

good morning to all of you in the last lecture we introduced the concept of an atom as we understand today and we said that the main task for us would be to understand what the structure of the atom is one knows that atoms are electrically neutral and atoms also have electrons in them because there is something that is experimentally seen therefore there must be a background positive charge which neutralizes the charges of the electrons

so the big question when it comes to the structure of the atom is the manner in which the negative charges namely the electrons and the positive charges are distributed and we also know that the atom is much much heavier compared to the electrons even if you put take the masses of all the electrons into account even in the simplest case of the hydrogen atom for example you can make use of avogadro's number etcetera etcetera to estimate the mass of the atom you see that the atom is 2000 times heavier than the electron

so what are we saying we are saying that the mass of the electron is of the order of 9.1×10^{-31} kg whereas the mass of the atom the mass of the electron is 9.1×10^{-31} kg whereas the mass of the atom is of the order of 1.67×10^{-27} kg

so it is of great importance to know whether this very very large mass thousands of times larger than that of the electron is distributed uniformly over the volume of the atom or it is concentrated in some particular region typically the center of the atom that is the question i also told you that there were there was one model due to thomson where thomson argued that the positive charge is distributed over the entire volume

so this is the picture that i was showing you

so please concentrate it at the second figure

so we assume that the background gray bluish gray color represents the uniform distribution of the positive charge and the small yellow pebbles or bullets that you see represent the electron

so this was the conventional wisdom also although there was no experimental evidence now what rutherford did was to set forth to verify this model we should remember that rutherford did not suspect this model but he wanted to verify this model this because it appeared to be completely plausible probably because people could not think of such a large mass being concentrated at one single point or in a very small region in the space that is what we try to do and of course in any case this model is quite different from the earlier primitive model which was advocated by kanada or democritus or newton or dalton all these people where they imagined atom to be attribute less except that it is a very very hard sphere but we have made a significant improvement in going from this to this we have the concept of charge we have the concept of electromagnetic interaction as i told you this picture cannot be taken completely literally because if you have a positive distribution of charge of this particular kind and the negative electrons which are sitting there we have to ask a number of questions for example what holds the positive distribution together where does the charge all not fly away that is a important question and even if you do not address that question at this particular point we would still have to answer what is it that maintains the equilibrium or the stability because as i told you at least twice it is impossible to have stability in an electrostatic situation even the least perturbation in any direction will disturb the atom but atoms are known to be there almost as long as the universe has been there atoms were synthesized very very early

so this is the apparatus which i spent a great deal of time with in order to explain to you what the experiment is

so the important things that we have to remember is that the alpha particles what we understand today to be helium nuclei are coming with a large energy of

5.

5 million electron volts that is a very very important piece of information for us and this gold foil is a very very thin foil which has very few layers of atom it is not exactly very few layers probably a few hundreds or thousands but it is still very small compared to the bulk gold foil and then even more importantly you have this zinc sulphide detector which scintillates every time an alpha particle hits it and then it is movable i also told you in the last lecture that we should not take this picture completely literally of course we know it is schematic because this lead shield which is used for collimation is also rather overblown because the detector could be moved very very close to the beam direction almost 180 degrees here it appears as if it is not possible and that is what we find here the results are illustrated in this figure where you see that there are individual atoms gold atoms which are distributed over the foil that is what you have and the helium particles are all getting scattered

so what is happening to the alpha particle you see this is already a picture which is consistent with the planetary motion

so i will come back to that later all that you have to notice here is that many of them are passing straight away some of them are getting slightly bent and some of them getting very largely bent there is almost a back scattering there is a rebounding like a ball goes and hits a wall and comes back when alpha particle is hitting and its momentum is completely reversed

so this is something that we have to understand

so it is worthwhile remembering what we did in the last class because this is very important data for us what is the most important data the energy of the alpha particle the kinetic energy was 5.

5 million electron volt and as i told you this energy is much much larger than the mass of the electron or the rest energy of the electron the electrons have typically of something like electron volt energy in the atom anyway even if you do not know that the mass is something like 0.

