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

Lecture - 43
RBS, PIXE, NAA, Summary

So, previous lecture I talked about Mossbauer spectroscopy basics of that and how the source emits a particular gamma ray and then the absorber has same similar species nucleus species in the ground state; that absorbs it and goes to higher excited state. And this gives us some absorption spectrum which we call Mossbauer spectrum, and the environment local environment at atomic scale of that mass more isotope can be proved through these absorption lines. And I said there is a catch; what is that catch? So, let us discuss that.

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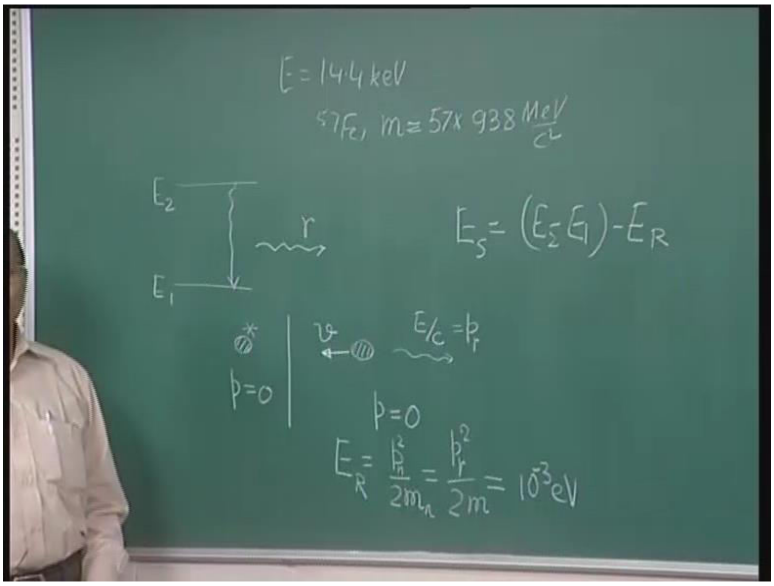

So, suppose you have a nucleus in excited state and that emits gamma ray; this is energy level E 2 E 1, and then it comes here and gives you this gamma ray. I said that because of the interaction with the solid, these energy levels are shifted little bit of the order of say 10 to the power minus 8 electron volts or so. And similar is the case with the absorber where this nucleus is in ground state. There also energy levels are slightly shifted from the free nucleus energy level values, but apart from that there is yet another thing involved and that is the recoil of the nucleus when it emits and the forward recoil when it absorbs.

So, this is school physics you know. If you have nucleus here in excited state at rest, this is the initial condition, and then it de excites and gamma ray is emitted and here is that nucleus in ground state. So, the total linear momentum here is zero, and therefore, if I apply conservation of linear momentum principle, the total momentum here should also be zero. And since this gamma ray is taking away a momentum of E by C, this is the momentum of gamma ray. If the energy of the gamma ray is E, it is a photon; the corresponding more linear momentum will be E by C in this forward direction in the direction of travel of this gamma ray.

And therefore, to make this total momentum zero this nucleus this daughter nucleus or the nucleus in ground state that must recoils here with certain velocity v, so that the linear momentum of this nucleus because of this backward recoil and the linear momentum of this gamma ray they add to zero. If that happens then there is some kinetic energy of this nucleus, and that kinetic energy of that nucleus will be we call it E recoil that will be p square this p p of this nucleus square divided by mass of this nucleus not neutron nucleus. So, that is the kinetic energy. How much is this? We can estimate. Suppose I take this E to be let us take this E to be 14.4 kilo electron volt.

So, from there I can calculate this p and the same p will come here because the total linear momentum is zero. So, that this linear momentum is same as this linear momentum in magnitude. So, with this you can calculate how much is this p gamma; that p gamma you can put here and mass of this nucleus. So, if I take this 57 iron then mass will be approximately mass you can write as 57 times mass of proton or that is 948 M e V by c square, almost this. So, all these things you can put here, and you will find that this energy is something like 10 to the power minus 3 electron volts, very large 10 to the power minus 3 electron volts; hundred thousand times larger than that 10 to the power minus 8 e V that we are talking.

So, from where this kinetic energy of recoil is coming? That also comes from this energy level difference. If the nucleus is coming from here to here, the energy which is made available is just this E 2 minus E 1. And from this E 2 minus E 1 itself you have a division; some energy is taken away by this gamma ray, some energy taken away by this nucleus. And therefore, this energy that is emitted will be this E 2 minus E 1 minus E r, and similar analysis you can do when this gamma ray falls on a nucleus which is sitting in the ground state, and it absorbs that nucleus and goes to the excited state.

So, there also there is an initial linear momentum of this gamma; the nucleus is at rest. So, there is a total linear momentum in forward direction. After this gamma ray get's absorbed, you only have a nucleus in excited state. Therefore, it must go in the forward direction with the same linear momentum, and it has to go to excited state. So, that difference it has to cover on top of it, it needs kinetic energy to go in the forward direction.

