

so far we have seen the wave nature of light we discussed that we called light a wave because it showed diffraction it showed interference but we will also discuss now about the particle nature of light the next next topic of discussion is particle nature of light it was believed that light light access light is a wave but then there were some experiments which which could not be explained if you use the wave nature of light you needed to reinterpret your understanding about the light to be able to explain those experiments we will discuss two of those experiments they are very famous experiments the first experiment that the wave nature of light could not explain is known as the black body radiation will come to this black body part little later let us talk about radiation first whenever we see an object object with a with a color for example this pen that you see this is blue in color why do i see it as as blue the light the white light in this room they fall on this pen the material that this pen is made up of it has this property that it absorbs all the lights except for the light that corresponds to blue color the wavelength that corresponds to blue color this particular wavelength gets reflected since it gets reflected it reaches my eyes or it reaches your eyes and therefore you perceive it as as blue

so we see a color of this color of a body because that is the color that it reflects you also might have seen ah if you if you if you put an iron rod in a furnace you see that ah as you increase the temperature of the furnace the iron rod will get hotter and hotter ah to begin with it would appear when it becomes very hot it would appear slightly dull red ah somewhat maroon color and then you increase the temperature further it becomes bright red slowly it will become whitish in color and then eventually it becomes blue why do we see different colors at different temperatures it

so happens that when you heat a body it starts radiating and it starts radiating lights of all wavelengths but what happens is that at one temperature at every temperature it is actually radiating all wavelengths but at different temperature the intensity of one particular wavelength becomes higher for example when we are heating this iron rod at initial temperatures the intensity of the red light was higher than compared to the intensity of any other light that is why we saw this iron rod as red as we increase the temperature of the furnace further it's very very high temperature the intensity of the blue radiation was high was large that's why we saw this iron rod as blue a black body is an ideal body is is an idealized body which observes is an ideal body which observes radiations of all wavelengths and it also emits radiations of all wavelengths

so this is what black bodies it actually absorbs radiations of all wavelengths it emits object radiations of all wavelengths ok

so there is many black experiments on this black body

so let us let us draw a plot

so in my x axis i am drawing wavelength  $\lambda$  the y axis i am drawing intensity call that i

so which wavelength has how much of intensity that is the radiation ah that is the color of the radiation that we will see when one does this experiment ah one says that a plot like this appears what did what does this plot say that this this is an intensity versus wavelength plot this says that at this plot was obtained at a particular temperature let us call this temperature t one this plot tells that at temperature t one the intensity of light intensity of the radiation of wavelength  $\lambda$  is is this much this is the intensity as we increase the wavelength the radiation the intensity of this radiation increases it increases up to this point at a particular value of  $\lambda$  the intensity is highest let us call that as  $\lambda_{max}$  and it is at a temperature t one and

afterwards the intensity of this radiation  $\lambda_{max}$  keeps falling this is what was experimentally observed and when we see that when we say that a particular object appears red or blue or whichever color at a particular temperature that means the  $\lambda_{max}$  corresponding to that temperature is that particular color

so if the iron rod is red that means  $\lambda_{max}$  corresponds to the wavelength of red color at that particular temperature when you heat the substance further so when you monitor the black body radiation at a higher temperature  $\lambda_{max}$  this is what the plot looks like like this

so you see again the same story the intensity of the wave intensity increases as the wavelength increases until one point that again we call it  $\lambda_{max}$  but this  $\lambda_{max}$  is at a different temperature and then again the intensity falls all right

so you see that this is the curve that I am getting at temperature  $T_2$  which is higher  $T_2$  is greater than  $T_1$  right

so at a higher temperature I can see a different color because my  $\lambda_{max}$  is different  $\lambda_{max}$  corresponds to one particular color all right

so this is what experiments showed if you use the wave nature of light and do a calculation without doing this experiment and try to explain the experimental result this is what one obtained this I am drawing in the blue color this is what one was obtaining this is the result from wave theory of light if you use the wave theory of light this is what your theoretical calculation gave you know it is very interesting it is very important to do this theoretical calculations because every theoretical calculation invokes a certain amount of understanding it proposes a theory it builds a fundamental hypothesis on the basis of which it explains its results if that result does not match with accurately carried out experiment it means that the hypothesis or the underlying assumption in the theory is perhaps wrong

