good morning all of you what we are going to cover today in this lecture is the structure of the atom which is extraordinarily important for all the developments in the 20th century for that matter even in the 21st century

so the structure of the atom essentially involves first of all an understanding of the classic experiment by rutherford when he scattered alpha particles of gold nuclei what we call as gold nuclei today and then of course the planetary model which followed from the rutherford scattering had to be reconciled with spectroscopic data and with the very problem of the stability of the atom for which bohr gave his model

so in other words what we are going to discuss in the class today is one of the most crucial developments in physics because after all if we understand the basic constituents of matter the rest of wood would be a matter of detail however complicated it may be as i told you in my last lecture the concept of deep rawley waves or the matter waves was actually introduced after bohr gave his model in fact many many years after bohr gave his model

so historically dee brawley was impressed he was influenced by these special orbits that bohr had proposed and he thought that that could correspond to standing waves of matter waves but that is not the viewpoint that we are taking in this course just as that is not the viewpoint that is taken in your 12th standard in crt course

so i will return to that concept but we should remember that the structure of the atom precedes the concept of a matter wave

so in the last lecture what we essentially did was to introduce the concept of matter wave and we gave an experimental demonstration of this idea this was a hypothesis which was put forth by deep rawley but then davison and dermer through their ingenious experiments were actually able to diffract electrons of a nickel crystal

so we should always remember the famous formula 2 d is equal to 2 d sin theta is equal to n lambda

so the scattering angle is governed by this formula n is the order of diffraction d is the spacing between the planes of the crystal lambda is the wavelength

so the scattering result was consistent with this formula which is valid for waves and not what they expected of electrons as particles however we should remember that experiments with cathode rays or for that matter even e by measurements strongly suggest in fact they provide great evidence that electrons are actually very very tiny particles

so again we have the same dilemma that we encounter the same duality that we encountered in the case of light with interference and diffraction it behaves like a wave and with regarding to photoelectric effect or compton scattering it behaves like a particle in a similar manner electron when it is getting accelerated by voltage when you are looking at its tracks in a magnetic field etcetera etcetera behaves like a particle but then when it is scattered off a nickel crystal then it shows beautiful diffraction patterns

so we have to remember that before i go on to discuss the structure of the atom i want to round up a discussion by cautioning you on how careful we should be in using the concept of wave especially when it comes to matter wave

so let me recall let me recollect what we have done both in the case of light and in the case of matter

so let us start with light electromagnetic radiation

so in the case of electromagnetic radiation we have two important expressions e equal to h nu and the second expression is obviously given by v equal to c all wavelengths propagate with the same speed given by denoted by c which is 3 into 10 to the power of 8 kilometers per second and this is nothing but new lambda in