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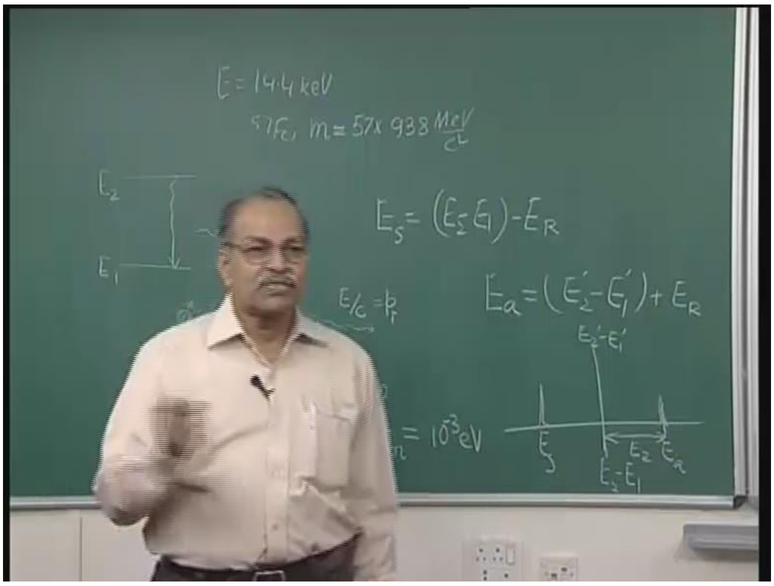

So, energy of gamma ray which is needed to do all this at resonance should be E absorption should be E 2 minus E 1; of course, there is slight difference here. You can write dash and plus here. This slight difference is because absorber nucleus is a different solid. So, there are some changes of the order of 10 to the power minus 8 electron volts, but I am not concerned that because this is much larger than that. This is around 10 to the power minus 3 e V's. So, how will the resonance absorption take place? So, energy of gamma ray which is needed is this much. If this is say E 2 minus E 1 which is almost the same as E 2 prime minus E 1 prime also, because that difference is only 10 power minus 8 electron volts, and this is E r.

This much energy is needed; this much energy is needed whereas, the energy which is coming is E r less than this. So, energy which is coming is only here. So, this is finally, E s and this is finally, E a. So, this much energy of gamma ray is needed for taking this nucleus from ground state to upper state, and this much energy is available when this is going in the source when it is going down to the ground state. And this gap is much larger with that vibration of a source; if you want to cover this gap you will need huge huge velocities. Then how that resonant absorption takes place and how you do you get those Mossbauer spectra. So, that was the catch I was referring to.

And the answer lies in quantum mechanics once again. It is a purely quantum mechanical phenomena that if you have this radioactive nucleus embedded in a crystalline solid, and then this crystalline solid has its own energy levels. And if there is a recoil it is a coupling, and this whole crystal has to recoil. And then this crystal has got discrete energy levels. So, if the recoil energy is less than the first possible excitement, then the whole recoil will not take place. And the gamma ray will be emitted as if there is absolutely no recoil, and the gamma ray takes away the entire energy the level difference E 2 minus E 1.

The conservation of linear momentum is still there, but not like particle collisions. You have to expand the wave function in momentum wave function Eigen functions and then each of that part has to be shifted by that much amount and all that. And when one does all that calculation, one points that there is a fraction; there is a probability that this gamma ray will come out without suffering this recoil energy loss, the complete E 2 minus E 1, and similarly in absorption. There will be a finite probability that the gamma ray of that energy which is just E 2 minus E 1 gets into the nucleus and takes it to the excited as if it has not gone into forward recoil mode. So, it is that fraction of recoil less emission and recoil less absorption; that is giving you the Mossbauer spectroscopy. So, with that I will just show you some examples some real examples of Mossbauer spectra which are there on the screen.

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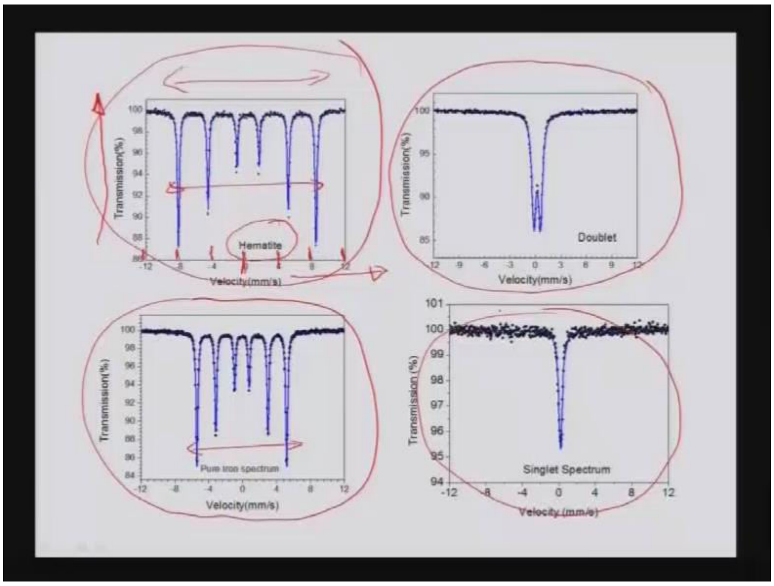