5 mbv by c^2 alpha particles have four to eight thousand times the mass of the electron i estimated that in the last lecture

so when i am looking at the interaction of the alpha particle here with the gold foil it may interact with the electron but then as i told you it is like a huge truck hitting a small pebble because it is eight thousand times almost ten thousand times heavier the pebble may get scattered but hardly anything happens to the truck which is moving with a certain velocity that means the momentum of the alpha particle is practically unchanged because of the collisions with the electrons the electrons may get knocked off it does not really matter the only care that we have to take in this detector is that this detector should respond only to the alpha particles and not to the electrons that supposedly will be given by the intensity of the scintillation or whatever rather for took care of it that is something that you have to remember that means whatever scattering is taking place especially the large angle scattering you should be predominantly because of the interaction between the positive charge in the atom and the positive charge carried by the alpha particle okay this is another figure that i showed you in the last lecture this is not rutherford result i will show you the result for result in a while after describing the whole thing actually it was an experiment performed by geiger and marston this is the scattering of proton hydrogen ion positive ion against gold against phosphorus and against boron the important point that we have to notice here is that there is a certain universality all of them have qualitatively the same features

so you see phosphorous has larger number of protons has larger positive charge than boron gold has larger positive charge in positron ah sorry phosphorous therefore if you look at the cross section which is essentially the number of alpha

particles that are scattered as a function of angle you see it is maximum for gold it decreases for phosphorus and it is further smaller for boron but otherwise the shapes are roughly the same you can scale them as if it can be translated and the other important point is that the scattering peaks in the forward angle that is where the most of the scattering is that is where most of the alpha particles are found and as you keep on increasing the angle of scattering you have 60 degrees 80 100 all the way up to 180 it is smaller but the most important thing is that it is not zero there is one more point that you have to notice in this figure if you look at it very very carefully there is zero one two three and there is a minus one written here which i did not notice yesterday do not be put off how can the number of scattered particles be negative this graph is in the logarithmic scale

so you know when a number is less than one the logarithm will become a negative quantity that is what we have that means when i go from 0 to 1 there is one order of magnitude jump in the scattering cross section this is not a linear scale

so what you are actually plotting here is the log that is what is shown here log of the number of alpha particles that are seen

so this minus one should not put you off because logarithm of a positive number can jolly will be a negative number that is something that you have to remember ok we summarize this this is the great this is the experiment which i will come back to from the plume boarding and this is the experiment of geiger and mars then but before we do that

so let me stay in this particular figure we have to do a certain bit of analysis i started this analysis in the last lecture but we ran out of time now i am going to complete it i am not going to work out everything for you i am going to leave a few things please work them out make your answers more accurate more realistic

so let us start looking at these things

so the hypothesis that we make initially which is exactly what rutherford did was to assume that the positive charge is distributed over the volume of the nucleus

so my nucleus i can pick up another color let us say red has a radius r

so let us say my atom is a spherical object and this has a radius r

so let us assume that my positive charge is distributed uniformly we do not have to take it very very seriously in fact it is all right even if you look at this scenario where my positive charge is probably contained in a certain region or volume in the nucleus and it is perfect atom and it is perfectly possible that the atom has this size that also we can assume what about the electrons maybe some electrons are here and maybe some electrons here

so the first one is strictly adhering to the thomson model is that okay because all the positive charges negative charges will be sitting inside here this is not exactly thomson model it is a partial thomson model we are saying some of the electrons are inside the positive charge distribution and some of the electrons are outside

so there are two limits if all these get inside the positive charge distribution then the red line becomes the size of the atom that is thomson model or if it

so turns out that all the electrons are outside the positive charge then we are negating the thomson model and in which case the location of the outermost electron will give me the size of the atom we have to remember that

so i can put a outer most electron here let us say and this will be my radius r

so this is the picture that we are going to start with what is happening now what is happening now is that i ignore the negative charges as i told you

so this is coming from the positive charges only and here is an alpha particle almost at infinity that is the statement that we are going to make and at infinity it has a kinetic energy e is equal to 5.

