Experimental Physics - III
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Lecture – 34
Nuclear g-factor

Today I will demonstrate NMR experiment, NMR spectroscopy, Nuclear Magnetic Resonance. I have already demonstrated ESR or EPR Electron Spin Resonance or Electron Paramagnetic Resonance. For NMR; the theory is similar also, experiment also is similar ok.

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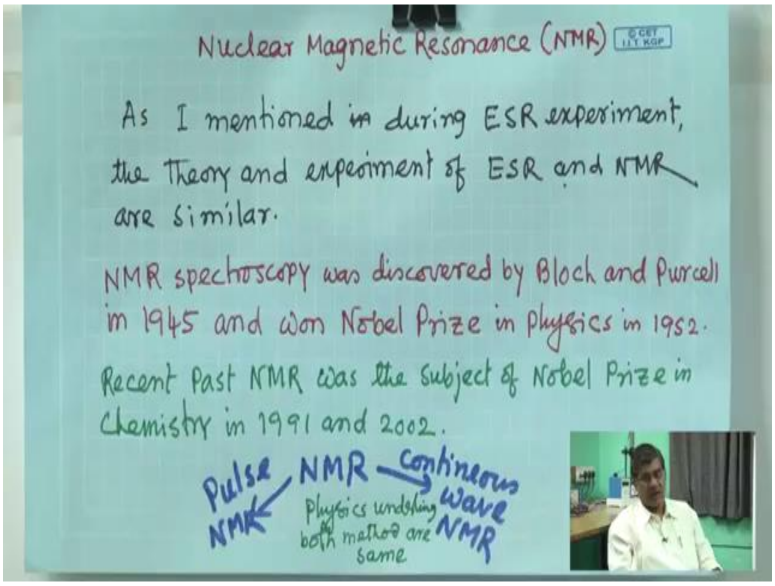

In addition, I will highlight what is the difference, there is a difference. what is the difference between the NMR and ESR experiment and what is the similarity in both experiment that I will also discuss. Magnetic nuclear magnetic resonance; as I mentioned during ESR experiment, the theory and experiment of ESR and NMR are similar.

NMR spectroscopy can was discovered it, discovered by Bloch and Purcell in 1945 and they own Nobel Prize in 1952 in physics. Recent past, NMR was the subject of Nobel Prize in chemistry in 1991 and 2002. You can see this is a very important experiment is a very important spectroscopy. This spectroscopy is used in this research laboratory for studying research samples.

Principle and experiment whatever I will demonstrate in lab. in research lab also this the spectroscopy works on same principle, but it has, it has versatile capacity means; there you can vary the, we can vary the temperature. You can do different kind of sample where you need very high magnetic field. Those options are there.

In research laboratory whatever the experiment, whatever the experiment setup we use here, this we use mini version small version of that instrument one can say. NMR is two types of technique or these two method one can follow is the pulse NMR and another one is continuous wave NMR.

Whatever radiation we used to excite the nucleus. that radiation whether it is continuously this radiation is put on the sample or the radiation is put pulse wise. Not continuous pulse wise as a pulse we put. based on that this two techniques, but physics underlying both method are same ok. In our laboratories, we will use this method continuous wave NMR method.

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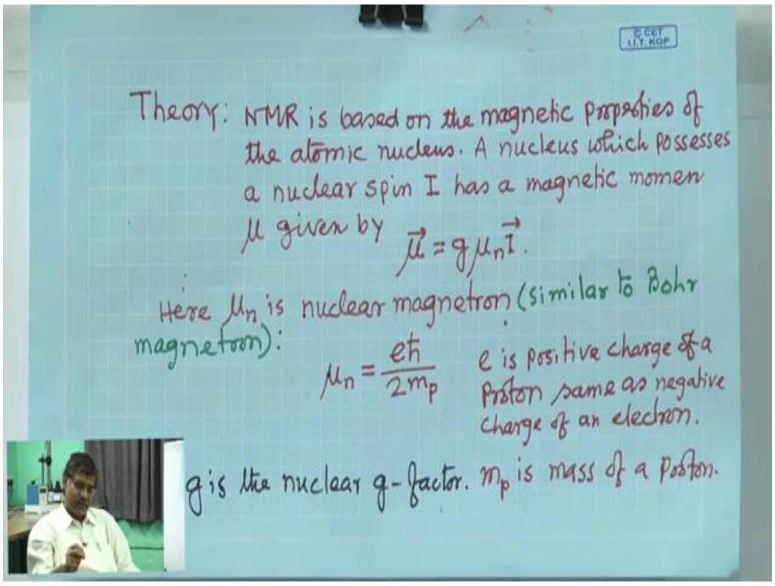

