hello my name is savisaji mishra i am an assistant professor in the department of chemistry and iit kharagpur in next few classes we will discuss about the fundamental particles that constitute everything around us whether you see anything around you whether living beings or non-living things a piece of wood a piece of metal a stone or the dress that you are wearing the food that you ate or even even our own body everything is made up of by same set of fundamental particles these fundamental particles are the building blocks using which the entire universe has been created in this lecture series we will see the properties of this fundamental particles we learn about the stories behind their discoveries and that their properties their experimental validation and their significance in modern science in last 200 years scientists have made significant progress in obtaining a very clear understanding of the structure and property of matter even long ago something about 2500 years ago roughly around 400 bc there are greek philosophers who are thinking deeply about the structure and properties of the particles that make matter these philosophers had great visions that they thought deeply about the subject when they saw some let's say a stone a metal ah a piece of metal the thought that i can break it into half and each of those that broken piece i can take and i can break it further into half and i can continue to break them into smaller and smaller particles until a situation would come where i cannot break this particle anymore then i attain a stage of uncut ability that i cannot cut this matter any further or i cannot divide this matter into half this uncut ability or indivisibility of the matter is what they called as atomio this is a greek word which means that something which is not cutable for you cannot cut cut it further this term artemia gave rise to the term that we know today which is atom that is fundamental particle and it was believed that it is something that cannot be cut further or cannot be divided into smaller pieces these philosophers had wonderful thoughts they were great ideas but they were not backed up with scientific evidence

so there are no experiments which were conducted to validate their hypothesis it was 1808 that the first scientific theory was proposed regarding the structure of the atom or the structure of the matter that was by dalton in his famous dalton's atomic theory which was proposed in the year 1808 john dalton was a british science teacher he hypothesized that the matter is composed of tiny particles tiny indivisible particles tiny indiv indivisible particles and he called them atom he imagined these atoms to be hard hard spheres now he saw that there are different kinds of elements there are iron there is there is platinum there is gold

so he said okay i see different elements and these elements are composed of different atoms and these atoms that constitute an element have identical properties let us see lets see let us imagine that we have element a ah which is which is ah composed of atoms a and we may have element b which is composed of another set of atoms i am showing them as as spheres with dots they are these are b atoms the properties of the atoms that constitute element a are all identical the properties of b atom are a b atoms are again identical but the properties of atoms a and atoms b are very different

so you can imagine there are other elements ah

so let us call them c

so we have now defined three different elements with three different sets of atoms and each atom atom a atom b atom c they have distinct uh physical and chemical properties but then john dalton also saw that we have compounds chemical compounds how do the compounds form the key suggested that the compounds form by the compounds are composed of several atoms with different composition or different ratio

so different atoms of different elements combine with different ratio to form a compound

so let us say i took one of a type atoms i took ah two b type atom and then i take ah one c type atom

so i made a molecule or a compound which is called a b to c because i have one a atom two b type atom and two b type atoms and one c type atom this is how the compounds form this is what john dalton professed then he also saw that there are chemical reactions during which the atoms change from one compound to another

so he described the chemical reactions chemical reactions is the place where the atoms are exchanged exchanged the atoms are excellent let us see you have let's suppose i have a molecule which is a b c and then i have another molecule which is b c and they are reacting what i do get is let us say i get a b two plus c two if you look carefully you would see that the number of atoms of a or b or c type in the left hand side at exactly equivalent to the number of atoms of a b and c type in the right hand side during this chemical reaction neither i created any new atom nor i destroyed any atom what i essentially did was to exchange an atom from one molecule to another molecule

so this is what chemical reaction was all about in daltons hypothesis it was an interesting theory it explained ah several experimental results but it also had a few drawbacks for example it could not say why the atoms of element a and atoms of element b have different properties