so therefore that requires a revisit

so this is what the wave theory of light gave us as described which is which which agrees well at higher higher wavelength but at lower wavelength or higher frequency the agreement is extremely poor you can see that it could not tell it could not correctly predict the intensity of the radiation of this wavelengths in this region right

so this was a major problem how did it get resolved it was it got resolved by the work of a German scientist Max Planck what did he suggest he said that well this black bodies are emitting radiation he assumed he took he made this assumption that let us say that molecules all molecules they absorb or they emit radiations but they do

so in a particular way they observe or emit these radiations as packets of energy in the wave theory it said that when the light falls on the on a body or the when the body radiates light it is a wave and it gets propagated but Max Planck invoked one assumption that absorption or emission of radiation occurs as packets of energy there are discrete they are quantized packets and these packets he called this packets he called as one packet is called quantum and the plural is quanta

so he said that molecules absorb or emit radiations as as as a spontaneous all right

so what is if this is some packet what is the energy of that packet the energy of associated with that packet remember this is a radiation it is it has a certain frequency it has a certain wavelength the energy associated with this radiation he said  $E = h\nu$  depends on one constant that is  $h$  and the frequency of that radiation he gave this famous equation  $E = h\nu$  where  $\nu$  is the frequency of radiation and energy  $E$  is the energy associated with this frequency where this  $h$  is actually a proportionality constant that is known as Planck's constant it has

got a fixed value which is  $6.626 \times 10^{-34}$  joule a second when planck invoked these two

uh postulates these two hypotheses he then reworked redid the theoretical exercise and his calculations show his calculations correctly reproduce the reproduce the experimental results this way max planck suggested or proved that indeed molecules observe and emit radiations as packets of energy because this hypothesis could explain the experimental results all right we will take one ah example let us say we have a wave we have a radiation whose wavelength is 5000 angstrom which is  $5 \times 10^{-7}$  meter all right now let us find out what is the energy associated with this radiation we know energy is  $e$  is given as by  $h \nu$  from planck's theory  $h$  is a known constant  $\nu$  is the frequency but what i have is  $\lambda$  but i know how  $\nu$  is related to  $\lambda$  that is  $c$  by  $\lambda$

so now now i have everything  $h$  is a constant  $6.626 \times 10^{-34}$  joule second multiplied by  $c$  which is  $3 \times 10^8$  meter second inverse divided by the wavelength which is  $5 \times 10^{-7}$  meter if you take this number six point six two six multiply it with three and divide it by five i got it as three point nine seven into ten to the power the powers will collect now is minus thirty four this is uh plus eight this is minus seven when minus 7 goes up it becomes plus 7

so it is plus 15 minus 34 it is  $10^{-19}$ .

what is the unit meter meter they cancel out second inverse second they cancel out i am left with this unit

so the energy associated with where the radiation 5000 angstrom is  $3.97 \times 10^{-19}$  joules which is actually a very small amount of energy

so the number has  $10^{-19}$  right and this unit actually is not a very convenient unit to use because you have to always tell  $10^{-19}$  unit we convert this unit will use a new unit which is called as electron volt it is written as small  $e$  capital  $v$  electron  $v$  for volt one  $e v$  is one point six into ten to the power minus nineteen joule now if you try to convert this energy which is three point nine seven to ten to power minus nineteen joule 2 to electron volt unit you would get energy as 3.

$3.97 \times 10^{-19}$  divided by  $1.6 \times 10^{-19}$

$6 \times 10^{-19}$  the unit is in electron fault and it comes about to comes out to be four point two point four eight electron fault and you can see this number is easier to handle

so often in these ah calculations on in this field of study one uses this electron volt unit for the convenience that i just established we saw how we needed to invoke the particle nature of light to be able to describe the black body radiation problem the other problem the other experimental problem that required the invocation of particle nature of light is the famous photoelectric effect what is this photoelectric effect the experiment was carried out by heinrich hertz ah this is here i am showing the experimental setup what you see here is a vacuum chamber this is a vacuum chamber here it has been fitted with one metal surface its a it is a metal surface you can take ah any metal and the other side is again a metal detector these two met this metal surface and the metal detector are are connected ah through each other ah by a potential difference

so here is a battery that you see this is the positive terminal this is the negative terminal let me write write that down positive terminal is the detector negative terminal is the metal surface this is the battery and here i have got one ammeter ah let us put a needle ah in this emitter

