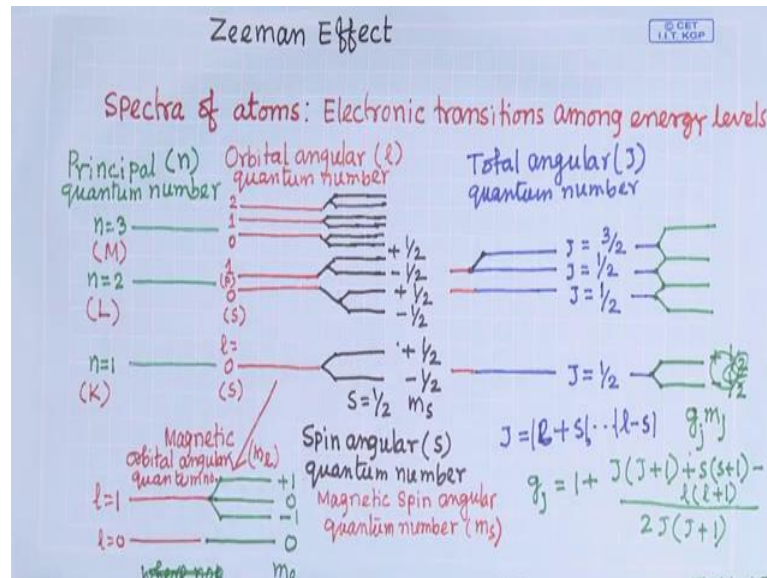


Experimental Physics – III
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Lecture – 39
Zeeman Effect

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Today I will discuss about Zeeman Effect and I will demonstrate the same in our laboratory. The Zeeman Effect it was discovered by Peter Zeeman in 1896 and he got Nobel Prize probably in 1902 for this discovery. Fundamentally, this effect is very important. Let us understand the effect first and then we will demonstrate in our laboratory. Zeeman Effect when we apply magnetic field in atoms. The spectral lines splitted. In presence of magnetic field, the spectral lines splitted that is the Zeeman effect.

Effect of magnetic field on spectral lines that was discovered by the Zeeman. You know the spectra of atoms forget magnetic field just spectra of atoms; that is electronic transitions among energy levels. Electron goes from all levels to other energy levels. Because of that, there are emission of electromagnetic wave. That is the depending on the wavelength. Wavelength dependence the pattern we gets that we will tell the spectral lines ok.

In atom, there are energy level. This energy level we designated by this principal quantum number. n equal to 1 we tell K shell, n equal to 2 we tell this is L shell, similarly M shell ok. These helps energy. Now, another quantum numbers that is orbital angular quantum number l . because of l . these levels are again splitted. Then we tell this is an orbitals or subshells SPBF. l equal to 0, 1, 2, 3 ok.

Then this energy level again it is splitted because of the spin of the electron. That spin and spin angular quantum number that is S . for electron S is half. This line again due to the spin it maybe it may split into each line it may split into 2. this is we tell m_s magnetic spin quantum number m_s . m_s is plus up and minus up plus up and minus up each energy level again it can they splitted into 2 ok.

Whatever splitting I am talking. splitted energy level; their energy may be same then we tell that degeneracy if their energy are different splitted energy levels; their energy are different then we tell there is a degeneracy is removed non degenerate state ok.

Now this l again it is splitted because of space quantization. That is call that is designated by another quantum number. That is call magnetic orbital quantum number. That is m_l . an l it can be splitted l equal to 0. It is an m_l is 0 l equal to 1 m_l is 0 plus minus 1. it is splitted into 3 again I am telling that the energy can be same or it can be different if same then we tell degenerate states, if different then we tell not non degenerate states ok.

The depends on the situation depends on the atom depends on other factors. quantum number here we are seen this principal quantum number, orbital angular quantum number, then spin angular quantum number ok. These three the quantum number which we use for designating the electronic state of electrons in an atom. Now there are two space quantization what is for orbital angular momentum and another is for spin angular momentum. About a, orbital angular momentum. It is a rotating on an ellipse or on a circle.

This is on a plane. Now whether this plane can be rotated in space ok; whether it is allowed. Yes, principle it can be any plane, but it cannot take any plane. That is it is quantized it is quantized ok. When orbital is moving on a plane. This direction of the angular momentum is perpendicular to this plane.

Now this is also quantized in space. That we express with this quantum number m_l . This m_l value it is about a fixed direction in a space. What is the projection of the direction of the orbital angular momentum on this fixed direction? This if you take the projection on this fixed direction. This length is it is expressed by m_l . This is $l \cos \theta$ you know m_l is $l \cos \theta$ ok.