So, on the screen you are seeing four spectra as we discussed. Take this first one. This vertical side is how many gamma rays I am getting through the absorber that counts, and on the horizontal side you have this velocity the Doppler velocity of the source. And it is in millimeter per second, zero here, then plus 4 millimeters here, plus 8 millimeters here, plus 12 millimeter here and minus 4 millimeter per second, minus 8 millimeter per second and minus 12 millimeter per second. So, it is velocity scale; its velocity of the source the Doppler velocity of the source and as this velocity changes, the absorption increase and decreases and you get this Mossbauer spectrum.

It is a six line Mossbauer spectrum and comes from ferromagnetic coupling where this iron 57 sees a large internal magnetic field, nuclear energy levels are spilt. And from this splitting this particular splitting from the first to sixth, this magnitude of the splitting and other positions I know this is for hematite. Hematite is Fe 2 O 3, alpha Fe 2 O 3 that is hematite. If you have this alpha Fe 2 O 3, you will have this kind of spectrum. Here also you have a six line spectrum, velocity versus transmission; here also you have a six line spectrum, but the splitting is less from first line to sixth line this width here and from first line to sixth line here is different.

So, this lower one is also a magnetically coupled case; you have internal magnetic field because of this coupling and this is for pure iron foil. So, from the position from the splitting, we know whether it is pure iron or whether it is Fe 2 O 3 or if it Fe 3 O 4 or it is iron in some other kind of metrics. Then on the right side you have two more. So, this spectrum is a two lined doubled spectrum, and this results when the solid has a non-cubic crystal structure and non-magnetic as well; magnetic will split in six parts. So, this is the kind of a spectrum for example, iron in clay or iron in some compounds iron carbonate and another things or olivine or pyroxene; yesterday I was talking of FeSiO4 olivine.

So, FeSiO3 this pyroxene this kind of mineral you will have this kind of Mossbauer spectrum, and this is a single line spectrum which will come steel like structure where you do not have ferromagnetism and you have a cubic crystal structure. So, if this is the kind of Mossbauer spectra, and these are pure physics that I am showing. In a real sample you can have more than one environment of iron, some paramagnetic, some ferromagnetic, some with cubic environment, some non-cubic. So, you can have superposition of all these things in a real Mossbauer spectrum which you will have to decipher using some kind of a computer analysis computer program.

So, that was Mossbauer spectroscopy. Another application of nuclear physics experimental tool based on this is using, say, helium ion, helium ion beam. Ion beam is a very, very advanced experimental tool with which lots of work varieties of work is being done. One simple is mostly with helium ion beam people do it alpha particle beam and that is Rutherford backscattering RBS Rutherford backscattering.

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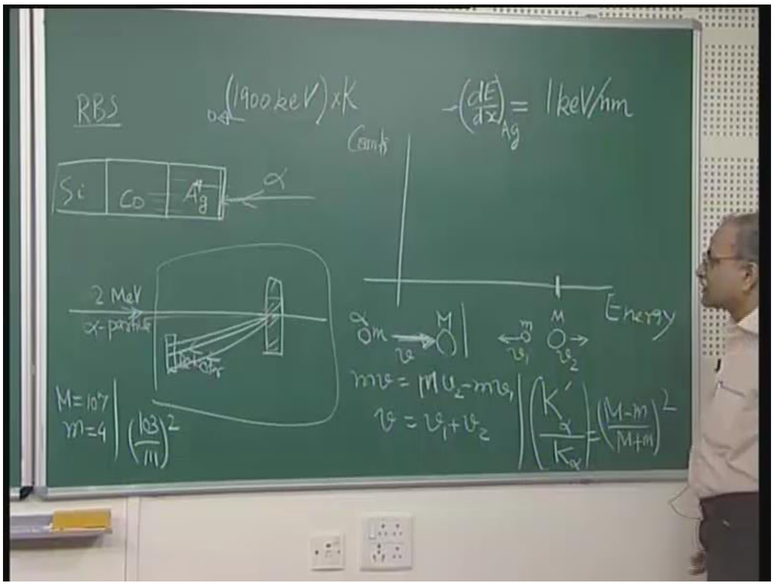

So, what is this RBS used for? RBS is used for finding the composition of certain trace elements not really trace can be higher concentrations also in some kind of a solid matrix as a function of depth. So, if you have, say, thin films or you have some coating on some substrate or the substrate itself has some, say, up to micron depth you have some other elements embedded. And you want to know the concentration of those elements in that sample as a function of depth. So, right at the surface what is the composition; if you go, say, 50 nanometers inside in the material what is the composition. So, those kind of things if you want to get the knowledge, this RBS is one technique which can be used.