5 million electron volt that is what we have and this alpha particle is shot by the radioactive nucleus in this direction of course the radioactive nucleus emits alpha particles in all the directions but i have put two lit shields which essentially collimate select those alpha particles which are coming in this particular direction and then as it moves it starts experiencing the field produced by this positive charge

so what is my nucleus my nucleus is gold gold has 87 electrons therefore the charge of the positive charge distribution the total charge is also equal to plus 87 it has an atomic mass which we should remember A is of the order of is equal to one ninety nine almost equal to two hundred just as my alpha particle is very very heavy compared to the electron you can see that my gold atom is also very very heavy compared to the alpha particle my alpha particle has a equal to 4 whereas gold has a equal to 200

so gold is 50 times heavier it is not as dramatic as in the case of alpha particle and electron but gold is 50 times heavier than an alpha particle atom therefore again when you look at the scattering you need not worry about the recoil of the gold atoms

so we are going to look up on the whole scattering as a scattering from a fixed target these are the essential things that we have to know that is what we have now let me look at the case where my alpha particle is arriving head on what does head-on mean if i extrapolate this will be the center

so in mechanics we say this has zero impact parameter with respect to the center that is what we are going to say and therefore this is next to the center this has zero angular momentum $r \times p$ is equal to zero where otherwise if it were somewhere here there would have been an impact parameter and impact parameter multiplied by the momentum would have given you the angular momentum that is something that you have to remember now at infinity it had an energy of 5.

5 mev but at any intermediate point it will have kinetic energy plus potential energy kinetic energy plus potential energy all of you know that in the field produced by the charges the total energy is conserved therefore total energy which is equal to kinetic energy plus potential energy is equal to 5.

5 mev always wherever the charge particle may be and this is valid not only if the collision is head on my alpha particle can be coming here it can be coming here it can be coming here whatever it does not matter wherever it may be coming it is going to be there

so you can see if it comes here it is going to get scattered like this if it comes here it is going to get scattered like this

so on and

so forth but this total energy is a conserved quantity and we are going to make use of that now what is the question that we are going to ask the question that we are going to ask is how close to the atom can an alpha particle get that is a question that we are going to ask and that obviously depends on the size of the positive charge distribution

so i am going to make one estimate for you and then i am going to modify that which you will yourself work out

so let us do a crude analysis what is the crude analysis that i can do

so imagine that all the positive charge is contained in a very very tiny region which is almost point like

so this is a underestimate of the closest distance almost point distribution that is what i have now in that case how will the potential look like the

potential is of course repulsive the force is repulsive therefore the potential will look like this even the force will look like this this is my one over r potential

so as you go far closer and closer to the target

so this is my target position my potential energy keeps on increasing and therefore and as you go very close at the target it almost becomes infinity it is becoming very large but then my total energy is a positive quantity my kinetic energy is a positive quantity therefore if a particle of a certain energy is coming here depending on what its energy is here it will come here at this point all the kinetic energy will become zero because my potential energy is equal to the kinetic energy at infinity then it will get rebound if you have higher energy it will come here it will get rebound

so on and

so forth but in this picture however larger energy may be my alpha particle will be never be able to reach the target because this virtually goes to infinity now for the time being let us ignore the finite size of the atom and let us make an estimation of how close the alpha particle can get to and then compare it with the size of the atom

so we are going to do it in two steps the first step is ignore the size of the atom estimate it is not actually an estimate it is exact yes but r_{minimum} this is the closest distance that the alpha particle can approach number three compare r_{minimum} with capital r this size is r that is what we want to do if this r_{minimum} is greater than r which is perfectly fine we do not have to worry about it but if r_{minimum} is less than r that is something that we have to worry and let us look at that the equations are very very simple the potential energy is simply given by $\frac{q_1 q_2}{4\pi\epsilon_0 r}$ not r_{minimum} is equal to the total energy at in kinetic energy at infinity which is the total energy and that is nothing but 5.

$5 m v^2$ this is what we are going to equate

so let us remember in the units of electron charge q_1 is equal to 2 this is my alpha particle and q_2

so alpha gold is eighty seven this is something that you have to remember that means $q_1 q_2$ is almost close to hundred one seventy four some such thing therefore the force of repulsion is very very large therefore the potential energy is also a large positive quantity $4\pi\epsilon_0$ is the constant that we people are aware of therefore what is my r_{minimum} r_{minimum} is $\frac{q_1 q_2}{4\pi\epsilon_0}$ naught into 5.