so different atoms different atoms have different properties dalton's atomic theory suggested that all the atoms of element a have same identical property all the atoms of b have same properties but atom b and atom a they have this different properties but why should they have that that was not explained by dalton's atomic theory then here for example i wrote down this molecule called a b to c suppose this a b to c molecule exists what dalton's atomic theory did not explain is that why a certain composition or a certain ratio of these elements form a particular molecule why the other compositions are not stable why do molecules have certain certain composition and why not some other ratio these questions were not explained by john dalton's atomic theory again there were some new experiments which ah took place after dalton's atomic theory was was proposed from which it was known that atoms absorb or emit electromagnetic radiations but john dalton's atomic theory could not explain why the atoms should absorb or emit electromagnetic radiations dalton's atomic theory was was in an interesting hypothesis which described some chemical some experimental results however it had many limitations in mid 1850s there were a series of new experiments which were carried out that showed that the atom dalton's atomic theory had several flaws we will discuss about those experiments uh some of those experiments they are called cathode road cathode ray discharge tube experiments which were carried out with in during mid eighteen fifties michael faraday was the one among the pioneers of of this kind of experiments this cathode ray discharge tube experiment will discuss about the experimental setup

so it is essentially a large glass tube that you can see ah it is connected to a vacuum pump using which you can evacuate the gas which is present with within this discharge tube then it has got two metal plates let us draw this way these two metal plates were connected by a potential difference

so a voltage was applied

so we we use this as positive elect positive terminal this has negative terminal

so my this is this is negative terminal this is positive terminal the negative terminal is called cathode the positive terminal is called anode one thing that you see is that i have kept a hole with in the anode plate the plate which to

which the positive terminal of voltage is connected to there are two important things here first we created a vacuum
so that means very low pressure exists low pressure and the second thing is that we are going to apply very high voltage when you do that we see in this cathode ray discharge tube experiments that several rays they originate from this cathode terminal and they travel towards the anode
so you would see several rays and these rays are called cathode rays you cannot see them see see this cathode rays in naked eye to to be able to visualize them what they did was create a hole in this anode plate
so that this rays can pass through this hole and come to the back side of this anode plate and will hit on this glass surface of this discharge tube before that this glass tube the side of this glass tube was coated with some phosphorescent material typically one uses zinc sulphide coating to have this phosphorescent coating the property of phosphorescent material is that when charged particle come and hit them you would see a bright flash a spark you would see here a bright light you would see that actually would be a way of visualization that this rays which we are calling cathode rays they have come and hit this surface this glass surface will discuss some properties of this cathode rays first was it was observed that they always travel in straight line they always travel in straight line as it was seen they originate from cathode and they travel towards anode
so that is why they are called cathode rays because they they originate from the cathode terminal and this rays also have kinetic energy how can we know that they have kinetic energy how can i know how can we know that if we can fix a propeller a small propeller here then you can see that these rays will hit on this propeller and then this ah the fans will start rotating
so you would actually convert the kinetic energy of this rays which are called cathode rays into mechanical energy these experimental setup was taken by another scientist j.
j thompson and he modified his experimental setup slightly instead of a a cylindrical tube that you saw in the previous ah picture j.
j thomson a british scientist he is cathode ray tube had a different shape it looks like an a bottle with an elongated neck we'll see why he has adopted this kind of shape for this for his experiment again like a typical cathode ray discharge tube we have one cathode terminal
so a metal plate cathode we have one anode here with a hole at the center and the two terminals are connected to very large potential difference
so this is negative this is positive this is my anode terminal first it was this glass chamber was completely evacuated and then a high voltage was applied across these two terminals at the cathode and anode plates when you do that of course we know that that rays will start from cathode and they will travel towards anodes
so androids because of the presence of this hole the rays will come and hit this screen this screen is again ah coated with phosphorescent material
so that when it hits the screen we get a spark let us call this point a all right
so this is what we had obtained from regular cathode ray discharge tube what jj thompson did was he tried to investigate the properties of this cathode rays
so what he did is he applied another electric field along in this manner
so he applied he subjected this cathode rays to his to another electric field he used a particular polarity let us assume that he we defined it this one this is the positive terminal this is the negative terminal when this electric field is applied what we saw was that this cathode rays which were going in straight line they started getting deflected and their deflection was in a particular

