hello in the last class we discussed the about the particle nature of light we also saw how using redwoods formula we can discuss the emission spectrum of hydrogen atom but we saw that redbucks formula was was was a nice construct to re which reproduced the emission spectrum of hydrogen atom but it did not give us any physical insight this was answered or this physical insight was given by niels bohr and this is what we are going to do today we will learn about the physical interpretation behind the hydrogen atom emission spectrum that was given by niels bohr next ah we are going to discuss bohr's model nils bohr the famous danish scientist suggested ah a new model for the atom which we call as a spores model before that we let us refresh our memory as to what we know

so far we know that ah up to now the most advanced model of atom was given by rather ford

so let us refresh our right ah memory about rather force atomic model rutherford suggested that every atom has a central core part which is nucleus nucleus contains all the positively charged particles proton it also contains ah the mass that is that is coming because of proton and neutron and the electrons go around the nucleus in some circular paths now electron is negatively charged which is going around in circular path around the nucleus which is positively charged but rather force atomic model had a problem the problem is that maxwell's theory suggested that if you have a charged particle and another charge particle is going around the former charge particle in a circular path actually when the when a particle is going around a circular path even if it is going into the fixed velocity since at every point in this circular path it is changing its direction it this particle is said to be in constant acceleration it is always changing the direction of its ah motion

so therefore it is under constant acceleration

so when an accelerating charge particle goes around in a circular path around another charged particle maxwell's theory suggested that this particle should follow a spiral path something like this and in no time should collapse on to the uh other charge which is around which this particle was orbiting

so that means what rather force atomic model should have led to this situation where electron goes in a spiral path and collapses onto the nucleus therefore the atom should not exist

so druther force atomic model could not explain the stability of atom the stability of wa atom this reason why the atom is stable could not be described by rather port rather force atomic model this we should keep it in mind when we discuss ah bohr's model all right

so starting from this discussion bohr ah suggested that ok let us think about it what is the problem the problem here is that this electron which is going around this ah fixed path it is emitting its energy and therefore it is undergoing this spiral ah path and that it is called it should collapse on the nucleus

so bohr suggested a few postulates through which we will study this atomic model postulates of bore bore first suggested that the electron moves around the nucleus in what he called fixed paths he called them orbits these fixed paths have constant energy or a fixed value of energy and we call them as stationary state

so what nilsport did was he said that this ah the electron goes around the nucleus in circular path but these paths are fixed they have a fixed radius and they have the electron as long as it goes around the circular path or the orbit it has the same energy it has a constant energy and we call this state of electron as a stationary state

so what niels bohr has proposed is something like this he said that nucleus is at the center the electron goes around the nucleus in concentric circles

so there you can see there are many concentric circles
so these are fixed orbits each orbit has certain energy and electron can choose to either stay in this orbit or in this orbit or in this orbit
so but as long as the electron is in a particular orbit it has a fixed energy it has a constant energy and since it has a constant energy the collapse of electron on to the nucleus that was arising in rather force atomic model disappeared because of this this definition that nil were postulated then again he said that all right electron goes around the nucleus in a particular orbit but it can also change its orbit when it does
so he said that electron moves from one orbit to another or one stationary state to another and how does the electron do that it does that by observing or emitting radiation or emitting energy
so he said that okay electron let us say electron is here it can go to the next orbit the next orbit will have has he said that the high higher orbits the orbits farther from the nucleus will have higher and higher energy
so if the electron is here let us call the energy of this orbit as e one ah the energy of this orbit let us call e two and the energy of this orbit let us call e three
so the electron can be in this orbit or this orbit or this orbit if it is in this orbit its energy is e one if because that is the energy of the stationary state one the energy of the stationary state two we call it e two and if the energy electron is in this orbit its energy is e two
so electron can move from this orbit to this orbit or this orbit to this orbit or even this orbit to this orbit but it can do
so by absorbing or emitting energy
so if it is going from a lower energy to a higher energy stationary state let us say e from e one to e two it requires additional energy
so therefore it has to observe energy from somewhere to go from e one to e two and if you want to come back from e two to e one it has got this extra energy which it can emit
so and then it can come back to ah the lower energy orbit e1 right
so this is what he suggested in the second postulate in the third postulate he said that what what is the value of this energy that it has the electron has to observe or emit
so let us say that the electron is going from two to one or second stationary state to the first stationary state the first stationary state we also call that as the ground state this is where the electron would like to stay unless you excite uh the the system
so 2 to 1 if we say the emission from stationary state two to stationary state one the energy difference between the two states are e two e two minus e one which let us call a fixed ah a number that is delta e if this is the energy difference between the two states
so if the electron is coming from stationary state 2 to stationary state 1 this much energy it will emit when it emits this much energy we know that the energy is has equivalence with the radiation or in terms of its frequency this was given by max planck
so we said that if there is an energy e it is associated with a radiation the radiation will have frequency nu
so this is what niels bohr suggested that if the electron is coming from e2 to e1 it will emit radiation of frequency nu such that h nu is delta e right
so if we know h nu we can of co if we know nu which is now e 2 minus e 1 divided by h that is delta e by h we can also get lambda which is nothing but c divided by nu the frequency
so we can write lambda as hc divided by e2 minus e1 we can also ah use nu bar