other words when we associate an energy with a frequency nu nu associates an energy e we are also associating the same energy with a wavelength because after all my nu is nothing but c by lambda
 so it is entirely a matter of test whether you want to relate energy to frequency or energy to the wavelength at least at this particular point and therefore i can write e is equal to h c by lambda that is what i have
 so in my lectures on photoelectric effect i also argued that it follows from classical theory all this is blank
 so it is as if we are reading two horses sometimes that of maxwell and sometimes that of planck now if i come back to maxwell the age old wave theory which of course has a great experimental evidence maxwell says that if i have a monochromatic plane wave let us say then the energy density is related to the momentum density by a factor of c
 so this is energy density and this is momentum density
 so what do i mean by energy density and momentum density that is the energy per unit volume carried by the radiation and momentum density is the momentum carried by the radiation per unit volume that is what we have now mr planck would like to associate a certain number of particles corresponding to this and corresponding to this
 so if you have an energy density corresponding to radiation of a given frequency
 so if you want i can put the subscript nu here if i did that then what we would do is to introduce the number density of the photons number density of photons we now couple this number density of the photons with the energy density
 so how do we do that each photon carries an energy h nu
 so let us write that down each photon carries an energy h nu therefore n photons per unit volume carry an energy n h nu therefore u is equal to n h nu that is what we have but then since this is given by pi c
 so i will put a subscript nu here i will put a subscript new here this is the energy density associated with that particular frequency what do we conclude we conclude that pi nu if you look at this is nothing but nh nu by c that is what i am going to get
 so and nu by c is nothing but what we are going to get regarding lambda
 so let us remember c equal to nu lambda is what i have therefore nu by c is nothing but 1 over lambda which is nh by lambda remember n is the number density associated with the photons
 so many photons
 so there is a natural interpretation for this h by lambda
 so we say that h by lambda is the momentum carried by each photon h by lambda is the momentum carried by each photon therefore the planck hypothesis not only associates an energy with a frequency it also associates with the momentum with the frequency or for that matter the wavelength and this is exactly what d broly employed even in the case of massive particles that is what he did this is essentially a very very short summary of whatever we covered in the previous lecture however when it comes to matter waves there is a complication and that is something that we have to remember we have a number of expressions
 so what i will do is i will look at matter
 so let us say electron
 so here i look at it from the viewpoint of a particle and here i look at it from the viewpoint of a wave let us try to understand that now from the viewpoint of a particle my energy is given by p squared over two m where p is the momentum of the particle
 so which is also equal to half mv square
 so the relation between energy and momentum is given by e equal to p squared by

2m and my momentum is of course m v

so these relations i will call nr nr is newtonian relation or non relativistic relation of course somebody may say why are you using this use the more exact expression for energy and momentum coming from relativity all of you are familiar with the expression for relativistic energy mass defect in fact we are also going to discuss that in the next few lectures after a few lectures

so there i would write e equal to m c squared over root of 1 minus v squared by c squared and p is equal to mv over root of 1 minus v square by c squared these are the expressions and this i will call e r coming from einstein's relativity

so these are the einstein relations these are the newtonian relations what about the wave whether it is a relativistic particle or a non-relativistic particle the planck hypothesis and the deep broly hypothesis does not change that is a very important thing

so for both of them we have a common formula e equal to h nu and p equal to h by lambda but the point is that the minute you give me e and p you are giving me nu and lambda therefore i should be able to immediately write an expression for the velocity

so here the v is the velocity of the particle particle speed let us say whereas here my v wave can be written as nu into lambda and what is nu into lambda that is e by h and lambda is h by p which is e by p when it comes to light it is of no matter to worry because we started with the relation e equal to pc but now we see we are going to have a problem with the particle picture because whether you make use of the non-relativistic formula or the relativistic formula you are going to get a different expression for the velocities let me write that down again we found that v wave is equal to nu lambda is nothing but e by p this is dimensionally correct there is no problem about it now what we shall do is to write v particle both in the case of non relativistic relation and the relativistic relation

so in the non relativistic relation my v is simply given by p by m if you want and that is it it is you do not have to express it in terms of energy but v is simply given by p by m and in the relativistic case v of the particle in the relativistic case will be slightly different

so i will have to work that out let me show you the thing again

so what i will do is i will multiply p by c square and divide by e that is what i am going to do

so this is nothing but p into c squared divided by e which has the correct definition of speed dimension of speed because please remember e by p itself for speed p by e is 1 over speed c square speed square divided by speed is this these are the expressions that we are going to get now clearly p by m is not equal to e by p nor is pc square by e equal to e by p unless e equal to pc and d equal to pc is valid only for radiation or for particles which do not have a red ma a rest mass that means there is a discrepancy this is something that we had not encountered earlier

so let us write a relation statement it appears as if the wave associated with the electron and the particle associated with the electron move with different speeds this is certainly of concern but not of very great concern anyway to round up the discussion i can tell you what the wave velocity will be my wave velocity will be particle velocity divided by two for non relativistic case and this will be c squared by v for relativistic case you can work that out because i have written all the and both of them are going to land us in trouble

