Atomic and Molecular Physics

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Lecture - 60
Resonance spectroscopy

So, I was discussing about the another spectroscopy that is as I told ESR electron spin resonance spectroscopy ok; and in NMR N M R nuclear magnetic resonance spectroscopy ok.

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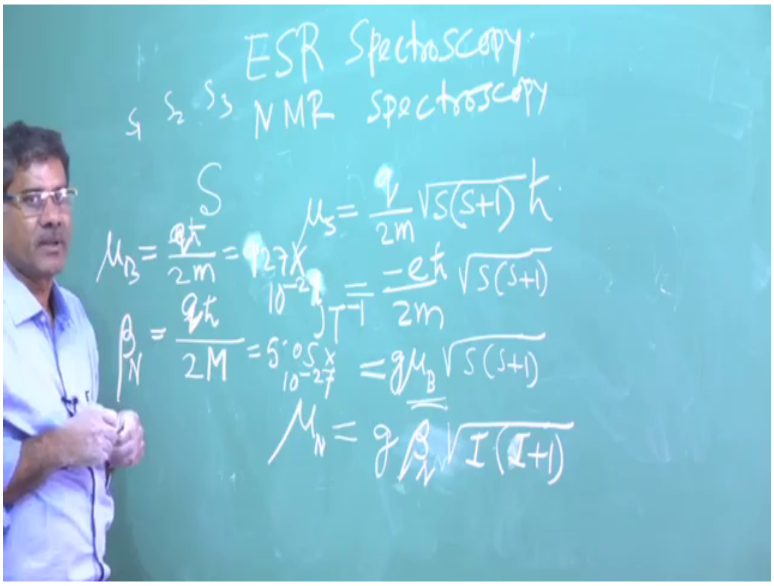

So, so here this electron have spin that we are; we are quite familiar we have discussed and considering this electron spin only, we are able to explain the fine structure and for explaining the hyperfine structure one has to consider the nuclear spin, nuclei nucleus is having proton and neutron proton also have spin half neutron also have spin half ok, similar to electron have the spin half ok.

So, now this interaction with the magnetic field it is, because of the magnetic moment of the electron or magnetic moment of the nucleus. So, if you have a multi electron system and then what will be the magnetic moment of this of this multi electron system. So, there we find out the result and total; not total result and spin of the of the multi electron system, so we use the vector model.

Similarly, that similar vector model one can use for also this nuclear spin same way one can use. So, just following the similarity for this first electron spin, whatever the way we have considered. So, for nuclear spin also one can consider same way ok. So, just so in case of, if you have a nuclear spin of an atom, if it has multi electron, so total spin is S ok.

So, spin S is not half, the total spin it will depend on how many electrons are there. So, S 1, S 2, S 3, they have individual spin, so all may be half, so now using the vector model, what can find out the resultant yes ok, if that the electro spin if S is the electron spin. So, magnetic moment mu we remember you remember, so that is a Q in general let me write; Q by 2 m ok, then I have to write S S cross; so S in quantum mechanics.

So, S it basically this spin momentum is square root of S S plus 1. So, we have a earlier and h cross ok; earlier we just use S h cross, but actually one should write square root of S S plus 1 ok. So, this is for this say yeah; for a for a electron for a system a multi electron system of this ok. So, there one can find out yeah; so this way if it is for one electron, then I think for one electron, so then this we can just write generally; S as a q, q it is the minus e for electron, q minus e for electron divided by 2 m and then here I can write e minus eh cross and then this one S S plus 1 ok.

And this is written generally this one, we write we write mu B we write mu B and square root of and we write g here on g we write, and then square root of S S plus 1 earlier we just wrote S; so actually if S is half; so g is 2; so it is the mu B for one electron; S if you consider half then it is for one electron if S is more; so there is a for; so ah; so this this called Bohr Magneton, Bohr Magneton is very important for the electron mu B equal to mu B equal to mu B equal to e h[noise] cross by 2 m ok.

Similarly, this similarly if we consider these, the if I so I will write mu S for spin if this; now, mu N if I write mu N nuclear have spin. So, following the similarity, I can write mu N equal to g g here I will write the mu N nuclear magnetic moment nuclear magnetic moment, I think I did mistake mu N here, generally people write this Bohr Magneton here, I think we write beta N beta N and then here, if nuclear spin; because proton have half neutron have half.