When this it is 90 degree. Its projection is 0. m_l is 0 ok. If it is in this direction. It will be m_l will be 1. m_l will be 1 because $\cos \theta$ this now 0 angle it is on. It is opposite direction it is the 180 degree. $\cos \theta$ is minus 1. m_l is minus 1 ok. It is projection $\cos \theta$ value on a fixed along with a fixed direction. Why it is call similarly this spin angular momentum. It also quantized in space. It is quantized in 2 direction either up or down ok.

That is expressed by plus up or minus up. Why it is call magnetic quantum number? It is called magnetic quantum number because, this in space we are considering a reference direction. Generally, in space we apply if we apply magnetic field. We apply in a particular direction. That now reference direction is the direction of the magnetic field direction ok.

That is why it is called magnetic quantum number. Now, you have two angular momentum l and s . now, these two angular momentum they are not; always they are not independent they coupled with each other ok. That then one can find out the total angular momentum. That is J ; that is J , J is the total angular momentum J it can vector addition of l and s . it can take value $l + s$ to $l - s$ ok; in between just difference $l + s$ minus 1, $l + s$ minus 2 up to $l - s$.

But I have taken mode always it is positive value because negative value you do not take because negative value is taken care by the projection by m_j . Similarly, this this for l there is a space quantization m_l , m_s similarly m_j ok. And g_j is Lande g factor. This g_j is equal to $1 + J J + 1 + s s + 1 - l l + 1$ divide by $2 J j + 1$. In case of this angular this orbital angular momentum. There also Lande g factor is there.

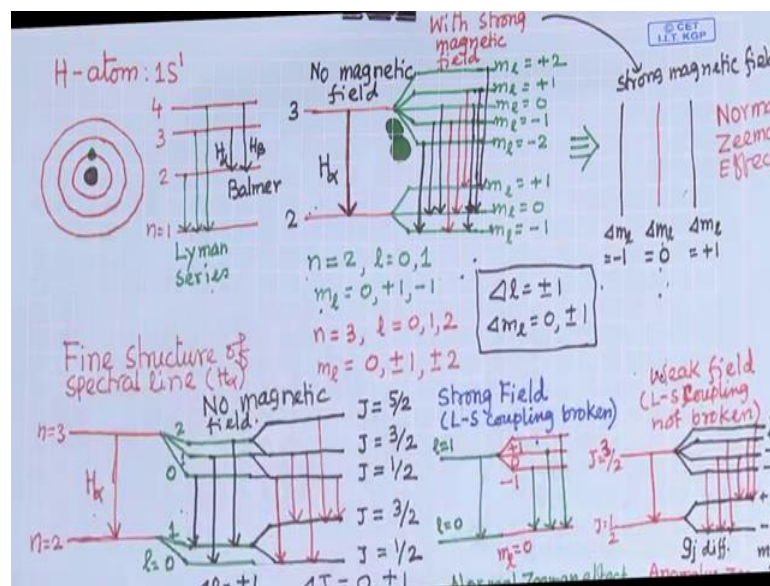
There we write g_l . g_l value g_l is 1, g_s it is a value is 2, and g_j it is value depends on this l s and J ok. one can for here if this one l equal to 0 and this one say l equal to 1. s equal to half for a one electron. J will be 1 0 and s half. J will be half. 1 1 J I think I have

taken to here $l=0$ and $l=1$, again $l=0$. It will be $J=1/2$ and $J=3/2$ ok. Depending on the spin orbit coupling. There will be splitting of the energy levels ok.

Further this again splitted again splitted due to the space quantization. This is the m_j for different m_j value it is again splitted. You can see here. There are different quantum number. Depending on the quantum number or using the quantum number, we can see the splitting of energy level it is a particular energy level it is splitted into varying energy levels. Their energy may be same or maybe different ok. Depending on the situation.

In an atomic system, there are many energy levels now transition among this energy levels transition of electrons among this energy levels gives the electromagnetic wave of different wavelength. And if you see this in a spectrometer if you see this light you will see you can separate the wavelength and there is we tell the spectra ok. This is the without any magnetic field the atom can give spectral lines and in spectrometer you can see this spectral lines.