because that is what we have been using that can be written down as e 2 minus u 1 divided by h c
so it does not matter i mean we can express the radiations either in terms of its frequency or its in terms of its wavelength or in terms of its wave number these are the three postulates there is one more postulate we will discuss next we are discussing ah boards model let us discuss ah the fourth postulate nelsport suggested okay ah the electron goes around this circular path with a certain ah with each orbit has a certain amount of energy e one e two e three ah but what is the value of this radius what is the value of the radius of these orbits can ah the electron choose any radius that it it wants or is there a restriction niels bohr imposed a restriction on them he suggested that only those orbits are allowed where angular momentum angular momentum of the orbiting electron which is given as mvr is a constant or let us i am let us discuss what is what this angular momentum is if i have a ah particle of mass m and it is moving with a speed v then i know that its momentum is given by p ah momentum p is given by mass multiplied by its velocity if the same particle instead of going in a linear path it goes in a circular path ah with around a circle with radius r where its tangential the particles mass is m the tangential velocity is v then this particle which is going in this circular path has got an angular momentum which is given as m v r
so the mass of the particle the tangential speed and the radius of the circle ah around which the particle is moving
so this is angular momentum that is given
so nilsbar suggested that not all orbits are allowed only those orbits are allowed which have certain value will come to the right hand side now
so mvr which is the angular momentum has certain value if you look at this right hand side terms we have n we suggested n can be one two three and
so on again numbers h is the famous famous planck constant pi is a constant
so we see that the angular momentum is essentially a constant but this constant the value of this constant depends on the value of n
so mvr the angular momentum of the orbiting electron can either be h by two pi or two h by two pi or three h by two pi or
so on
so forth
so niels boss suggested that you the electron cannot make any radius it wishes it is restricted by the fact that it has to find a certain radius such that the small product of mass velocity and the radius of that circle is either s by 2 pi 2 h by 2 pi 3 s by 2 pi the angular momentum in the first stationary state or the ground stationary state is h by 2 pi the second stationary state is 2 h by 2 pi the third stationary state is 3 h by 2 pi this is how the the postulates of bohr's atomic models were formulated starting from these postulates nilspor solved the problem of hydrogen atom ah his essential assumption is that ah this method of the solution method that was adopted by niels bohr to solve hydrogen atom ah insisted that the system should have single electron
so one electron it can have many protons in the nucleus but it should have maximum one electron which is going around in the circular orbits the four ah postulates of bohr were starting from the postulates that both formulated the four postulates that we just discussed was solved the problem of hydrogen atom the essential assumption in his solution was that this that solution was applicable to any system which has got one electron it could have more any number of protons
so it had one nucleus with certain charge
so certain number of protons around which one electron is orbiting as long as this is ah this is this is given the bohr's atomic model could be used to solve

