Atomic and Molecular Physics
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Lecture - 11
Structure of an atom

So, in last class, we have seen the success of Bohr model, but there are also failures of this Bohr model means there are some things, some more things Bohr model cannot explain.

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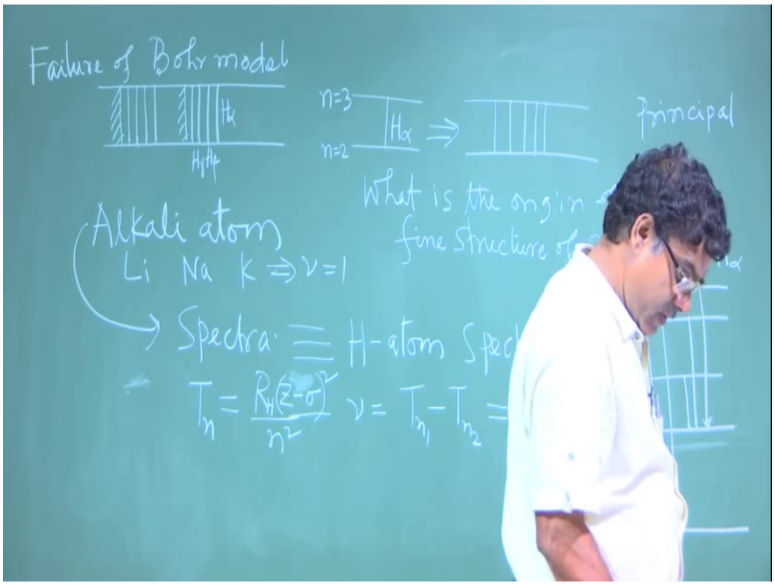

So, this initially this hydrogen atom spectra as I have shown you. So, let me tell you failure of Bohr model. So, according to Bohr model what we have seen in hydrogen spectra simple spectra so, there are series like Lymen series (Refer Time: 01:30) series so, and many others right. So, in Balmer series we have given name of this line wave line H alpha H beta H gamma etcetera, when this spectra was observed in a powerful spectrometer with very high resolution. So, then it was observed that H alpha line, H alpha line, H alpha line from where it is coming H alpha line it is coming transition between n equal to 2, n equal to 3 from this between these 2 line this transition this give H alpha line right.

And then H beta is gamma etcetera this 1 successive transition from n equal to how to n equal to 2 n equal to 5 to n equal to 2 etcetera. So, this H alpha line this is in powerful spectrometer which is having very high resolution. There it is seen it is observed that it is not a single line it is composed of 5 lines 1 2 3 4 5 it is composed of 5 lines. So, this is called fine structure of spectral line fine structure of spectral lines.

So, what is the origin of this 5 five lines so; that means, this all other lines whatever had seen in ordinary spectrometer it is not a single line, each and every line are having is composed of many lines how many depends on it depends, but in this case H alpha 1 it is composed of 5 lines. So, what is the origin of this origin of the fine structures of spectral lines, spectral line say H alpha. So, that Bohr model cannot answer of this of this question. So, another fact is that this you know this alkali atom, what is alkali atom lithium sodium potassium their valency is 1 hydrogen atom also valency is 1.

So, this alkali atom their spectra is quite similar to the hydrogen spectra of alkali atom is quite similar to the to the hydrogen atom to the hydrogen atom spectra of course. So, means this hydrogen spectra have it shows the series, different series this alkali atom also shows different series we will see later on, but it also shows different series. So, this from Bohr model it was since their spectra are has similarity. So, Bohr from Bohr model it is possible it may be possible to explain and that that was (Refer Time: 06:53). So, this because here in case of this atomic alkali spectra alkali atom.

So, this as I told this term value well we write this R H Z square by n square right term value and the spectra lines basically nu equal to difference 2 term (Refer Time: 07:26) this T n (Refer Time: 07:26) we write T n. So, 2 difference between 2 term value T n 1 and T n 2 so, it is R H z square by n square. Now this term value was adopted. So, these are for hydrogen like atom these term value was adopted. Since this alkali atom is having more than 1 electron, this lithium is having 3 electrons, sodium is having 11 electron right so, but generally outer electron participate in the in the transition. So, difference between these main electron and (Refer Time: 08:34) electron atom and 1 electron atom that 1 electron. As I discussed in case of (Refer Time: 08:39) law. So, this for (Refer Time: 08:42) electron this is after electron it is in that case this that positive charge Z, it is not fully active or this outer electron cannot see the full charge positive charge because, it is (Refer Time: 09:07) by the other electron. So, effective charge positive charge will reduce.