so when there is a current flowing through the circuit the ammeter will show

how much of current this is the experimental setup what they did what heinrich hertz did was to shine radiation onto this metal surface when it did that when electromagnetic radiation fell on ah the metal surface some interesting observations he made first thing he saw is instant ejection of electrons

so what he saw when light fell on this metal surface he saw that electrons came out of this metal surface and they started going along this direction you see electrons are negatively charged particle and here is a positive ah terminal so the electrons will go this way that is why we have kept this particular polarity

so what we saw is that ah when the light fell on this metal surface instant ejection this word instead plays an important role in this discussion instant ejection of ah electrons from this metal surface was seen how did he say that because when electrons pass come from this side to this side the ammeter actually shows that current is flowing

so that's how he got that instant current flows does the other thing is what he observed is that he changed the frequency

so this he's sending shining the radiation he played a bit with the frequency of the radiation what he did what he saw is that he started with very low frequency and then he saw there was no electron coming out then increase the frequency slowly and then he saw that electron ejection the ejection of electron ah starts only when only when ah the frequency is greater than a certain value of frequency let us call that  $\nu_0$  and he call that as a threshold frequency only when the frequency of radiation is above  $\nu_0$  that the threshold frequency he could see the ejection of photo electron the photoelectrons are essentially the instant ejection of electrons from the metal surface upon shining of irradiation all right

so this is what he saw by changing the frequency the other thing that he observed is that when increased frequency of course after a certain value of frequency the photoelectrons are coming out but when he increased the frequency even further he saw that these electrons which are coming out of this ah photoelectron they start moving faster and faster

so the kinetic energy of electrons the kinetic energy of the ejected electrons increases with ah frequency with increasing frequency

so as you increase the frequency it it ah the kinetic energy of the ejected electron increases but the current does not change for a given value when you when you change the frequency for a given intensity the current value does not change that means number of electrons coming out remains the same but the kinetic energy of these electrons are faster then he did something else he said ok let us fix the intensity at a particular value and that particular value he chose as greater than threshold frequency and let us play with the intensity of the radiation

so he first he took a particular value of frequency and he started shining the radiation of low intensity that frequency light then increase the intensity of the light without changing the frequency and then he observed the following what he saw is that it does not matter what is the intensity of the radiation as long as the frequency is greater than threshold frequency  $\nu_0$  he always saw the ejection of photoelectron even low intense radiation could eject photoelectron right but what he saw by increasing the number of increasing the intensity what he observed is that number of electrons number of photoelectrons photoelectrons ejected from the metal surface increases with with intensity as you increase intensity the number of photoelectrons that are coming out increases but their kinetic energy does not ah change they come out more in more number but they all travel in the same speed kinetic energy is unchanged these are the observations that heinrich hertz experiment showed now after at that point of time if you use

the idea that light is a wave the energy of that light was believed to be coming from the intensity if light is a wave it could not be explained that why instant ejection of electrons occur because if it is a wave it gets it hits the surface it has it gets transmitted and then it does its action

so there has to be a time lag but in this experiment there was no time lag it happened instantly as if it was showing as if light was not a wave but it's actually a bullet which comes hits the surface kicks out the electron instantly

so it was already indicating that wave nature of light is inadequate to describe photoelectron ah photoelectric effect the second thing is that intensity was as i said was believed to be uh the form of energy

so higher intense light was believed to have higher energy if that were the case conservation of energy would have suggested that if you shine high intense light which has now high energy according to that belief it will come and kick out the electron to kick out the electron of course you have to give some energy because the electron is bound to the metal

so to kick kick out that electron you have to pay some amount of energy the remaining amount of energy will be reflected as the kinetic energy of that electron

so if you give high intense light that should have shown that the electrons are actually moving ah coming out and they are moving much faster because they have now got more kinetic energy but that is what that was not what observed in these experiments on the contrary what was observed is that when you increase the frequency the kinetic energy of this ejected electrons increased this indicated that ah the place or uh the the frequency is the quantity which carries the energy of the light okay

so this is these are the indications that were coming out of this photoelectric experiment and it was successfully explained by ah albert einstein by making the following hypothesis we will discuss what i what einstein did to describe ah this ah effect all right einstein said ok ah this is what we have we have to solve this instant ejection of electron