This theory of this one is similar to the theory of ESR Electron Spin Resonance. NMR is based on magnetic particles of the atomic nucleus, a nucleus which possesses a nuclear spin I. in case of E S R. electron spin here nuclear spin if it is I there we consider that is s.

this nuclear spin I has a magnetic moment mu given by mu equal to g mu n I. in that case, ESR we wrote mu equal to g mu v this s. mu n is called nuclear magnetron is mu v was Bohr magnetron now here it is nuclear magnetron similar relation like nuclear like Bohr magnetron. mu n equal to e h cross by 2 m p. e is positive charge for proton and negative charge for electron in case of Bohr magnetron and this m p is the mass of the total.

For a proton in an in nucleus. If it is its magnetic moment, is mu n and the same expression like Bohr magnetron one can write replacing the same charge only sign will be different and mass is here Bohr magnetron and nuclear magnetron.

You see this difference only this m e and m p; the mass of electron and mass of proton. Mass of electron is very a small compared to mass of proton ok. This nuclear magnetron this mu n is very small than smaller than the Bohr magnetron. Because of these, heavy mass of the proton compare to the mass of the electron.

you can see that in case of nuclear this magnetic moment is very weak compare to the electron moment, magnetic moment of electron due to spin of course, in both cases. It is that is why it is the it is slightly difficult to probe the nuclear magnetic moment than the electronic moment.

these the difference mu b and mu n. here the mu is in terms of mu n which is very small compared to mu v, but in electron case; there is the mu is in terms of mu v is very high value compared to this mu n and g is the nuclear g factor. This g, g nuclear g factor we want to calculate for a sample from this experiment.

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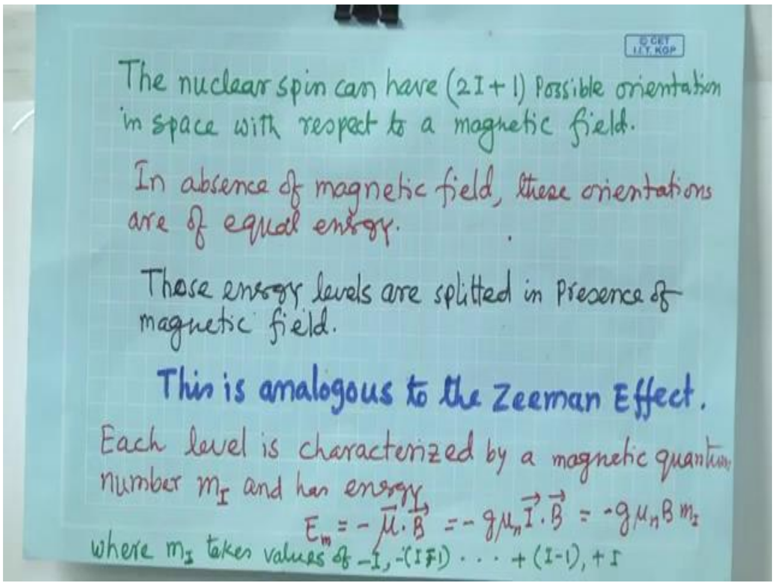

Same way one can proceed as we did for the ESR. Nuclear; nuclear spin I. nuclear spin can have 2 I plus 1 possible orientation in space with respect to a magnetic field ok. If we apply, magnetic field in space, so with respect to that direction of the magnetic field this spin of nuclear if it is I then, there are possible orientation will be 2 I plus 1 is the same as electron case.

