Nuclear Physics Fundamentals and Application
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Lecture - 42
Mossbauer Spectroscopy

So, in the previous lecture we talked about how elements are synthesized inside the core of star and we reached up to that 56 iron region ironical region where the binding energy per nucleon is highest and then further fusion is not energetically favorable. But we do have elements much beyond that; all gold and silver and many things beyond that, uranium. So, how these elements are formed how these nuclei are formed and then we talk little bit about that; that is the neutron which can sneak into these stable nuclei and make higher and higher isotopes and from there one can get these bigger heavier elements. So, today we will discuss the synthesis beyond that iron nickel region and then maybe we will talk also of some applications. So, I will go to screen.

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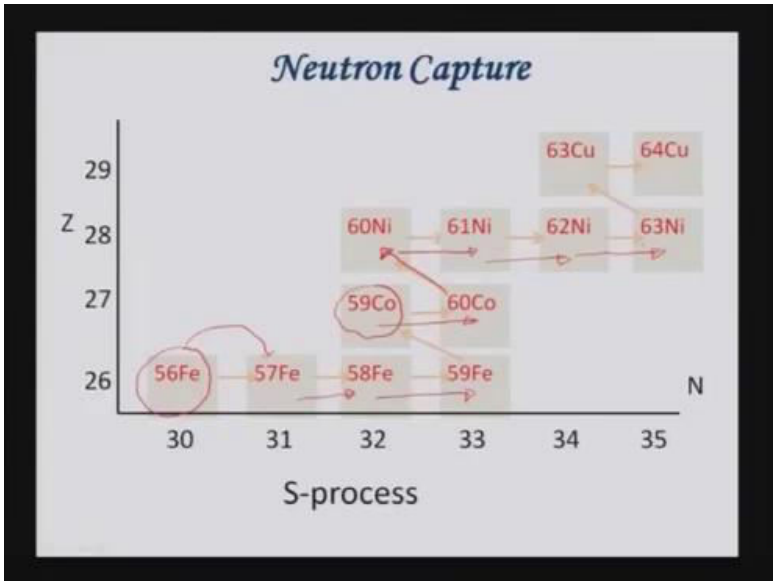

So, here is the process. Suppose, supposing that neutrons are present and from where the neutrons are coming? Some stray reaction that we talked; normally reactions proceed through alpha particle capturing but then, there are some stray reactions we are once in a while a neutron is produced. So, in the core of the star you do have some neutrons and at one place if a neutron is produced maybe after many many years, hundreds of years or 50

years a second neutron will be produced there because these neutron producing reactions are rare, but neutrons are there.

So, look at your screen suppose, we start with this iron 56 and a neutron just sneaks into it. If that happens, it will make iron 57 and iron 57 is a stable nucleus will stay there and then after many many years another neutron comes and that also goes into this 57 iron and then it will go to this 58 iron. 58 iron nucleus is also stable and will stay there once it is formed it will stay there; and then again after many many years a neutron comes there is produced there and that goes into iron 58 and that makes it iron 59. But iron 59 is not a stable nucleus now, we have post too many neutrons in it alright; the proton number is still 26 but the neutrons we opposed to many neutrons and it is beta active, beta minus active and it decays and where will it decay? 59 iron when it beta minus decays it will produce 59 cobalt.

So, see from iron we have gone one step ahead in the periodic table, we have gone to cobalt. So, now we have cobalt 59; now this cobalt 59 is a stable it will be there for whatever time till a neutron arrives, till a neutron sneaks into it, till a neutron gets absorbed into it and makes cobalt 60. Now, cobalt 60 is once again active, beta active and this will decay to nickel 60 so, this will decay to nickel 60, it will go from here to here. So, we have gone yet one step ahead in the periodic table from cobalt we have reached nickel then 60 nickel will absorb a neutron and will become 61 nickel; 61 nickel is also stable, this will stay there and when neutron comes it will become 62 nickel then from 62 nickel, it will be 63 nickel. So, these slow neutrons; slow means, slow in time neutrons are coming once in a while so, that is why slow does not mean here that they are moving with low speed slow means it is a processes slow, this whole processes very slow it takes years and years for a fresh neutron to come and get into it.