$5 m v^2$ that was an oversight this is what we have if the charges become larger and larger the minimum distance that you can approach becomes also larger and larger because you cannot penetrate the barrier that is what you are going to get and this is a consistent expression

so let me repeat that calculation $\frac{q_1 q_2}{4\pi\epsilon_0}$ naught r_{minimum} is equal to five point five m e b

so i push r_{minimum} here and i bring five point five here i know everything is fine

so that is what we have and of course as the energy increases our minimum decreases because you are able to go through the potential barrier

so basically it is a competition between the charges of the projectile and the target and the energy of the incoming projectile this is the correct expression i wrote a wrong expression but we have corrected them no harm

so long as we correct as i told you q_1 and q_2 values we have already written let me repeat that here q_1 is essential of alpha which is equal to 2 in the units of electron charge q_2 equal to 87 what we can now do is to plug in the numbers i will not plug in the numbers i will leave that as an exercise for you

so if we plug in the numbers what do we get we get r_{minimum} is of the order of 10 to the power of minus 14 meters r_{minimum} is of the order of 10 to the power of minus 14 meters and what is the size of the atom my size of the atom is of the order of 10 to the power of minus 10 meters

so we are saying that my alpha particle can penetrate very very close to the center of the atom assume making this assumption whether r_{minimum} is an underestimation or an over estimation that will come together therefore r_{minimum} over r is ten to the power of minus four it is a very very tiny fraction that means you are almost hitting the center because this r_{minimum} is 10 to the power of minus 14 meter obviously my analysis is incorrect because i assume that the potential is 1 over r everywhere

so now what i am going to do is to correct that scenario

so what we will do is to consider a uniform positive charge distribution because that is the model that we are going to look at this distance is r that is what i have and i am going to look at the potential as a function of r that is what i am interested in now what happens you people know from gauss's law that

so long as your projectile is outside the spherical charge distribution my projectile or the test charge will look upon the field as a field produced by a point charge that is what goes to slot

so so v of r is equal to we are interested in the potential energy q one could q two four pi epsilon naught r if r greater than or equal to r that is what gauss's law tells you now once you come inside there is a uniform charge density ρ such that integral ρ d cubed r is equal to q 2 that is what we are rating which is equal to 87 in the units of proton electron charge except that it is of the opposite sign again you can use gauss's law inside the sphere

so if you use gauss's law inside the sphere everyone knows that the field raises linearly and therefore the potential will be quadratic

so inside the sphere field raises linearly potential is quadratic in r is a very trivial exercise which you can all people are that is what we have what is the field at the center of the atom the field is zero because if you look at a spherical distribution of charge and if i put a test chart at this center then it is pulled equally in all directions actually because of the repulsion actually it will be it depends on the size of the charge whatever it does not matter and therefore the net force acting on the test charge is equal to zero whereas if it were a point charge the force at the origin would have been equal to infinity now we see there is a great conflict between where the charge whether the charge is concentrated very close to the center or whether the charge is distributed uniformly over the sphere that is the most important thing for us

so let me draw the field for you and then let me draw the potential for you

so this is my r this is my electric field as a function of r okay electric field is positive because it is produced by a positive charge distribution

so what happens inside the spherical distribution it starts raising linearly

so this point corresponds to r and the outside it falls off like 1 over r squared we should contrast this with what happens if the charge distribution is almost point like then what would have happened this line would have continued and it would have gone up to infinity 1 over r squared everywhere that is what would have happened but now you see this is the tipping point at the surface of the charge distribution now there is something very interesting that is going to happen to us and that is very very important for us let me write the energy diagram and in order to do that let me draw this figure once again there is no harm in repeating that because it sort of allows us to settle our thoughts

so i am going to draw a big picture here

so i have one here and another thing i will turn it for a minute which is going

to infinity ok assume that this is going to infinity here now let us look at what happens to the charge particle let us see what happens to the alpha particle which is coming

so this is my

so now this is my force

so when my alpha particle is coming if its energy is great enough let us say more than this

so that it can reach a minimum distance more than this then it can simply pass through not only will it pass through as it gets more and more into this region the magnitude of the electric field becomes smaller and smaller therefore the repulsive force becomes smaller and smaller therefore it is made further easier that is the most important thing

so a better way to depict this is actually in terms of the potential energy because we want to show the energy diagram

so what we have is potential energy v of r as a function of r

so what is my potential energy can somebody tell me potential energy is very very important here because v is minus $e d r$ we should not forget that therefore for r less than r my potential energy becomes what negative that is something that we have to remember for r greater than r of course it is a positive quantity