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In case of hydrogen atom it is the simplest atom; it is the simplest atom. Energy levels are there. You know this n equal to 1, 2, 3, 4. transition from higher levels to 1 it give Lyman series transition to n equal to 2 from higher energy level this give Balmer series. In Balmer series H alpha line H beta line H gamma lines. H alpha is $n=3$ to $n=2$ transition it gives this H alpha line. If I take this H alpha line transition between n equal to 2 and n equal to 3. Now, this is $n=2$ $n=3$.

it will have; it will have this say if this is one spectral lines; if it is one spectral lines without any magnetic without magnetic field if you do not apply any magnetic field. Now this if we apply strong magnetic field this spectral lines will splitted in to many lines. Actually what happens here what happens here? When we apply magnetic field with respect to that direction now this magnetic moment of the of these electron which involved in this transition. There it will be oriented it will be it is an angular momentum will be oriented in space.

There this m_l is coming to pictures ok. $m_l = n$ equal to 2 means n equal to 2 means l equal to 0 1. m_l will be 0 plus 1 minus 1. It will be splitted into 3 lines in presence of magnetic field ok. n equal to 3 l equal to 0, 1 2. m_l will be 0 plus minus 1 plus minus 2. It will be splitted into 5 lines ok. Here 2 energy levels. Due to transition one lines you are getting. Now this energy levels in presence of magnetic field it is splitted into here you can see three and here 5 8 lines ok. Then there would be lot of transitions among them following the transition selection rules Δl equal to plus minus 1 and Δm_l equal to 0 plus minus 1.

you will see many transition, but here this energy separation; in this case this energy separation for Δm_l equal to 0, for Δm_l equal to plus 1, Δm_l equal to minus 1 if you see this here 9 transitions are there 3 of them are for Δm_l equal to minus 1. there will have the same energy these three lines will have the same energy other three line for Δm_l equal to 0 it will have same energy and this other three lines Δl Δm_l equal to plus 2. It will have different energy.

actually this nine lines we are seeing that will be basically; this is we will see three lines, three spectral lines, three different wave length ok. As if here what you are seeing in absence of magnetic field there was a one spectral lines, but when we apply strong magnetic field that one line is splitted into three lines. Out of this three; one is the original one and other two will have the different energy, other two will have the different wavelength, other two will have the different frequency ok.

As if one line is splitted into now three lines. This is called normal Zeeman Effect ok. Here H alpha one line I told, but it is not correct. This H alpha line it consist of more than one line it consist of 5 lines ok. That is fine structure that is fine structure of spectral lines, but they are very closely space ok. However, H alpha line if you consider the l s

couplings. Then energy level without magnetic field energy level will be like this and we will get five spectral lines. Their wavelengths are very close. H alpha line is not one line it is five lines.

If you pick up or if you if L S coupling is not there. l and s are independent then you will see the three lines ok. Alternatively, if you applying here I have beaten with strong magnetic field not with weak magnetic field while this strong magnetic field. When we apply strong magnetic field then ls coupling will break ok.

There will not be coupling between l and s . then instead of 5 lines instead of 5 lines. It will have the three lines it will have the three lines. Now, each line each line each line will be will splitted into many more lines into many more lines. Here each line will be splitted into three lines when magnetic field is strong ls coupling will break. One line will be splitted into 3 lines. Whatever the line whatever any line if you take. it will all the time it in strong magnetic field it is splitted into 3 line it is splitted into 3 line, but if we use weak magnetic field, where ls coupling exist will not break ok.

Then your quantum number is J , J will play role. In addition, this splitting this splitting will be asymmetric it is not symmetric because of g_j because of g_j will be different for different J ok. Here this splitting was here this splitting was symmetric in case of m_l . that is why 9 lines equivalent to 3 lines, but here this splitting are not symmetric. It is a asymmetric because of g_j and you will get this line this line is a transition between J equal to $3/2$ to J equal to $1/2$ this line will be splitted into 6 lines; this line will be splitted into 6 lines ok.

This is called Zeeman Effect, but this called anomalous Zeeman Effect ok. normal Zeeman effect and anomalous Zeeman effect so; however, we will concentrate in normal Zeeman effect because in anomalous Zeeman effect there are lot of lines and it is difficult to resolve them you need higher resolution of your spectrometer.

In our laboratory, we will demonstrate normal Zeeman Effect ok. I tried to explain what is Zeeman Effect and that will demonstrate in our laboratory.

(Refer Slide Time: 22:43)

Generally Cd or Hg source is used for showing Normal Zeeman effect.

$\text{Cd}^{48} : [\text{Kr}^{36}] 4d^{10} 5s^2$ $\text{Hg}^{80} : [\text{Xe}^{54}] 4f^{14} 5d^{10} 6s^2$

In ground state $L=0$ $S=0$
 So no L-S Coupling. Thus small magnetic field can show the normal Zeeman effect.