For example, suppose you have some kind of a bilayer. Suppose you have some kind of let us say cobalt here and silver here or multilayer, you have repetition of this cobalt silver cobalt silver and so on. These kind of multilayer's where ferromagnetic films or ferromagnetic parts are separated by a nonmagnetic spacer layer are in between because I have this cobalt here, silver here and then again cobalt here, silver here and again cobalt here. So, this is ferromagnetic; this is ferromagnetic; this is nonmagnetic. This kind of structure with proper depth, proper thicknesses and proper choice of the material also, but ferromagnetic material is separated by nonmagnetic materials.

These are used for, say, GMR giant magneto resistance which is used for this hard disk in computers reading the data from that disk and so on. So, suppose you have just a bilayer, say, cobalt and silver and we want to know how much of this thickness here; suppose on cobalt we have deposited some this thing and this whole thing may be deposited on some other substrate silicon or so, this is the surface. And from here we want to know how this silver concentration varies as a depth. So, if it is pure silver it is just same concentration and then cobalt same concentrations, but at the interface there will be diffusion.

Cobalt will come this side, silver will go that side and many on the physical properties will very sensitively depend on how sharp is this interface and how diffuse is this interface; how much is the mixing here or deliberately people do mixing to make different phases. So, they want to know how much is cobalt as a function of depth, how much is silver as a function of depth. So, these kinds of situations can be handled with this Rutherford backscattering. What is the experimental setup? You have some kind of a vacuum chamber in which you put the material.

This is the material, and then you send an alpha particle beam generally it will be the alpha particles, but it can be done by other things also proton beam also. So, this beam is going say 1 M e V, 1 to 2 M e V type of alpha particle beam. It goes here; it falls on this material, and then it will go inside; normally it will see electrons electrons electrons because you know the nuclei are at a much larger separations. In atom you have a nucleus only hundred thousand times smaller than the size of the atom. So, the alpha particle will generally go into this material; it will have certain range maybe a micron or two micron or like that depending on the solid.

But occasionally it will go close to the nucleus just like in Rutherford's or Geiger-Marsden experiment. It will go close to the nucleus and then through Coulomb interaction it will be deflected. And then we put a detector here; we put a detector here to receive if this is to receive it in the detector. So, if it encounters a collision, collision means this columbic interaction with the nucleus. It reaches close to the nucleus, and from there it backscatters at this particular angle. Then it will go into the detector, and it will be counted. Normally it is put as close to this direct beam as possible 170 degrees or 150 degrees, 160 degrees like that.

So, how will this count look like as a function of energy? So, that is RBS spectrum. If I analyze these alpha particles coming into the detector in energy and then counts here that is known as RBS spectrum. So, what happens when you have a sample? An alpha particle is coming and it is here; suppose one alpha particle encounters a silver atom right here at the surface. So, the usual linear momentum conservation and energy conservation things can be used to find what will be the kinetic energy of this particle which is scattered at this particular angle to get into the detector.

So, if I take this angle to be just 180 degrees; of course, I can put the detector at 180 degrees. I have to put at some 160 degree or 170 degree or 165 degree something like that. But for calculation or showing a typical type of calculation if you do that the analysis is very, very simple. If you have a nucleus here, mass capital m if this is alpha particle mass small m and suppose it goes and comes back and nucleus goes in this direction. So, this is the initial condition when the alpha particle is going, and then after scattering what is happening? After scattering this capital M will go in this direction and this is small m will go in this direction.

So, if this initial velocity is v and this is v 1 and this is v 2, then you can write m into v is equal to capital M into v 2 minus small m into v 1; that is linear momentum conservation. And for this particular case at least the energy conservation will finally give you velocity of approach is equal to velocity of separation, and from this you can work out algebra is very, very simple. The kinetic energy of the alpha particle after the collision and divided by kinetic energy of the alpha particle before this collision will be just capital M minus small m, capital M plus small m square. So, if it is scattered from the surface, the energy of this alpha particle as detected here will be reduced by this factor.

If you take a count of proper theta at which this detector is placed, the expression will be slightly more complicated and people do use that. This is only to show that there is a factor by which the kinetic energy is reduced. So, if this beam is a 2 mega electron volts and for silver you can work out M is 107 and small m is 4. Helium there is four particles two protons and two neutrons; total mass number is 4, for silver this mass number is 107. And so, this factor will be 103 divided by 111 square. So, it will be reduced from there, something like 0.96 or like that.