so how would we answer this is the concept of a wave wrong or is it that we have made a mistake the answer is that the definition of velocity is a rather delicate one and later when you go for higher studies in physics when you study wave phenomena you will realize that velocity is given by the speed with which

some information is carried and we would have to replace the definition what is the definition that we had v equal to new lambda this v is what is called as the phase velocity that has to be replaced by a more rigorous definition more accurate definition called the group velocity you will learn that but at this point you should know that we should not naively use all the formulae available at our disposal sometimes it works sometimes it does not work i am not going to spend any time on introducing the concept of group velocity for you that is possible to do that by looking at the superposition of two waves whose frequencies are very close to each other but let us not digress

 so this should conclude our discussion of the matter waves we know that our matter waves carry an energy they carry a frequency and then of course they propagate with a certain velocity and as i told you if you do a careful calculation that will agree with the particle velocity but then as always we should remember that the relation exactly between the particle and the wave is not clear deep brawley himself imagined that every particle was associated with a wave and the particle used to sit somewhere here and it would ride along with the wave and he called them pilot waves

 so this was the deep broly wave of imagining matter waves but then today one does not subscribe to this viewpoint the except probably for a very very small minority of physicists because all these ideas get replaced by the concept of what is called as a wave function or a probability amplitude which again you will study in your higher classes

 so let us conclude the discussion on matter waves and let us move on to discuss the structure of the atom if there are two things that have attracted the attention of humankind you know all thinkers have thought about it one is the nature of our universe how big it is and what its structure what we call as the large scale structure of the universe and other is the ultimate constituents of matter

 so now what i am going to do is to show you a number of slides to give you an idea of how the atom concept has evolved over centuries in fact over millennia thousands of years and how in 17th 18th 19th century contributions from physicists chemists engineers in fact thermodynamics people actually contributed to sharpen our idea of an atom

 so let us look at the next slide now as to what the ultimate constituents of matter are hinges on the question whether matter is continuous or whether matter is discrete

 so it is the age-old question if i look at a smooth surface or if i look at the distribution of air in the atmosphere or if i look at the flow of water or any fluid they appear to be continuous all solids appear to be continuous therefore what is it that would happen if i took a microscope and started looking at minute and minute more and more minute parts there is a question that we have to ask it is true that matter appears to be continuous to us except when we join them or except when two very big units may be joined but it is also true that this continuous distribution of matter apparent continuous distribution of matter actually is not absolutely continuous in the sense that you can break it of course the important observation that we have to make is that you take any piece of matter and as you start breaking into tinier and tinier pieces the energy that is required to break that keeps on increasing therefore in the classical language the way our ancient geniuses thought about it one good question that one could ask is as i keep on breaking is it possible that i will reach an ultimate limit which is impossible to be broken that means you should imagine that ultimate constituent to be essentially a perfectly hard sphere perfectly hot sphere and to break which you would require an infinite energy in other words it is immutable it is unbreakable or the other concept is that no

there is a continuum you can keep on going to smaller and smaller units you may require higher and higher energy but there may be no fundamental unit and both of them are useful viewpoints in trying to understand whatever we observe in nature we should remember at this point that it would be unfair on our part in fact incorrect on our part to pass any judgment on whatever theories the ancient physicist and philosopher might have had in light of the experimental set evidence that we have today there is a pitfall into which many many of us tend to get into that is to be avoided

so to put it very broadly in the ancient world especially in india and greece there were two broad philosophies not necessarily in contradiction with each other the first philosophy which i am indicating here was proposed by this intellectual called kanada who started a school called the veisheka school we know that in india there were six major schools of philosophy or they can be listed actually the first one was called nyaya which elucidated the logical principles the second one is vaishashika which was an atomistic theory then you had the sankhya which proposed the idea of what we call as prakriti and purusha the nature and the soul they had their own theory of the world in terms of three gunas or three attributes what they called sattva rajasthan thomas then there was the practical aspect of sankhya which came to be known as yoga which was propounded by patanjali

