Nuclear Physics Fundamentals and Application
Prof. H. C. Verma
Department of Physics
Indian Institute of Technology, Kanpur

Lecture - 1
Brief Overview of the course

So, this is our nuclear physics course and this course is being recorded at a very important time. You know nuclear physics is started with few experiments and some theoretical modeling and we have just completed hundred years of that. So, this is an auspicious occasion, to start this particular course. As you know all the matter is composed of atoms and atoms are made of protons, neutrons and electrons. All these protons and neutrons are in a small volume which we call nucleus and electrons go around that.

So, but how people came to know about this so, as I said hundred years ago it was nineteen hundred and nine and two gentlemen Geiger and Marsden. They did some experiments. The experiments were, alpha particles were bombarded on some metals and then some of the alpha particles came back to towards the source itself, that means the scattering was ninety degrees, which we will call back scattering. So,, some foil was there I will show you a slide.

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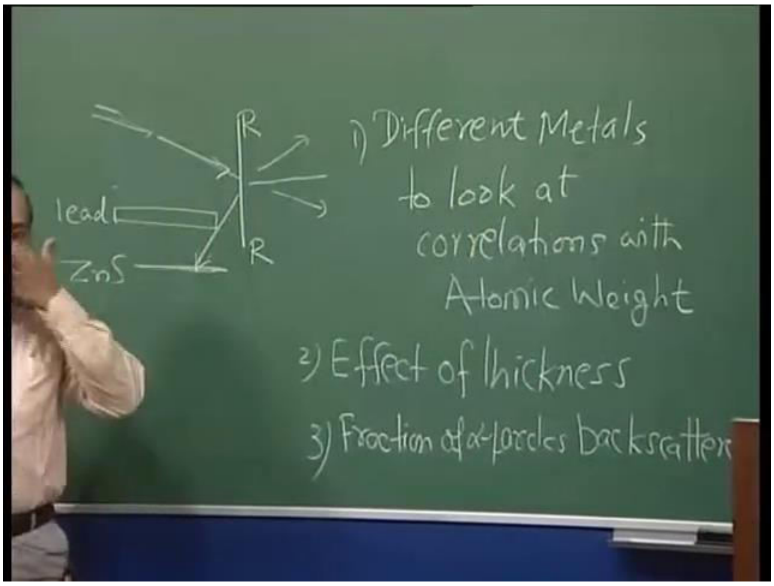

The foil, some foil was there a metal foil and alpha particles were going and these alpha particles interacted with these atoms here and then they came back, some of them. Most of them were going in the forward direction, but some of them came back and from there it all started. So, I will just show you a slide, which I have on the power point where the diagram that is published in that particular paper that is there. You will come to see how that experiment in nineteen hundred and nine was performed.

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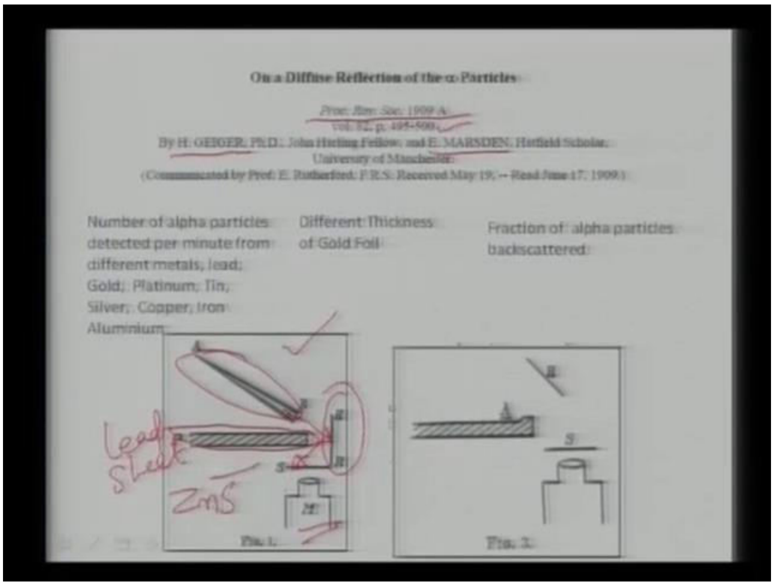

So, here it is you can see this slide here and it is the title of the thing was on a diffused reflection of the alpha particle. It was published in proceedings of royal societies in 1909 A, volume 82 page 459 to 95 to 500, by these people Geiger and E Marsden. This is the first diagram and in this diagram you can see this is their alpha source. It contains some material which had, the which we are emitting alpha particles and this P, this is lead sheet, this was lead sheet.

Here this S this is a zinc sulphide screen and the property of zinc sulphide screen is, if you bombard alpha particle on this it gives scintillations which one can see. So,, this microscope is here to see those scintillations and this R R that you can see here, this R R this is a metal foil. So,, the alpha particle will go from this source and will fall on the metal and then will come to this zinc sulphide create a scintillation and that scintillation will be seen in the microscope.

So, this is the diagram and with this diagram, with this kind of experimental arrangement what experiments they did. So,, let me draw this diagram on the black board once again, so that I can explain it better. So,, I am going the blackboard and showing you this diagram in a better fashion. So,, you have this lead sheet, let me do it here itself, this is a tube, this is a tube and from that tube alpha particles are coming falling on this R R that is metal. Here is that zinc sulphide screen, which is used for detecting whether the alpha particle is coming or not, where it is coming.

From here one can look at it and no direct alpha particle should come. Therefore, you have that lead sheet. So, this is the thing now the alpha particle falling here, most of them will go in the forward direction. But then what we are looking here or these Geiger and Marsden were looking, were if any alpha particle come back, back scattered, if any alpha particle is coming in this side. So,, that is, that was the goal and what they did, they did find some alpha particles coming here making some scintillations here. They counted all those scintillations and then many things they did.