So, correspondingly this particle will have this energy; nothing will be more than this. No alpha particles will have energy more than this. If they are scattered from the surface, this is the energy. And if they go deeper inside and then get scattered from a silver nucleus, then during this transit into the material they are continuously losing energy because of their interaction with all those electrons present there. So, if the nuclear encounter is at a depth then at that encounter, the incident energy is already smaller than the initial beam energy. So, if the initial beam energy is say 2 mega electron volt 2000 kilo electron volt K e V, and let us suppose d e d x minus d e d x for silver. All these things are tabulated standard tabulated; suppose it is 101 K e V per nanometer.

So, all this d e d x stopping power; these are all well tabulated for different elements. Then if it goes say 100 nanometer inside and then encounters a nuclear interaction, then in 100 nanometers it has lost 100 K e V’s. So, that when it makes this encounter with this silver, the incident energy is 1900 K e V. If the encounter is at the surface it was 2000 K e V, but if the encounter is 100 nanometer deeper, it is only 1900 K e V. And that will be multiplied by this factor; the kinetic energy will be reduced by this factor. So, this will be multiplied by whatever is that factor; let me write just k, this factor or alpha or something. So, with that energy it starts coming towards the detector, but then it has to cross all that distance.

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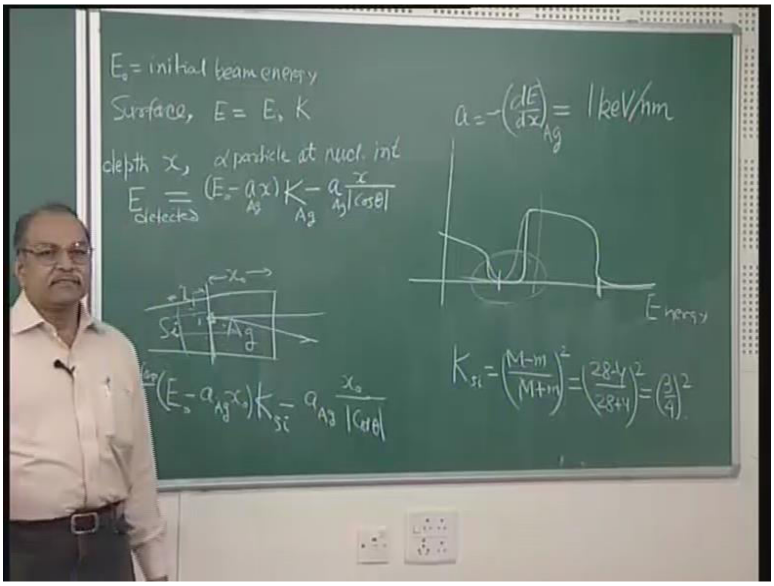

So, I am making an exaggerated figure. Suppose this alpha particle gets into and at certain depth x it encounters this collision, and then from here it comes back, and here is the detector. So, how much is this distance? This angle is theta, the angle of scattering is theta, then this distance will be x divided by mod of cos theta. So, as it comes back towards the detector it loses energy, and that energy will be lost during this transit path x by mod of cos theta. So, how do I get the energy which is received in the detector? The initial energy where do i do? So, say initial energy is let us say E naught beam energy alpha particle when it is in beam that energy is say e naught.

Now if it is coming from surface, then the energy detector will be this e naught multiplied by that kinematical factor is called kinematical factor depends on what nucleus is the target nucleus, what nucleus is the projectile nucleus. So, that and at what angle it is coming, 150 degrees or 170 degrees. So, that will decide this kinematical factor k. So, the energy received is just this if it is from the surface. And if it is from depth x, first thing is the alpha particle interacting at the time of this nuclear interaction that is e naught minus this quantity; let us call it a. So, a into x. It has lost this much of energy; per unit length it is losing this energy or whatever kilo electron volt per nanometers or so.

So, this is the energy which falls on or with which this alpha particle collides or interacts with that nucleus, then multiplied by that kinematical factor k. So, alpha particle when it backscatters it has this much of energy, and then it is coming through that solid will come out of the solid and then reach the detector. During that process it has a lost this much of energy. So, this is the energy which is detected. As your silver layer it goes through that silver layer and collides at different places and comes back, you will have alpha particles of lower energies. So, nothing on the right of this, but there are alpha particles to the left of it and you will have a spectrum something like this.

Suddenly you have a rise and then you have all these types. So, each depth corresponds to a particular energy; each depth x each x corresponds to a particular energy, and that is how we are getting different energies. So, each point here corresponds to a particular depth, and then this height how many counts I am receiving; that depends on the cross section and other things, alright. So, normally cross section decreases when energy is increased. If you remember that Rutherford equation, it is energy comes in the denominator and then than z 1 z 2 divided by the sum epsilon naught, etcetera, and the energy in denominator whole thing square.