so he assumed that let us assume that light contains a beam of particles light is not a wave he said no light is not a wave rather light contains a beam of particles it is a series of bullets that are coming and he called them as photons one for one is photon the plural is photons its exactly this in similar language that max planck said and he called it quantum einstein now calls it photon and he said okay this is the photon the light contains a beam of particles which are photon and each photon carries the an energy the energy of this photon is again following ah it came out to be the same as max planck's he said that the energy of this photon which is a which has which has a certain frequency because it is a radiation the energy of this photon is given by equals  $h \nu$  where  $h$  is the planck's constant and  $\nu$  is the frequency of this light that is coming then he said ok how about intensity the intensity of a light does not reflect its energy rather it reflects number of photons in the slide

so light the frequency corresponded to the energy of the light the intensity corresponded to the number of photons of each and each photon carried the same an energy e number of photons in that light present is given by the intensity this is what is his absorption with these three assumptions he could explain everything now why did you why do we see instant ejection of electrons because light contains a beam of particles

so the its it works like a bullet the light comes as a bullet as a as a particle it hits the metal surface kicks out the electron and it happens instantly there is no problem

so this problem this observation could be explained the second observation can be explained if we say the energy frequency corresponds to energy

so now it said that okay that makes sense because at a lower frequency we could not see the photoelectron coming out it required a threshold value of frequency so beyond that frequency that means beyond that energy all radiations of higher frequency can do this photoelectron can eject photoelectrons because they have sufficient energy to do it because you need to give a certain threshold value of energy to the metal to be able to remove that electron because the electron is bound to the metal you have to give that energy we'll come to that and then again when he said that okay you keep on increasing the frequency

so what happens there is a conservation of energy

so this is what is the next the conservation of energy he said  $h\nu$  is your  $h\nu_0$  plus  $\frac{1}{2}mv^2$   $\nu$  is the frequency of the light that is getting radiated the energy correspond to corresponding to that light is  $e\nu_0$  is the threshold frequency starting from which you see photoelectrons

so this is the energy that you have to give to the metal in order to be able to take that electron out

so this is the binding energy of that electron through the metal

so this is called as  $\phi$  given as  $\phi$  and called as work function different metals have different work functions because you need to pay different amount of energy to remove their electrons and the remaining amount of energy

so the radiation brought energy  $e$  and it had to pay  $\phi$  or  $h\nu_0$  as the work function of that metal that is the minimum energy that you have to have to be able to eject the electron the remaining energy is reflected as the kinetic energy  $\frac{1}{2}mv^2$  of these ejected electrons

so when you increase the frequency here the kinetic energy increases of course when you increase the frequency this is a constant for a given metal

so the remaining amount of energy that is  $h\nu - h\nu_0$  is reflected as  $\frac{1}{2}mv^2$

so mass is  $m$  a constant for electron

so that the remaining term is  $v$

so the speed increases and what happens to the intensity story his the experiment showed that when you have more intensity with increasing intensity you have the same kinetic energy but more and more photoelectrons come out that is that also can be explained by this hypothesis that intensity corresponds to number of photons in light when you have when you are using a higher high intense radiation you essentially essentially are sending more and more photons of that energy and since more and more photons are coming each photon now is a particle each photon comes hits the surface kicks out one electron

so you have more and more number of photons

so you can see ejection of more and more number of electrons for this from this metal surface

so in this way einstein could explain the photoelectric effect but to be able to do that he had to invoke the the particle nature of light

so we saw light had particle nature from photoelectric effect from blackbody radiation but light also had wave like nature because it shows diffraction it shows interference

so at the end of the story it was it was very difficult for scientists to believe at that time that point of time but this is now well established that light possesses dual behavior it shows wave like nature it shows particle like nature depending on the experiment that we are carrying out

so far we have seen that there are two sets of experiments namely the black body radiation experiments and the photoelectric effect of experiments these two experiments showed some results which could not be explained with the wave theory of light that required in case of black body radiation the effort of max planck and in case of photoelectric effects the efforts of albert einstein these

two scientists they invoked the particle nature of light and could explain the experimental results that were coming out from black body radiations and photoelectric effect now we will discuss another set of experiments which could not be explained by using the wave theory of light this sets of this set of experiments are called we will call them they are from atomic spectra the atomic spectra that were obtained for various atoms they showed some results we will discuss those results which could not be discussed or which could not be described in terms of the wave theory of light before we go to the atomic spectra and how they were