So, what kind of things they did, first was to use different metals foils, foils of the same thickness and material different. So,, they used lead, they used gold, they used silver, copper, eight materials, eight metals, different metals of the same thickness they looked at. That time, there was nothing like z proton number or atomic number or those things, this was beginning of nuclear physics. So, but atomic weight was known, so from hydrogen how many times different atoms are heavy, that was known from chemistry. So,, they were trying to see if these number of alpha particles are related to the atomic weight.

So different materials copper, silver, gold, lead, have platinum, have different atomic weights and for that correlation they use this different metals. So, that was one part of the experiment. Different metals to look at correlations with atomic weight. Then the other part of the experiment was to have, what is the effect of thickness, is it coming from the surface or it is coming from interior. If it is coming from surface, then you increase the thickness of that metal foil and the number of alpha particles detected will not change because, the surface is only the surface.

But if it is going in the interior of the metal foil and then being getting scattered from there, then if you increase the thickness then you will have different number of alpha particles. To look at that effect what is the relation between number of alpha particles that back scatter and the thickness of the metal foil, they used gold. They had identical foil, so they first put one foil and then did the experiment. Then, they put two foils and then they did the experiment then, three foils then they did the experiment and this way the thickness variation was studied. So, that was the second part and the second part was effect of thickness.

Then the third part was they just wanted to get quantitatively, how many alpha particles that are falling on the plate are getting back scattered. So, some of the alpha particles are going this side, some of the alpha particles are going this side. So, of the total number of alpha particles that are falling on this metal plate, how many what fraction is scattered in this half, this side. So, for that they did some experiments, for that the setup also was slightly different. I am again going back to power point slide and I will show the set up for this third part of the experiment.

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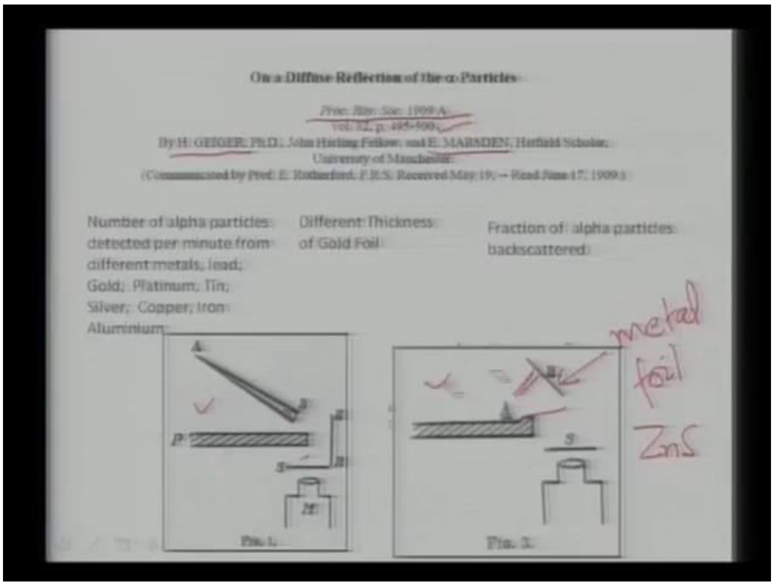

So, look at the power point slide, the same slide once again so, this is second one, this is figure three of that paper and this is the experimental set up for the third part. Here the radial source is a very small point source, this radium compound was deposited in a very small area and that was used as a point source for alpha particles. Here is the metal, this is the metal and here is that same zinc sulphide screen and so on. So, since it is a point so like source and knowing how many milligrams or micro grams of this radium compound is taken and what is the activity from that one knows how many alpha particles, total number of alpha particles are emitted.

Then from geometry, how many of them are falling on this plate that can be calculated. Then from there how many are detected here on this zinc sulphide plate that is that is the experiment counting the scintillations and counting the number of these things. So,, the geometry of this figure and this figure is different because the purpose was different. Here the purpose was to get the fraction of alpha particles so, the total number of alpha particles going and how much of that is scattered in this direction.

So all those things were seen and based on this what they found is that, of the total alpha number of alpha particles that are going on a metal plate about one in 8000, about one in 800 alpha particle back scattered. That means, if I take this number seriously one in 8000; that means 7999 alpha particles were gone in the forward direction. They crossed the metal and appeared on the other side and one was so largely deflected; that it came back towards the source side, so that was the experiment. So, this was the third part right, so the third part of the experiment was that fraction of alpha particles back scattered.

Now in this paper, if you read this paper they have expressed a surprise that alpha particle can come back because, before that the model that was in practice was given by Thomson that, all this positive charge in an atom is distributed in the entire volume. Similarly, the negative charges are also distributed in ((Refer Time: 12:30)) or discrete. But the things are distributed and if it is distributed the electric fields are quite weak and alpha particle being a heavy particle and the velocities with which this alpha particle comes out of the radioactive material and those velocities are quite large.

So, such a heavy particle and with such a large velocity so, lot of momentum so, that is going into some kind of a smeared cloud type thing and then coming back. Some surprise was expressed, but no explanation was conceived that time. 1 year later Geiger did some more experiments and in that experiment the studied that forward direction alpha particles. The alpha particles which came through the metal foil and appeared on the other side so, at what angle the most of the alpha particles were coming and how that was distributed, so those things were done by Geiger.

