Atomic and Molecular Physics
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Lecture - 13
Atomic structure of an atom (Contd.)

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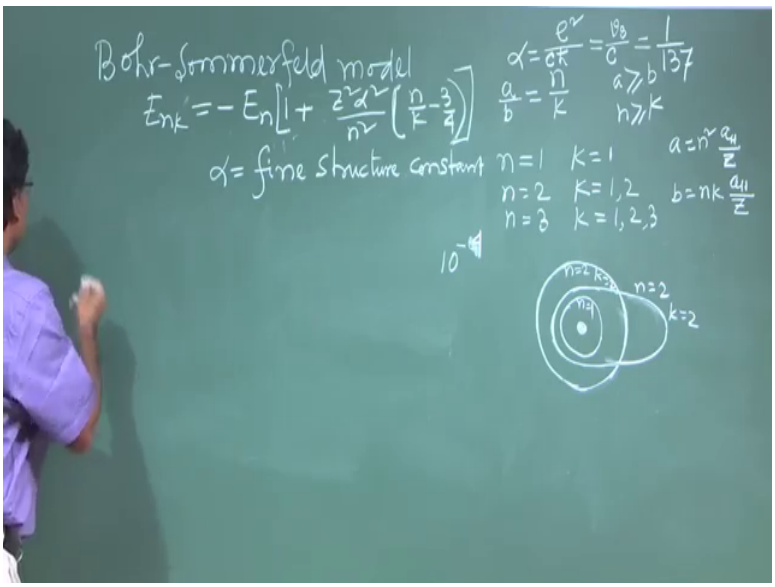

So, we have seen in last class that considering the relativistic relativity the energy level now depends on n and k. So, what will happen this we have seen that I have discussed that for a particular n value. So, if n equal to 1 then k will be equal to 1, n equal to 2 k will be equal to 1 and 2, n equal to 3 k will be equal to 1 2 3 right. So, so corresponding. So, if I draw this orbits. So, also here we have seen that from here we can see when n equal to k means here n equal to 3 k equal to 3, then a equal to b then equal a equal to b means it will be circular. So, whenever n equal to k, then that will be circular orbit and for other cases it will be elliptical orbit. So, if I draw just. So, we have a nucleus we have a nucleus. So, for n equal to 1 we will have this first orbit. So, that will be basically circular that will be basically circular. So, that is n equal to 1. N equal to 2 I will get next orbit n equal to 2 I will get next orbit. So, for n equal to 2 k equal to 1 and k equal to 2. So, k equal to 2 n equal to 2. So, that will be again circular

So, let us draw this next orbit next orbit it is not perfectly circle, but. So, more or less it is circle. So, this is n equal to. So, this is n equal to 2 and k equal to 2. So now, n equal to 2 and k equal to 1. So, it will be orbit a elliptical orbit, but its, but it is a will be sent length of a will

be sent, because as you remember that I wrote a equal to n square by z and b equal to n k by z right. So, n a does not depend on k, but b depends on n and k. So, for n equal to 2 k equal to 1 a will be same, but b will change b will sink it will decrease. So, this whatever this a value here radius. So, here you will get basically shifting of this one keeping the same so, this basically I will get say basically one can draw like this.

So, this kind of elliptical orbit one will get. So, keeping the a same keeping the a same b decreased. So, and keeping this nucleus at one of the focus foci. So, this will be for n equal to 2 and k equal to 2. So, this way now we will go for n 3. So, again for k 3 right will be circle and this there will be other 2 elliptical orbit. So, that way one can draw the orbits for hydrogen atom, considering the Bohr sommerfeld model. So now, here one thing I have not mentioned that here I have used alpha what is alpha? A alpha is basically is constant alpha is constant. And so, alpha is constant and it is it is e h cross by e h cross by it is called fine structure. So, this alpha value is I think it will be e square by c h cross it is it is a constant e square by c h cross e square by c h cross. So, e is constant c is constant h is constant h cross is h by 2 pi. So, if you put value. So, it is come it is it is basically one can write VB by c also one can write. So, what is VB? VB is basically velocity in Bohr radius electron when it is in Bohr radius n equal to 1 for original Bohr energy if you look their expression if you look their expression of B velocity. So, it varies with n for n equal to 1 what about the velocity let us call n equal to 1 Bohr orbit and electron Bohr orbit what is the velocity that B V.