so the potential energy v of r is minus half $k r$ squared for r less than r and this is equal to $q_1 q_2$ over $4 \pi \epsilon_0$ naught 1 over r for r greater than r okay we have to be a little bit careful here this is not a very consistent way of writing things why is it not a consistent way this expression $q_1 q_2$ over $4 \pi \epsilon_0$ naught 1 by r is written assuming that the potential is zero at infinity whereas minus half $k r$ squared is written assuming that the potential energy is zero at the equilibrium point but you are allowed to choose zero of the potential at only one particular point therefore what i should i do i should write plus a constant that is the most important thing

so this is a lesson that we learn here

so let me work it out

so we are saying that v of r is minus half $k r$ squared plus a constant this k you know which comes from the force i will fix that in a minute that must be equal to $q_1 q_2$ over $4 \pi \epsilon_0$ naught 1 over r at r equal to r this is something that you have to remember

so this constant is very very important for us now how do i fix my k i fix the value of k by simply equating the electric forces at r equal to r

so k is fixed by equating forces at r equal to r

so that is what we are going to do that means we are going to write k capital r is equal to $q_1 q_2$ over $4 \pi \epsilon_0$ not 1 over r square by equating the forces

so what is my k going to be my k is simply $q_1 q_2$ over $4 \pi \epsilon_0$ not 1 over r cubed

so i will now write my potential to be v of r is equal to minus one over $q_1 q_2$ over $4 \pi \epsilon_0$ naught into r squared by r cubed plus constant if r less than r and this is equal to $q_1 q_2$ over $4 \pi \epsilon_0$ naught 1 over r if r greater than r now we can equate the potentials the potential is continuous across the boundary in fact in this case the field is also continuous across the boundary unlike the case of point charges are line charges whatever

so we are going to equate

so what am i going to get i am going to get 1 over $8 q_1 q_2$ over $4 \pi \epsilon_0$ naught r squared by r cubed will be one over r plus constant is equal to $q_1 q_2$ over $4 \pi \epsilon_0$ naught into one over r

so the left hand side is coming from the sphere inside the sphere and this is outside the sphere and at the boundary we match now my c can be easily fixed

so i am going to get a $\frac{1}{8}$ plus $\frac{1}{4}$ which is three by eight
so if i put a eight here i get two three by eight therefore my c is three by eight
 $\frac{q_1 q_2}{4 \pi \epsilon_0 r}$ this is my constant

so we have to do this much work in order to fix to be able to write the picture of a potential i am taking some care

so that you people appreciate what is going to happening therefore i can now write my v of r is nothing but i can pull the $\frac{q_1 q_2}{4 \pi \epsilon_0 r}$ out

so let me write everything carefully my c is three by eight $\frac{q_1 q_2}{4 \pi \epsilon_0 r}$ minus that is the most important for me one by eight $\frac{q_1 q_2}{4 \pi \epsilon_0 r}$ not r^2 by r^3 this is my expression for $r < r_0$ and of course $r > r_0$ is simply $\frac{q_1 q_2}{4 \pi \epsilon_0 r}$ please notice that dimensionally everything is correct and probably we should at this point introduce a notation

so that we do not keep on writing $\frac{q_1 q_2}{4 \pi \epsilon_0 r}$

so let us introduce a constant big k at this and call it as $\frac{q_1 q_2}{4 \pi \epsilon_0 r}$

so now if i am to equate the total energy i have to make use of these expressions

so since i already know that my alpha particle can penetrate inside the nucleus i have to substitute in this particular expression that i will leave it as an exercise for you and you will find that it can go even much closer and in fact at five point five m a b the alpha particles you simply zoom through the nucleus there should be no back scattering that i will leave it as an exercise for you

so what are we saying i can now draw the potential

so at $r = 0$ if you look at this expression there is a $\frac{3}{8}$ there is a $\frac{1}{8}$ $\frac{3}{8} - \frac{1}{8} = \frac{2}{8}$ which is $\frac{1}{4}$ it is a positive quantity

so it is not starting with a negative quantity

so my potential starts from a positive quantity it decreases quadratically up to this particular point at r_0 that is what the potential is going to happen and after that it will change slope and will go like $\frac{1}{r}$ this is $r > r_0$ this is quadratic decrease and one can show your five point five m a b is something like this and it can simply pass zoom through therefore there should be no back scattering at all is that okay please remember this is the picture of a potential we have chosen the zero of the potential to be at infinity and my energy can simply go through whereas the point particle picture would have given something like this

so this is 10^{-14} where it would have got repulsed but now it simply passes through