So, in that concept so this for term value for this atomic spectra alkali atom it can be written in like this, as I already discussed this skinning effect. So; that means, this alkali atom it has valency 1 means outer size electron only active it is hydrogen like atom. So, only correction we need for skinning effect so, that will be introduced. So, then this should be the term value for alkali atom so, for hydrogen atom using this term value so, all spectral lines was explained.

So, using similar seeing this similarity so this Bohr model was adopted for this alkali atom and it seemed this should be the term value for the alkali atom. And then then you will see you will see the transition among energy levels, and corresponding spectral lines 1 should see.

So, in this case also this what should be the energy level, so spacing should be smaller and smaller when you are going towards higher, I think this I should so, in sodium there were 11 electrons. So, this outer electron so transition as I told these spectral lines will get due to the outer electron. So, this outer electron it is really at n equal to 3. So, whatever at n equal to 1 and n equal to 2 they are inner electron it will not participate in in transition. So, n equal to 3.

So, there this outer electron is staying there, and then that can go at higher energy level n equal to 4, n equal to 5, n equal to 6. So, it is a similarity from the similarity of hydrogen energy level so 1 can draw. So, 1 should get 1 spectral lines 1 should get spectral that series limit, 1 should get different series, like another series would be this. So, that way or different series and in alkali spectra that series was observed their (Refer Time: 12:58) 4 series was observed it is called I think principle series here, I can write principal series.

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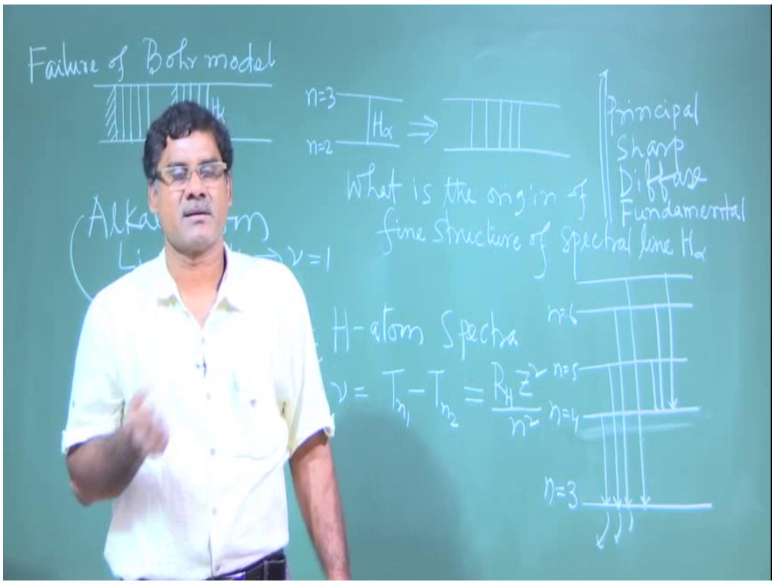

And then of it is other series is called I think that is yeah yes principle series, sharp series then diffuse series and then fundamental series. So, like Lymen series of Balmer series etcetera here, also this kind of series similar type of series are observed.

So, but unfortunately the wavelength of each series using this model this term the value whatever this term from Bohr model whatever the value is giving. So, it is there is no it cannot explain it cannot give the correct value of the wavelength of frequency of this series spectral lines of this series. And it is not only connect and give it is a there is a huge difference, and it has to be it has to be look towards the validity of this Bohr model for alkali atom. So, later on we will see what is the source of this series, and in series this is not the source this is not the this model whatever it is given it is not enough to explain the this series to get the exact wavelength of the of the spectral lines of this series.

So, as for this 1 whatever the wavelength or as for this 1, so this number in principle in principle whatever this transition I showed later on we will see at n equal to 3 transition from this other n equal to 4 5 6. So, this each line basically each line is not single line, each line will have again it is composed of many lines. And this each line is composed of many lines, but it is not giving a series. So, is the mixture of this also all other all this, but basically with this full lines each full each lines is composed of many lines spectral lines and they are distributed they are arranged in a such way they build up this 4 series.

So, we will get from this full lines whatever this from Bohr model we are we are getting. So, this series are not visible or this may exist, but it is not prominent 1.

So, here also again this same thing is happening it is not a single line it is not a full lines, have many lines, each line is having many lines so, but ultimately from Bohr model what about this full lines we are getting these full lines will give this 4 series, each line will not give 1 series, but as I told this we will see that mixture of this 4 they will form this different series (Refer Time: 18:07).