So, that is again constant all the time it will not change universal constant. So, Bohr orbit is taken as a universal you cannot change. So, whatever the velocity energy that is also constant all the time. So, this value comes is basically 1 by 137 it comes 1 by 137. So, that is a is a alpha is a constant and it is a very, very smaller than one very small quantity and it is called fine it is called fine structure constant. Why it is called fine structure constant? That I can explain. So, alpha is called basically alpha is called fine structure constant because you see here for a particular orbit or particular nucleus. So, this energy how much energy will decrease or increase from one energy level to another energy level 1 orbitals to another orbitals. So, that alpha decide value of alpha decide for a particular n for a particular k value for a particular n for a particular or 2 successive k value what will be the energy difference. So, that is decided by this this term and this term basically it is this value will depends on the alpha square and alpha square is very, very small in we do not know.

So, it is you can you can say this t to the power minus 2 square of it will be 10 to the power minus 4. So, this contribution is it is 1, 1, 10 thousand times of this this of this value. Whatever there for what about the energy original energy. So, that will be that contribution increase or decrease. So, that will be it will be by factor of 10 to the power minus 4. So, change energy between this level. So, if I draw now for

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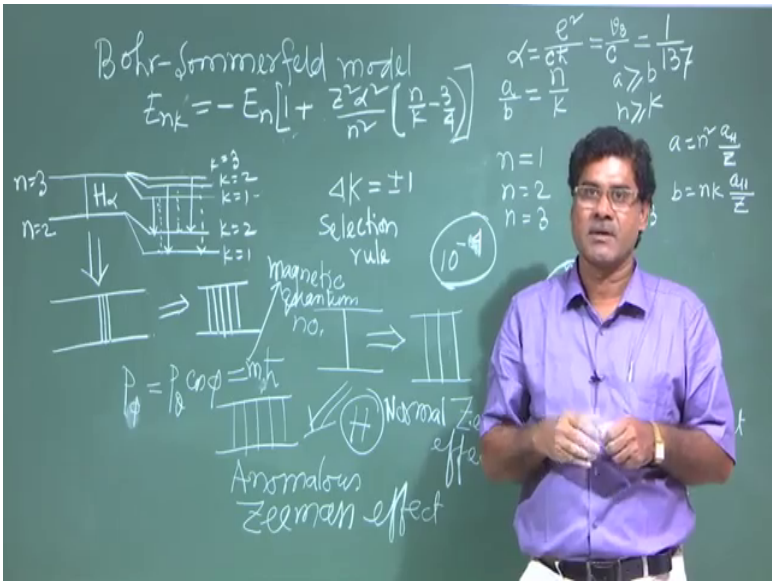

Hydrogen just let us take one spectral line say H alpha it is wavelength was around I think around 6000. So now, these lines these lines came from n equal to 2 transition between n equal to 2 and n equal to 3 n equal to 2 and n equal to 3.

Now, this lines are now due to due to this or according to sommerfeld model. So, n equal to 2 means k equal to 1 and 2. So, this energy level will split it will be basically 2 energy level for k equal to 1 and k equal to 2 that already I have discussed. So, k equal to 1 it is a lower than this k equal to 2. So, this separation is very, very small this separation is very, very small because this factor control this separation similarly for n equal to 3 what I will get n equal to 3 I will get n 3 lines one is this. So, this k equal to 1 then I will get k equal to 2 then I will get another level k equal to 3. So, earlier it was one line means for n equal to 2 one line energy level and n equal to 3 another energy level transition between these 2 level was given a spectral line.

Now, this this energy levels are splitted into higher than the one levels and now if you consider transition. So, looking at the experimental result. So, transition rule selection rule

was considered that transition only possible when it will satisfy the change of k delta k it is plus minus 1. So, this call selection rule selection rule again it was hypothesis it was considered their all transition is not possible. So, only it follows some selection rule. So, it was considered that this here this transition will be only for this case delta k equal to plus minus 1 for other case it will it will not be possible. So, here you just in adhoc basis it was considered there is no explanation only looking at the experimental result it was considered, but from quantum mechanics we will see later on that it comes this rules comes automatically.

So now we have to take it as a adhoc or the atom basis. So, if I consider this rules then if I start from here. So, k equal to 1 and here k equal to 1. So, if transition this transition is not possible because delta k equal to 0 that is not allowed, but k equal to 1, 2 k equal to 2 this transition is possible because this it is it is plus minus 1 if you consider this is this is the initial and this is the final. So, final minus initial if I consider this way final minus initial. So, it will be plus 1 2 minus 1 plus 1. So, this transition is possible fine. So, from this level it is not allowed only this is allowed. So, I will get one spectral line and then if I start from here k equal to 2. So, here k equal to 2 it is not allowed delta k equal to 0 k equal to 2 and this k equal to 1 it is allowed because 1 minus 2 it is minus 1. So, final minus initial in that way if I consider. So, this is allowed. So, this is allowed and then from k equal to 3 k equal to 2 it is allowed, again it is minus 1, delta k is del k is minus 1 and k equal to 3, 2 k equal to 1 is not allowed because it depends in minus 2. So, selection rule do not permit.