So, 63 nickel that is beta active and when it decays it proton; this neutron one of the neutrons decay to proton that will make copper, so this way the process will go on and you will get elements beyond this iron nickel region, this is called slow process or s process because the time scales involved are decays and centuries. So, this way many of the heavier elements can be formed and all these elements as you see, are going at the edge of that beta stability valley, where it is between stable and beta minus active nuclei. But then, all the elements of periodic table up to uranium and everything cannot be reached through these s process neutron capture, I will just give you an example.

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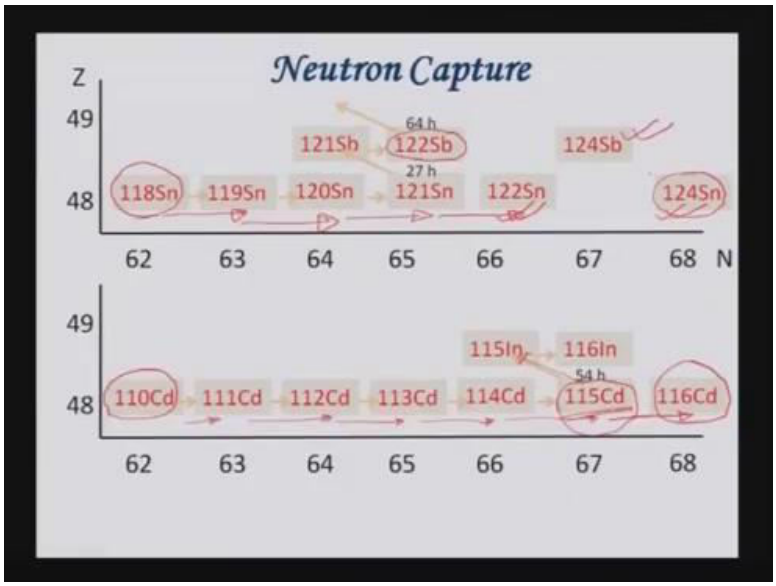

Suppose, you have this 110 cadmium, 110 cadmium is a stable nucleus and then it if it absorbs a neutron it will become 111 cadmium then, 112 cadmium, then 113 cadmium, 114 cadmium and 115 cadmium this is beta active this nucleus here this nucleus is beta active.

So, if I go by the process that I described this will decay to indium 115 indium, but we do have a stable cadmium isotope 116 cadmium and that is available; on earth that is available. We do have 116 cadmium nuclei cadmium isotope this will not be reached through this s process because 115 cadmium here is radioactive it beta minus active before this second neutron, next neutron comes it will become indium. Similarly, you can see about tin; tin also start with 118 tin it will go 119 tin, 120 tin and 121 tin is radioactive, beta minus active. Already, too many neutrons so, one of the neutrons will decay with a lifetime of 27 hours to this antimony 121 antimony, but we do have this 122 tin 124 tin; we do have these isotopes available.

So, how these type of things can come; similarly, here this 122 antimony, this is beta active it should decay but then, we have on earth we do find this 124 antimony. So, here the process is different, and that process is called the rapid process, r process and that is if there are some events in the star such that, a large number of neutrons are produced all of a sudden. So, the neutron flux become very heavy if we have too many neutrons, the time scale of one neutron coming and the next neutron coming; if that kind of time scale

becomes so small, that beta decay lifetime is much larger than this time then it will jump then it will jump these beta active particles, alright. For example, this 115 cadmium here is beta active with a lifetime of 54 hours but if, neutrons are made available every milliseconds every or every microseconds you have neutrons; then, before it beta decays it can absorb another neutron and go to 116 cadmium.