so it is said that when rutherford asked the student marsden to do this experiment he did not expect any back scattering at all because he worked this out and he said that there should be nothing interesting

so this is the essence of rutherford scattering

so please work that out like i like that i worked it out for $\frac{1}{r}$ potential by equating the potential inside and you will see that it can actually hit 0 there is no problem very very close to 0 and therefore you should certainly not expect whatever the experimental is fine for example in this figure

so in this logarithmic scale if i look at very very large angles

so let me show that for you in the logarithmic scale if i look at very very large angles the back scattering if it all it occurs should be

so very small the number of particles should be

so very small it is a very very small number compared to 1 therefore in the logarithmic scale this should go to minus infinity because you know $\log 0$ is

minus infinity when you are very very close to zero it should go to minus infinity but there is a significant finite value now there is one more interesting that we have to inter worry about if you have a uniform positive charge of this particular kind and let us say the two alpha particles of the same energy are coming at the head on and at the periphery now whatever is coming near the periphery experiences a larger electric field compared to the one that this because it has already penetrated that means the scattering angle for this must be larger than this because this will simply pass through whereas if it is a point charge the situation is different whatever is coming at the periphery of the atom barely gets scattered because it is far far away from the scattering center but whatever is coming with zero angle it is seeing an infinite force as it approaches the point particle therefore they should be rebound in other words the plum pudding model predicts the particles which are coming at the periphery all of them have the same energy should get scattered more but then the field is already small therefore it cannot get scattered too much the ones coming with zero impact parameter will not get scattered they will simply pass through because they have enough energy to pass through because the electric field starts decreasing inside the medium and this is just the opposite and what does this experiment tell me this experimental tells me that this picture is not supported this picture is not supported who is it not supported and that is exactly what is shown in this cartoon if you look at this here is an alpha particle which has zero impact parameter with to this with respect to the gold nucleus it is getting rebound very badly whereas here is an alpha particle which is at the periphery of the atom which says very electric electric field therefore it almost passes through and here is another one which is not exactly head on but close to the central positive distribution it is again getting scattered this picture is wrong because they have shown an attractive force instead of a repulsive force never mind about that is that ok but this picture is correct because the particle is coming very close the repulsive force is very large therefore it flies away this unfortunately is a mistake in the on the part of whoever made it in encyclopedia britannica but we completely understand this and therefore we have to make a consistent picture and this seems to be the consistent picture okay now there is another thing about the finite size distribution this was qualitative quantitatively what do we expect if you work out the cross section it is you learn it in your first year of your engineering or in your bsc whenever there is a size the cross section falls as a function of scattering angle but it does not fall monotonically regularly there is a periodic thumb it reaches a minima then there is hump it comes down it reaches a minima there is a hump it reaches a minima there is a hum

so on and

so forth and do not be surprised too much by that because in the case of deep rawley waves you already saw that my deep broly waves were conducted with electrons right the daves and german experiment it can behave exhibit a wave like behavior in a similar manner even alpha particles can behave like as if they are wave like and they should show minimum maxima minima maxima and this is what is going to happen this is some kind of a vindication of whatever you see in the case similarity with whatever you see in the case of davis and german experiment but this minima maxima occurs if and only if the positive charge is distributed over a size that is the condition but what is it that the experimental is found this is the true experiment of geiger and marsden geiger and mars then found this is their other first scattering experiment see this is the logarithmic scale 10 to the power of 7 10 to the power of 6 10 to the power of 5

so on and

so forth you see there are no humps there are no minima it is falling off regularly like this ok that is what we are finding and from this we can conclude that the radius over which the positive charge is distributed is at least 10^4 times the radius of the atom this is a clinching experiment because there is no evidence for the size of the positive charge distribution and more importantly for you you see there are two things here one is the points and another is the curve the curve is the theoretical curve which you get from the rutherford formula and the points are the experimental points and you see that the experimental points are hugging the theoretical curve there is absolutely no deviation that means that whatever hypothesis that we started with that there is a what we call it plump pudding model is ruled out we have to assume that the volume over which the positive charge is distributed is very very small compared to the volume of the atom this is indeed the most crucial experiment for us

so once rather forgot this experiment he was mighty surprised and he immediately came up with an explanation