Then Rutherford, in schools you must have countered this phrase Rutherford’s gold foil experiment or alpha particle experiments popularly known as Rutherford’s experiment of bombarding alpha particle on gold foils. ((Refer Time: 13:56)) experiments are done by Geiger and Marsden, but then the genius of Rutherford. Of course, they were in Rutherford's group only. But the genius was that, from that data, Rutherford could see that this large deflection can come only if there is a large electric field that is encountered. Large electric field cannot be created by a distributed charge and therefore, the charge must be concentrated somewhere which can produce a large field. You also know that, if you have let us say you have a spherical charge distribution.

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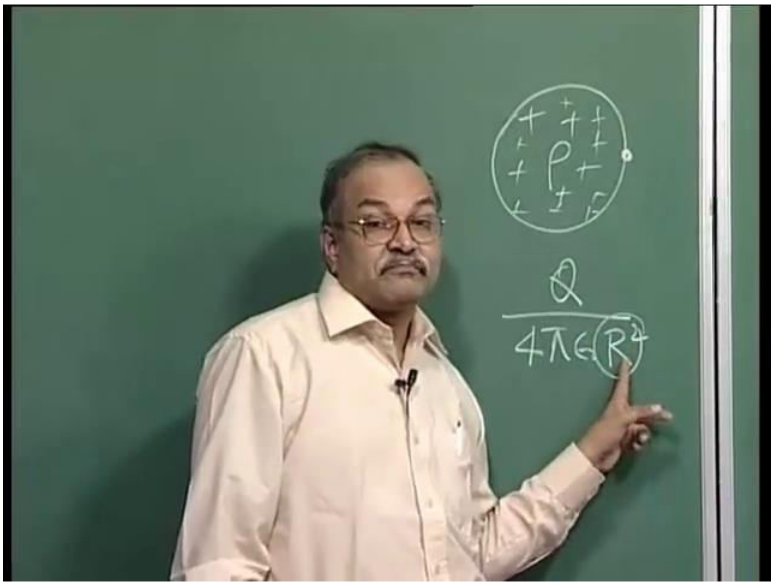

So, if we have a spherical charge distribution some rho, some positive charge, everywhere here, here, here, here, here and then at this surface, if you look at the field, that field will be some Q divided by 4 pi ((Refer Time: 14:54)) naught capital R square. Then inside you know, at the centre the field will be 0 and as you go towards this surface, the field will increase and it will reach this.

The field everywhere will be less than this, if you go outside then also the fields is less, if you go inside then also the field is less, at the surface where it is maximum there it is, this much. Then if this R is more or less known then ((Refer Time: 15:26)) minus 8 centimeters. The, so if you do anything with that radius with that particular distance, the maximum field will be utterly incapable of creating such large deflections.

So, the Rutherford thought of this model or came out with a new model, if you have large electric field, which can deflect the alpha particle by more than ninety degrees, this

R has to be very very small. If it is very very small that means, entire at least one kind of the two positive and negative, one kind of the charge has to be concentrated in a extremely small volume. So, that was Rutherford's model that he gave in 1911, that original paper reference also I am going to show you on this power point slide.

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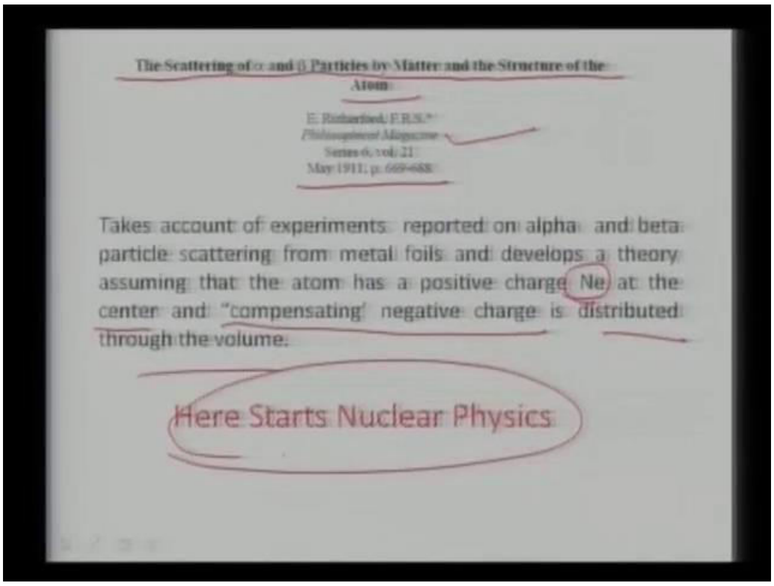

This is scattering of alpha and beta particles by matter and structure of the atom. This is May nineteen hundred and eleven and this is in philosophical magazine by Rutherford, volume 21. This takes a count of experiments reported on alpha and beta particles scattering from metal foils and he ((Refer Time: 16:47)) theory. Then he in the theory he assumes or he establishes that atom has a positive charge, capital N times e at the centre and compensating negative charge.

The whole atom is neutral therefore, if there is a positive charge Ne at the centre then, the negative charge also has to be there and that must be distributed throughout the volume, that must be distributed throughout the volume. So, that when the alpha particles encounters the charge Ne at the centre, those negative charges do not create big field to compensate or to reduce this large field. So, that was the kind of thing he suggested and there starts nuclear physics, there comes nucleus first time into the scientific world and there from there starts this nuclear physics.

So, then in that particular paper Rutherford's developed the full theory, that theory is now by any standard class 12 or say B.Sc first year, so physics is only involved. So, if there is a positive charge Ne at the centre which he assumes as a point charge. He writes in this paper anything less than 10 to the power minus 12 centimeter will be assumed as a point. So,, with that kind of estimates of the lengths in mind, he assumes a point charge at the centre, negative charge is so distributed that for those particular alpha particles which are coming close to this nucleus. The negative charge does not make any much difference considerable difference, then he calculates the ((Refer Time: 18:38)) orbit hyperbolic orbit. If positive charge is here and then some other positive charge repulsive force.