Whether L or whether S or J total angular momentum. is splitted it's the energy level have degeneracy or energy level splitted in magnetic field into these 2 J plus 1 or 2 S plus 1 or 2 L plus 1 or 2 I plus 1. depending on the sample where the magnetic moment whether it is spin magnetic moment only or orbital magnetic moment only or total magnetic moment or it is only nuclear magnetic moment.

In absence of magnetic field, these orientations are of equal energy. There will be orientation, but they will have that same energy equal energy ok. That is why it is called degeneracy. Now, if we apply magnetic field these those levels energy levels are splitted in presence of magnetic field. this is just analogy of this Zeeman effect In Zeeman effect; if we applied magnetic field then energy levels degeneracy are removed and there will be more position and you will get more lines spectral lines in presence of magnetic field.

without magnetic field if one line was there spectra lines now after applying magnetic field it is splitted into it is this lines as if the splitted into many lines depends on the situation whether it is normal Zeeman effect or whether it is anomalous Zeeman effect ok.

In case of normal Zeeman Effect of course, it is always one line splitted into three lines. this actually line is not splitted. Actually, these energy levels are splitted. That is that is why more transition are possible and because of that, more transition, we get more spectral lines. that is equivalent to the splitting of the spectral lines. in this case also its a similar to Zeeman effect that energy levels will be, nuclear energy levels will be splitted into these many levels, these many energy levels.

In addition, in case of if the you are sample have the nucleus of single that that that nucleus have there are many electrons and many protons and neutrons, but effectively it is just one proton nucleus. Not one proton nucleus the nuclear spin, we will be because we will be because of one proton whatever the spin. This nucleus of the sample have the same spin ok.

That is spin half a proton have nuclear spin that is spin half. if your sample have the spin half, spin half angular momentum, nuclear angular momentum, spin angular momentum of nuclear, if it is spin half, if it is half, then this you can say this one energy level without magnetic field. That will be splitted into two because of m I this orientation 2 orientation will be possible m I equal to plus half and m I equal to minus half at that the energy the energy of the actually, here you can see this when a magnetic moment is in a magnetic field.

Its energy is E dot B minus E dot B. from here we can see mu is g mu n I dot B. I dot b from this this projection of I on the on the direction of magnetic field. That is m I, this magnetic quantum number. Minus g mu n B m I. for half spin nucleus spin m I is plus half and minus half ok. However, m I can take of course, this value 2 I plus 1 number of value. I have another slide let me see where it is, here it is.

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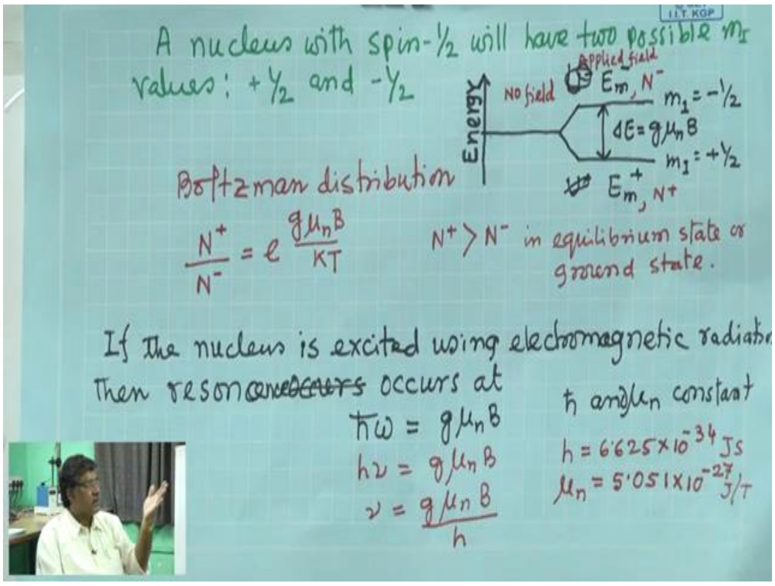

this, so if nuclear have the magnetic moment due to the nuclear spin half then, the energy level will splitted like this because of m I equal plus half and minus half. no field, so if single energy level. Now, applied field so you can see this; you can see this splitting of this energy levels. This splitting of this energy level, it is energy say m this is the inn presence of magnetic field E m minus and E m plus.

here I have taken this this minus half having the higher energy in ESR case I this I wrote that plus half have higher energy, but it does not matter, just one convention on should use. generally plus half when we tell that is why it is align to the magnetic field. This energy is lower. if it is minus half then it is aligned in opposite direction of the magnetic field. Its energy will be higher. in that sense it is better to write that m I or m S equal to minus half at higher energy level, at higher energy and the other one lower energy.