so you have nyaya veisheshika sankhya yoga and there are two schools which are completely dedicated to the interpretation of the vedas one was the

so called purumi mamsa which concentrated on the ritualistic aspect and then the uttara mamsa which concentrated on the spiritual aspects

so these schools of philosophy also gave a world view for example the puru imam school believed very seriously that the universe can be neither created nor destroyed it had to be eternal for the sake of consistency within their theory the poor mimsaka school was not particularly worried about the ultimate constituents of matter because they said that that is something that is to be decided by observation and they need not be worried about that the validity of their philos school of philosophy that is also true of the vedanta or the uttara mimsa was quite independent of that

so when we are speaking of the schools we are interested obviously in the atomic school which was propagated by kanada and he his school of philosophy is called vaisheshika vishesha is an attribute

so he attributed the number of properties to his atoms that is why it is called as the vaisheshika school and they give an elaborate theory where they assumed that all matter is composed of ultimate quanta or ultimate particles which can be called as anu that is the word that was used interestingly the word kanada itself is some kind a pun because kana is a very very small particle and kanada means the one who eats small particles small fragments or small pieces or whatever and this school actually developed an elaborate theory where they said that two atoms can form a molecule that was called a divino

so let me write that down

so let me start describing the indian atomic school let me write the name in hindi in devanagari script

so that there is no confusion about the pronunciation it is not canada or some such thing it is kanada

so you have atoms which were called anus and you had a molecule which is obtained from two atoms and they were called the venus we know and then if three of them joined that was called

so on and

so forth and they have developed a theory as to how many what is the minimum number of atoms arose that are required to be seen by the naked eye of course in

order to argue you may empirically look at the atmosphere around you if there is a beam of light passing you can see very very small particles what we today understand as the tyndall effect or if you close your eyes and press it hard you will see some very very small strands which are moving

so the atomic school imagine that these are the smallest particles that can be seen and i do not remember exactly they probably said that what one requires is there you know a minimum of three molecules to be there is a counterpart school which said that all matter is composed of five elements in greece it was four elements and what are those five elements these are earth water fire air and what we call as akasha loosely translated in english as ether that is what they did now we should not confuse the word earth to be the earth that we see the word water to be the water that we use for drinking or washing or other purposes fire is not to be confused with the fire that is used for cooking or burning these were representative names earth was supposed to signify solidity water was supposed to signify fluidity

so on and

so forth and there was a sensory organ associated with each of them corresponding to the sense of sight touch audition hearing taste etc that is what we needed and they made an elaborate theory and at this juncture the theory of the five elements is not necessarily in contradiction with the atomic school because it was perfectly possible that these fundamental atoms actually corresponded to the quantal version quantized version of these units of sensory perception in a similar manner in greece if you look at this slide it was democritus who propagated the idea of ultimate constituents of matter

so much

so he made a statement atoms are the only real objects and everything else is a figment of imagination and again there was the complementary school in greece due to aristotle who postulated that all everything that we see in the universe is composed of the four atoms sorry four elements they let the ether out now this is at the realm of the speculation and as i told you today we cannot actually judge either kanada or democritus based on the fact that an atomic theory has been supported by modern experiments because the atoms that they had in mind were completely different from the atoms that we are going to discuss today in a similar manner the concept of a graha in indian astronomy for example is completely different from the concept of a planet that we have today therefore we should not rush to draw conclusions by saying oh the ancient mathematicians ancient astronomers ancient philosophers already knew whatever we are doing today or to jump to the conclusion they did not know what we are doing today because the language and the purport or the purpose are quite different what we should gain by looking at our history the ancient history of all civilizations is to see how sharp the intellect was how good the reasoning was that is what we should put to good use when we study science and that is very very precious that is something that we have to remember in fact you saw evidence for that in your course on gravitation when we saw how people were very able to intelligently estimate distances and size of astrophysical objects now obviously all these ideas remained as undercurrents but once the medieval period started after the renaissance started and experience in chemistry and mechanics started newton actually reignited this discussion and apart from his great principia mathematica where he gave the three laws of motion and also the law of gravitation newton has written a very very important book called the optic optik optic where he described all his experiments on light starting with the experiment on prism the resolution of seven colors dispersion and then of course reflection refraction