direction
so they started from here and they felt the presence of electric field and then they started getting deflected and by getting deflected they hit the screen at a different point b instead of point a
so these cathode ray beams were actually bending in the presence of electric field we know one thing is that like charges repel each other and opposite charges attract each other
so what we see here is that this cathode rays are getting attracted towards positive terminal and they were getting repelled from the negative terminal this suggested that this cathode rays are negatively charged he then switched off this electric field and what he did was to introduce a magnetic field let us assume that he used ah a magnet in this manner and when he used this magnetic field he saw that this cathode rays
so ah before he introduced the magnetic field he switched up the electric field
so that means the ray cathode rays instead of hitting the screen at point b they came and hit the screen at point a now again by introduction of a different film this time it is magnetic field the cathode rays again get deflected but this time they are deflect getting deflected to another opposite direction let us call that where the point where the cathode rays hit the screen let us call that point c
so now we using these two setup one was electric field another was magnetic field one was electric field second was magnetic field by using these two different fields jj thompson showed that this cathode rays are getting deflected in opposite direction now we have got two different ah fields whose strength we know because we are doing the experiment on that now if we think why these cathode ray beams are getting deflected we would think that ok of course they are charged particles in addition to their charge they also will have some mass because if a particle has different mass you would require a different amount of field to deflect it by a certain magnitude
so the deflection the degree of deflection depends on two properties of the particle one is charge and the other one is mass what jesse thompson is did is that he adjusted the electric field and magnetic field now he switched on both electric field and magnetic field simultaneously and he adjusted the strength of the electric field and the magnetic field in such a way that the cathode ray beam instead of getting deflected towards point b or getting deflected towards point c was brought again back to the straight line and it can be achieved by carefully tuning the strength of the electric field and the magnetic field
so we have two field strength that we can tune and we have two different properties on which this deflection depend on the basis of several careful experiments ah it was obtained that these particles the cathode rays they have a fixed value of e by m which was determined to be 1.
758 into 10 to the power 11 coulomb per kilogram right this is very interesting
so he saw he could get an estimation about the charge per mass ratio he repeated this experiment by changing this metal from one metal to another metal by using different metals for cathode and anode and he saw that no matter which metal he is using as cathode and anode the e by m ratio remains the same for all metals this is very interesting because to begin with this cathode ray discharge tube was completely vacuum there was there was nothing inside this tube except for the cathode and anode terminal now by passing high voltage some particles which have certain mass certain charge certain value of charge per mass ratio
so these particles they are created and they they these these particles have same e by m value irrespective of the nature of the material
so that means there are two things one is that now john dalton's hypothesis said that atom was the smallest building block the tiniest particle that you can

see but here thompson said that ah no there is another particle which is negatively charged and this negatively charged particle is present in all metals different elements

so there exist another particle which is fundamental in nature and is present in all the metals that it tried out

so he suggested

so there is something other than atom which is which is a fundamental particle now what he obtained from this experiment was the charge to mass ratio but he neither had an estimation about the charge of this particle nor he did he have an estimation about the mass of this particle and this was resolved by another set of experiment which this time it was carried by ah robert milikan this experiment is very interesting it is called millikan's oil drop experiment the experimental ah setup some looks something like this you have a large ah chamber ah which is fitted with two metal surfaces you have one metal surface at the bottom ah one towards the ah top and the top metal plate has a hole it's a tiny hole at the center of this at this plate to this chamber millican connected is some thing that is called an atomizer this is an atomizer atomizer is nothing ah but a mechanism with which you can create small particles it is also used for example in the perfume that you use you press the perfume and then you see small particles coming out of the perfume and there is very very tiny particles

so this is this has similar mechanism and this atomizer was connected to some oil

