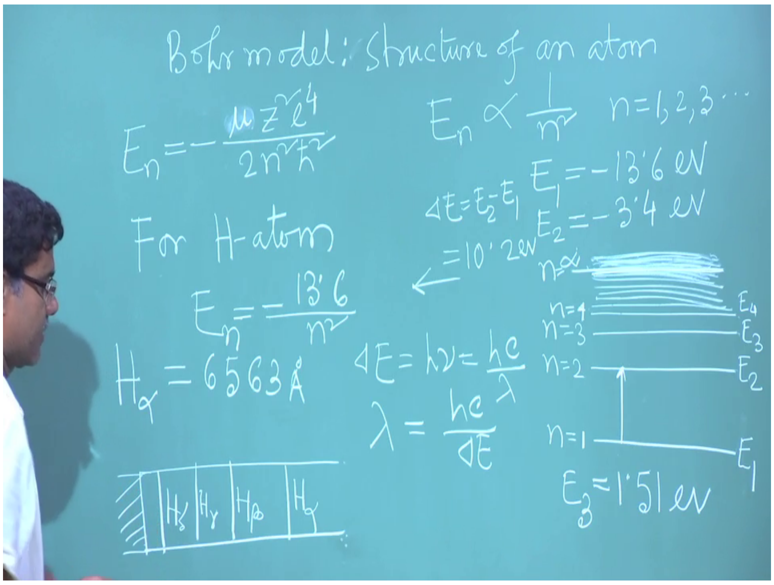
Atomic and Molecular Physics
Prof. Amal Kumar Das
Department of Physics
Indian Institute of Technology, Kharagpur

Lecture - 9

Atomic structure of an atom

(Refer Slide Time: 00:21)



So, we are discussing about the Bohr model of an atom, Bohr model for structure of an atom. So, what we have seen that energy expression E n equal to minus m z square e to the power 4 divided by 2 n square h cross square. And in terms of, that is the energy levels. Energy levels is inversely proportional to energy level, its inversely proportional to n square 1 by n it is proportional to 1 by n square right.

So, if we draw energy level n equal to. So, n equal to 1 2 3 all integer see if I draw n equal to 1, then n equal to 2, n equal to 3, n equal to 4. So, then basically this is a. So, basically you will get. So, say n equal to basically tell infinity. So, from here one can find out the energy E 1, E 2 , E 3, E 4 like this.

So, for hydrogen atom if we put n equal to 1, then E 1 you will get. So, E 1 you will get 13.6 minus 13.6 E v. E 1 for a hydrogen atom E 1 you will get minus 13.6 electron volt then what will be the E 2? Say it is from here itself you can tell E 1 equal to. So, n equal to 1 so; that means, this value is 13.6 minus, 13.6 minus, 13.6 divided by n square. So, n equal to, is a divided by 4. So, it basically you will get minus 4 means 3 2 l 1 say minus 3.4 sometimes 3.39 also people write electron volt ok.

Similarly, E 3 E 3 we will get. So, 9. So, 1 point of then 9 4 46. So, 5. So, 5 1 electron volt. So, this way one can find out the energy then. So, you can see the separation between 2 energy level it is decreasing, it is decreasing and this transition from one energy level to the another energy level. So, this separation, here you can see this say E 2 minus E 1 or E 1 minus E 2 from here what can find out the separation del E equal to E 2 minus E 1 and that will be how much. So, I think it will be 2 find 10.2 electron volt ok

So, this energy difference you will get a as a radiation and if you calculate corresponding wavelength. So, this should be 1 h alpha line this should be h alpha line h alpha line. So, this wavelength we have seen I think 6 5 6 3 angstrom yes probably I have written correctly. So, this energy from this energy one can find out this wavelength, maybe you know this energy equal to. So, that del E equal to h nu h nu equal to h c by lambda. So, lambda equal to h c by del E ok.