Similarly, here from 121 tin, before it decays to antimony there the lifetime is 27 hours if lot many neutrons are available, do one of the neutrons can go into it making 122 tin and then 123 and then 124 and so on; in between if there are some beta active things they will over the period of time decay. But if, there are some stable like this 124 tin stable then it will be just form. So, this is known as the rapid process or r process; from where this sudden burst of neutron can come; that can come through what we know as there are many processes possible in stars and it is a matter of observation and understanding and theoretical modeling and all that. But when, important process which is known as supernova process; if you have heavy star say 10 times, 12 times, 15 times mass of the sun then once, the core becomes iron nickel core first it will be hydrogen fusion, then helium fusion, carbon fusion and so on silicon fusion then finally, it will be iron, iron core.

What happens after that? If this mass of the core is a large more than that so called Chandrasekhar limit 1.44 mass of the sun then, the gravitational collapse will continue. Because now, there is no fusion inside this core it is all the iron; so, the gravitational collapse will take place and in this gravitational collapse and the certain favorable conditions of finally, the electrons will combine with protons of those iron nickel nuclei and making neutrons. So, all the protons convert into neutron and it becomes neutron star but in the process then, this electrons are combining with protons that time lots of neutrons are made, lot of neutrons are produced and when it collapses and collapses and collapses and the outer layers also go towards the center. Then, these velocities of these outer layers maybe become very high some 20 of the speed of light and all that.

And then, when neutrons become too close to each other so that, Pauli's exclusion principle becomes important and they cannot go further towards each other then, this collapse halts and outer layers are still coming with large velocity. And, all of sudden this collapse stop, so there is a rebound the outer years are coming with high velocity and the core was also going down and everything was collapsing and the core suddenly stops

going down. So, there is huge impact and shock waves are sent and on this material, outer layer material that rebounds; during this process which may last only few seconds during this process, this huge burst of neutron that is there, that is produced that drives this r process and all these heavy elements which cannot be reached by that slow process s process that are synthesized.

And then, from that rebounding outer layers you have explosions the supernova explosions these only one process I am telling, there are many more processes; supernova itself is of various varieties supernova one supernova two and so on. I am just describing one process that too very brief; so, all these explosion takes place and this all these heavy elements that are synthesized in the outer layers all those are thrown off in the space. So, that becomes some kind of a debris, some kind of remains and that keeps floating in the space and later on when somewhere in this space, these clouds collect and make a new star then, all these heavy elements which are there are already present in whatever proportion there may already present there and this new star will have all these elements.

So, that had happened for our solar system too when sun was created it is not the first star from the hydrogen helium of big bang. Some heavy star had gone through this explosion and there in that heavy star all these heavy elements were synthesized and all those things were thrown in the space and from that, this sun was created. And therefore, in the solar system we have all that carbon and nitrogen and oxygen and everything iron and platinum and phosphorous and calcium and uranium all those thing, that we have in solar system that has come from these earlier heavy star which has gone through these process. So, that is about formation of elements in star; everything that we see in this universe everything that we have on this earth in the solar system that was at one point of time was created, all these nuclei at one point of time where created inside the stars. So, this is known as nuclear synthesis, alright.

So, I have almost cover the topics that I wanted to do in this course, starting from the Geiger Marsden experiment of alpha particle hitting metallic foils and then interpretation of that by Rutherford and atomic nucleus or nuclear physics coming into picture from there 100 years in 100 years nuclear physics has advanced a lot. We now have lots of understanding of all these processes inside the nucleus and also it has resulted in many many experimental tools which are used by variety of people. So, I will describes some

of two or three of these experimental tools based on nuclear physics which are being used by different engineers and scientists and researchers and industry and all that.