so when you press this atomizer you actually create lot of oil drops here in this part of the chamber and these oil drops because of gravity they will come down and since there is only one small hole these oil drops will come out of ah this this region of the chamber only through this hole and they will travel downwards because of gravity because of gravity which is pulling the oil drops down they will come down what he did is was to introduce a small telescope here what would you what would he do with this telescope he can look at the motion of these oil droplets when they travel along this direction through this telescope by doing this he can monitor how long these oil drops are taking to travel in the distance from there he can have an estimation of the mass of these oil droplets that his autoimmune atomizer is creating

so we have an initial estimation about the mass of these oil droplets all right ah this was not the end of this ah arrangement he connected these two metal plates to a potential difference ah let us say that we have the there is a battery here

so we have a pos with the positive terminal this side negative terminal this side of course when i apply a potential difference if this oil droplets are charge less this is not going to affect them they will simply go by a gravity it is not only gravity which is actually playing a role there is also a role of viscosity because we are creating these small droplets and when they go down in the air there is a viscose force but for our discussion we will ignore that we will consider that only because of gravity these oil droplets are coming down now what he additionally did is that he introduced x-ray in this manner when you introduce x-ray x-rays are radiations with extremely high energy they have

so much of energy that the they can ionize the gas present within this chamber

so when you apply the x-rays the x-rays hit the gas molecules and they ionize them and when they ionize them these gas molecules release negatively charged particles and these negatively charged particles stick to our oil droplets

so now i had this oil droplet but this is now sticking with some negatively charged particles right now after introduction of this x-ray this oil droplets are no longer charge less now they have a certain charge and i am applying an electric field depending on the polarity of the electric field that i have

chosen now you can see because these are negatively charged oil droplets they would be attracted towards the positive plate
so they will go upward
so now there is another field that another force because of electric field which will pull this charged droplet upwards and gravity is anyway pulling it downwards now we have two different ah forces the gravitational forces can be written down as mg and the electric forces ah forces due to electric field can be given as q u q e e is the strength of the electric field that i am applying and q is the charge of this oil droplet now if i use a very very strong electric field which is much stronger than gravitational pull then of course you would imagine that these oil droplets will suddenly go up and will get will stick to the upper plate if i use a very weak electric field the gravitational pull will will win and this oil droplet will come downwards instead of going upwards but if i can carefully manage or carefully tune the strength of the electric field i can attain an equality where q e the upward pulling force because of electric field will be now equal to the gravitational pull which is mg g is a universal constant i know that mass of the oil droplet i have an estimation already e the strength of the electric field that i know because i am doing the experiment the only unknown that i am left with is the charge of the charge on this oil oil droplets which are called q
so he tried out different values of electric field and he saw that he was getting some interesting values for the charge
so he was getting sometimes he was getting one point six into 10 to power minus 19 coulomb sometimes he was getting 3.
2 into 10 to the power 9 minus 19 coulomb sometimes he was getting 4.
8 to 10 to the power minus 19 coulomb and
so on
so forth if you look carefully at these numbers you see that all these numbers are integer multiple of this value
so what he was getting as charge as the integer multiple of 1.
6 into 10 to the power minus 19 coulomb from his experiments he concluded that the base elementary value of this ah charge particle is 1.
6 into 10 to the power minus 19 and if two of these particles are sticking to the oil droplet he is getting three point two and if he is get three ah of these particles are sticking to this oil droplet he is getting 4.
8 into 10 to the power minus 19 coulomb and
so on and
so forth but the basic value the fundamental value comes out to be 1.
6 into 10 to the power minus 19 coulomb
so he suggested
so this must be the charge which is which which we call it q and we call that the charge of the electron must be 1.
6 into 10 to the power minus 19 coulomb since already we know that these are negatively charged we can use a negative sign here from previous experiment that is the experiment of j j thompson we had an estimation of e by m as 1.
758 into 10 to the power 11 coulomb per kilogram now we have an estimation of e we have an estimation of e by m from these two equation i can get this well the value of n which is 9.
01 into 10 to the power minus 31 kilogram which is now the mass of this fundamental particle which has a negative charge of this value 1.
6 into 10 to the power minus 19 and this particle we called electron if you look at this the mass of this electron it it turned out that it is several thousand times smaller than the smallest atom that was known that is the hydrogen atom
so dalton's hypothesis was at was that the atom is the smallest indivisible