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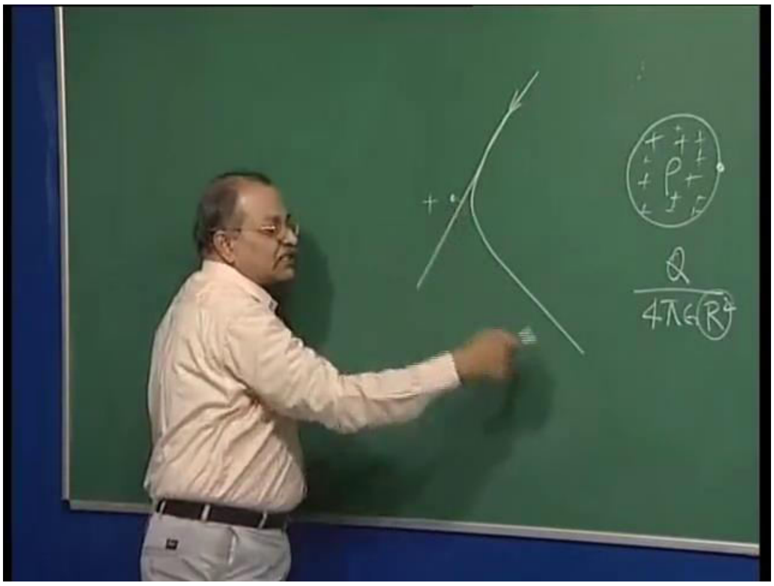

That comes, so if you have a center and you send some charge positive charge here and some positively charged particle, it will be repelled and will go in a hyperbolic path. Then, by what distance it is missing, the centre that will decide how much will be the reflection. If it is missing with a large distance here, it will almost go straight and if it is, it is encountering it closer then of course, the deflections will be large. So, he makes all kinds of calculations of this hyperbolic orbit and he comes out with an equation which tells that all right the number of alpha particles, which are scattered through an angle between theta and theta plus d theta.

What should be that number and on which quantities that number should depend? For that he writes an equation he derives an equation in this 1911 paper, which we today now as Rutherford's scattering formula. So, I am not writing the formula, but I will just show you what are the conclusions, from that formula that one can obtain and that is written in the 1100 1900 and 11 paper. So, I will just read it from that slide once again.

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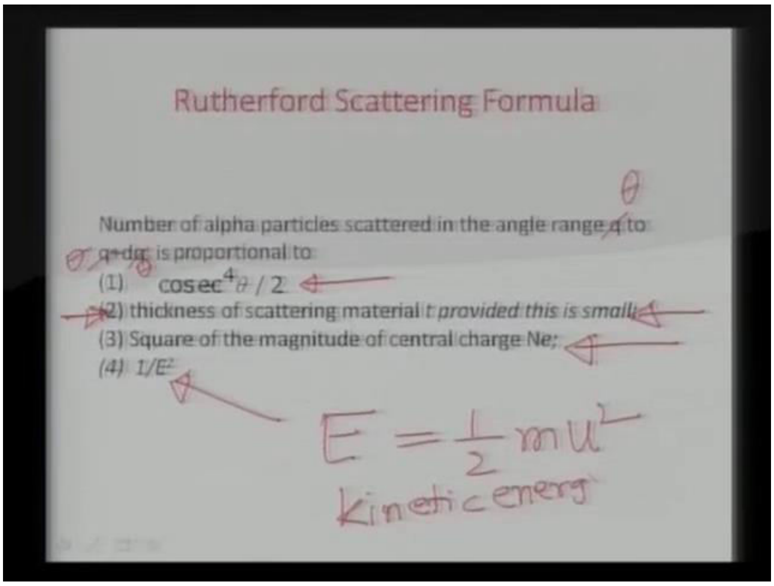

So, the number of alpha particles scattered in this angle, it is theta, read it theta here, read it theta here and read it d theta here. You know this once you go into the symbol format q becomes theta. So, this number is proportional to cosec to the power 4 theta by 2. Let me just explain little bit more what is number. Number of alpha particles scattered in the angle, range theta to theta plus v theta.

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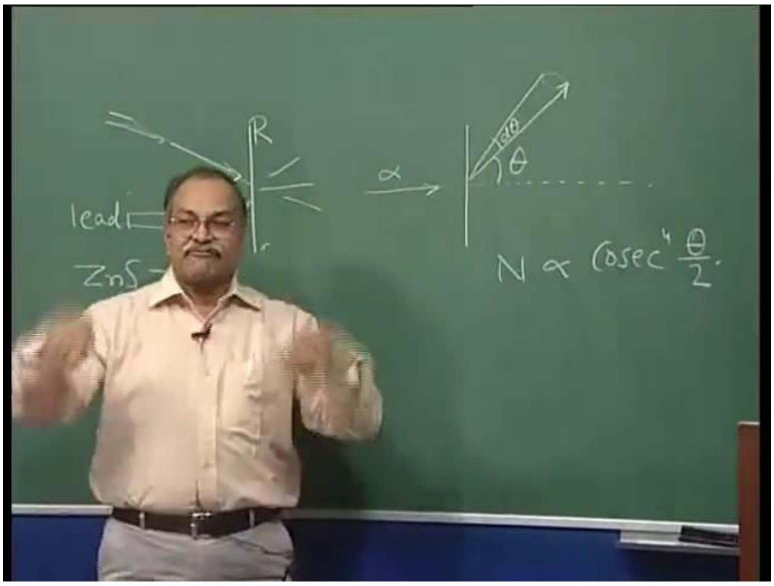

That means if I write it here on the board, if this is the metal foil and this is the direction in which alpha particle is incident and if the alpha particle emerges in this direction at the end, then this angle is theta. If you find how many and this is theta plus d theta, so this cone, so this cone how many particles are going in this direction. That is the number which he is looking for and that number is proportional to cosec 4 theta by 2. So, that means if you change this and change this theta put your detector here, put your detector here, put your detector here, put your detector here, you are changing theta.