So, with the same concentration, lower energy will have larger cross section and counts will be larger; that is why it is slightly going up; if the concentration is same it is going up. And then suppose you have this surface, suppose your silver is up to here and then suppose you have another material here, some material cobalt copper something else say silicon something else. So, up to here this is at particular depth, and therefore, there will be a particular energy corresponding. After that you will not have those alpha particles coming from silver, and the silver parts should be like this. These values can be calculated using all these numbers once you have these numbers.

Now comes silicon. So, now the alpha particle which is coming and hitting this silver and backscattering from here, what will be its energy; that also we can calculate similar way. First thing let me write it k Ag, kinematic factor for silver. Kinematic factor for silicon will be different. If you assume theta equal to 180y degrees, it will be once again m minus m, m plus m square and that will be m is 28 now. So, 28 minus 4 and 28 plus 4, so, 24 by 32 3 by 4 square; so, you have a different kinematic factor heavier the nucleus, the kinematic factor will be larger closer to one. And lighter nucleus lot of energy is taken away by that lighter nucleus in recoil, and this alpha particle will have small energy. So, this factor will be small. So, that is this.

So, when it falls here, at that time it is e naught minus a Ag is also for silver, a silver time this whole depth now this whole depth x naught; with this energy it reaches the interface. And then from here, when this alpha particle rebounds or backscatters the kinetic energy is reduced multiplied by this kinematical factor k si, and from there it has to go again in silver. So, this is again a silver and x naught over mod of cos theta. This is when this is scattered from the silicon surface; that means the interface. Now depending on what this depth is, this number can be much this side. It can be somewhere here or it can be somewhere here. So, that will depend how thick is the silver, and so on.

Supposing that this number is here after that it is all silicon, then similarly now it goes into the silicon and then some depth say x here or x 1 here and then it rebounds and then it will be lower energies. So, you will have something like this. The cross section for silicon will be normally smaller than the cross section from silver. So, this height is related to cross section; quite often in different region of spectra different scales are used different vertical scales are used because at this is scale this maybe very, very small. So, this part can be multiplied by 5 or 10. So, that one can see how much it is. So, proper scale has to be used.

So, this kind of a spectrum you will absorb and then from there you can work out. Now if there is a mixing here if there is a mixing than all the things will be diffused; you will have silver atoms here also, you will have some silver atoms here also. Then it will not fall that sharply; it will get diffused. Similarly you have some silicon here. So, it does not have to really go to x naught before also it can get this silicon. So, all those things will be reflected in this region and you will in this way get a spectrum. So, different varieties of I have just taken very simple case where you have two elements, one, say, silicon and one silver. But then for varieties of samples in which the elements are having varying concentration as a function of depth, those things can be quite reliably obtained from this RBS spectrum.

It has its own limitation, very light elements it will not work. So, it has its own limitations. There is an accuracy limit; if the total concentration is very very small, then all this statistical uncertainties and fluctuations in the counts that will takeover. So, all those things are there, but still there is a good applicability region where this RBS is used for composition analysis as a function of depth.

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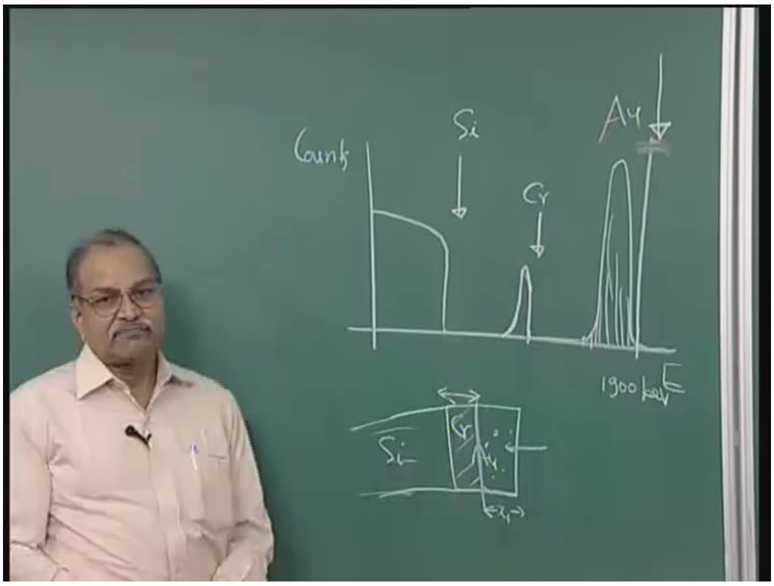

Now I will show you RBS spectrum for a particular case. So, you have a sharp peak here and then you do not have anything for some time. And then again you have a sharp peak here and then again you do not have anything and then again you have a sharp rise and then it just continues. Even if I do not know anything about this composition of sample I do not know what that sample was and this is the spectrum given. And I am told that this is incident alpha particle is 2 M e V and the angle theta is this much 160 or 170 if that is given, I can work out from where all these peaks are coming, from where all these spectra are coming and what kind of sample is that.