the atomic spectrum of any other atom using this we would now go through the results of bohr's atomic model we will not discuss how they were obtained rather we will see the essential results that were coming out from bohr's atomic model and we will try to appreciate how these results could explain the very complicated hydrogen atom emission spectrum next we discuss the results obtained from bohr's atomic model first key factor is that nils boats ah assumed that there is a ah this is the bohr's atomic models uh picture that first thing is that there are several orbits the orbits let us these are some ground rules the orbits are numbered one two three
so on
so forth n goes from one two three four will uh understa will soon understand the physical significance of uh this this n but at the moment let us use it as a book keeping exercise where n is an in the index which indicates the or orbits one two three and
so on
so using bohr's atomic model board could find out what is the radius of any orbit
so his the expression that he got for radius of the in f of any orbit that was given by rn he found it out as 0.
529 multiplied by n square divided by z and this is given no in the unit of angstrom if you look at this expression you have a number 0.
529 this number has the unit of angstrom because the remaining term this is n which is the ah index here it can be 1 2 3 this is a number and z is the atomic number of the nucleus
so results from bohr's model these are applicable applicable to all single electronic species what are the single electronic species of course once one we know is hydrogen atom that has got single electron but who else can have single electron ah helium has two electrons but if i we ionize one electron we remove one electron then it becomes single electronic species h e plus we can take lithium and ionize two electrons then that also becomes single electronic species
so we can use bohr's atomic model for hydrogen or helium plus or lithium two plus and
so on
so forth only difference is that the z value the atomic number of hydrogen is one helium is two lithium is three and
so on
so forth
so we have to keep this in our mind if we use look at the expression for the radius of this orbit we see that for hydrogen atoms z is one
so it is essentially zero point five two nine multiplied by n square angstrom in in the unit of angstrom
so what is the radius of the first orbit that is n is one
so therefore the value is 0.
529 angstrom what is the value of r 2 i'll put n as n n is 2
so therefore n square is 4 4 multiplied by five two nine angstrom and that comes out to be two point one two angstrom what is the value of three ah radius of ah third orbit this comes out to be four point seven six angstrom if you use n n as 3
so n square is 9 9 multiplied by 0.
529 in this way we can calculate the orbit of ah the radius of the bose orbit for hydrogen atom these are all for hydrogen atom because we have used z as 1 if we use z as 2 then we will get the radius of the orbit for helium plus right what is the final value of what is the maximum value of n n can be anything it

can be as large as as large as you want but when is when n is very large you see the radius goes as n square
so therefore the radius becomes infinite
so therefore bohr's atomic model said that electron has or electron can if it chooses if it can take that much of energy then it can choose to go to a very high value of n in that case it will be extremely up far away from the nucleus as far as when r goes to the distance between them goes to infinite all right
so next we will discuss some more results from bohr's atomic model
so we saw that a bohr's atomic model could ah explain or could give analytical expression for the radius of these orbits we can also use bohr's atomic model ah to get the speed of electron in orbit n in any orbit this expression is given as v n that the speed of the electron in the orbit n is two point one eight into ten to the power six z divided by n meters per second again z is a number n is a number
so this they they do not have any unit
so the unit that we see here meter per second is coming from this term if you want to convert this unit to any other unit of your choice you can simply ah change this number in the new unit and it it works we can write down the speed of the electron in the first orbit if you see for hydrogen atom z is one
so for first orbit n is again one
so the speed of electron in the first orbit is essentially two in 2.
18 into 10 to the power 6 meter per second speed of the electron in the second orbit is when z is 1 because we are still in hydrogen atom n is 2
so it will you will get it at 1.
09 into 10 to the power 6 meter per second and
so on
so forth you can see v3 0.
72 into 10 to the power 6 meter per second what you see here is that first of all the speed of electron is somewhat closer close to the speed of light speed of light is 3 into 10 to the power 8 meter per second
so it is only 2 orders of magnitude less than the speed of light
so it is quite high high speed but we also see that as we go further and further from the nucleus the speed of this elect the elect the speed of the electron keeps decreasing we saw the radius of an orbit we saw the speed of the electron in an in a given orbit next we discuss the energy that we said e1 e2 e3 the energy of an electron when it is orbiting one particular orbit next is energy of orbit n or stationary state n this is the worst atomic model that we have from bohr's atomic model the solution of boars atomic model suggested that e n the value of energy in the nth orbit is minus 2.
18 into 10 to the power minus 18 z square divided by n square and this is given in the units of joules you see this this number again z is a constant for hydrogen it is 1 n is a number which goes from 1 to 3 4
so on
so forth
so the unit that is coming here is coming because of this number if you want to change this unit from joules to any other unit you can play with this number ah we discussed earlier that this is not a very convenient unit to deal with because it always has 10 to the power minus 18.