So the number of alpha particles that you will get in the same detector, the same angle d theta that will depend on theta as N will be proportional to cosec 4 theta by 2. So, that was one conclusion from that Rutherford back scattering formula. Similarly, look at the power point again, ((Refer Time: 22:24)) other conclusion was second, thickness of the scattering material t provided, this is small, this one, this one. So, the number depends on the thickness of the scattering, what is scattering material? It is that metal foil on which you are bombarding alpha particles and looking for the scattered alpha particles.

So, number of alpha particles is proportional to the thickness of the scattering material, that means from here, that means this thickness, this metal, thickness of this metal, that thickness, if you write t then N is proportional to t. Remember it is not time, we are not taking time. Of course, it will also be proportional to time, for how much time you are collecting the data. If you collect it for 5 minutes you will get some count, if you collect it for 10 minutes you will you are going to get double the counts. So,, it is proportional to time also, but this t here is written for thickness. Then it depends on other things one is, back to the power point slide, one is square of the magnitude of the central charge capital Ne, he writes it capital Ne, today we write capital Ze.

But in that Rutherford's original paper, he writes central charge capital N times e, so square of the magnitude of the central charge. Magnitude means whether it is positive charge, whether it is negative charge little he establishes that it should be positive charge. But in the original paper positive, negative both could. As far as the scattering formula is concerned both will give the same result, so square of that. Then finally, 1 by capital E square, what is capital E, capital E is half m u square or m v square. This is the kinetic energy of the alpha particle, incident alpha particle.

So, it is inversely proportional to kinetic energy square, so all those things are there and then he takes data, actual data which are reported in Geiger's paper and Geiger Marsden paper and then he compares the data with this formula. What is predicted from this formula and what are, what data are available and taking care of all experimental uncertainty and this and that. Everything he finally, establishes that it must have a nucleus inside, it must the positive charge must be concentrated in a very small volume and negative charge should be distributed here and there.

The question of stability, how this negative charges are still there, they are not falling in the into the nucleus, into the positive charge. He says in eleven, nineteen hundred and eleven paper that, we will not talk about the stability of the nuclear, of this atom how, if the nucleus is concentrated at the center and the electrons are everywhere in the volume. How those electrons are not falling in the nucleus, so that stability problem he ((Refer Time: 26:12)). Although, he makes a hint that the electrons must move in such a way that they are stable, so that is the birth of nuclear physics.

So, we have completed just completed hundred years of nuclear physics and we should celebrate through, looking through these original papers of Geiger and Geiger Marsden and Rutherford. Then there was series of papers after that because, once the nuclear model of atom came into existence number of researches and number of publications where made through. Now, I will give you a small overview of the course, that we, course content that we will be doing in something like forty lectures or so…

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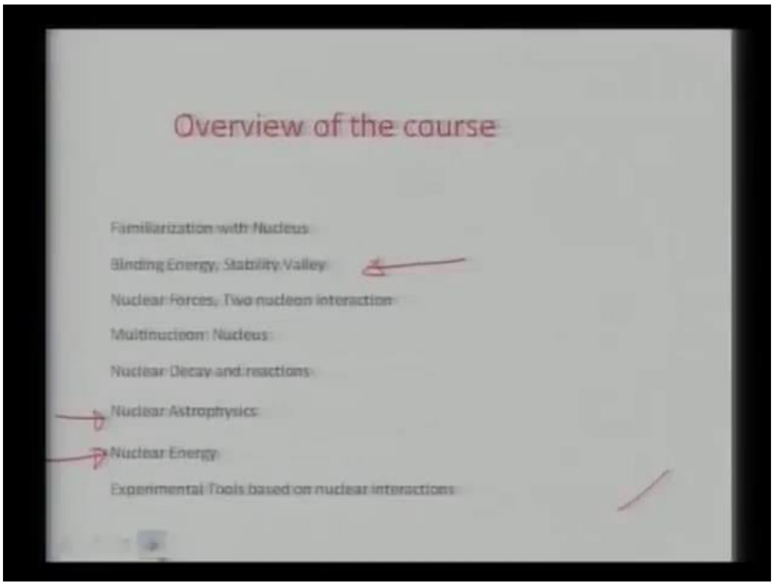

So, overview of the course, the first is familiarization with nucleus. So,, one has to get familiar with the nucleus, how it looks like? For that I will spend some more few lectures on that. What I mean by this familiarization is, just to get to know if, you want to familiarize with a person or with some machine or some object, you just want to know the shape and size and structure. First how it looks and then you want to go deeper inside, inside what is there and so on. So, that is familiarization, there will be several things that will be talked about in this section, let us say in this group.