The first one I would like to do is called Mossbauer spectroscopic. Mossbauer is name of a person Rudolph Mossbauer, who during his PhD work discovered this particular effect now known as mass power effect. And, that has lots and lots of applications is being used widely for the 60's to this time, now 50 or so. Rudolph mass power passed away only recently 14th September 2011 so, this Mossbauer spectroscopic; what is this Mossbauer spectroscopic? Let us consider one nucleus iron 57 most of the mass power spectroscopy work is done with this iron 57 that is why I will take that as the example, but there are many more.

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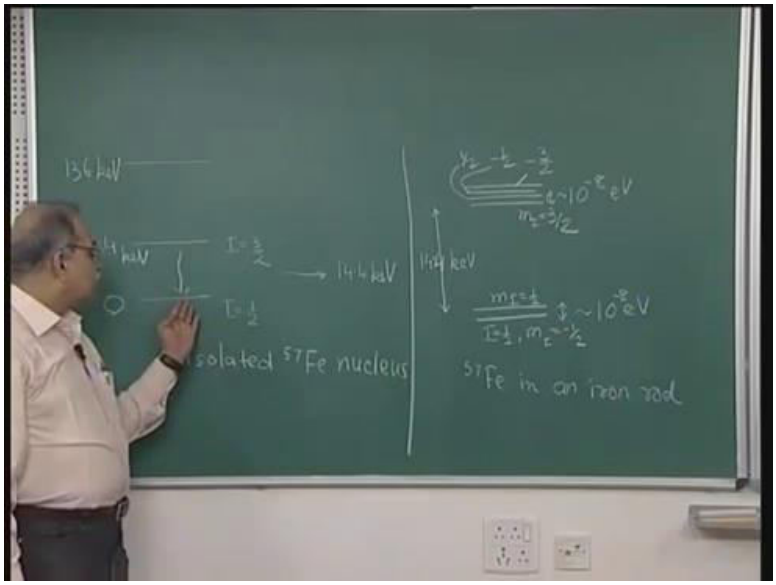

So, let us look at the ground state and first excited state of iron 57, and that is at 14.4 kilo electron volt; this is the ground state and this is first excited state, this spin is half year and spin is 3 by 2 here. And, when it decays if iron nucleus is in the first excited state when it decays to ground state then it will emit a gamma ray supposedly 14.4 KeV.

The next one is at 136 kilo electron volt, that is; this is the energy level of iron 57 nucleus but we do not have in general isolated iron 57 atom or nucleus. So, we have this iron in some kind of a material; so if you think of an iron nail or an iron plate, iron door or iron handle anything of made of iron as such, iron energy levels are different. What are energy levels of this 57 iron nucleus in say an iron sheet or an iron nail or an rod;

those energy levels are something of this type, so, this is isolated 57 iron nucleus and now, what we are talking is iron 57 iron in say an iron rod. Normally, natural iron you have almost 98 percent of that will be 56 Fe and 2 percent will be 57 Fe, alright. So, these; this is there we do not have to put it iron 57 is there in the iron rod of course, about 2 percent of the iron that we have is this one and almost the remaining thing 98 percent will be 56 iron.

So, what will be the level of this nucleus here; here the level will be you will have two levels very close to each other and then at 14.4 you will have 4 levels; cannot draw the scale to the drawing to the scale this differences still about 14.4 KeV whereas, these separations they are of the order of 10 to the power minus 8 eV electron volts not KeV. And, this I equal to half, you have m of I that is minus half here and m of I is plus half here. Similarly, here it will be 3 by 2 m of I; this will be 3 by 2 then, you will have 1 by 2 then, you will have minus 1 by 2 and then, will you will have minus 3 by 2. When this iron nucleus is part of an iron piece; then, this ground state I equal to half the two sub states m I equal to plus half and m I equal to minus half these will split, and how much is that energy splitting energy? That will be of the order of 10 to the power minus 8 electron volt is 10 nano electron volts.