So, actually taking the difference of energy level whatever the wavelength was h c. So, that one was slightly. So, it was not the same wavelength whatever observed experimentally. So, here I have written correctly, but its value was slightly different. So, actually this one has to take mu reduced mass m has to replace mu as I mentioned, and then you will get this were these value are correct value. But if you take a mu, then these value slightly changes and E 1, E 2 slightly changes and corresponding this del E will not be 10.2 its slightly different and the that spectral line radiation. So, it will be slightly different than the experimental absorb wavelength ok.

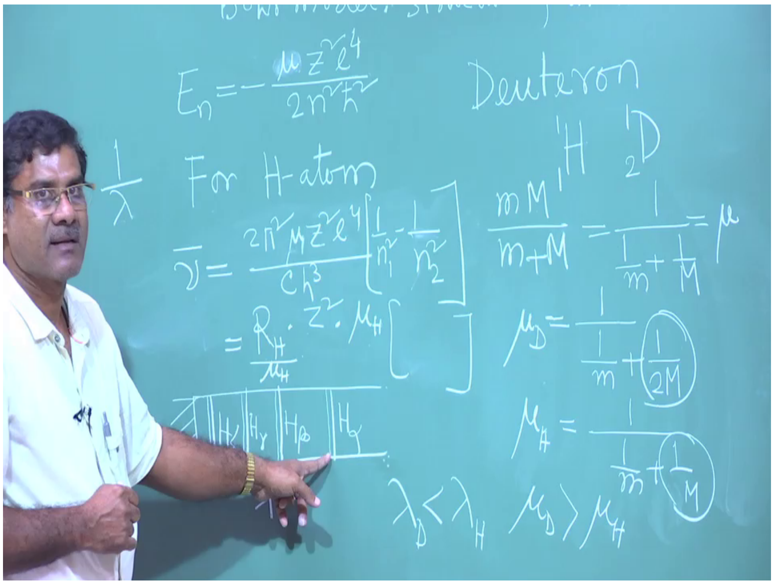
So, another, from there basically this reduced mass concept came, as that I have mentioned that if the nucleus is not at rest. So, then one has to consider the motion of the electron and the nucleus together with respect to the center of mass. So, since experimentally it was not fitting with this Bohr model calculation. So, to when this reduced mass concept was introduced and finally, result from the Bohr energy, and that was the same that was the that result was the was same with the experimental result ok.

So, another thing was that reduce mass concept that is required. So, from another spectral line in hydrogen atom it was found that, as I mentioned this H alpha line, H alpha line, H beta line etcetera H gamma, H gamma, H delta and then series this limit then series limit. So, each line it was seen initially it was not absorb, but later on when this when this spectra was observed in ah in powerful spectrometers resolution was better, resolution is nothing, but the how to resolve how to see how to separate 2 closed spectra lines there wavelengths are very close separation is very small ok.

So, if one can resolve these 2 spectral lines with small difference of wavelength, then we tell we define the resolution of this instrument in terms of this separation, how small this separation? If smaller the separation the resolution of the instrumental better, so in higher resolution it was seen that this each spectra lines bright spectra lines is associated with a faint line, each spectral line was associated with a very weak faint line very weak or faint spectral lines.

So, what is the source of these lines? So, again that is basically because of the reduced mass and these spectral lines was coming from the isotope of hydrogen that is deuteron think this I do not need them. So, to get this one, basically isotope was discovered you do not come from.

(Refer Slide Time: 13:43)



This isotope of hydrogen that is deuteron and deuteron this hydrogen it has one it has at the atomic number one. So, it has one electron and one nucleon that is proton, but in deuteron, it has one electron and one proton and one neutron. So, its mass is double charge is same, but mass is double than the hydrogen atom ok.

So, now, mu is basically what m M by m plus M. So, this the nuclear mass and this is the electron mass. So, this we can write 1 by m plus 1 by M right. Now for spectra line we used basically nu bar right what was that? Nu bar was as I remember. So, 2 pi square mu z square e to the power 4 divided by c h cube and then 1 by n 1 square minus 1 by n 2 square and this is basically mu, this is mu. So, so here we used to write I think this we can write as a Rydberg constant for hydrogen and then into. So, for hydrogen is z equal to 1 one has to take. So, z square, z equal to z equal to 1 is taken for in this R H. So, z square ok.