so difficult to be described let us discuss what is this spectra how does one get them these atomic spectra they are obtained from these sets of experiment that are called spectroscopy it is a very useful branch of science using which one obtains the structural information about matter this branch of science essentially deals with the introduction of radiation with matter ah by matter i mean it could be atoms molecules ions

so it says how light interacts with these matters and from there how what in structural information can we obtain about the matter that we are studying and from the structural information of course we can go and discuss about their property

so therefore spectroscopy is a very important branch of science let us begin our discussion by the electromagnetic spectrum that we already have seen if you remember ah electromagnetic spectrum consists of ah a series of electromagnetic radiations uh that differ those differ in terms of their frequencies in this case we discussed ah already that the frequency range from  $10^0$  to the power 24 to  $10^{24}$  and the wave numbers correspondingly change if you remember we also discussed about this important region that is the visible spectrum these are the wave numbers these are the wavelengths that our eyes can perceive we call them visible spectrum they range from 400 to 750 nanometers and you can see a continuous series of colors starting from violet indigo blue green yellow orange red you see a continuous spectrum of colors in between 400 to 750 nanometers and they constitute the

so called visible spectrum we also discussed that electromagnetic radiation that they do not require a medium to travel in vacuum all electromagnetic radiations travel with the same speed that is the speed of light which is  $3 \times 10^8$  meter per second however when these electromagnetic radiation are passed through a medium they show different speeds they show different ah they show different speeds uh with respect to their wavelengths different wavelengths behave differently in different media you might be you might have done this experiment ah as a hobby experiment when we pass sunlight just ordinary white light through a prism the prism actually splits the white light into the seven continuous colors that you can see here the rainbow colors starting from violet till till red we we the incident radiation was white light the prism converted this white light into series of this visible colours why did that happen because when the when the radiation passes goes through the prism the prism offers a different medium in this medium different wavelengths that is the blue wavelength gray green well length yellow orange red these different wavelengths they get deflected from their original path by a different magnitude the lower wavelength the colors with lower wavelength get deflected or they get bent by a greater magnitude than the colours of of higher wavelength that is why the prism can split the incident white light to a series of continuous colors from violet to red but in our discussion we'll talk about two different forms of spectroscopy one is what we call absorption spectra two emission spectrum what happens what what do we mean by absorption spectrum or emission spectra let us redo this experiment the splitting of white light into

the rainbow colors but in a slightly different manner let us say that before i shine this before i allow this white radiation to go through the prism i did something else

so i started with white light i passed this white light through what i call my sample it could be ah the atom that you are studying it could be a molecule it could be an ion

so this is the sample this is let us say a certain molecule or a an atom

so we passed first the white radiation through the sample and then we took the light that is coming out of the sample and then allowed that light to pass through the prism when we did that you see that the prism again ah splits the white light into ah several colors but if you compare this spectrum from with with this spectrum ah the one thing that you notice is that the yellow color that is present here is missing something has happened here instead of yellow i see a dark patch i see red i see orange i see green blue indigo violet but i do not see yellow what happened to that yellow color what has happened is that the sample that i have the molecular the atom that i have in this sample they can they have actually observed this yellow light

so the white light came the sample absorbed that yellow yellow light from this white light white light has the wavelengths of all these seven colors but the sample could only observe the yellow light for whatever reason this is just an illustrative example the sample absorbed the yellow light and the remaining light when they were passed through the prism all the lights were present but x except for this yellow light

so what has happened to this yellow light the yellow light has been absorbed by this sample

so what i get now this spectrum this is the regular spectrum that i i get by passing ordinary white light through a prism and now this is a new spectrum which i call absorption spectrum why absorption because my sample has observed one color and the spectrum does not show that particular color okay now this is what we mean by absorption spectrum there could be another possibility that is the this next ah ex type of spectrum that is emission spectrum let us keep ah the absorption spectrum here ah how do i get emission spectrum now ah to be able to uh get emission spectrum we have to do a few other things when would uh a molecule or a matter emit radiation when we are discussing black body radiation we saw that when we heat let's say we when we eat an iron rod in a furnace at different temperature we see a different color for for the of the iron rod at one temperature it was red bright red another temperature at even higher temperature it was blue that is because when we eat the substance the substance absorb a lot of energy and it does not feel happy there