The energy difference between these two. as I showed this formula, the energy formula of the energy level. If you take difference of these two, so it is del E equal to g mu n B; g mu n B. Now, in presence of magnetic field; the energy level, the nuclear having spin half that is in this energy level. Now, if we apply magnetic field; this energy level will be splitted. Now, this where this nuclear nuclei will go.

Generally, it is expected that they will lie on this lower energy level. They will lie on the lower energy level and their magnetic moment will be aligned; aligned along the magnetic field direction. This magnetic field direction, now what happens? In this, in this energy these two energy levels; some nuclear will be here and some nuclear will be nucleus will be this at higher energy level also. However, at ground state in equilibrium condition; it is expected that this here the more number of nucleus will be here ok.

reason is that this Boltzmann distribution, Boltzmann, so if this number of nucleus N minus and number of nucleus N plus. these are the number in these two energy level. In that case N plus by N minus. It can be number density or total number equal to e to the power that energy difference of these two divided by K T ok.

It will depend on temperature of the system as well as it will depend on the magnetic field. Magnetic field will control the, control the energy separation between these two. If energy separation if magnetic field is high separation will be high these term will be; these term will be high right.

Therefore; that means; N plus will be very greater than N minus. Most of the nucleus will be at this at this energy level. If temperature is high, you can see, so in this term will be smaller, so this term will be smaller, smaller compare to earlier term. In that case this N plus maybe equal to N minus or greater than N minus ok. It cannot be less than N minus in general.

you can see that it presence of magnetic field there will be splitting of the energy level and the most of the nucleus or atoms having this having the nucleus of spin half. they will stay at this energy level.

Now, if you excite this system; if you excite this system with some radiation, electromagnetic radiation. Now, a radiation you are putting on the sample either in pulse wise or continuously you are pouring you are hitting this sample. In that case, what will happen? This, nucleus from this lower energy level they will be excited in the higher energy level ok.

For that it will absorb the radiation, absorb the radiation, it will overcome this energy difference, and if you come here. it will come here. How long it will come here. As long as the number density or number of nucleus at these two levels are equal ok. When it will be equal then it is saturation it cannot it will not go anymore. However, this is continuous process because this the nucleus it is going to the excited state and it does not stay longer time. Just within few second or within fraction of seconds it come down ok.

It will be continuous process that because of this excitation, they will go or the high energy levels and then it will come down again here. this this how long it takes time to come down in the in the lower energy state. That time is it is called the relaxation time. From NMR people can study the relaxation time of these of the system nuclear system.

Anyway, we are not going to do that. here this is a physical picture of the of the of the things happening and that we implement in experiment. We did this sample and then there we have to apply magnetic field and then we have to we have to irradiate this sample with electromagnetic radiation ok.

Now this they are going there they are going there. this it is going up going up it is absorbing energy. It is only possible it is only possible when this energy of this radiation h cross omega or h nu will be equal to this g mu n B ok. that is the resonance condition. If it is h nu is less than or greater than this. this it will not, it will this it will not be excited to the higher energy levels.

When it is going at a higher energy level, so that is equivalent to as if this it is from plus half it is going to minus half. whatever the nuclear magnetic moment it was aligned along the align parallel to the magnetic field. Now, it will be antiparallel; it will be antiparallel ok. it is going to the opposite direction of the magnetic field. It cost energy and that energy supplied by this radiation ok.

Now here if you want to measure the g; if you want to measure the g. we have to know mu and the magnetic field other are constant other values are known ok. From experiment, it is similar to the ESR experimental setup, but slightly difference is there that I will tell you. one things we have seen this this magnetic moment is very small for nucleus compared to the spin magnetic moment of electron. mu n is very small compared to mu v ok.