The first excited state is at 14.4 kilo electron volt, the first excited state will also split in 4 parts m I going from 3 by 2, 1 by 2, minus 1 by 2 and minus 3 by 2 and there also the splitting is about 10 to the power minus 8 electron volt. Why did the nuclear energy levels split? That is because many have an iron piece, you have ferromagnetic domains and because of that you have internal magnetic field inside that domain if you look at one particular iron nucleus there you have magnetic field coming from ferromagnetic coupling of so many atoms, the electrons, the electrons overlap in from there is ferromagnetic coupling takes place. And, that creates lot of magnetic field and because of that magnetic field, these nuclear energy levels split in this particular fashion. If you think of steel, stainless steel; stainless steel also contain iron apart from other things. So, there also you have iron and 2 percent of that iron will be 57 iron. So, in that steel environment, steel is not ferromagnetic in this stainless steel environment the nuclear energy levels of iron 57; they are changed in a different way, they do not split.

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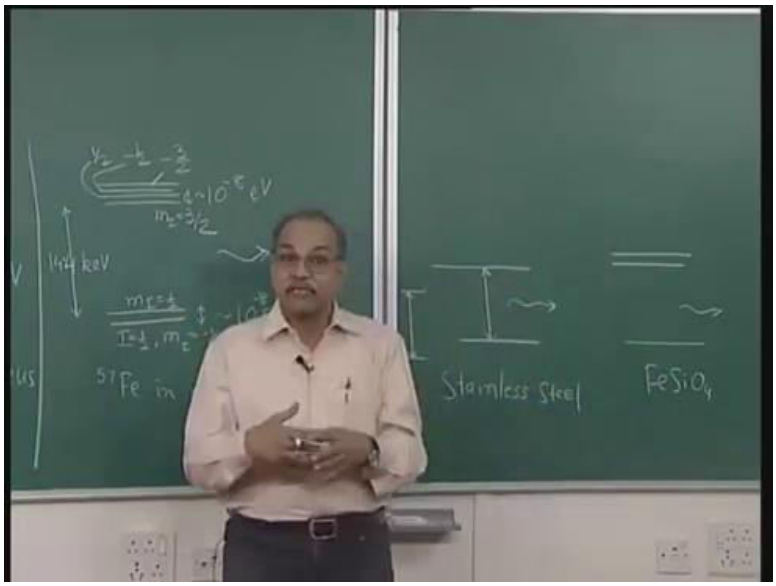

If you think of stainless steel, if the isolated energy levels are here than in stainless steel it will just shift, no splitting but there will be change, there will be a difference. So, this energy difference here and this energy different here will be different. So, the levels have shifted the ground state I equal to half had shifted at I equal to 3 by 2 it is shifted so, in this variety this stainless steel variety there is no ferromagnetic coupling as such; but still you do have electrons, lots of atoms. And, all those atoms have electrons, they are not ferromagnetically coupled, but these electrons interact with the nucleus and because of that, there is shift. That shift is here also, apart from splitting shift is also there, because the electron are there; they interact with the nucleus so this has both shift as well as split. Here, you only have shift and then mineral only varieties of this compounds, iron compounds carbonates and this and that.

So, that is another variety so let us say this is FeSiO 4 is only, so there it is the ground state remains the same and this first excited state that splits. So, energy levels can change because of interaction from that solid in which this iron 57 is embedded. And, if I can measure this change in energy level remember this changes is of the order of 10 to the power minus 8 electron volts and if a gammas rays that is accessible to me; if this is the situation some gamma ray is emitted, if this is the situation some gamma ray is emitted. So, what we have in experiments, the thing that we have an experiment are these gamma rays and gamma ray is the energy difference. So, instead of the pure isolated level different instead of that we are slightly less or slightly more energy of gamma rays,

maybe there is a splitting I have some gammas rays of one energy some gamma ray of another energy but the difference is only ten to the power minus eight electron volts type.