so it starts irradiating energy in form of radiation this is exactly what we are going to do in in terms of spectroscopy what we will do is that will take our sample but will excite this sample how can we excite the sample we can simply heat it that is a form of excitation we can also pass light through it thats also a form of excitation because light contains energy or we can also support this ah sample in a electric discharge tube you remember those cathode rays were going through

so if we apply very high voltage lot of electrons will be produced between the cathode and anode and these electrons will hit the sample and then the sample will get excited though it will get it will absorb a lot of energy and then it will get excited and once the sample is excited it has got a lot of energy but it does not know what to do with this energy

so what it essentially does is it emits this extra energy this is what we are going to discuss next here you see i have prepared an excited ah the sample in an excited state

so i have done something either i have given ready irradiation i or i have heated it up or i have subjected to subjected it to ah discharge tubes electric discharge tubes in any case i have this excited state sample which has an absorption m absorbed some energy and when i allow it to relax it emits that those radiation when i take this radiation but remember in previous experiments these arrows meant ordinary white light in this experiment the arrow that is the light that i am passing through the prism is the irradiation that is coming from the excited sample

so when i allow this radiation to go through the prism the prism again splits them but in this case the sample heart in my previous experiment the sample had observed this color and in this experiment ah after after when i allowed the sample to relax the sample has emitted the yellow color and this yellow color comes out of the prism

so what we see here in this ah second experiment we call that as emission spectrum in the absorption spectrum we saw all the lights except the light that was absorbed in the emission spectrum we saw only the light that was emitted this is the basic difference between absorption and emission spectrum now this emission spectrum is a very important tool to identify atoms is in fact it is called it can be every atom produces a unique a signature emission spectrum this can be used for fingerprinting the element using the atomic emission spectrum several new elements have been discovered even the presence of helium in the sun was discovered or was established by analyzing the emission spectrum of helium atom since the emission spectrum is carries signature properties uh of an atom will now discuss how does the emission spectrum of hydrogen atom look like we call that as line spectrum of hydrogen will get to know in a minutes time why we call it line spectrum is essentially a form of emission spectrum this is how the emission spectrum of hydrogen looked like when ah scientists carried out these experiments what you see here in a typical line spectrum of hydrogen atom you see series of lines and then you see at different intervals some bands that you see there are some bands then there are some lines then there are bands then there are again some lines again some bands i have intentionally colored them ah so that we can see that here is a group here is another group here is another group and they appear at different wavelength wave numbers

so you can see that it they go from 91.

2 nanometer to more than 820 and and above right

so there are the series of ah these are the there are various groups of ah lines that we see and this is why we call them line spectrum of hydrogen ok if you look these lines which are shown in yellow color they come between 364 nanometer to 656 nanometer that's the normal visible range of the electromagnetic spectrum

so when scientists recorded this ah emission spectrum of hydrogen atom we they had no clue about what is happening why are these lines and then there are bands

so there are they were completely clueless there was no theory available which could explain why such as spectrum should appear for hydrogen atom which is extremely simple and again ah for all heavier elements helium lithium they also their emission spectra were also recorded and their spectra also showed some somewhat similar structures but they were even more complicated will now focus on this region which is shown in the yellow color which comes in within the visible range of electromagnetic spectrum

so i have now ah zoomed this region

so let me turn this

so this ah spectrum ranges from 364 to 656 nanometer and if you see carefully again the same thing that appears in the previous spectrum there is one line here there is another line here then one more line which is ah closer and then

you can see that the spacing between the two lines keep on decreasing as we go lower wavelength and finally you see a continuous band it is a very wide band so as if several lines are all appearing together

so they form it they have given given rise to a band now this was very puzzling but one a mathematician swiss mathematician his name was johan balmer in the year of 1885 the swiss mathematician he was not a professional uh spectroscopist but he uh tried to understand these lines that were coming at different numbers and he said all right let me see if i can fit these numbers to a to an analytical formula which can explain why why we are getting all these bands

so we suggested a formula which is called bauma's formula as  $\bar{\nu}$  which is the wave number as this very ah strange number he said that these lines that use that you are seeing in the hydrogen atom uh emission spectrum they can be explained with this equation where he has a number here one zero nine six seven seven then there is another number one over 4 and then here is  $1/n^2$  where he said that n can be 3 4 5 it goes on

so its essentially n has to be greater than 2 because if n is 2 then this term becomes 0 and the wave number disappears the it becomes 0.

if you look at this equation let us see when n is 3 what do we have the new bar will be one zero nine six seven seven in i'll do it for one case one by four minus one by nine and this is this number is in the units of centimeter inverse if you do the if you solve it you would get fifteen thousand two hundred thirty two centimeter inverse which is equivalent to six hundred fifty six point five nanometer

so when you when you plug n equals 4 the new bar comes out to be i am writing here 20 564 wave numbers which is 486.