so i would convert it to the better unit more convenient unit that is electron volt when i do that i get this expression and this is now in the units of electron fault right if you do a bit a small exercise and find out the value of read burst constant we know that that is 1 0 9 seven seven centimeter inverse please convert this number to the units of joule or to the unit of electron volt

and you would see that this corresponds to thirteen point six electron volt this corresponds to 2.
18 into 10 to the power minus 18 joule
so what we have now here as the solution for bohr's atomic model the energy for the bo in the bohr's atomic model is essentially the read box constant multiplied by z square divided by n square all right we will write down the energy of few orbits the first stationary state e one its energy is given when i use ah n is 1 z is again 1 because it is hydrogen atom
so the energy is minus 13.
6 electron volt the energy of the second stationary state is obtained when n is 2 z is again 1
so this number comes out to be minus
so essentially minus 13.
6 divided by 4 electron volt which is minus 3.
4 electron volt e3 the energy of the third orbit is minus 13.
6 divided by 9 which is minus 1.
51 electron volt and
so on
so forth if i go for a very large value of n and n is very large in that case you see the energy decreases as n square
so very soon when n is very large e n goes to 0.
one interesting thing that you see is that the energy of these stationary states are all negative and it approaches to 0 when n goes infinite n tends to go to infinite what is this negative energy mean the negative energy means that electron which is orbiting around the nucleus is stabilized by the nucleus
so the electron is happy in this nucleus that is that that is reflected by this negative value of energy which is which refers to stability
so the atom is stable which is reflected by the fact that energy of the electron is coming out to be in minus in negative numbers
so minus 13.
6 electron volt of energy in the stationary state means that if you want to bring out the electron from the first stationary state or the ground state of hydrogen atom you must supply an energy of 13.
6 electron volt if the electron is in second stationary state then you must supply the energy of 3.
4 electron volt to bring out this energy
so this energy that we are getting e1 e2 e3 that essentially the binding energy of the electron to the nucleus
so electron is bound to the nucleus by an energy of 13.
6 electron volt and if you want to take it out you must supply that much of energy and the negative number as i said refers to the stability of the atom and we see that as n goes higher and higher n goes to very large number then the energy is goes to zero and what does that mean that means that when n is n is very large if you remember the expression for rn rn goes to infinity that means the distance between the nucleus and electron is is very high and the energy of the electron is is nearly zero
so this is a state where we call it its a free electron
so the electron has completely escaped the field of nucleus and it is moving freely it does not it has no uh connection with the elect with the nucleus anymore and we call that a free electron
so the at the nucleus is called to be ionized that the electron has completely left the sphere of influence of the nucleus
so far we have discussed the postulates of bohr's atomic model and the results of pores atomic model we saw from bohr's atomic model we could get an analytical

expression for the radius of the different orbits we could get an analytical expression of the velocity of the electron at the speed of the electron when it is occup it is in a particular orbit and we also could get the energy of a given stationary state or an orbit but we started with the this fact that bohr's atomic model was necessary to describe the hydrogen atoms emission spectrum and now we will see that how bohr's atomic model could explain the hydrogen atoms at emission spectrum

so we saw that the energy of the stationary state nth stationary state is given as rh which is the read box constant multiplied by z square divided by n square for emission we know that from both atomic model if we are discussing an emission spectrum

so that means the electron is going coming from a higher orbit higher energy orbit to a lower energy orbit

so let us say that electron is going coming from n2 to n1 where n2 is greater than n1 in that case the energy of n 2 the higher energy orbit is given as the energy of the stationary state to which the electron is going is given here the difference in energy delta e which is e n 2 minus e n 1 is given as i can ah re write this equation in the following manner this is the delta e that we get where n two is greater than n one if you if you remember the expression that ah reid bugs reedberg gave to explain the the hydrogen atomic spectrum is now reproduced by bohr's atomic model reedback proposed that equation purely on the basis purely for the sake of explaining the numbers that were coming however niels bohr's atomic model could reproduce the same equation starting from a set of postulates a set of fundamental rules and therefore thereby he developed a theory within which one can explain this the height the emission spectrum of hydrogen atom this is what we will ah do next now what i am showing you here is that the energy levels of different stationary states of boards are coming out from bohr's atomic model