Because once I know this energy say 1900 K e V, I know for different elements you have different kinematical factors; of course, if there are very close by in the periodic table you take just next neighboring nuclei, the kinematic factor will be almost the same. So, those uncertainties will be there, but then different elements do have different kinematical factors. And from this I can work out what kind of material is this and then as it goes. So, it is gold here. So, as the alpha particle goes in, you are having counts at these energies; you are having counts on these energies, and they are coming because of this collision events at different depths, but if the gold is only up to this some thickness say x 1, then after that you do not have this gold, and therefore, this peaks ends here.

So, this whole thing corresponds to gold, and this is the surface of the gold this point. This is the surface of it; generally people write it with a vertical arrow like this, telling that this is the surface of the gold. These counts are coming because of the collisions at the surface, and these cunts are coming because of the collision at the end of this gold layer. Of course, there will be some diffusion at the interface, and you also have chromium. So, you have chromium here, but these are all thin layers very thin layers. So, the energy loss is there very much there. So, you have a chromium layer. Now chromium is this side or chromium in that side; that also one can work out from these energies.

So, from this chromium now the kinetic factor is much smaller than what it was for gold. And therefore, even from this interface even if the chromium m c is sitting here, the energy of that backscattered alpha particle will be much smaller and that is here. So, this is chromium surface, chromium starts here. So, this is the chromium, and similarly whatever is the thickness of the chromium because of that you get this kind of peak here. Then there is a gap here. Why is there gap? In the sample there is no gap. This is silicon substrate; on this right on the silicon you have all this chromium and gold's, but here you have gaps.

These gaps are because of different kinematical factors for silicon, chromium and gold; the loss in kinetic energy is different in different cases. So, from here it starts silicon. So, this is our silicon surface, and then you have silicon silicon silicon all through. So, it just goes. So, that is the kind of analysis one does with RBS spectrum; one can obtain how much the thickness of this layer from this width; one can obtain how much is the thickness of chromium from this width, if there is some interface diffusion that also can be inferred from this spectrum.

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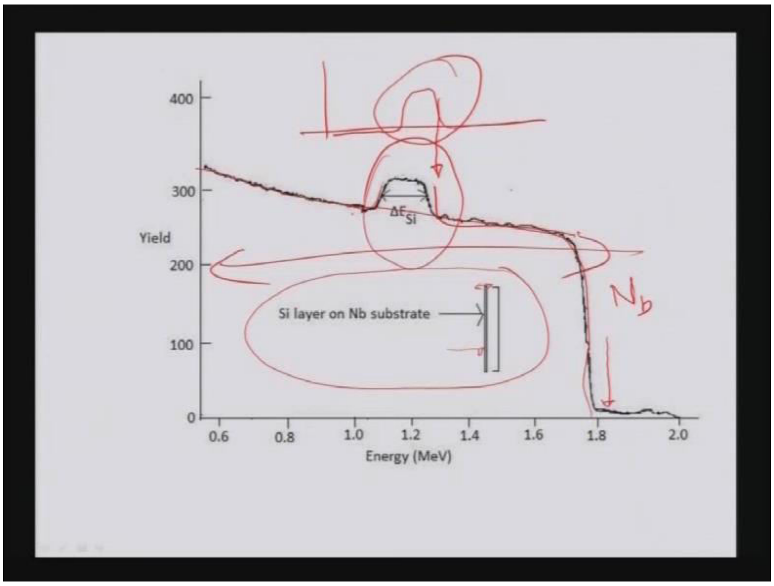

Now I will show you the actual RBS spectrum for a particular case; look at your screens. This is sample were silicon layer is sitting on niobium substrate. You have a niobium substrate on which silicon layer thin layer is sitting; niobium will have some kinematical factor. So, the surface of niobium is somewhere here, and then you have niobium all through. So, you get this spectrum here for niobium and this silicon which is sitting at the surface of this niobium substrate. So, that silicon surface will be here because of much less kinematical factor, the alpha particle will have lower energy. So, this silicon surfaces starts here and then you have only a small thickness of the silicon. And therefore, it will end here.

If it were a simple silicon, it would have started here and since you have thin layer it could have gone here, but then already niobium counts are there right from here to here; everywhere you niobium counts and at these energies you also have silicon counts. So, this silicon is riding on the niobium. So, you have a step here this step. This step tells that silicon has started, and then this step down, down step here the silicon has ended. So, from this you can find what is the width of this silicon layer and all those things? So, that is the kind of an analysis this RBS. So, this is one application of ion beam helium ion beam; you have many many applications.