To align you see this moment in a magnetic field; it is align to the along the magnetic field direction. moment is in in it was in some direction. Now, when will apply magnetic field, so it will align along the magnetic field direction ok. It has to rotate. for rotational motion always you need the need the torque not force.

This torque is this magnetic moment cross, mu cross, and magnetic field ok, so that will be torque. Now, the field we use for the, field we use for the ESR that field that field was very small field, but torque was high because mu cos B. mu was for electron spin, this mu was very high ok. However, in case of nuclear spin now, mu n; mu n is very small. Torque to get appreciable torque to align this moment along the magnetic field direction ok.

mu cos B; mu is very weak. we have to use very high magnetic field in case of NMR to get the appreciable torque to rotate the to rotate the moment along the parallel or anti parallel to the magnetic field. One difference I told I mention now that in case of NMR; we need very high magnetic field compared to the magic field in ESR. Therefore, arrangement there is a difference in arrangement because of this requirement of high magnetic field.

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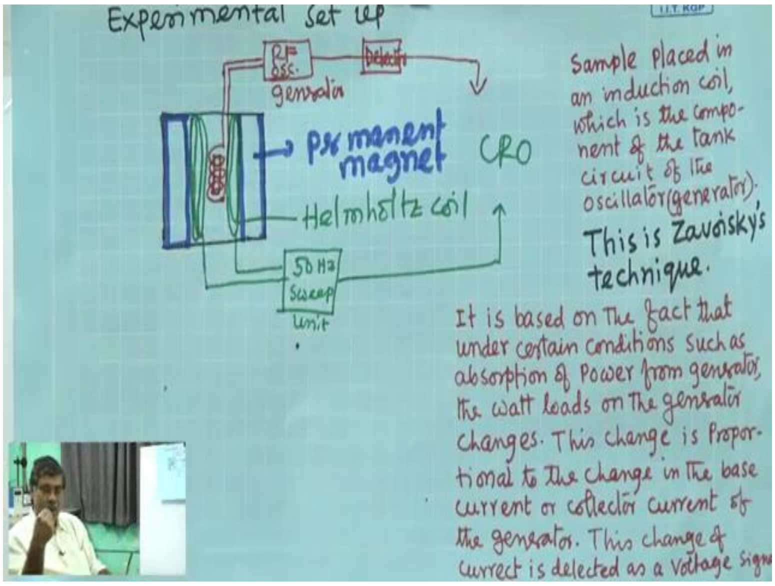

Let me tell you this experimental arrangement. in NMR; this experimental arrangement, so we use this permanent magnet ok. This is the some magnetic material. Permanent magnet at the centre of this permanent magnet this this magnetic field is few hundred Gauss few hundred Gauss and now these two Helmholtz coil is attached with this this permanent magnet. there small A C current will pass through it and then it will give small a c current. A C magnetic field. That will be modulated with this permanent magnetic field ok

Now again you see the difference there in case of ESR, there was no D C field; only A C field with respect to the 0 base. A C field from this some positive peak value then negative peak value ok. 0 to this positive field and then coming 0 again then negative field.

Now, in case of this when you are using permanent magnet and this this Helmholtz coil. Helmholtz coil current you are flowing current depending on the 0 current. this it will be 0 magnetic field. Now, current is increasing like A C current is increased. Say few Gauss field A C field will be generate. this peak value say 5, 5 Gauss or 10 Gauss ok.

Whereas, now this is modulate with the constant field from the permanent magnet. This field is it depends on the experimental setup in some experiment we use this 5 kilo Gauss, but at the present experiment probably it is around 5, 500 gauss. Now this this 10 10 A C field. It will be modulated with this with this 500 Gauss. 500 Gauss to it will go to the 510 Gauss, and then it will come to the 490 Gauss.

It will be vary; it will vary this 500 plus minus 10, peak to peak plus minus 10 Gauss ok. As I told this in case of ESR; what will happen? This your field here I have diagram.