so this is the ground stationary state

so n is 1 n is 2 n is 3 n is 4 n is 5 and

so on

so forth now if i am talking about emission spectrum

so my electron is always in the excitatory state

so the electron if it is in two state two then it can come down to one thats one emission

so what will be the emission radiation coming out of this emission process the radiation corresponding to the energy that is minus 3.
4 minus minus 13.
6 electron volt this energy difference corresponds to a particular ah frequency and that will be the frequency of the light that comes out when the when the electron jumps from second orbit to first orbit and if electron comes from third orbit to first orbit it gives our emits another radiation and similarly it can we can go on ah doing this

so in this in this four lines you will see that the initial state can be 2 3 4 or 5 but it is always coming down to the state n equals 1.

this if you calculate from these numbers where is what we know as lyman series the similar way we can also say that if electron is to begin with electron was in the third state and it comes back to second state or it could come from four to two second state or fifth state to second state or sixth state to second state these are all these lines they all represent bomber series and similarly now this is ah straightforward

so if the x emission is from three or four to three or five to three or six to three or

so on

so forth we call them posture series
so this way cornell sport suggested that these are different energy levels the electron can stay either in this energy level this energy level this or this or this depending on how much of energy you have provided if it wants to come from a higher energy level to a lower energy level it emits radiation this is what we do and we are getting emission spectrum and when if it wants to go from a lower energy level to higher energy level it must absorb energy that will give rise to the absorption spectrum now since we are talking about this emission spectrum you would see that you do not see emission line at every energy every possible energy values actually what you see emission is that at certain energy values for example this line will come out minus three point four minus minus thirteen point six this line will come out the second line this one will come out the energy minus 1.
5 minus minus 13.
6 electron volt but in between these two numbers there will be no line
so this explains why we get series of lines separated from each other in the hydrogen atoms emission spectrum but then what happened what about those bands that we are seeing the bands come because you see as you go higher and higher in energy this n equals 6 7 8 and 9 and 10 their energy level they are very closely spaced
so the emission that are coming from those energy levels to energy level 1 at energy level 2 they will all be closely spaced they will have essentially same energy emission energy
so therefore they will appear in this almost the same num they will appear or they will give away the radiation of almost same wavelengths this is how nils bohr with his simple atomic model could explain the very complicated features of the emission ah spectrum of hydrogen atom we saw bohr's atomic model could explain the emission spectrum of hydrogen atom but there are several limitations to bohr's atomic model we will discuss the limitation limitations now the limitations of boards model one very important limitation is that this model is applicable only for single electronic species the you cannot use this ah bohr's atomic model to describe the emission spectrum of spectra of spectrum of helium atom or lithium atom or beryllium atom or any other atom this is not possible you can only do that either for hydrogen or helium plus or lithium plus two and
so on
so forth but nature is full of elements which are in the neutral state or which have more than one electron
so boards model could not explain ah multi electronic species that is a major limitation the other limitation of bohr's atomic model is that it could not explain the splitting of spectral line when the syst when the matter is under the influence of ah magnetic magnetic field or electric field what was seen is that you one could record the emission spectrum of of a particular any atom ah in normal condition and then they got emission spectrum but if you re record this emission spectrum by subjecting the matter to ah in the under the influence of magnetic field or electric field we saw that the spectral lines actually splitted you got many additional lines in addition to the lines that you were we have already seen and these were actually explained by zeeman effect that they are known as the man effect or when under the influence of electric field they are called stark effects
so bohr's atomic model could not ex explain siemens effect or stars stark effect this this is again another major limitation of boar's atomic model nils the third at limitation of bohr's atomic model is that we wanted an atomic model which will not only describe the structure of an atom which will also take us to the to describe the bonding in molecules but nils bohr's atomic model could not

describe chemical bond and that was another ah major limitation of bohr's atomic model we will see how the limitations of bohr's model could be overcome and what we can do to accurately describe uh that the more the atomic structure of hydrogen and other heavier atoms before we could venture into the accurate description of atomic structure we need to take a break and discuss a few other developments that were occurring in the field of science that changed our understanding of the matter foreign we will discuss two such major fundamental breakthroughs one of them the first one that we discuss is what we know what is known as debroise hypothesis de bruy it is written as broglie but he's a french scientist whose name is pronounced as bro de bruy and this d later is written in small case deep roy a young physicist french physicist in the year 1924 thought something very important he said ah that all right we have already established that light can have wave like nature or particle like nature the duality of light or duality of radiation was established because we saw that some features could not be explained by particle property of light and some other features could not be explained explained by the wave property of light