Now you have ion beams for any element from proton to uranium, any element, any charge sheets and varieties of work are done there. We also have now radioactive ion beams. So, that has its own applications. Another experimental tool based on this nuclear physics is for trace element analysis say proton induced x-ray emission PIXE.

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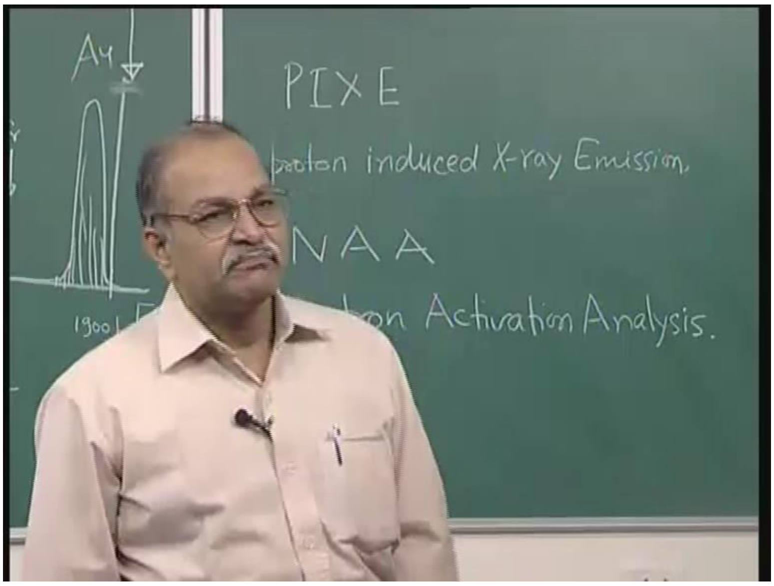

PIXE commonly known as PIXE proton induced x-ray emission. If you want some impurity analysis, an impurity is very small parts per million or even smaller, aerosol samples for example, you want to know how much arsenic is there, cadmium is there, toxic elements are there or you are creating some very sophisticated pure materials, and there are some impurities involved. And you want to know the level of those impurities. So, this technique can be used if proton beam comes and hits the target and this proton beam if it interacts with the electrons the atomic electrons and it has energy of say mega electron volt or so, it can just knock off those electrons from the atomic orbits.

And if that happens, the vacancies are created in those atomic orbits. Then electrons from the higher orbits will fall on it and x-rays will be emitted, and the energies of these x-rays will be characteristic of that particular element. So, in one go if you have some three, four, five, six types of impurities, this proton beam goes and interacts with those atomic electrons and k alpha and k beta and l alpha and all those x-rays are emitted from those elements and from the energy of those x-rays, those x-rays will be detected with their energies. And from the energies of those x-rays, we will know what kind of elements are sitting there from which these x rays are emitted.

And from the number of counts at that energy level or the counts under the area under the peak we will know the amount the concentration, how much of which impurities it sitting there. So, this is trace element analysis technique based on proton beams, hydrogen beam, hydrogen ion beam. Similarly another trace element analysis technique which is used is neutron activation analysis NAA, neutron activation analysis. Again if the amount of this element is very very small not even in PPM, PPB or so, then this NAA is very useful. What we do? We put this sample in a neutron flux generally with reactors where the reactors are you have lots of neutrons produced.

So, in neutron flux this material is placed and neutron gets absorbed into this material this nucleus and this new isotope is in some excited state. When this neutron falls on this impurity nucleus and it gets absorbed into it, then a new isotope is created and that will be in general at an excited state. And it will decay by emitting a gamma ray, and the energy of that gamma ray will be characteristic of that particular element. So, by detecting those gamma rays and analyzing their energies and of course number of counts, we will come to know what impurity is there or what is that element from which this gamma ray has come and then its concentration. So, many, many things which are very small in amount and it is needed very significant.

For example, iridium in soil samples 65 million years ago, there was a big impact of a meteorite on earth and because of that some 60 percent of life got extent. Now at that time the sediments which were deposited in the sea, they are still there in rocks. And it is found iridium concentration in those sediments are say thousand times higher than the sediments below and above, but even then the concentration is extremely small. This NAA is used in such cases to find out the concentration of iridium and from there identify that okay this particular layer is of that era of that time when all those dinosaurs, etcetera were gone.

So, there are many, many more applications of nuclear physics; medicine is one that you know, medicine is one in which nuclear techniques are used very extensively at gamma ray camera and other things and then the radiation therapy and all those things. So, in this hundred years, nuclear physics has come out as a very powerful; it has given us very powerful techniques in various areas which people are using. The basic understanding has increased, but still this lot much to do. In this course I have tried to cover only the basic concepts and few applications only. It is a vast vast subject and there is much more to learn. I have not talked how detectors work, how accelerators work and all those things. So, I think that is the end of this course.

Thank you very much.