So, these are nuclear spin we tell because both are having the same; so how many neutron and proton are there? So together using the factorial model one can find out the resultant ah nuclear spin ok. So, it can be only for proton it can be only for neutron or it can be for together proton and neutron, but since all are similar in terms of in terms of spin. So, because both are having half; so that is why and mass also both are having more or less same mass. So, that is why; it so we tell nuclear spin not proton spin and neutron spin separately both are same in terms of spin half and in terms of mass. So, these are nuclear spin. So, nuclear spin generally here nuclear spin whatever here electron spin S we use for nuclear spin we use from I ok.

Notation I ; so I is basically, so one can write this say nuclear spin for nucleus of this nuclear magnetic moment spin magnetic moment that is in terms of Bohr Magneton one can express; so here in terms of what is called some some nuclear; some special name it is still exactly drive anyway. So, it has what is this beta; it is similar to mu B Bohr Magneton it is similar to Bohr Magneton it is not Bohr Magneton ah, but beta N from this similarity beta N is basically beta N is basically e h cross. So, it is charged; so generally there so people generally it is just use q charge of charge of nucleus. So, here then 2 m ok; what is 2 m; m is what is m; m is the mass of the proton or neutron mass of the proton or neutron ok.

So, this is the nuclear magneton and Bohr Magneton these are yeah; I think this nuclear magneton is called nuclear magneton. So, these from similarity it is tell it we tell; so these value is different, see this now here this question is this we neglect this nuclear effect most of the time, why; only magnetic moment due to the due to the electron we considered, but magnetic moment due to the nucleons we neglect, but it has effect it is minor effect verifying effect ok.

So, that is reason is that just from here you can see; so you see this it depends on mass. So, mass of electron and mass of proton; so you see is what is the difference is I think this is 10 to the power mass of this electron is 10 to the power minus 27 and this is 10 to the power minus minus 24 ok. So, it is order of writing 1000 order of 3 magnitude vary. So, that is why this magnetron is value 9 it is it is I think, what is the value of Bohr Magneton; I think this is the yes; so it is minus 27 and then other one is other one is to check it I have to check it. So, what is the value? That I have written same where or it is not there well.

So, it is yeah 9.27 into 10 to the power 2 ok. So, it is the 9.27 into 10 to the power minus 27 joule testla inverse whereas, this one is value is 5.05, 5.05 5.05 into 10 to the power minus 10 to the power minus or this is 27 or this other one is I think 24 yes; that is why this is 24 10 to the power 24 and this is 10 to the power 27 ok.

So, you see this you have 10 to the power minus 24 and here 10 to the power minus 27. So, three orders of magnitude difference ok. So, magnetic moment of a nucleon and magnetic moment of a electron; so this difference is you see three order of magnitude the difference at there ok. So, these are smaller than this other one, that is because of the mass of the proton or Newton and that is why; this is a very weak magnetic moment of nucleons and thus this we most of the time, we neglect the nuclear effect on the atomic spectra, but it is there although it is fine, but it is there and in there are many event many cases.

So, this effect is one can one can see this effect and one can one can analyze ah analyze the system using some spectroscopy, because as I told this is the electron or see electron spin there is fine structure effect is small and considering the electron spin is the hyperfine structure even, if it is this splitting a second is a even very small.

Now, fine structure alpha ah this hyperfine structure that change energy level change it is it is very small. Now to now that effect is seen in the atomic spectra, but how to it is a to you need again to see this one again you need very high resolution of the spectrometers high resolution of the spectrometer and that is what people used to do, but it is again it is difficult to resolve this fine structure and hyperfine structure to reserve this hyperfine structure it is really very very difficult.

So, to overcome this crisis this spectroscopy resonance spectroscopy is very popular very useful, because resonance phenomena you see this is very strong and one can one can use the resonance to show to show to core this kind of finer splitting of the energy levels ok. So, that is why that; so that is the that is the reason, why these two spectrometer spectroscopy are very very popular to see this kind of tiny change of the tiny effect of the effect on the on the spectral lines. So, here directly, if we one can find out one can directly one can find out this separation of this; so here, so this it is this spectrometer spectroscopy in which range that easily you can easily you can see or I can tell you, so what yes.

So, now; so if in both cases one has to apply magnetic field, if you apply magnetic field what happens? So, there will be change of energy interaction this one that is mu dot B there is the energy right mu dot B.