so on and

so forth in fact newton even tried to measure the speed of light but he could not and therefore he concluded that the distances and clocks that they had were not good enough to measure the speed of light he did not necessarily believe that the speed of light is infinite then of course came the chemists who started looking at the chemical processes and then they were able to make a great distinction a very important distinction between a molecule and an element rather a compound and an element and thanks to dalton all the way up to mendeleev people were able to write down the periodic table where they had about let us say 80 to 90 elements starting with hydrogen and much of the chemistry could be understood now if you go through the periodic table which you will certainly go through in your chemistry course you can move along the row or you can move along the column you will see that there is a very very definite pattern the way in which the chemical properties behave and therefore it became extraordinarily tempting to actually assume that all these elements are composed of fundamental objects called atoms and the constituents of atoms themselves must be the same for all these elements that was the great idea meanwhile experiments had on the other direction had already shown the existence of electrons to the cathode rays they had shown the existence of the protons through radioactive decay or other observations the other radioactive observations

so one wanted to tie whatever we saw in the cathode ray experiments whatever comes from chemistry and of course the great idea of newton that probably there are very very small objects which are infinitely strong that was the thing

so what we are going to say is that one had a rather vague idea of what an atom is but now we are in a position to actually define that very precisely

so again if you look at this slide you see these are the great names which contributed to actually sharpening the concept of an atom priestly who actually got hydrogen for the first time low visor who was able to isolate was able to isolate oxygen then of course dalton and mendeleev who get the periodic table and from the radioactive side we have the great couple may ray and pierre curie who actually did the number of studies on radioactive materials to the determinant of their own health and becquerel who actually discovered radioactivity all these allow us to actually formulate the concept of atom

so now today when i speak of an atom i do not speak of an object which is infinitely strong or a hot sphere we shall now define atomize which i am showing in this slide atoms are fundamental units of chemical reaction that is they are ultimate constituents of elements what do i mean by ultimate ultimate to the extent that i am studying a chemical reaction there can be some other reaction for example radioactive decay cannot be understood in terms of chemical reactions cannot be classified as a chemical reaction although mericury probably pure curie also got a nobel prize in chemistry those days there was no great distinction between x and chemistry and one important consequence is that when we say that they are fundamental units of chemical reaction they may be or they may not be ultimate constituents of matter at this point we should also remember that thermodynamics gave a very very great push to the concept of an atom boltzmann made its great molecular hypothesis and developed kinetic theory from which for example the thermodynamic relations ideal gas equations etcetera could be understood

so a confluence a coming together of all these ideas from thermodynamics from chemistry from physics give rise to the concept of an atom and these atoms are for real and what is the fundamental question that we have at our disposal what is the structure of the atom

so this long long introduction brings us to the main question that we have and here is a cartoon which is probably picked up from encyclopedia britannica which

gives you what the concept is please please remember that people had seen alpha particles but then they were not able to measure what their sizes are etcetera etcetera

so there are two major conductors contenders one is the

so called plum pudding model due to thomson and another is planetary model i am afraid that there is a typing error here that p should be missing even if p were there it would be silent but in any case p should be missing and the planetary model due to rutherford the plum pudding model which i will come to in a minute was just a model it had no experimental basis whereas the planetary model of rutherford was forced by experiment and obviously there is no wonder that this is what we are going to advocate and we are going to give support to in the rest of the course let us remember that

so if you look at the first figure this is the elementary primitive picture of democritus in 460 bc dalton in 18 not 380 probably kanada was also somewhere in 200 bc or whatever i do not know the age okay