So, only 3 transition is possible other transitions are call forbidden transition. So, from here it is not allowed it is forbidden and from here this is forbidden and then only this is allowed and now from here it is allowed or this is forbidden. So, what I we are getting we are getting this this now this is basically it is according to Bohr model it is the wall line it is not composed of 3 lines they are very the difference are very small. So now, it is splitted into it should split into 4 3 lines, but experimentally as I told that no it is not 3 this h alpha line it is composed of 5 lines it is composed of 5 lines it is composed of 5 lines 1 2 3 4 5. So, even sommerfeld model or Bohr sommerfeld model partly it can partly it can explain the splitting of the energy level, but it is it is it is cannot explain fully we need more transition.

So, Bohr sommerfeld is that model is again it is not yet correct model or full model which is which will be able to this explain the exponent result, but still some more lines we need means we need. So, this result is indicating that s whatever 2 quantization we have

considered and 2 quantum number we got this principle quantum number and angular quantum number or azimuthal quantum number. So, there are some more quantization. So, that one has to consider one has to find out and also it was observed that that when we apply electric field or magnetic field, then each spectral line without electric or magnetic field without electric or magnetic field each spectral line.

So, it may not it is not this line you know whatever here we are getting. So, each of them each spectral line without applying electric or magnetic field, whatever the spectral line you are looking at a particular spectral line now just if you switch on the electric field or magnetic field means your sample your atom is under electric field or magnetic field, then this lines is splitted into more number of lines. So, when you are applying magnetic field due to this magnetic field this lines are splitted, and this effect was discovered in I think 1896 moreover exactly I didn't remember, but I think 1896 this effect was observed by Zeeman and it is called Zeeman effect it is splitted into more lines it is splitted into more lines.

So, here I have drawn 3 lines. So, in Zeeman Effect again 2, 2 types of Zeeman effect one is called Normal Zeeman Effect another is called Anomalous Zeeman Effect. Normal Zeeman Effect what is that when you apply a higher field they it Zeeman observed that when we apply higher field in higher field this any spectral line splitted into 3 lines any spectral line splitted into 3 lines. So, it is independent of this what is the origin of the spectral line does not matter, but any line splitted into 3 lines at higher magnetic field. So, that effect was called normal Zeeman Effect, but later on it was found that if you use weak magnetic field, if we use comparatively weak magnetic field low magnetic field.

So, this splitting of a spectral lines into few number of spectral lines. So, that number is not same for all spectral lines. So, it depends it depends on the origin of the spectral lines. So, it is splitted all the time it is seen that it is splitted more than the 3 lines splitted into more than the 3 lines. So, in some cases it is splitted into 6 lines some cases it is splitted into 4 lines etcetera. So, it is more than 3 lines at weaker field weaker magnetic field so, that is called. So, if under weaker field. So, if you if you see that it is splitted into more than 3 lines it can be 5 it can be 4 it can be 6. So, then that is called the Anomalous Zeeman Effect. So, Normal Zeeman Effect and Anomalous Zeeman Effect.

So, I define that. So, what is the origin that we do not know yet we have to find out. So, here 2 clues is there one is that this from sommerfeld model we are getting more lines, but it is not

submissioned yet we get we get more even more lines number of lines. So, another is when we are applying the magnetic field then we are getting one line is splitted into more lines. So, tendency towards the more line. So, there should be more splitting of the energy levels and splitting of the energy levels only possible from the quantization. So, more quantization we need another aspect as I mentioned that, this if you even if you apply electric field then also these spectral lines splitted. So, that effect so, this is for magnetic field this is for magnetic field it is H this is for magnetic field and for electric field and for electric field.