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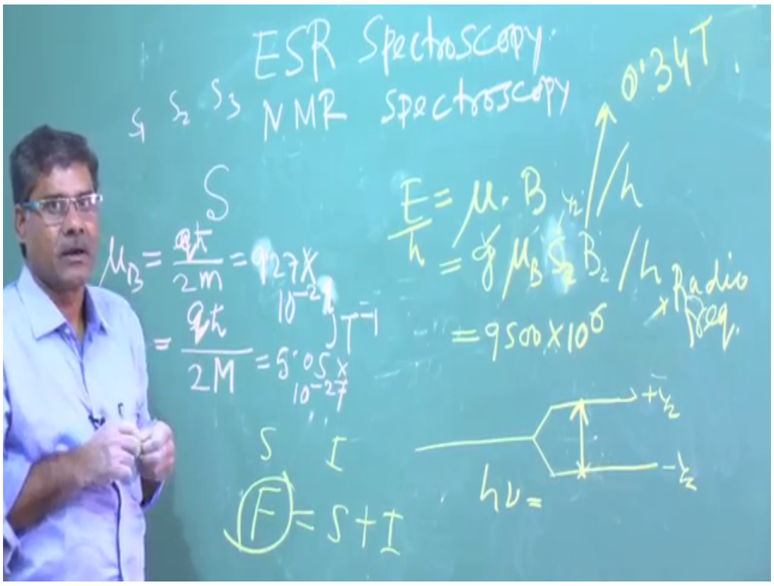

So, this energy mu dot B there is the energy due to magnetic field due to interaction of magnetic field with the magnetic moment magnetic moment due to the spin or due to the neutron or both together ok. So, ah; so if you have nuclear spin as well as electron spin, so S and I; now what will be the resultant spin. So, the resultant spin generally we write F F equal to just simply S plus I just vector addition ok.

As similarly j equal to l l plus s. So, the way resultant total angular moment we find j similar, way here this total spin angular moment one can find out that S plus I. So, that if will be this. So, it is similar to j ok, in the same way one can find the total spin magnetic moment of the; of the of the atom ok so, these mu dot B and this if you apply this along the z direction this one along the z direction ok.

So, and then this one mu mu is I; so it is the j, it is the j g ok; in case of electron it is mu B g mu B and S z I can write ok, generally this is S z. So, this we write m m or m S and then your magnetic field along the z direction it magnetic field along the z direction, one right I can write B z also no this is S z this is we have writing m ok. So, let me write S z ok.

Now, these this energy mu B that value you know for electron g you know 2 ok, if for one electron this is half and now you can find out this value this e e this value in the range of this will be I think say some value into 10 to the power 6, just I think I have to say ok. And this seems just; if you take this just divided by h ok, then it will be mu divided by h divided by h divided by h and it put this all this value, so this it will be then frequency and that frequency comes this frequency comes 100 into 10 to the power 6 Hertz, if this magnetic field for; if this magnetic field B z it is 2 point exactly; so you have to put this value 2.3487 2.3487 tesla ok.

So, 2.34 or 3; 2.35 if you apply magnetic field, if we apply magnetic field ok, then what will happen; then this will be the change this will there will be the magnetic interaction. So, you remember; so if I have before I applying magnetic field this is the; so this if I apply magnetic field ok. So, this will be splitted into 2, because because of S z plus half and minus half; so before applying magnetic field it was degenerate.

Now this is it will be splitted into two lines ok. So, this for plus half and minus half right so, for spin up electron and for spin down electron this will be separation, so this splitting because of this because of this magnetic field, if we apply magnetic field. So, so; so due to electron spin it is there magnetic moment also it is there. So, if there is no magnetic field, so there the states are degenerate, it will have the same energy.

Now, if we apply the magnetic field if we apply magnetic field of this amount 2.35. So, this splitting this it will be splitted and it will be splitted by in terms of energy one can write, but I have written in terms of frequency. So, this energy difference and corresponding frequencies is 100 mega Hertz ok. So, this splitting will be in mega Hertz range ok. So, this is basically it is a radio frequency, this range is radio frequency range radio frequency range this will be the radio frequency range.

Now, I did one mistake I did one mistake I think yes this whatever I am showing I think this I have done mistake; this is the it should be this for this it is calculation I have done for electron it is I did mistake for electron it will be just whatever here I have shown you this here I have shown you it is it is for just I think I will write beta N, I will write beta N another is same other is same. So, then if we apply this magnetic field, then nuclear spin this before I apply magnetic field whatever the for nuclear that they are degenerate states.