so they imagine very very hot spheres then came all the experimental developments as we said

so we jump let us say from 460 bc to 1900

so we are speaking of 2500 years you have the thomson model in the thomson model what is happening is that this is my full atom is that okay of about 10 to the power of minus 10 meters 0.
1 nanometers and the blue hairs that you see all throughout is the uniform distribution of positive charges and the yellow small bullet like things that you see are the electrons

so the uniform positive charge distribution adds up to your total charge q then then there are these n electrons whose total charge also adds to q with the opposite sign and the atom is overall stable this is the thomson model actually this model can be tested on grounds of stability because one knows that in electrostatics it is impossible to have a stable configuration of charges that means atom would not be stable then you would have to assume a more complicated model where those all is all these electrons are probably moving within the positive soup that is why it is called the plumbing the pudding model is that okay

so electrons are like plums which are there in the pudding okay and probably there is a certain flow of current because of the positive charges themselves but we do not have any information on the details of this model here comes the rutherford model which shows that all the positive charge is concentrated in this purple center which is a very very small region compared to the total size of the atom in fact this is not to the scale because we will see that a the nucleus where the positive charge is all concentrated is ten thousand times smaller than the atom

so we are speaking of something like you know one centimeter and a hundred kilometers or some such thing

so mean we cannot even plot it in a figure like this

so it is highly exaggerated these are illustrations then of course there is a bohr theory which resembles this but it is much more complicated it is sufficient to look at these two figures and we have to decide whether which of the two are correct and this is the experiment which rutherford undertook in order to settle the matter it is not that rutherford disbelieved the plum pudding model it is thus that he wanted to verify in fact nobody thought of a planetary model because as we shall see planetary model although it gets an excellent confirmation from the rutherford experiment gives rise to other problems which people were already aware of it can explain the rutherford experiment but it cannot explain the stability of the atom and atoms have been

there for billions of years many many billions of years that is something they have to worry about

so we are interested in the experiment of the rutherford and this again is a picture taken from the encyclopedia britannica that is written here and this illustrates very well what rutherford did

so probably i should describe this and then go to the experimental detail

so he took a radioactive source which is essential which was nothing but bismuth bismuth has an atomic weight of 214 and an atomic number 83 that means it has 83 electrons 83 protons in our modern language and the rest are all neutrons and bismuth decays by radioactivity and it emits alpha particles and alpha particles carry two units of charge and four units of mass it is essentially helium nucleus that means it is made up of two protons and two electrons and they come up with a rather large energy the energy is about 5.

5 million electron volt this number is very very important for us because in an atom later when you do bohr model or even when you look at the spectroscopic data all energies are in the electro electro electron volt range or a fraction of an electron volt

so we are speaking of energies which are 10 to the power of 6 times larger than the energies associated with the atom now what was the target the target was a very very thin gold foil in fact it had a thickness of 2.

1 into 10 to the power of minus 7 meters and that means it had only very very few layers of atoms that is a very important thing it was not a thick target where my alpha particle could actually undergo multiple scattering that was an unlikely event now what rutherford used in his experiment was a zinc sulphide detector which is essentially scintillation

so what we are saying is that the alpha particle goes gets scattered off by gold atom alpha particles have come from bismuth okay they get scattered off and they go and hit this zinc sulphide target and every time they hit there is a scintillation counter

so what you do is to take a microscope look at scintillation count the number of scintillations that will give you the number of alpha particles that have been scattered at an angle

so with this description let us go back and look at this illustration there is a similar illustration which is there in your textbook also this is a little bit more colorful

so what you have is a radioactive source here bismuth by this time physicists knew the perils of radioactivity