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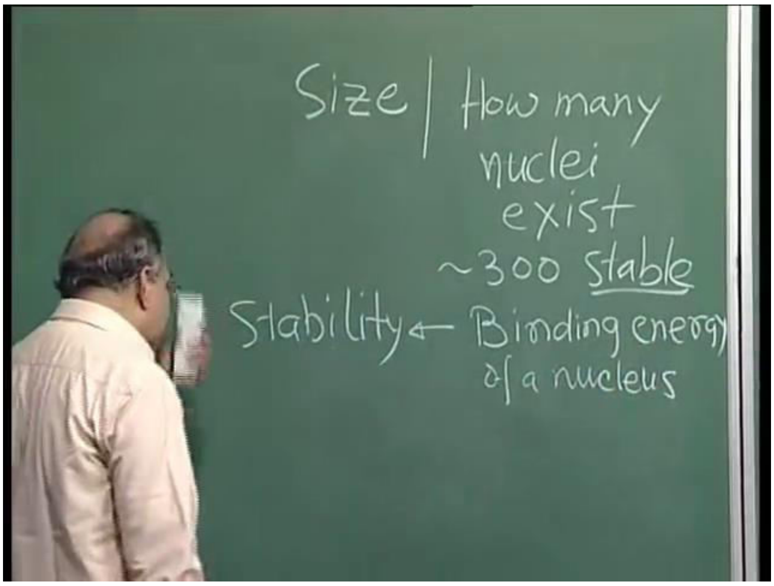

The first will be, let us say size, how big will be the nucleus, Rutherford says that its very small and he puts number something like 10 ((Refer Time: 28:03)) to minus 12 centimeters or so. But ((Refer Time: 28:07)) different nuclei today, we have about hundred, that is also familiarization with nucleus. How many nuclei are there, how many varieties of nuclei are there, so we have say almost hundred atoms in the periodic table.

Each atom in the periodic table has different nucleus, a different proton number, so hundred different nuclei are surely there, but then for the same atom that means with the same proton number z, you have different neutron numbers and that is also stable. For example, you know hydrogen and heavy hydrogen, both are hydrogen, hydrogen has one proton. Whereas, heavy hydrogen has one proton and one neutron, both have one proton and therefore, both are hydrogen, but here is an extra neutron.

Similarly, look at iron, iron has 26 protons and then 30 neutrons. Most of the iron that we have iron nails and iron hangers, iron chairs and doors and whatever iron you see in any form, iron form or iron oxide form or anything. That iron most, of the iron will have 26 protons and 30 neutrons that is the nucleus of iron. But then 2 percent about 2 percent of the natural iron is also, iron 57 that means 26 protons and 31 neutrons.

That is also a good nucleus and it is a nucleus of iron, so iron has at least these two varieties of nuclei, in more. In fact 58 also is possible. So, z is 26, but neutron number can be 30 or 31, 32, so all these are stable. So, for one atom you can have two or three or four varieties of nuclei. So, total if you look at it, about there are 300 or more stable nuclei. So,, that is also an attribute, how many nuclei? We will talk more about these things, I am only giving you an over overview at this moment. So, that number so could we say 300 stable and what do I mean by stable that is also a question.

Then if there are so many three hundred of nuclei, not all will have the same size. You have hydrogen atom, you have beryllium atom these are light atoms, lithium these are light atoms and then you have iron, you have copper, you have zinc. You can say they are middle weight and then you have uranium and platinum and all those things those are heavy weights. So,, all these 300 nuclei are not going to have the same size, some of them will be small, some of them will be large. How this size is related to? Let us say number of protons, neutrons and so on and how it is experimentally measured?

So, those things we will familiarize our self. The size, the number, then the stability. Why cannot I have a nucleus of iron with 26 protons and 80 neutrons or 26 protons with? Let us say five neutrons, we cannot have it. So,, that is a question of stability, what decides the neutron versus proton number or ratio, so that a stable nucleus results ((Refer Time: 32:01)) stability we will talk. In this, we will talk what is called binding energy of a nucleus, then we will talk about nuclear forces. The inside nucleus you have protons and neutrons and then the neutrons are electrically neutral and protons are all positively charged. So,, many protons with positive charge are packed in a small volume, why do not they fly apart? Because of the ((Refer Time: 32:54)) repulsion.

So, you know apart from the ((Refer Time: 32:57)) force, apart from this electromagnetic interactions, you have a different kind of force which we call nuclear force or nuclear interactions, which is attractive at those length scales and that binds. So,, to know about that force, we know about gravitational force, we know about electrostatic force ((Refer Time: 33:18)) force or magnetic force Q V cross B, what is the formula for nuclear force between say proton proton or proton neutron or neutron neutron. So, that will also be a ((Refer Time: 33:32)) topic. Let me come to power point and let us see what other things I have written for that.

So familiarization and then binding energy and stability valley, what makes the, what kind of combinations are stable and then we have this nuclear forces, two nucleon interactions and then we will come to this multi nucleon nucleus. Multi nucleon nucleus means, see when you start a topic or start studying about something, first you start with a simple system. So, the if I am talking of a nucleus, where do I start nuclear forces, where do I start, we start with a nucleus, if possible with just two nucleons, proton and neutron a collective name for that is nucleon. So,, proton is a nucleon and neutron is a nucleon, so we call them nucleons.

So, two nucleons that is the minimum the simplest possible, the simplest possible nucleus is nucleon, two nucleon system, what two nucleon system exist that we will study in the, in the course. But then once I know how two nucleons interact with each other, the next thing is when in a nucleus you have more than two nucleons what happens, it is not a simple superposition. Similarly, in atomic physics you start with simplest atom that is hydrogen, one proton and one electron, next is helium two electron system.

Once you go from hydrogen to helium lots of complications will be, will be there. Similarly, here we will go to multi nucleon system that means a nucleus in which there are several protons and where there are several neutrons. Then how these protons and neutrons together, how the forces are there, how the interactions are there? Structure, if there are 50 of them, how these 50 are distributed or arranged? Are all of them uniformly distributed or there are selected shells or paths, whether they are all just at rest or vibrating or they are rotating or what they are doing there? So, that internal structure that also we will study in this and then our next topic will be nuclear decays.

