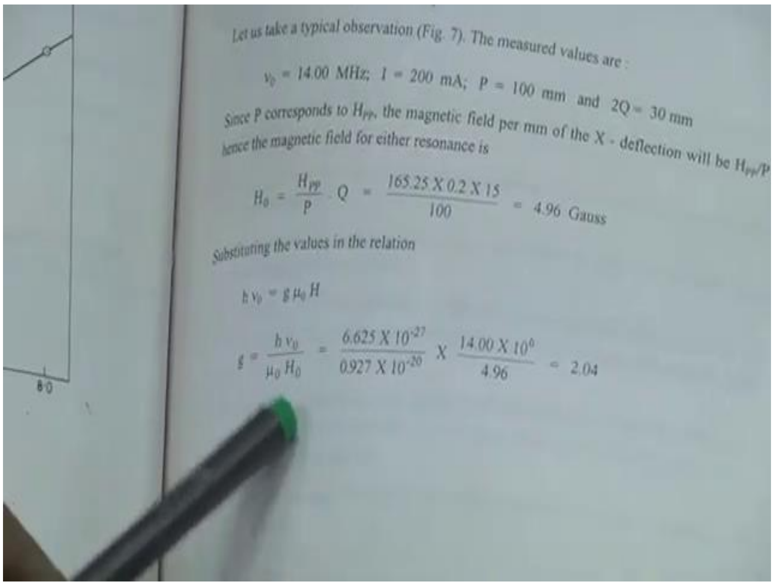

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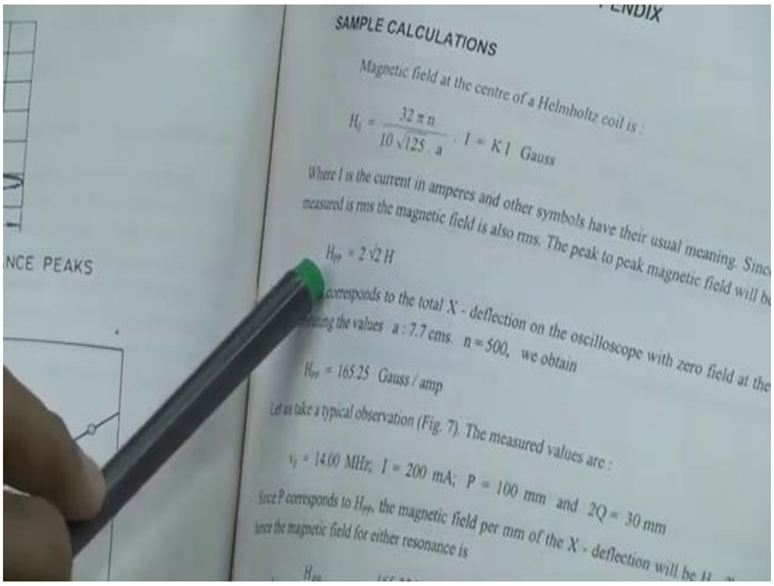

That Q I am noting down for different current. 1 by Q and this Q value here so from slope you have to take slope from slope that is H 0, one can find out Q by P. P and other value this from slope I here this is constant k I H 0 magnetic field at the center of the Helmholtz coil H, it should be H that these value. Now H PP 2 square root of 2 H so H PP; H PP peak to peak from a and n, one has to calculate this H one has to calculate the H it should be H; it should be H Calculate this H and then H PP I am getting. You see 1 by I why they put 1 by I here you can check it I is the current in final formula actually g is H nu 0 nu 0 H 0 ok.

Now, if you put H 0 now if you put H 0 in terms of this I in terms of this I and this other factor here I believe so H is related with the I and g. g is a 1 by H you know so H 0 it has I value. Here 1 by I, 1 by I and corresponding Q you are get Q you are plotting here. many Q are you are getting. from here you will get the slope will be, slope will be that Q by 1 by I so that is Q I. you will get Q I Q I. from the slope you will get Q I, I from where it will come I will come H if you put this H value I is there.

Here Q I are there so from slope that Q I we will get from the slope of this graph Q versus this 1 by I from this graph you will get Q I. Because this H is will be replaced by this I, other things are known P is known from this graph and nu also nu also known you can calculate P value ok.

this is this graph for a particular nu value particular nu value Now for different nu value I will change this nu value say 13.5 now it is now say 14.5 5 take slightly change I will take yeah 14.5 more or less 14.5 again I will do the experiment for different current. now, nu are different corresponding P value also similar way the P value also you have to find out ok.

And then you do the experiment for different magnetic field and draw a graph find out Q I and put in this formula you will find out the H 0 resonance frequency for at least 3 frequency one should do the experiment and get the g value; 3 g value you will calculate an average of the P you will we will report. this should come close to the 2 value. Generally, our student it gets 2.04 or 1.96 this gets so it is very close to this true value that is that is 2 ok.

This is very nice experiment and this is a very simple experiment-teaching lab, but for research purpose this, this very big instrument is used. Because here the for a particular sample we have chosen this very small field, but for research samples there will be various kind of sample. You should have provision for applying up to maximum say 1 tesla magnetic field depending on the sample. That provision for that provision now magnet, it will be very huge large magnet and then you need this is a radio frequency one.

In research generally we use microwave one. microwave here radio frequencies because for this resonance will come at small field. That radio frequency field is or radiation is ok, but for higher for research sample if you need to apply very high field. you need here also this microwave. Microwave is producing microwave is very costly. that arrangement also one has to use in the research laboratory also the I think rest this is this frequency and I thought of telling that aw then yes; another important factor this measurement we are doing at room temperature ok.

to do to get the stabilized signal and to trace the weak field, weak signal so one has to do the experimental lower temperature now, in research equipment there will be provision for varying the temperature it can be room temperature it can be higher temperature. the same principle same thing would be used in bigger forming research the research laboratory that I told this is principle wise the same, but only it will be more powerful because you will have the variation of temperature you will have the variation of maximum higher field maybe few tesla.

Power supply of the of the magnet it is it has to be stable and here this frequency whatever showing it should be used in means microwave so that also is a costly. This is the difference between the teaching laboratory and this research laboratory just you can think this as mini version small version of the laboratory. Whatever principle we have learned so that will be useful for research laboratory research equipment also. I will stop here.

Thank you.