So, for see in case of deuteron z is 1. So, Rydberg constant this looks same, but it is not the case because if you consider. So, this now mu is different. So, mu one has to write here h. So, one has to write I have to what I have to do this. So, in Rydberg constant mu is there. So, I will divide it by mu H into mu H. So, yeah into mu H. So, this I can write and this part is there. Now, here. So, whatever the this in case of mu h. So, for now if I consider this mu D, for deuteron mu D. So, mu D and mu H. So, what I can do from here I will get 1 by m that is common; m is common for hydrogen and this deuteron, but this is different. So, here I have to write 1 by 2 M. If m is the mass of the proton see Deuter on 1 proton and 1 newton. So, if we consider the same mass of both. So, here it will be 2. So, whereas, mu H is 1 by m plus 1 by 2 M sorry 1 by M.

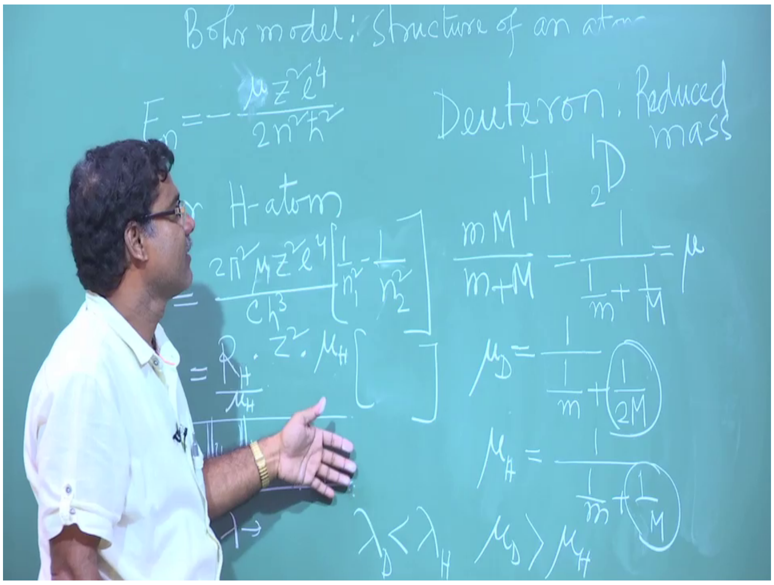
So, here you can see that in case of mu D this is smaller, this is half basically it is half than this one. So, what about these values this is half this is smaller. So, this is smaller means mu D will be this is smaller. So, mu D will be higher than mean H right. Because in denominator this is whatever this value this is higher value and this is lower value. So, its lower value in denominators. So, mu D this will be higher than this H ok.

So, when E n. So, mu when it is mu H or mu D. So, this is higher value in this case this separation, in case of wave number. So, what you will get? So, this is higher value this is higher value. So, this value will be higher, this value will be higher. So, nu bar will be higher for nu D, nu bar will be higher. So, what is nu bar? 1 by lambda. So, nu D nu bar D is higher. So, lambda will be smaller. So, lambda for D will be smaller than corresponding lambda for mu H ok.

So, it will come at lower side. So, that is why see at lower wavelength its lambda. So, this always at lower wavelength, there is a faint spectra line associated with a each spectral lines of hydrogen. So, this spectrum lines is basically is from deuteron. So, hydrogen, hydrogen always some percentage of deuteron is there in hydrogen gas. So, 1 cannot avoid the presence of deuteron, but its vary 1 2 3 percent. So, that is why this spectral lines are weaker. And later on intentionally the increasing the deuteron ratio in hydrogen gas, it is seen that this faint line become brighter.