3 nanometer and if you if i show you the spectrum again you can see the first line appears at 656 the second line appears at 486.

3 and then if you use this formula you will get the numbers that the where this new lines other lines should come where will this formula end if you see this term n if n is very large here you have only one by four if n is very large

so this second term will become close to zero

so we have when n is very large we have essentially one zero nine six seven seven divided by four wave numbers this four is coming from here which is twenty seven centimeter inverse or equivalent to 364.

7 nanometer and this is where you actually see this continuum band 364.

7

so when n is very large number let us say n is 100 then you would get 364.

7 when n is goes from 100 to 101 the change in the new bar will be very small

so therefore the lines will be extremely closely spaced and they will appear to form a continuous band this is what you say

so using this formula he could actually explain this series remember this series is only one part of the entire hydrogen atom spectrum i i started to analyze these yellow lines this is the complete spectrum and this is the zoomed out version of the visible range

so let us go back to the complete spectrum right this is actually not complete there are there are against many lines towards the right hand side

so these lines these lines that are there in the yellow color they could be explained by signed swiss scientist yuan johan baumart

so therefore we call these lines as bomber series okay following the work of balmer there are other scientists who could who could ah see that that they can also explain the remaining part of the hydrogen atom spectrum for example ah this part this region could be solved by lyman

so we call this as lyman series the equation that lyman used was very similar to the equation that baumar used he used  $\bar{\nu}$  is one zero nine six seven seven

the same number multiplied by one divided by one square minus one by one  $n$  square and the number is centimeter inverse and in this case  $n$  goes from 2 to 2 3 4 and

so on if you compare this the first line with the second equation with the second equation you can see the second equation is actually the equation given by bomber

so the first equation that you see here was given by lyman

so we call the lines that were described because of this equation as lyman series this is this was due to burma and then you can see a trend

so here  $n$  remains same 1 square 2 square 3 square 4 square 5 square and

so on then this was given by past chain bracket  $p$  fund these are diff various scientists who ex who used different forms of equations to explain this ah hydrogen atom emission spectrum

so we call this the numbers that are coming from this equation lyman series bomber series positions it is bracket series  $p$  fund series right

so you can see we have a series of equations now but there is there are some similarities the similarities if you see is that ah we always have this  $n$  over here and then the term that is present here it keeps on increasing one two three four five then there was this swedish scientist reid berg who who saw the pattern here and said ah we do not have to use all these equations we can generalize that then he generalized them in this way he said that ok let us use the same he made it one minus  $n$  one by  $n$  one square minus one by  $n$  two square and this numbers are in centimeter inverse where his only ah precondition was there that  $n$  one is anyway again integer one two three go it goes on  $n$  two is always greater than  $n$  one if you use this formula you can actually reproduce lyman series lyman formula if you put  $n$  one is one if you put  $n$  one is two you can reproduce bomber  $n$  one is three you can reproduce position and

so on

so forth and this number that ah was used by everyone we call that as read works constant or we denote it is denote it as  $R_H$  although readworks formula could reproduce the lines present in the hydrogen atom's emission spectrum what was not clear is that what are the physical significance behind the uses of this  $n_1$  and  $n_2$  it was very puzzling to see that these integer numbers are used in this relation because we always thought that we human beings invented numbers we we invented numbers because we needed them for counting what what these numbers  $n_1$  and  $n_2$  are doing in this relation was not clear

so all the readworks formula can explain the hydrogen atom's emission spectrum but it is merely an equation that reproduces some lines nothing more than that we needed a physical interpretation that would give us a physical idea about what is happening in hydrogen atom and this is what we are going to discuss next we will talk about the idea of niels bohr and we will talk about bohr's atomic model and how bohr's atomic model could explain the complicated emission spectrum of hydrogen atom this is what we are going to do in the next class thank you you