Now, after applying magnetic field this will be splitted into 2 for plus half for minus half if one nucleon is there like just you consider for silicon, for other you see this if just two line two splitted into two lines that I have considered, but, if that I; if it is not half, if it is 1 or if it is 2 or it is 3 by 2 etcetera. So, it will be splitted into more. So, for simple cases to just we have considered spin half ok, spin half nuclear spin half ok, so then it is splitted into this and then will get splitting and that splitting is in terms of frequency, that is and that is 100 megahertz ok; it is basically radio frequency. Now, I have system if I apply magnetic field, then I am getting splitting of the lines in this fine.

Similarly, if I consider this electron spin mu B electron spin, then this value will come it comes around 9 yes; that. So, this value I will get this value I will get this value I will get 9500 into 10 to the power 6. So, this we kept them in megahertz sure and; so that is just applying very small field this is 0.34, 0.34 tesla ok.

So, in case of electron spin ok, so it was d generate that; now if you apply magnetic field of this 0.34, this very small field then it will be splitted and that splitting in terms of frequency, that is in megahertz range it is the; it is the it is now you can see this earlier it was 100, now it is 1; 10000. So, 1000 more, so it will be in radio frequency, then microwave range it will be microwave range ok. So, in case of; so just in case of electron spin applying magnetic field, I can I can split the energy levels; they are splitting purely, because of electron spin.

And this splitting it is in the in terms of frequency it is in the range of it is in the range of microwave frequency. And in case of nuclear spin, if we apply magnetic field you have to apply magnetic 2.35 tesla, then this splitting due to nuclear magnetic moment or due to nuclear spin. So, the splitting will be 100 megahertz since it is in radio frequency range ok.

So, now point is that to sense to sense the energy levels splitting of the energy levels ok, due to may due to due to due to the electron spin or the nuclear nuclear spin. So, one has to nuclear spin ok. So, that apply magnetic field, that I can I can separate them effect of nuclear spin effect of electron spin I can I can I can I can split them applying magnetic field, how much splitting I want to do, so that I can control using the magnetic field ok.

Now applying magnetic field it is splitted, both the same way one can see ok. The splitting due to nuclear order adjust only it is a magnetic field for nuclear spins you need to apply higher magnetic field for electron spin, it is the you need lower magnetic field, but splitting are in the in microwave range in one case and another case it is in radio frequency.

Now, you see now external in this spectroscopy, now ESR and this NMR these both are based on this concept. Now, in case of NMR; now to make resonance ok, so something externally I am putting here, that is basically I am putting the radiation on it of this radiofrequency radiation, if I put on it, so it will be it will resonance; so, if when frequency will match with this separation of these energy levels ok, then there will be resonance and that resonance we detect ok, because resonance is a strong very strong phenomena.

So, only now one has to be variable either incident radiation is fixed or the incident yes or; then we can vary the magnetic field to get resonance to get the frequency in the same range same for this ok. So, either varying the magnetic field also to externally, I can control using the two parameter: one is magnetic field, another is incident radiation or incident electrical signal yeah better to tell radiation of frequency microwave frequency or radio frequency, so ah; so one is called ESR spectroscopy.

So, in that case we use the microwave radiation or microwave frequency externally signal, we put on it and either we can vary the frequency of the signal or radiation of the incident signal or radiation keeping the magnetic field fixed or other way one can do putting this radiation of particular frequency microwave radiation we can just change the magnetic field, so this frequency this frequency or separation will change.

So, when these 2 h nu of this h nu it will be equal to this energy e magnetic interaction energy. So, then there will be there will be resonance, and now one is known to use the magnetic field, how much he replied and this what is the frequency at which frequency resonance is coming, so that is known to you. So, then you can study this effect of electron spin or effect of nuclear spin. So, this other one is NMR ok.

In that case the same explained same way externally we are using the microwave radio wave and magnetic field here using. So, so, so then you will get the nuclear information this magnetic moment of the nuclear. So, that is the spectroscopy resonance very powerful and useful, and that is why; and because resonance phenomenally and principle also very simple ok. So, applying magnetic field and applying the radiation in one case radio frequency, in case of NMR and in case of ESR it is micro frequency ok.

So, this is the two spectroscopy very useful for studying the nucleus spin as well as the electron spin as well as this their effect of this F as I told effect of the F also this together result and on also this using the this spectroscopy one can study ok. So, more or less I think I complete this course and I think this good enough for undergraduate students. So, I will stop here all the best for this course and yeah; so if you have any questions, so you can ask in for I am I will try to answer.

Thank you.