particle there is nothing inside the atom atom is the basic building block but because of the experiment of jj thompson and robert millikan it turns out that all all elements have these electrons which have a particular value of mass which is much smaller than the mass of an atom

so therefore there exist a particle which is smaller than than than an atom and these particles have negative charges now this was wonderful however there is one problem the problem is that these fundamental particles which we call them electron are negatively charged but atom as a whole is charge neutral

so there was a need to propose a new model for atom and this is what was done by ah jj thompson in his famous plum pudding model of atom he said that okay ah the atoms undoubtedly have electrons which are negatively charged particles

so to counter these negatively charged particles there must be a positive charge in the atom

so imagined he imagined that atom is a atom is spherical he said that okay the positively charged positive charge must be distributed uniformly over the atom

so the positive charge is uniformly distributed

so there is a positive charge density over the atom this is what they believed and then electrons which are the negatively charged particles electrons are embedded into the atom or the positive charge to the positive charge density he imagined the item to be something like this as is shown here the atom is spherical in shape the green color shows the positive charge distribution and then blue colored dots that you see they are electrons which are embedded ah randomly ah in this positive charge distribution uh of the atom he uh likened it to the famous british desert plum in pudding plum pudding model this is what is called plum pudding model which can also be ah imagine in terms of watermelon you see the watermelon the flesh the red flesh of the what the fruit part of the watermelon can be imagined to be the positive charge distribution and the seeds the black seeds that you see are essentially the electrons which are embedded into this fruity part of watermelon you can call it plum pudding model or watermelon model this was a revised version of the model of atom which was proposed by jj thompson which is this one step advancement of dalton's atomic model because dalton did not distinct did not imagine the presence of electrons he just said that atoms are hard spheres but then there were a series of experiments uh which were carried out that suggested that jj thompson's thompson's plum pudding model is is not that accurate it has got its flaws we will look at those experiments now one of one such experiment was carried out by ann stratherford which is called which is famously known as rather force gold foil experiment that was carried out in the year uh 1911 the experimental setup is ah shown somewhere something like this where you have a large circular screen you have a large circular screen which is coated with phosphorescent material again you can use zinc sulphide

so this the inside is is is coated with phosphorescent material he has used a gold foil here gold foil is a it's a it's a very thin foil that is kept in this way it's just like a piece of paper he has a source of alpha particles you can imagine it like a gun which emits alpha particles alpha particle is simply doubly charged ah helium

so these are positively charged particles with with known masses

so what he does is that there is a gun in this source uh that shoots alpha particles and these alpha particles they pa they are passed through a lead plate and then these alpha particles they come they hit the gold foil like this and if they pass through the gold foil they will come and hit the screen at this point this as i said these alpha particles are positively charged particles and this is coated with a fluorescent phosphorescent material ah the characteristic of this material is that when it is hit with a charged particle you see a spark you