Because now the ratio of the hydrogen gas and the deuteron. So, this mixture now this ratio is higher. So, that is why these lines become hydra brighter than the earlier one. So, that is, this again this means basically this reduced mass the reduced mass is very that was the correct got it that was the proper correction to the initial Bohr result where initially it was taken.

(Refer Slide Time: 23:10)

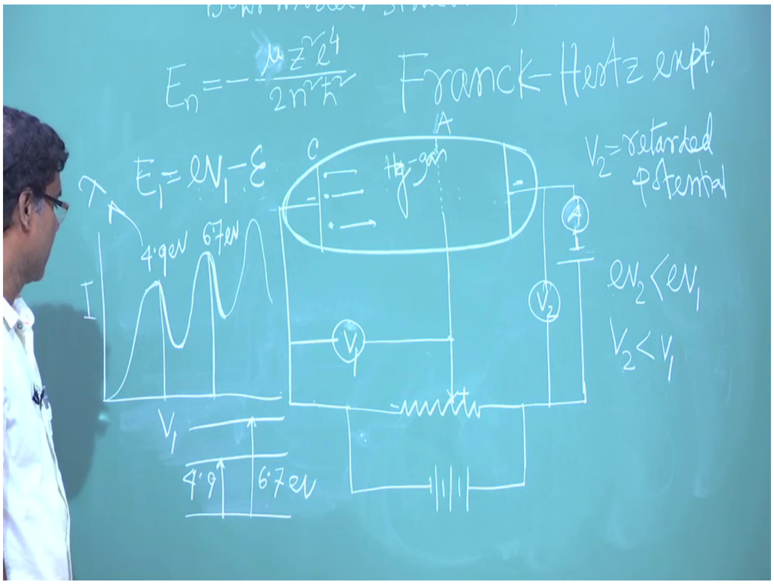


So, later on it was properly it was replaced by nu and there is the pigeon of deuteron hydrogen gas as isotope. So, that was determined from the spectra lines of hydrogen. So, this reduce must correction was given to the original Bohr expression, energy expression and that helps to explain that helps to get the correct wavelength of the spectral lines of hydrogen atom as well as that helps to discover the pigeon subtitling hydrogen gas ok.

So, then from here as I drawn the energy levels. So, Bohr model is telling that energy levels are discrete and from the transfer of electron from all level to the another level or d to jump of electron from one energy level to another energy level. So, we are getting radiation and corresponding spectra lines we are seeing right. So, there is a nice experiment which gives the direct confirmation of the discreteness of the energy levels in atom ok.

So, that is the that experiment is called Franck hertz experiment, and it is very famous to for the direct.

(Refer Slide Time: 25:53)



I think I will keep it. So, Franck hertz experiment and this is very simple and nice experiment and it gives this the direct evidence of the presenter presence of the discrete energy level in the atomic structure ok.

So, this Bohr model is basically it was given for a hydrogen atom. So, for one electron system, but it is valid for any atoms it is this concept is valid for any atoms is not directly this formula is not directly valid for all atoms means multielectron atoms, but the concept of discreteness of energy levels in any atoms. So, that concept is valid so; that means, the energy levels of in any atom it is single electron more electron they are discrete ok.

So, one experiment was designed my Franck and hertz. So, what was that experiment? There was a tube there was a tube, and it was kept at low pressure means it is evacuated and kept in low pressure. So, there is a cathode and there is a anode it has some of hole perforated, it has some hole. So, this is cathode this is anode and there is a plate collector. So, this cathode emit electron. So, one power was given say. So, what I will do the testing voltage divider. So, this was connected here. So, this side is basically plus and this side minus. So, this was connected here.

So, this basically is minus. So, it is a minus cathode its plus. So, this is positive bias and then here plate here it is given it is a negative. So, this is positive is connected with positive. So, and here one when a 1 when a meter is attached, see can and measure the current and this voltage difference between I think here one volt meter, I think this s here 1 volt meter here 1 voltmeter V is connected is connected and here another vole meter is connected.