In our experiment, we will use Hg source

In excited state, $6s^2 \rightarrow 6s^1 7s^1 \rightarrow 6s^1 6p^1$

Spectroscopic Term $2S+1 L_J$

$6s^1 7s^1$ (circled in green): $L=0$, $S=0,1$, $^1S_0, ^3S_1$
 $6s^1 6p^1$ (circled in red): $L=1$, $S=0,1$, $^1P_1, ^3P_0, ^3P_1, ^3P_2$

~~$1s$
 $2s^2 2p$
 $3s^2 3p^2 3d$
 $4s^2 4p^4 4d$
 $5s^2 5p^4 5d$
 $6s^2 6p^4 6d$
 $7s^2 7p^4 7d$
 $8s^2 8p^4 8d$~~

In laboratory, generally people use cadmium or mercury source to show the normal Zeeman Effect. Now why this cadmium or mercury it is used. To understand that one here you can see cadmium it is a wave this atomic number is 48 and electronic configuration is this is the krypton configuration we have guessed krypton, helium, neon, argon, krypton. 36 d 4 10 5 S 2 and for mercury it is 80. This is it is a genuine configuration and then after that 4 f 14 5 S 5 d 10 and 6 S 2 ok.

What you are seeing here. All sub cells are filled so; that means, these are ground state. In ground state, total L total angular momentum orbital angular momentum L will be 0 and total spin angular momentum will be S will be 0. L is 0 and S is 0 in ground states. L S coupling there will not be any L S coupling. In both cases in ground state, there will not be any L S coupling. That is why; that is why we can use; we can use small field to see the to see the normal Zeeman Effect.

If L S coupling is there the to first you have to break it. For that you need very high field and in laboratory we use the electromagnet and then electro magnet generally it is a maximum field it can generate it 2 to 3 tesla. 2 to 3 tesla for normal Zeeman Effect is not enough for most of the atoms, but in this case less than 1 tesla is enough because this L S coupling is not there in ground state.

Now in our experiment we will use mercury source. 6 S 2 ok. These 4 f 14 then 5 d 10. these electrons are more tight in a it is a in the atom, but comparably this S electron it is a

you can it is an outer most electron; and it is an exciting, excited to excite it is a you need less energy compare to other electrons. In ground state, we can think that a system this system have 2 electrons, which we can with which, we can easily take in higher energy levels.

For that, we need less energy external energy we have to give to the atom then only electrons will go to the higher energy levels. That we tell this atom in excited state. In ground state electrons 2 electrons are in 6 S. Now, one of this electron can go to the 7 S electron, 7 S next one is 7 S.

6 S 6 S and then it can go to higher energy level 7 S ok. In excited state, one electron is in 6 S state and another electron is 7 S state ok. 1 1 these 2 electrons. 1. for these for this pair of electron for this pair of electron L is L will be equal to 0 because L 1 this for S is the 0. Total L will be 0 capital L and this total S.

Now when these 2 electrons in same S L. they have to be in opposite direction one will be spin up and another will be spin down. S will be 0, but in this case, they can be both can be spin up and both can be spin down ok.

S can be either 0 or it can be 1 ok. Spectroscopic term generally we write this 2 S plus 1 L J with this notation. Here S equal to when it is 0. 2 S plus 1 is 1. L is 0 S it is S L is 0. It is S and J will be L is 0 S is 0. J will be 0 and for another state spectroscopic term, you will get. That is it is L equal to 0. s then s equal to 1. It will be 3 2 S plus 1 if it is 3 and this is 1 J will be 1.

Here we can get one is 0 and 3 S 1 ok. This is here 1 and this 3 this is a call multiplicity. These state we tell singlet state and these state we tell triplet state ok. Now from this ground state if atom goes to these excited state and J L in excited state it is stay very small time JL is after 10 to the minus 9 second ok. It come back to the lower energy or it jumps to the lower energy ok.