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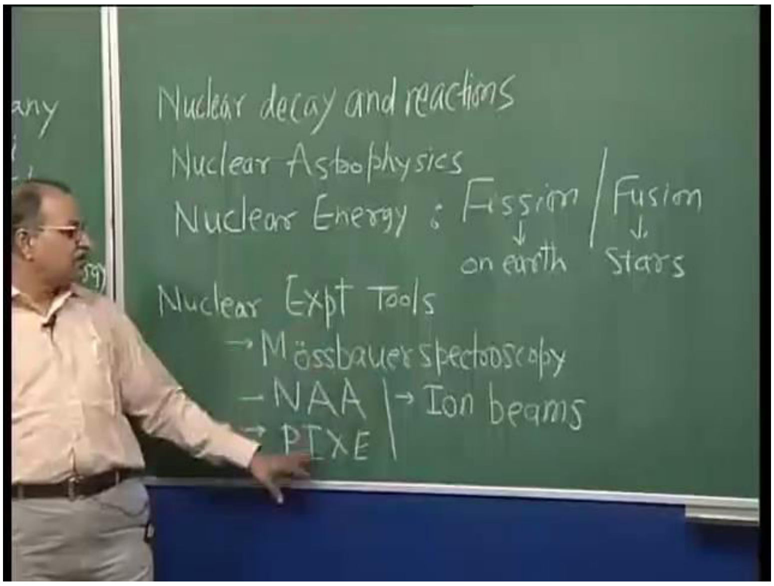

This also you are familiar with radioactive decays, from your school days alpha decay, beta decay and gamma decay, gamma decay is not exactly nuclear decay because, in the nucleus only energy changes. But in the alpha and beta particles, nucleus changes itself the structure the number of protons and the number of neutrons. So,, those radioactive decays are there and apart from that you have varieties of reactions, so that also can be grouped with this. So,, nuclear decay and reactions, I can write it nuclear decay and reactions.

All this going to have a lot of quantum mechanics, this alpha decay, how that alpha particle which you know is two protons, two neutrons combination in nucleus of helium. So, how that alpha particle comes out of a nucleus, alpha decay, to understand that you have to invoke lot of quantum mechanics. So, I suppose that you have done some quantum basic quantum mechanics. When I will be doing these lectures, I will be trying to do as much basic calculations as I can, but still remember lot of quantum mechanics will be needed to understand alpha decay or beta decay or and kind of reactions.

Then our next topic will be on, let us look at this, our next topic will be nuclear astrophysics, very good, very nice topic nuclear astrophysics. You know astrophysics, Physics beyond the earth, physics in space. So,, astrophysics and then nuclear astrophysics, nuclear physics which is there in space, in stars for example, is absolute fantastic stories. If you read about stars and read about what kind of nuclear reactions are going on stars in fact, that makes make star, a star. It is a star because nuclear reactions are going on, because nuclear fusion are going on. That is why the moment this nuclear reaction stops, the star will also, will die, will end its life and will not give any light.

Our sun is a star and you know in the sun you have, all this protons becoming helium and all those things and from their energy is coming. Not only proton becoming helium,for bigger ((Refer Time: 39:25)) lot of temperature and lot of pressure and a variety of nuclear reactions take place there. All the elements that you see on the earth or in the solar system or in the universe, all kinds of silicon and carbon; and nitrogen andiron and everything phosphorus and calcium and sodium and uranium and everything.

All these things were found inside some star through nuclear reactions and at their those temperatures and pressures, many of the nuclei are formed which we do not know on the Earth, because we do not have those temperatures and those pressures in our laboratories. So,, neither they are commonly around nor we can produce them in our laboratory because, those kinds of temperature and pressure that we do not have here. So, all this nuclear reactions at those temperatures, at those pressures where some nuclei are formed which we do not have on earth called exotic nuclei. For example, those things are going on and the whole universe is stable and is there because of these nuclei reactions inside those objects, celestial objects.

So, all these come under the term what we call nuclear astrophysics. I will be talking a little bit about that. Then, we have topic nuclear energy that everyone is familiar with nuclear energy. A good fraction of the energy, that we consume comes from nuclear reactors and through, what is that fission. So, this is on earth and fusion in the sun or in the stars. So, our reactors in ((Refer Time: 41:49)), they do this nuclear fission there using uranium ((Refer Time: 41:56)) and from their energy in the form of electricity is produced and that electricity is sent to our houses and so on.

So those energy production is there using this nuclear fission on earth and stars produce their energy using nuclear fusion. So, at least in the nuclear reactors the way we produce our energy is controlled, we know how much energy we are producing and at what rate we are producing. There are also uncontrolled nuclear energy production that you know which you call weapons, nuclear weapons where huge amount of energy is produced in a in a very small time and so much destruction takes place, because of that controlled an uncontrolled nuclear energy.

So, there is a good physics behind and then a good engineering behind to make a reactor, to run a reactor all the safety issues and all those things it involves a lot of physics and engineering. We will talk a part of this course, will be on nuclear energy issues also. Nuclear fusion, we are trying to do on earth, for a long time scientist are trying to make energy, make electricity from nuclear fusion as it is done in stars not electricity. But energy is produced in starts through fusion. So, here also on earth scientists and engineers are trying to do that, trying to make energy from fusion.

So, far is it has not been very successful, but if it succeeds then it has great advantages, because it will create much less radioactive pollution and also the supply, fuel supply the basic with which one has to work. That also is much more abundant as compared to what is needed for nuclear fission. So, we will talk about these things as the course proceeds. Then we have something on experimental tools based on nuclear interactions. In 100 years, nuclear physics has developed in different shades. So,, to understand the nucleus itself, is still an ongoing activity and then how nucleus or nucleons interact and how this all these things are there?