see a bright light here
so this experiment was carried out ah in dark room all right
so what he did is that he started shooting ah alpha particles after alpha particles thousands and thousands of alpha particles and his try to see where these alpha particles are hitting in this screen what did he observe he observed first the most of these alpha particles most alpha particles they go undeflected unreflected means these rays simply travel in straight line as if there was no barrier that was one of one primary observation that most of these alpha particles are just going through the gold foil as if nothing nothing is there in in on their way but he also saw a small number small number of alpha particles they undergo small angle deflection what is that when these alpha particles come they hit here this on the gold gold foil and instead of going straight they go like this and they hit the screen at different point or they can also it can also go and hit somewhere but this happens only in some small number of cases very rarely but it's a significant observation rarely there is a phenomenon of bouncing back the ray the alpha particles simply bounces back
so that means it goes and hits the gold foil and it comes back or it undergoes a large angle deviation deflection and it hits the screen somewhere in this region is either bounces back or very large angle these are the three primary ah observations that he made first most alpha particles go through this gold fall on deflected as if this fall doesn't exist as if there is no barrier on their path a small number of alpha particles they undergo small angle deflection that means some something is obstructing their path and only rarely they calculated about one in twenty thousand one in roughly twenty thousand ah alpha particles they actually either bounce back or undergo very large angle deflection now this this was an interesting observation but it required some amount of thinking as to what might be happening now you imagine that this is your gold foil this is very thinly thin foil
so there is only if the thickness is extremely small in the order of a few nanometers you can imagine uh in the following way imagine that this is your gold foil that you saw that was standing on within the circular loop and i am showing you the uh cross section from from this direction you see that well the gold atoms since the foil is very thin i imagine only a few layers of atoms are present i do not know the structure of the atoms but i know that this gold foil is composed of some atoms let us first imagine if dalton's atomic theory were true what would have happened if
so i am shooting this alpha particles i am shooting this alpha particles if daltons atomic theory were correct would have seen that these ah hard spheres would have deflected this particle
so most of most of the times the alpha particles would have come back but that was not the case what was observed is that most of the times these alpha particles they pass through that
so they were going through like this since most of the times they were going through his first conclusion was that atom has a lot of empty space that was the first conclusion because ah these alpha particles felt nothing they just simply passed across the gold falls as if no nothing was there
so it must the atoms must have lot of empty space this is what he concluded fair conclusion the second thing is that this what what he saw is that when some cases when they were the alpha particle was coming it saw something we do not know what but it saw something because of which it got deflected instead of going straight it went it went i went ah this way it under went some deflection why did it why would that happen that could happen if remember these are positively charged particles they have certain mass this ah alpha particles this positively charged with certain mass particles they are going and they are

getting deflected it might have happened that there are some positive charges in this in this atom which is actually repelling the alpha particles that are coming and these positively charged particles have certain mass because of which there is a collision and then there is a deflection

so from this it turned out that well the atoms atoms have some positively charged particles with some mass right that is why you see some deflection but what was the third observation that was only rarely 1 in 20 000 times that you saw that this was the ray that was coming was getting completely was was bouncing back when you did when would that happen the complete bounce back will happen only when if if the ray the sorry the alpha particles that were traveling hits a massive charged particle positively charged particle if it hits directly then the complete retract retracing of the alpha particle pathway can be observed

so from the second observation it was it can be concluded that atoms have positively charged particle with with mass and these positively charged particles with with mass they are concentrated at one place only when the alpha particles hit this particular place where the charge and mass are concentrated you see this bouncing back by carrying out this experiment several times he concluded that by then it was known that depth that a typical atom had the size of 10 to the power minus 10 meter

so this positively charged core with mass must have the size of 10 to the power minus 15 meter and this core that we call which has which is where all the masses are concentrated and the charges are concentrated it was called as nucleus

so from rudder force rather force gold foil experiment it was uh learnt that the atoms have a core which is known as nucleus that where the charge and the mass are concentrated

so now we can propose rather force atomic model

so he imagine that that atom has a central place the nucleus which has which contains the mass and the charge positively charged and the electrons they go around the nucleus in in fixed orbits ah we can imagine we can we can reimagine this experiment by considering that ah what is what would be the outcome what would be the observation if jesse thompson's plump pudding model were true plump pudding model would have said that the positive charge is uniformly distributed if the positive charge were uniformly distributed you would have seen that the most of these alpha particles should have got deflected but that was not the case since only a few particles got deflected and very rarely you saw a complete deflection it was said that the plum pudding model was wrong and here comes a new model for atom where which says a positive charge of the atom is centered at a core place that is called nucleus and the electron which carries the negative charge they go around the nucleus this is the story of the discovery of nucleus in the next class we will discuss about the internal structure of the nucleus we'll see that the nucleus is composed of a new neutrons and protons and will also learn about the stories behind their discoveries thank you you