So, 1 thing is clear what about from Bohr model whatever the spectral lines we are getting, but actually each line is composed of many lines spectral lines. So, this indicates that and spectral lines actually we are getting due to the discreteness of the energy level. And discreteness of the energy level we got due to the quantum condition right. So, 1 quantum condition taken in Bohr that is the angular momentum is quantized and that is basically lead to the quantization of the energy level ok.

So, as if transition between 2 energy level gives the spectral line. So, as if it looks that this each energy level from Bohr model we got this level is not a single energy level it is composed of it is composed of many energy levels, their separation maybe small or they may have same energy, but there are many. So, if energy levels are composed on many levels few levels or many levels and then there is a possibility to get many spectral lines. So, that is the indication it is failure of Bohr model, but it giving indication that there are more discreteness among this energy level in this in each energy level, it is not a single energy level. So, we need more quantization we need more quantum number. So, that is the of from the failure of Bohr model we could learn something, and in that direction people started to think how more quantization is possible so, that we will discuss now.

So, what we have learnt some more spectral lines. So, more energy level we need more quantum number or quantization. So, 1 thing people started to think and Wilson and this Wilson and Somerfield they yes.

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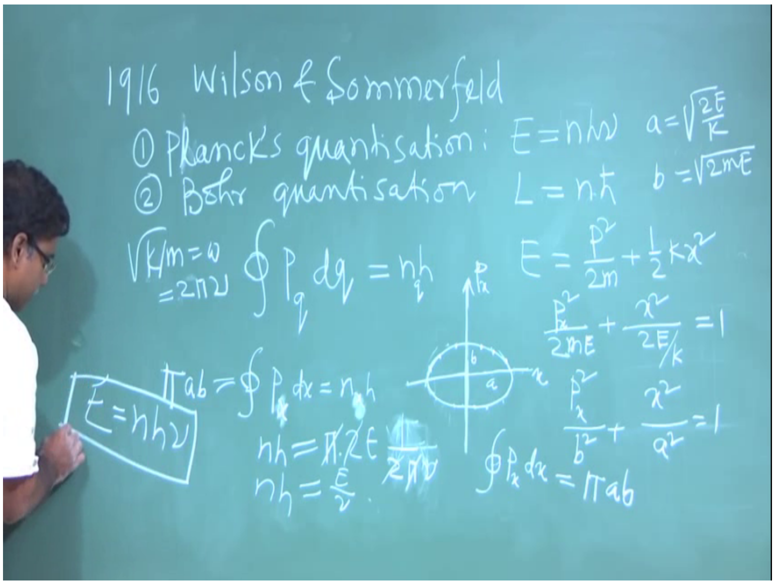

In 1916 Wilson and Sommerfeld; they started to think on this issue and they tried to understand the quantization process. So, 1 first quantization was given by planks quantization so, sometimes I write z in American English and UK English so, but you can write either s or z. So, a plank quantization what was that energy of a oscillator is quantized energy of an oscillator is quantized right in black body radiation.

So, electron or this atom on the surface of the black body cavity so, it oscillates and due to this oscillation it radiates. So, this energy of the oscillator is quantized. So, that is the planks quantization right. And then second quantization was the Bohr quantization what is that Bohr quantization was that the electron rotate will rotate in a revolve in a circular orbit, but it cannot choose any orbit the orbit radius will be such that the angular momentum will be quantized, angular momentum of that electron revolving in a circle is quantized. So, here Bohr consider this quantization n H cross l equal to n H cross you see this quantization is a complete different in nature 1 is energy quantized another is angular momentum is quantized, and energy of an oscillator is quantized.

So, then Wilson and Sommerfeld they started to think that what should be the who what are the perimeters, what are the things, can be quantized and they found the general rule that any system to describe that system we need coordinate. So, if coordinate is a periodic function of time for that system. So, that parameter has to be quantized.

So, that is the general it is a neither oscillator nor angular momentum it can be any system to describe that system we need coordinate right, and all coordinate may not be the periodic function of time those parameter which is which will be the periodic function of time that parameter can be quantized. So, that s was the quantization rule setup by Wilson and Sommerfeld. So, based on that so, this; that means,. So, they gave this general action equal action in real. So, to describe a system we need say momentum and space coordinate so, P q to generalized coordinate.