So, I think I will not connect this a. So, this is positive. So, here 1 voltmeters I think this is V 1 I will give. So, this changing this one this voltage is between these 2 and here its current is flowing current is flowing due to the do the same positive here. So, this positive and this one is negative. So, this here another voltmeter is connected is V 2 ok.

So, this the experimental arrangement, now you see this voltage difference between these 2. So, cathode negative dispositive. So, electron emitted from this cathode it will be accelerated; it will be accelerated and it will move towards the anode. So, its energy will be its energy E 1 will be e V 1 energy of the electron.

Now, since there is a hole in this anode. So, electron will pass through it, when it will pass through it. So, when electrodes are reach here. So, if energy will be e V 1 and when is coming in this region with e V 1 energy. So, it will reach to the collector, if this V 2 is basically retarded potential ok.

So, what will happen? This electron will reach here if e v 2 is less than e v 1 this is retarded potential it will. So, whatever electron is coming with this energy. So, it will be repelled by this plate, but it can overcome if this energy is higher than this or V 2 is less than V1. So, generally this retarded potential is kept smaller than this V 1. So, now,. So, electron will reach here. So, electron is coming here. So, it will circulates. So, you will get current.

Now, if I plot this current, current I an if I change the voltage V 1 keeping, V 2 fixed smaller value then the V 1. Now if I change this V 1 so that we can change here. So, this current if I note down the current and plot it. So, Franck and hertz they are getting like curve like this like this, it will move away. So, I think this I can make I can slightly smaller. So, this way. So, some peak here you can say peak it is not peak, currently voltage is increasing current is increasing more and more electron are reaching there.

So, then it is reaching at the highest value, then suddenly drop current suddenly drop from peak value to this smaller value, and then again if we continue to increase this one voltage says them unit is increasing increasing physic then in atom another voltage suddenly drops. So, why drops. So, basically here what happens this mercury initially any gas can be taken, but in the original experiment mercury gas was taken mercury gas ok.

So; that means, mercury atoms are they are and in low pressure mercury gas was taken. So, mercury atoms are there what happen. So, electrons are moving and they collide with mercury atoms, but since mercury is very heavy, mercury atoms of heavy mass is very heavy. So, there was the elastic collision and without losing energy they used to they can move and these to the plate.

Now, at a particular voltage V 1 say. So, this energy when E 1 equal to e V 1. So, then suddenly current graphs. So, these value was seen that it was 4.9 electron volt and then again it was the second drops m it was I think 6.7 most probably 6.7 electron volt it was it can 6.7 electron volt ok.

So, these are peaks was coming. So, then it was why it happens? And then simultaneously this spectrum of this helium gas was also studied and found that and exactly corresponding this wavelength corresponding this energy its found in that in the spectra lines of the mercury gas ok.

So, what happens? So, when electrons are moving there is a elastic collision, but when the energy of this electron is close to the energy left close to the separation of the energy level of mercury, then this mercury atoms it absorbs this energy, it can absorb fully or partly then this electron will lose the energy. So, if energy whatever they observe it observe that is separation of the energy level. So, the energy of the electron it will be the less by that amount say it was energy separation was E ok.

Now, this energy of the electron it will be reduced by this amount. So, now, this energy it will be less than the retarded potential energy e v 2, and that electron cannot reach here cannot reach here that is why this return potential is used. |It may have some energy after after losing this energy. So, if this retarded potential is not there it could reach there ok.

So, this now this energy of this electron after this partly transferred to the mercury atom, now that energy is less than the retarded produce energy and it cannot reach to the collector or plate and thus it is just suddenly decreased. So, again if you increase this energy, it is going to the this to the second level . So, from this experiment it is. So, one can think of energy level in the mercury atom, and the separation of this energy level it is 6 point 4.9 electron volt, separation of this energy level with respect to the ground state that is 6 5 7.

So, similarly other energy level one can find out. So, these the direct proof of the existence of the discrete energy level in atom. So, the Franck hertz experiment is very simple it is very simple, but this gives first direct evidence of the discreteness of the energy level in atom. So, I will stop here.

Thank you.