so therefore light is both wave and in a and a particle what the de broglie wanted to ask is that well if light or if radiation has both particle and wave like nature with radiation we initially thought is a wave then he said he asked this question that why cant particles or any particle or any matter have wave like nature that was a big question now wave heard light as a wave light heart wave like nature and particle in the nature now de bruy is suggesting that why not matter has both particle like nature and wave like nature

so far we always thought that matter had a particle like nature the electron or the or a cricket ball or the pen that we use they are all they all are particles but deep royce suggested that mata has a wave nature or in other words particle has a wave nature all right if it has a wave nature then wave is usually characterized by its wavelength or frequency then what is this wavelength he says he gave this relation he said that the matter has a wave nature and this wave has a wavelength of lambda which is given by h the famous planck's constant divided by the momentum of that particle momentum of that matter what is momentum we can all again rewrite this as h divided by m v where the m is the mass of the particle and v is the speed with which the particle is moving and this was a very important hypothesis when it was suggested it was suggested as a hypothesis because dick broy could not provide a proof to his hypothesis ah nor was there any experimental evidence but later on we got some experimental evidence that matter actually has wave like nature will come to that but let us explore a bit more about this very puzzling ah statement that matter matter has a wave like nature that means it it if it is extended that it would also mean that you and me as as massive bodies or the pen that i am holding or every everyday objects that we see they all have wave like nature

so if they have a wave like nature then what is the proof but before giving that proof let us first establish let us first take let us take let us try to find out the wavelength of an electron which is in the first bohr's orbit what do we need to know for that we need to know the mass of the electron which is 9. 1 into 10 to the power minus 31 kilogram which is already known ah the speed of the electron in the first orbit we discussed two point one eight into ten to the power ah six ah meter per a second if i know mass we know i know velocity then i actually know for using diplois hypothesis i can know what is the wavelength of this of this particle

so lambda is given as h by m v

so h i know which is six point six two six into ten to the power minus thirty four joules second divided by nine point one into ten to the power minus thirty one kilogram multiplied by two 2.

18 into 10 to the power 6 meter per second if you solve this you would get 0.
33 nanometer
so an electron when it is orbiting the first boards orbit or the ground state it emits it has a wave like nature which is given as the wavelength of 0.
33 nanometer all right but let us do another exercise let us say we have a an object whose mass is 100 gram and it is ah moving with a spread speed let us say 100 kilometer per hour if i want to calculate the wavelength correspond for this particle the debroise wavelength for this particle i have again the same ah equation ah h
so 100 mass is 100 gram
so i wrote it 0.
1 kilogram and the speed is 100 kilometer per hour which is coming out to be about 20.
7 27.
5 meter per second
so i am using all s i unit and if you solve it you would get this number an everyday object object with mass 100 gram has of course a wave like nature but its wavelength is 10 to the power minus 33 nanometer
so you can see debroise hypothesis although it sounds very puzzling that how can matter have a wave like nature but it is all right because for massive objects for the everyday objects that we encounter for them this wavelength is is negligible
so it is nearly a particle like it shows nearly particle like behavior but microscopic objects like electrons where mass is very small and their speed is quite high in those cases the wave like property of electron is is very significant depressed hypothesis is not merely a theoretical construct it has got major practical implications of course when de bruy proposed the hypothesis there was no experimental evidence to support his idea but later on there are experimental evidences available which suggests that matter actually has wave like nature for example electrons have wave like natures they have been experimentally demonstrated and their wavelengths have been calculated and they match well with the deprois relation using this concept that electron has wave like nature using this concept several equipments have been built for example the electron microscope which is in modern science is current routinely used to investigate very very small object at molecular level and this very interesting equipments are actually built on the fundamental concept that electrons have wave like nature today in today's class we discussed one very important milestone in the history of science that was depressed hypothesis we will continue our discussion and we will see another radical idea that change the face of science forever that will be heisenberg's uncertainty principle and this is what we are going to discuss in in our next next class thank you you