So, P momentum less coordinate d q, and then d q it is a integration close integration it will be n q h. So, that was the general quantization given by Wilson and Sommerfield. So, if that you see now just consider the harmonic oscillator. So, it is what is it is energy E equal to P square by 2 m plus half k x square remember (Refer Time: 28:00) system, it is oscillating. This k is the some constant spring constant so, these are potential energy these are kinetic energy. So, this we can write P square by 2 m E divided by E 2 m E plus x square divided by 2 E by k I can write equal to 1 right. So, this I can write it is like this, so it is the E q here q I have taken x. So, this I will write P x P q q I have taken x and P is momentum p x.

So, this I can write P x this square divided by say b square plus x square divided by a square equal to 1. So, this is a equation of ellipse right, but in (Refer Time: 30:00) space momentum and space coordinates it is called (Refer Time: 30:08) space so, it is motion in a (Refer Time: 30:15) space is I think I have to draw ellipse. So, it look circle so, this is P x this axis, x axis, so P x these 2 coordinate E 2 is basically each point coordinate is basically to fix the position of the particle right. So, in (Refer Time: 31:03) space using P x and this x we can fix the position of the in this case of the motion of the oscillator. So, from here this is the elliptical as if elliptical motion is (Refer Time: 31:28) space of this oscillator and from here, you can get this a equal to comparing this a equal to what you are getting a equal to square root of 2 E by k and b equal to you are getting square root of 2 m E ok.

So here this is a, and this is b. So, now integral of this is the P x d x what will be the integration value, integrating value for a 1 complete rotation it is nothing, but the area of this ellipse right. So, area of this ellipse is basically pi a b so, this integration is basically pi a b. So, this directly without considering any quantization so, we just I have started from the simple (Refer Time: 32:46) oscillator I wrote the energy and from here I described this nothing to do with the quantization. Now if I consider quantization so, in this case I can so, 2 parameter P x and x right it is describing the system oscillator. So, they are periodic in nature E x, because this x value and p x value, it is it can take it change here as a function of time it is changing and it is periodic in nature.

So, this I can apply quantization for that so, here if I start from quantization that action in real. So, P q means in our case P theta not P theta P x, and then this is d x equal to n q h. Now from here what you are getting P x d x this integration, if you take this integration because this I cannot write, if I do not consider a system which has this elliptical path means periodic nature. So, I have taken this 1 system is like this there I can apply quantization this quantization rule, And I can write this so, P x d x is basically pi a b. So, what I am getting, I am getting pi a b equal to n I think I will write n x n x h ok.

So, then pi what is a and b a into b, what I am getting a into b, I will get 2 E 2 E square root of n by k or 1 by k by n. So, k by n you know (Refer Time: 35:45) system it is nothing, but k by m square root of k by n is omega. So, square root of k by n is omega and omega equal to 2 pi omega equal to 2 pi nu frequency 2 pi nu. So, I can write here 2 E this k by m is omega 2 pi nu so it is a square root I can write here just square root so, 1 by this 2 pi nu so, this I can write replace this 1 by 2 pi nu, and this this equal to n x h. So, just write n h you can write n x or n fine. So, from here you can see pi is going, and 2 is going, and I am getting n h equal to E by nu.

So, nu from here what I am getting E equal to n H nu so from here I am getting E equal to n h, what is this this is exactly that planks quantization. Similarly you can also starting from this action integral quantization rule, if you take an electron rotating in an orbit for that you need coordinate what you need coordinate R and theta right. So, if it is circular orbit then R is constant, but theta is a periodic function of time.

So, to describe that 1 we need our theta, but R is constant if it is circular and only theta is a periodic function of time. So, if you consider this electron whatever Bohr considered, and then if you proceed the similar way you can show from this starting using this action integral or quantization rule, you can show that you will get that this angular momentum is quantized. So, that is your homework you can show easily, just 1 example I had given rest 1.

So, whatever we have quantization this is a general rule, and that rule is it can reproduce this. So, it is not only for this it can so, it is a general rule for other system also 1 can use. So, that was the then Sommerfeld that is called Sommerfeld model, Sommerfeld introduced the elliptical orbit for electrons in atom Bohr considered circular orbit, and Sommerfeld introduce no it is not the elliptical circular orbit, it should be elliptical orbit.

And that is what planet also in planet, and in any central force which is 1 by R square gravitational force pull on force 1 by R square so, in central force so there this orbit is generally the elliptical orbit. So, Sommerfeld introduced elliptical orbit considered elliptical orbit and so, basically he introduced this concept in Bohr model. And then if it is elliptical orbit then R theta 2 parameter and both are variable with time both are periodic function of time ok.

So, we will have 2 coordinate so, there will be 2 quantization and we will get 2 quantum numbers. So, that we will discuss in next class I will stop here.

Thank you.