so you have to shield yourself

so there is a nice lead shield it must be a thick leg shield actually probably i don't know of the order of even a meter or a centimeter and this radioactive source emits alpha particles this experiment is delicate and requires care because radioactivity is a completely statistical process you cannot know unpredictable process you do not know when the next dk will take place you can only assign probability that is something that you will study when you look at steady radioactivity it is completely probabilistic

so when this bismuth nucleus decays by emission of an alpha particle there is a small hole made here and alpha particles come through but then you want as narrow a beam as possible

so what you do you put one more lit sheet and you make an even more small beam which collimates and this comes and goes goes and hits or impinges on this yellow sheet which is nothing but the gold foil that is why it is to go into a gold color and then the atom starts getting scattered now these are representations of the the zinc sulphide crystal and you can see that these sort of thing sulphide sheets they can move along unfortunately this illustration is

not very true to the experiment this lead shade cannot be this big it should be much much smaller because the zinc sulphide detectors could be actually moved very close to 180 degrees very close to the beam direction in other words rutherford endeavoured to cover all of 180 degrees coming from this direction to this direction we say 180 degrees and not 360 degrees because by symmetry the probability for alpha particle getting scattered in this direction is the same as probability getting scattered in this direction for the same angle theta that is what we have and these are the movable fluorescence screens that is the experiment and this is a representation of the experimental result we find that particles which are moving farther away very very far away are probably not getting scattered at all far away from the atom whereas particles which are moving very close to the center of the atom are getting back scatter i am going to discuss this experimental result in great great detail because as i told you this is one of the defining experiments in the history of physics like galileo's observation of craters of moon or moons of jupiter or for that matter the observation of halle comet etcetera etcetera or michaelson modelling experiment this is one of the defining experiments and let us see therefore what the import is ok these are the experimental results i want you to present these experimental results and then go back to analysis of this experiment okay first caution this is not exactly rutherford experiment but a different version but the results are qualitatively the same and therefore they are equally good in analysis here you are not using helium alpha particle but you are using proton itself which is 2mb therefore lesser mass and also lesser energy that is what you have and you are scattering the hydrogen nucleus against gold this is against p phosphorus and this is against boron all of them show the same qualitative feature that is very very important on the x axis is the scattering angle or the recoil angle which i am going to write in a minute you start with zero that means absolutely no scattering at all almost no scattering that is called the forward scattering as you keep on increasing the angle you are looking at the hydrogen nucleus or the hydrogen ion getting more and more scattered and when you reach something like 180 degrees the electrons actually sorry not the electrons the hydrogen nuclei retrace their path and this is the differential cross section the cross section is maximum in forward scattering it starts decreasing as you keep on increasing the angle of cross section and what is the cross section angle of scattering what is the cross section for our purposes cross section is essentially the number of particles that come in a given angle of course this number must obviously the fraction of the particles that are coming at a given angle what is important is that for us is that although this is going to be smaller and smaller this is not going to zero that is very very important for us but it is saturating at some finite value and that is something which is very important for us

 so this figure is something that we have to understand
 so what were the important features whatever i told you there
 so i have made a mistake in taping this i am very sorry about it most of the alpha particles are unscattered they just pass through undeflected and the number of alpha particles getting back scattered is relatively quite large and this is going to be a problematic issue for us in order to interpret again i am repeating this must not be an electron it must be an alpha particle in both the lines
 so please pay attention to that okay now let us get back to do some hard analysis analysis of the rutherford experiment
 so let us make a crude picture of an atom
 so this solid line denotes positive charge
 so positive charge is distributed here and all dashed lines denote electrons

that is what we have thompson would say that all the electrons are inside but without being prejudiced we will put some of the electrons inside some of the electrons outside and we will see what rutherford experiment would have to say that is very important for us now if you look at some numbers mass of the electron is 0.

5 m e v by c square

so when we do atomic physics it is not convenient to use s i units it is convenient to use atomic units and the relevant ones

so it is good to use 0.