So, in 14.4 kilo electron volt difference of 10 to the power minus 8 electron volts, that is say one part in 10 to the power 11 or 12. So, with this accuracy if we can measure these changes then we can gain insight about that atomic or solid environment around iron 57. If I do not know if some material has come from the space, I do not know what it is? But iron is there; or some isotopic there. If we can measure these gamma rays coming from is iron 57 if that is populated and coming from there then, we can come to know whether it is what kind of environment is, what is the kind of s electrons and how much in the overlap of these electrons or what is arrangement cubic or non cubic arrangement which will split and give me this type of structure or is there is a ferromagnetic coupling which will give me this type of structure.

If there is a ferromagnetic coupling how strong that ferromagnetic coupling is all those things we can get about information about that solid at atomic scale and that level. So, microscopic level we can get information about that solid and but then the challenge is to measure gamma ray energies with accuracies of one part in 10 to the power 12 and Mossbauer spectroscope is precisely that the Rudolph Mossbauer when he discovered this during 57, 58 this is work. So, from there this process this methodology was developed when we can do that; how we do that the process involved some arrangement, experimental arrangement first I will tell that.

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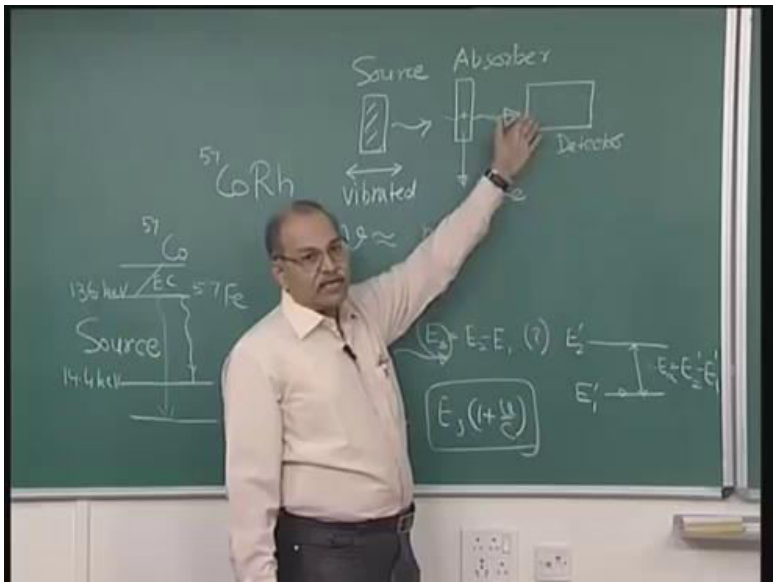

And, one is that you need a source what we call source of what; source is cobalt 57 I am just taking this iron 57 as a prototype for describing what Mossbauer spectroscope is, it can be done with many other elements also. So, Cobalt 57 is radioactive material through internal conversion it decays to iron 57 and when it decays to iron 57 that is created at 136 KeV and from there it decays to that 14.4 kilo electron volt and from there to the ground state. So, I have this cobalt 57 this isotope is embedded in a cubic non ferromagnetic material, most of the time the choice is rhodium Rh so, cobalt 57 is embedded it goes and sits at rhodium sides in very dilute proportion, very dilute proportion.

So, you have a rhodium it is a cubic material crystal is cubic structure and in that or the manufacturer puts these cobalt 57 nuclei here and there; so this whole thing becomes a radioactive source which emits gamma rays. And, of course, these internal so that is there and after that it is 136 KeV gamma rays will come if it goes directly from here to here and then minus 14 that is 122 KeV those gamma rays will come and 14.4 KeV gamma rays will come.