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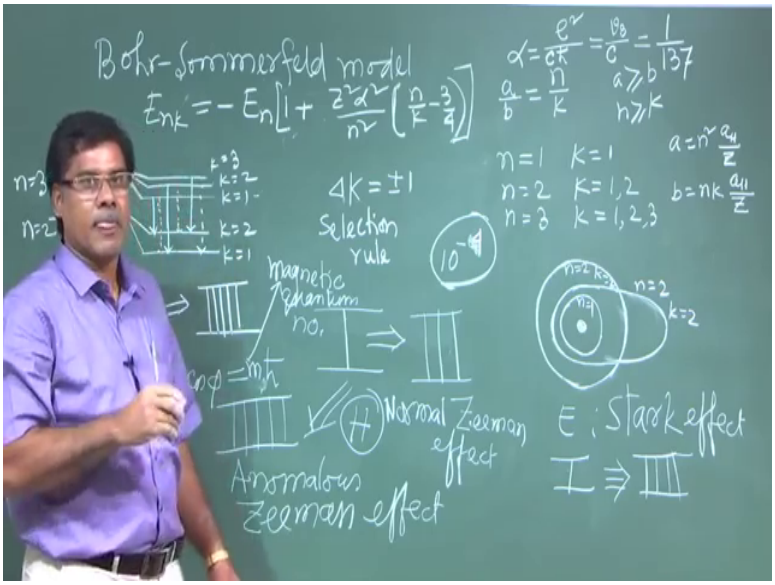

If we apply electric field then one lines one lines splitted into more lines. So, how many lines again it depends on this origin it is not same for all spectral line.

So, when we apply electric field. So, whatever effect we are getting. So, that call Stark effect. So, these are the event was experimental observation was available and then then people start to search more quantization more quantization of the system. So, we need more coordinate. So, then next I think this sommerfeld itself he pointed out that here quantization whatever we have considered that it is elliptical orbit 2, 2 coordinate we need r and theta and their periodic function of time. And so, considering this 2 coordinate what we are getting? We are getting basically planar motion. So, orbit ellipse in a in a in a plane we are getting orbital motion in a plane or planar motion.

Now, now in which plane if I consider the planar motion. So, in which plane atom is 3 dimensiona, say spherical shape. So, it is in space now we are considering the in in spherical

shape, now we are considering a or ellipse side we are considering an orbit. So, orbit is on a plane. So now, which plane we will consider. So, whether it is in this plane or whether it is in this plane or whether it is in this plane. So, any plane it can. So, answer is so far it can be any plane. So, direction of the plane can be any there is no restriction on the direction. So, angular motion of the electron right it has angular momentum. So, direction of the angular momentum is basically perpendicular to the plane right.

So, if it is in this plane. So, it is perpendicular to the plane this direction of the angular momentum it is sparking to the plane now this it can be different plane and this direction of the angular momentum will change right it can be in any direction in space it can be any direction of the space. So now, here I think this it is called space quantization. So, it is considered that no it cannot be in any direction, it cannot be any plane. So, there is a quantization. So, it is quantized this direction is quantized in space. So, it cannot take any direction. It can take it is again it can take this direction and then these are not allowed then it can take another direction then it can take other direction. So, all other direction all directions are not permissible these directions are quantized and this is called space quantization.

So, to take space quantization one has to fixed reference direction in space right one has to fixed reference direction in the space. So, since applying electric and magnetic field then we are seeing the splitting of the spectral lines. So, that is why direction of the magnetic field or electric field. So, I have atom or system of atoms now I am applying electric field or magnetic field. So, I am applying magnetic field in a particular direction. Now with respect to this direction if I fix this direction take as a reference in space now with respect to this what are the plane orbital planar motion of the of the of the electrons are permissible. So, this motion we have considered r and theta now with respect to this this plane this is fix now if this is the plane or this is the plane in this plane so orbital motion.

Now, if I take angle between this reference direction or magnetic field direction and my plane direction. If it is a plane direction or I think it is taken generally in the yes plane direction is perpendicular to the plane. If this is the plane direction means plane is like this perpendicular to the plane. So now, angle is if I consider phi. So, angular momentum P phi angular momentum angular momentum basically P phi P 6 I think if I consider P phi. So, that P phi will be basically P theta cos phi. So, in space momentum if in space in space now if you take this projection along this direction. So, it will be P theta angular momentum it is projection on this ps direction it will be P theta cos phi now it is telling let us say that if I write P phi that

equal to P phi. So now, it is telling that P phi is quantized the P phi is quantized and this will be equal to some h cross, earlier we have used n then k, here it is used n or n phi n phi h cross n phi h cross here one can take the same quantize integration integral. So, P phi now again it is angle direction phi angle right.

So, this that integration will give you 2 phi. So, equal to n phi h divided by 2 phi. So, n h cross. So, you will get m phi h cross. So, about that we have m phi. So, in general n phi like this m h cross. So, this m is called magnetic quantum number, magnetic quantum number. So, we have now another quantum number. So now, is 3 quantum number? So now, with taking this again we will try to explain whether we are whether we can we can get from H alpha whether we can get 5 lines whether we can get this Normal Zeeman Effect Anomalous Zeeman Effect and this Stark effect whether we can explain or not that we will see. So, I wll stop here in next class I will continue.

Thank you.