5 mbv by c square if you really want to convert it into ordinary units you know how to go from electron volt to joule

so you can do that whereas mass of the alpha particle is 4 gev by c squared let me remind you 1 mev is 10 to the power of 6 electron volt and 1 geb is 10 to the power of 9 electron volts

so what are we saying we are saying that the ratio of the mass of the electron to the mass of the alpha particle is what we are looking at is essentially 0.

5 into 10 to the power of 6 divided by 4 into 10 to the power of 9

so which is 10 to the power of minus 4 let us say that is what we have

so that means my electron actually i can write a precise number is eight thousand times lighter than the alpha particle that is the statement that you are making

so it is suppose it is actually equal to one over eight thousand

so if i think of a scattering of an electron and an alpha particle that is if i imagine that the alpha particle goes and hits an electron it is almost as if a huge truck is going to go and hit a small brick or a ball and that means the truck will continue to move at the same speed but the balls will all get scattered and it will hardly affect the motion of the truck or another example which one of my colleagues gave is that of a ball and a small number of pins suppose you put a lot a number of very very small pins and you throw your ball what is going to happen if the ball is very heavy and the pins are all very very light the pins will all go a helter skelter there but the ball will continue to move its along its direction without any appreciable change in their velocity that means in this scattering if at all there is a change in the angle that is the momentum of the alpha particle that should come because of the positive charges

so all scattering is essentially due to the positive charges that is very very important

so for all future purposes we are going to ignore electrons maybe some of the electrons got hit badly and they flew away we are not worried about that however what is important for us is to know that the detector should be able to make a distinction between the alpha particle and the electron because the electron could also cause a fluorescence but zinc sulfide was

so chosen that it will be sensitive to the alpha particle and not the electrons that might be hitting the shield now they are hitting the detector

so detector is important otherwise we may get false cones now let us assume that all the positive charges are distributed over a distance r

so this is a sphere and this distance is r

so when i am making this picture i am not making any particular assumption

so i can always draw a sphere which will enclose all the positive charges whether it is continuous or discrete and this r is the minimum radius sphere of the minimum radius which will encroach all the positive charges

so now what i am imagining is that there is an alpha particle which is coming towards this nucleus or this atom let us come to that what should be the maximum r r cannot be greater than the size of the atom greater than the size of the

atom and what is the size of the atom atom size is of the order of 10 to the power of minus 10 meters

 so if at all the positive charge is distributed it should be r is less than or equal to 10 to the power of minus 10 meters let us assume a positive distribution and let us ask what is it that happens to the alpha particle

 so i have a spherically symmetric distribution and my alpha particle is coming with an energy equal to five point five m e v we can now crudely estimate not very crudely approximately estimate what is the minimum distance that this alpha particle can approach visa with the nucleus the positive charge

 so you have a positive charge plus that which is equal to 87 gold has an atomic number 87 and this has your partition positive charge q is equal to plus 2.

 so alpha particle carries two units of charge the gold carry atoms carry 87 units of charge like charges ripple and therefore there is going to be a barrier

 so what we are asking is what is the minimum distance of approach before it gets turned back that is a question that we are asking

 so that is very easy to compute what will i do i will write 87 into 2 into e square over 4 pi epsilon naught r minimum this is the minimum distance of approach must be equal to the energy of the alpha particle which is 5.

5 mev is the energy this is what we are going to equate

 so we are essentially equating the kinetic energy of the alpha particles with the potential energy when they both become equal then the kinetic energy when the at infinity the total energy is 5.

5 mub when all of it becomes potential energy then the alpha particle would have to trace its path back

 so what we are have is the distance of minimum distance of approach is nothing but 87 into 2 into e square over 4 pi epsilon naught into 5.

5 muv that is what i have now what we have to do is to actually look at this and ask what is its relation visa v r and then we have to worry about what the structure of the atom should be and that we will take up in the next class

 so i ask all of you to work this out and verify this is of the order of 10 to the power of minus 14 meters this is a very important number of for us and we will continue our study in the next lecture you