The understanding part of it, the theory part of it, but in these 100 years nuclear physics has given the mankind lots of tools in medicine, in many things. So,, those experimental tools that we will be discussing some of them are… Now, let me write nuclear experimental tools. So, some of them are let us say, Mossbauer spectroscopy. Now this Mossbauer spectroscopy is a kind of experiment, which is used by physicists, by chemist, by biologists, by geologists, by archeologists. So, it is such a huge application, what it does, it gives you? The changes in the nuclear energy levels with an accuracy of say, one part in 10 to the power 10 or 10 to the power 11.

So, this is the kind of experiment which is used by chemistry people, by physics people to understand the very local environment of some specific nuclei on which this Mossbauer spectroscopy is can be done. There are some limitations also, it cannot be done on any system. Iron is, iron 57 is the most favorable nucleus on which Mossbauer spectroscopy can be done. So, if you have any system superconducting system or any system in which iron is there and you want to know the local environment of that iron. So, this is one of the very very powerful tool, we will talk about that.

Similarly, you have the neutron activation analysis NAA, neutron activation analysis. Here also very minute quantity things can be, can be ((Refer Time: 46:59)). If we have a sample and you want to know its composition and other things. You activate by neutrons, you put neutrons into it and then then neutrons go there and they make it radioactive, gamma rays are emitted and all those things. So, this is also a tool which is very widely used by scientists and engineers. Then you have for example, PIXE what is PIXE, proton induced x ray emission, proton induce dx ray emission.

So, if you have for example, in pollution studies you have some aero fold sample in which you want to know some concentrations of, some toxic elements which are in parts per millions, very small concentration. So,, this is one tool, this is one tool with which you can do that, what it does it sends a proton beam and that proton beam falls on the sample and excites the atoms or the electrons. Then x rays are emitted these x rays are characteristic of a particular atom, that is there a particular z, that is there from there you know, how much is cadmium or how much is mercury and so on. So,, for trace element analysis you use that.

Similarly, there are many of them which one can, so there are many varieties of nuclear experimental tools, then ion beams, ion beams you have ions and you accelerate the ions and then you allow these ions to interact, to fall on some materials. Then these ions do some kind of modification in the material. From that ion matter interaction many things can be done it is a. It is a very hot area, so using these ion beams alpha particles Rutherford alpha or that Geiger Marsden alpha particles experiment. That was some kind of, some kind of ion matter interaction, but today we have ion beams where starting from hydrogen to uranium any kind of ion with, any kind of charge state, charge state 2 plus 3 plus, 4 plus, 5 plus, 10 plus, 15 plus that can be accelerated through mega electron volts or giga electron volts or even more, to do what is desired.

So, we will talk about some of the nuclear experimental tools that are there. So,, this is the kind of overview what you can expect in this forty lecture or about forty lecture course. So, I have given just glimpses, the nuclear physics is quite exciting, it interfaces on two sides, one atomic physics, atom is there and then electrons are there. In atomic physics, mostly you talk about electrons, but then those electrons interact with the nucleus and therefore, this nuclear physics has interface with atomic physics. Then the nuclear physics also has an ((Refer Time: 50:32)) interface with what you call particle physics, inside the nucleus when you go outside, you get atom you go inside. Inside you have protons and neutrons, but then inside protons and inside neutrons you have quarks and other things.

So, all that leads to particle physics so, this has both interface with atomic physics and particle physics and basic nuclear physics when you do, you are prepared for both of them. So, that is it now, I will give you list of some useful books which you can get from library or if you can have them, that will be helpful. I will be talking about all this here, but then some material if you can go back and study at your own place that will be nice.

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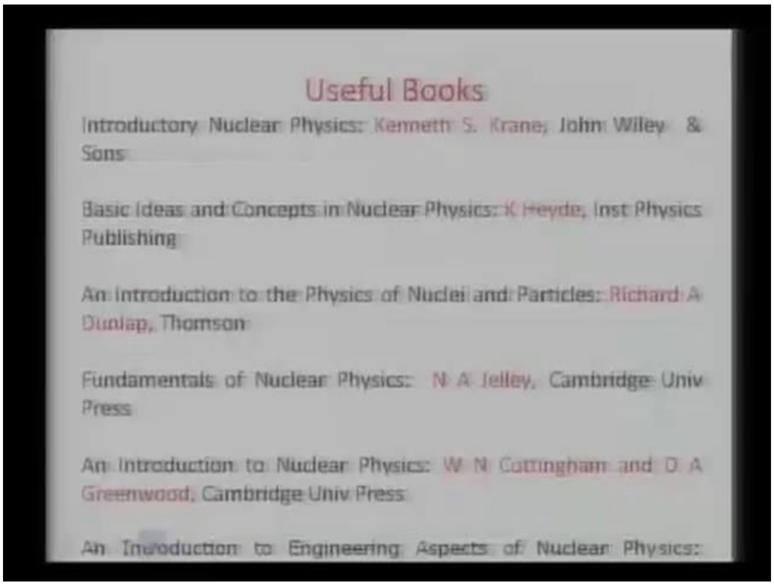

So, you would like to note down some of these books one is, you can see here, one is introductory nuclear physics by Krane published by John Wiley and Sons, very good book, very good text book slightly older. Then you have this second book basic ideas and concepts in nuclear physics this is K Heyde and this is institute of physics publishing, that is also a very nice book. Then you have this Dunlap book, Richard A Dunlap, introduction to the physics of nuclei and particles, Thomson publication, now the name has changed ((Refer Time: 52:09)) or something.

Then you have fundamentals of nuclear physics this is Jelley, Cambridge university press publications. Then you have this introduction to nuclear physics W N Cottingham and D A Greenwood, Cambridge university press. Then you have this new book, just come introduction to engineering aspects of nuclear physics, it has just come and it is published by Delhi publication this I K international or so, Shantanu Ghosh is the author. So,, these books if you can procure that will be helpful time to time you can refer to these books and that is it. So, that is all for today.

Thank you.