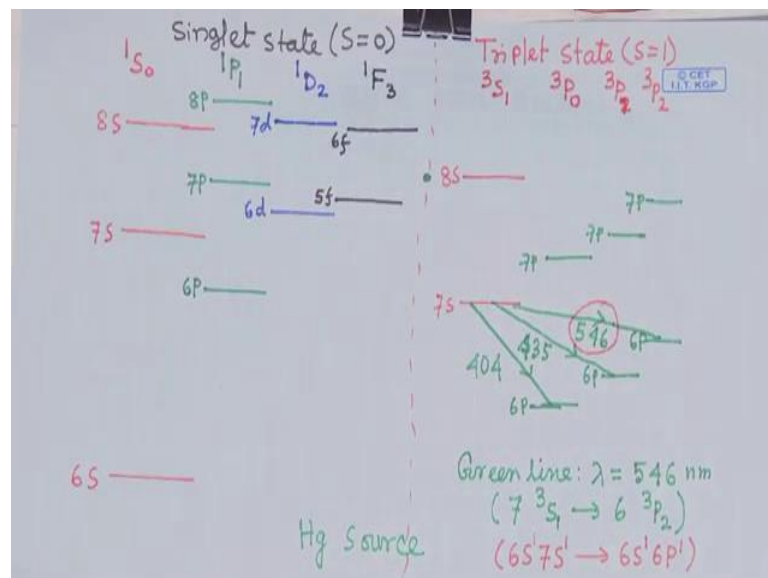
It can jump to the again this state or it can jump to the 6 S 1. 1 electron was there and another electron from 7 S 1 it can go to 6 P 1 because 6 P 1, 6 P 1 have it is also is back end higher energy state. 6 P 1 yes I think yes 4 7 ok.

Lower energy from 7 S to this 6 P is a lower energy. It come to 6 P state or 6 S state 6 S state. say it is going to the this state 6 S 1 and 6 P 1 it can go in many states, but these I have taken an example, say from here it is going to the there. This is the lower energy state. In this case L is total L will be 1 because S for S 1 L is 0; L 1 is 0 and for this P L 2 is small 1 2 is 1.

Capital L total L it will be 1 and S again spin both spin half. Both can be up or 1 can be up and 1 can be down. S it can be 0 or 1. L is 1 means I will get P P. far S equal to 0 singular state and J will be 1 L 0 L 1 and S 0. P 1 1 P 1 then we will get triplet state 3 P. Now, S 1 and L 1 J will be 0 1 2. 3 P 0 3 P 1 3 P 2 ok.

In mercury in mercury. Basically. You can see you will be able to see the transition among this whatever spectroscopic terms we are telling. These all will have different energy. They have energy levels ok. This each one will have different energy. There will be transition from either from here. This state to the any of this or this state to the any of these ok. Because of this transition, you will get spectral lines ok. Let me show you the transition and.

(Refer Slide Time: 32:42)



As I describe that in case of mercury, in case of cadmium also you will get singular state and triplet state singular state, triplet states singular state S is equal to 0, and triplet state S is equal to 1 ok.

If you calculate all sorts of excited state ok. Just I have shown you 1. 1 S 0, 1 P 1, 1 d 2, 1 f 3 this will be the singular states 3 S 1, 3 P 0, 3 P 1, 3 P 2 then 3 d 2 etcetera I have not written. These spectroscopic terms you will get for this mercury.

Their energy levels if I here. 1 S 0; 1 S 0 energy level 6 S, 7 S, 8 S for 1 P 1. This is 6 P, 7 P 8 P 1 d 2. This 6 d 7 d. this way these energy levels are arranged. Similarly, here for triplet state 3 S 1 this is 7 S, 8 S. this is 6 P. Now for 6 P 3 P 0, 3 P 1, 3 P 2. here I have written 6 P means 6 P there this there will be 3 triplet state there will be 3 triplet states and their energy are different ok.

if I just consider the transition between 7 S to 6 P as I told this 1 electron say 1 electron it is in 6 S 1 another electron it has gone through 7 S and from there it is coming back to the 6 P ok. Then there will be transition between these two means 3 S 1 to 3 P 0. you will get this spectral lines this spectral lines it is the wavelength is 4 0 4 and then you will you may get the transition between 3 S 1 to 3 P 1 3 P 1 here.

This transition is wavelength is 435 and then you may get transition 3 S 1 to 3 P 0 transition between these 2. It is wavelength is 546 ok. This type of there are many transitions. Here I have taken 1 example. Now, here this is very strong line intensities very high. This 1 wavelength is 546 this is the in mercury this is the prominent spectral lines, green spectral lines ok. We will take in our experiment we will select this spectral lines without any magnetic field.

This is the spectral lines we will see it is the wavelength is 546 546 0.07 nanometer probably. I have written approximately. This is the green line we will select for our experiment from mercury source. What is the origin of this line? That I tried to explain. This is a single line spectral lines there will be many spectral lines out of that we will use filter and we will select this green line for our experiment ok.

I think I will continue in next class.

Thank you for your attention.