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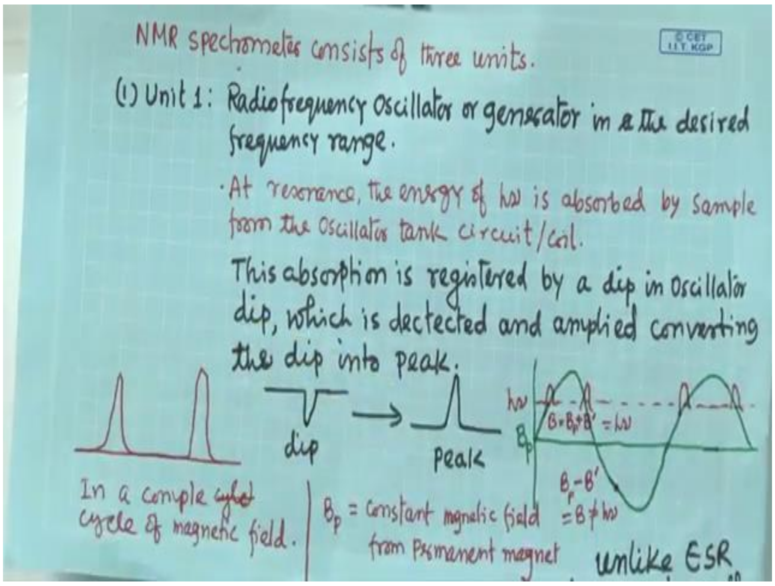

In this case, you can see; in this case, we can see that. This is the you see this is the b p I have written this the magnetic field from the permanent magnet. Now, this field is varying like this. If it is, say 500 gauss. 510 and then 490 this way. Now, the radiation we put that is if it is h nu frequency. In case of ESR, I showed you that ok. this this h nu energy will be equal to the that that magnetic energy coming from magnetic field.

Here you can see h nu, it will satisfy because it is A C variation. this h nu will be equal to that that energy at this point, at this point. For a complete cycle, in case of ESR; I told that it will satisfy the other side also at this point and this point, but here it will not only it will satisfy at this point at these two points, other two points it will not satisfy. Because, this you see here it is this field is between 500 and 510 and here this 500 and 490 ok.

this h 2 it can be just one value if it is say 505, h nu is 505,then then it can satisfy at this because its variation up to 510, so it will satisfy at this point. And at this point at this point it will not satisfied, because it is not 505, it is 495 ok.

Other side, other side it will not satisfied unlike E S R. in this case we would get two peak for an ones complete cycle. In case of ESR, we got four peaks ok. It is another difference. now, these two peaks. This is the is the absorption it is converted to the dip converted to the peak. Is the in circuit these options are there? These two peaks you will get in a complete cycle of magnetic field ok.

Now these two field; these two field will be these two field will be will bring it at the in coincidence by using the phase shifters as we dip for the ESR. in ESR this four peaks. We make it two peaks and that using the phase shifter. Now there also that magnetic field that was A C field that is the DC component.

We have to at which magnetic field this resonance occurred. That field also we have to measure that p value and q value, q by p with this and hpp peak value. that we have to we have to find out and that we need. But, here we do not need to find out the magnetic field because, now just it will not be much error if we just take the magnetic field as this whatever permanent magnetic constant magnetic field we are we are using. Because if it is 500 then this variation 5 to 10. 1 can it is a less than 1 percent change of the field. 1 can neglect.

Here we want need to measure the magnetic field. whatever the permanent magnet, what the magnetic field. One can just find out either company will supply or one can find out just using also. Only here we have to find out that what the frequency is ok.

Using the phase shifters; we will make them coincidence and then just will just slightly we will tune the tune the frequency to take this this coincidence peak at the middle of the display. At the middle of the display because, in C R O, this display always it complete it will complete say one cycle or two cycle or three cycle. In that way we check that the frequency will change slightly it is slight change. its display will be at the middle.

If we change the frequency, there will be display at different position. when display will come at the middle. Then that will be the resonance frequency and that we have to note down. here the experiment is comparatively simpler than the ESR, because there we have to measure the magnetic field also with the frequency ok.

I will show you the experimental setup and describe the experiment. Let me stop this theoretical part and then next I will show you this the I will demonstrate the experiment in our laboratory.

Thank you.