so he said that if atom has a certain radius r which is 10^{10} meters my positive charge is concentrated in a very small region which is less than 10^{-14} meters we are not asserting that the positive charge is a point charge we are not asserting that we are only asserting that my alpha particle does not have enough energy to probe lengths less than this you have to send alpha particles of even higher energy or for that matter it could be even electrons of higher energy this kind of experiments were done by hofstatter in nineteen sixties they are great experiments which reveal to us the structure of the nucleus itself now when you are encountering this particular situation that means the electrons are all here and you look for a model and there is a god given we mean kepler newton given model up in the sky and that is the planetary model therefore rutherford immediately postulated the planetary model for the atom

so he said that there is a central kernel or nucleus which is attracting all the electrons towards it and the electrons because of their own kinetic energy they get trapped but they do not fall into the elect from the positive charge which is today's come we know is composed of proton and neutron thanks to chadwick and others and it keeps going round and round and this is your famous planetary model

so it should be aesthetically pleasing to everyone who wants to see a systematic pattern in nature therefore you say you know if you are looking at length scales of the order of 10^7 to 10^8 or 10^{10} meters let us say astronomical case and you are looking at a scale of 10^{-10} meters over this case gravitation is there and they have the planetary model for the solar system and in fact we know that there are binary stars which go around each other according to newton's gravitational law there are galaxies which are bound to each other by gravitational law all that happens when we come from 10^{10} to 10^{-10} is that the gravitational law gets replaced by the coulomb but both of them are one over r^2 potentials

so what we essentially have is the same thing reproduced at a smaller scale with a different interaction

so rutherford should have been a happy man but unfortunately electrodynamics electricity and magnetism are much more complicated than newtonian gravity

so electricity and magnetism the combined where it is electro magnetism or electrodynamics much more complicated than newtonian gravity i use diver newtonian gravity because we know that there is a more advanced theory of

gravity which is called the general theory of relativity and that is as complicated or even more complicated than electricity and magnetism but for our purposes that is not important comparison with the newtonian gravity is important and let us see what it is

so if you look at this model now in this slide this is the conventional picture that you have in your text book this is again from britannica

so you have all the positive charge concentrated at the center but then the positive charge does not account for the full mass therefore you have to postulate the existence of the neutral particles chadwick discovered them

so the blue ones are the neutrons the gray ones are the protons there are many many more blue ones than the gray ones don't think neutrons are some passive objects which are sitting there they have a very important role to keep the nucleus together there is a big question of what keeps all the protons together when there should be a great repulsion that is because at such short distances the electromagnetic force is not the dominant force but it is the nuclear force we will learn that when you do nuclear physics after a few lectures and their neutrons are very important because they also participate in the nuclear force and now you have a picture where you show

so let us say two electrons in one orbit four electrons in another orbit so on and

so forth do not take this numbers two and four very seriously although they have some basis in the bohr model at this point you need not take this is your planetary model

so all is well and good just as you have planetary model for the solar system which we realized after thousands of years of observation remember astronomers have been looking up the sky and mapping the path of the planets and the stars over many many years but now this is not as simple as that because there is a complication

so i want you to look at this picture what we have on the left hand side is the energy in geV of a proton in an accelerator

so let me describe you what that accelerator is it is called the synchrotron

so let me write down the picture of a synchrotron

so basically in this synchrotron what you have is protons moving in circular orbits because of a magnetic field all of you know charged particles but somewhere here i am showing it very schematically do not take it seriously they will get accelerated and they will gain energy and again they will go in a circular orbit and again they will gain energy this accelerators are called synchrotrons

so this is like a planetary model for a proton and you see in a synchrotron what is happening is that it is continuously emitting radiation the energy that you are supplying even if you do not supply energy simply because of its acceleration it is continuously emitting radiation i am sorry this is the energy of the radiation that is coming and this is the intensity of the radiation that is coming in a synchrotron and in a synchrotron proton can have as large as an energy as 30 mev in fact it is there even in the cosmological scale this is a radiation jet in space basically what i want to tell you is that all radiating charges accelerating charges should necessarily radiate

so the big question is how is the electron able to go around the proton without radiating

so pausing this question i will stop at this particular point in the next lecture we will investigate this feature even more and there is another surprise called the spectral lines and we will see how bohr was able to get over both the problems with a stroke of a genius

so we will address it in the next class meanwhile please solve the problem of

the potential barrier you

Prutor@iITK