Then, our electronics will just pick up that 14.4 KeV so, this is known as source and in this because of the interaction of that rhodium solid, the energy levels of iron 57 are shifted, not split there just shifted. So, you will get some kind of mono energetic gamma rays of 14.4 KeV without splitting of course, it will be different from what the energy

level difference is, in an isolated nucleus. So, gamma ray comes from here so, I have a source; so, this is let us say I have a source fixed, cobalt 57 in rhodium and it is all the time giving me that 14.4 KeV gamma rays. That the material under study the material for which we want to know where electronic configuration or the arrangement or crystal arrangement, cubic, non cubic, ferromagnetic, non ferromagnetic strength of the coupling all those things. The solid that we want to study that solid is placed in front of this and that is known as absorber and this solid must contain 57 iron in ground state. Normally, if I take a solid although, all things are in ground state places unless it is a radioactive material so, arrange 57 is already there we can suppose it just a iron foil so, you can just place that iron foil or a steel foil, stainless steel foil or any material that we want to study.

So, make a foil of that or powder eight and make sprinkle that powders somewhere and make a some kind of film or thick thin palette type of thing. So, that is absorbers of this is the material which you want to study which contains this iron 57 in ground state. And then, so the gamma rays are coming here they are going through this absorber and coming on the other side and this side we put a detector; detector for gamma rays to count these gamma rays how many gamma ray are coming in a given time so that detector is there the counting system is there and then the electronics all that electronics. Apart from this, the source which is mounted on some kind of a stand or something is vibrated so, you need electronics for this vibration also, this is vibrated to and fro some kind of a oscillatory motion the maximum velocity generally is few millimeters per second, ten millimeter per second also in case of iron few millimeters per second.

So, this is the arrangement so, how does it work first the source has energy levels this is iron 57 energy levels I am drawing, iron 57 energy level ground and 14.4 KeV I am not doing the rest. So, it is giving me some kind of energies and this energy is let us say, call it E s which is if this energy you call E 1 and this if you call E 2 we would think that this is E 1 minus E 1. There is a catch here I will talk more about it later. But the gamma ray which is coming is say this energy E 2 minus this energy E 1 so, that is coming here. Now, in the absorber you have once again iron 57 and this iron 57 is sitting in the ground state so, it is here and the first level is here a maybe shifted maybe split or so whatever.

So, let us just take a case of simple case of stainless steel variety where it is just shifted. In the source the energy levels are shifted because of this rhodium thing and there, the

energy level are shifted because the of this steel, stainless steel environment. So, the shift will be different and so this energy is say E 1 prime this energy is E 2 prime and this difference is E a and that E a is let us say E 2 prime minus E 1 prime somewhat different about 10 to the power minus 8 E v. All changes are that of 10 to the power minus 8 E v so, it is slightly different. Now, since we are vibrating it, the gamma rays which are seen by this absorber are coming from a moving source; sometimes it is going away from the absorber sometimes it is coming towards the absorber. So, it is Doppler shifted so, the gamma rays which are coming they will have this E s 1 plus v by c this is the energy and v is variable, v will be changing from v max to minus v max.

So, as this source vibrates as a function of time its velocity changes because it is oscillatory motion and when velocity changes the energy of the gamma ray that is coming to this absorber, that changes and it goes from some minimum to some maximum. So, at certain time this change in energy because of this Doppler shift will make the energy coming from this gamma coming from this source equal to the energy difference which is there; to start with this E 2 minus E 1 if not the same as E 2 prime minus E 1 prime. Because this shift is coming from rhodium environment, this is coming from steel environment but then, when I vibrate this source and change the energy of the gamma ray because of the Doppler effect, because of this shift, accident point of time this E s 1 plus v by c will become equal to E a if the velocity are proper. And then, at that time and it is a periodic motion so, in every cycle that will come so, then there will be a larger probability of this gamma ray getting absorbed in this, in a solid.

That is why, it is called absorber. If the energy of this gamma ray which is coming to this solid, it is equal to the energy difference is here and this iron 57 here it is sitting in the ground state; there will be large probability of absorbing this gamma ray and going to the narrow state. After that it will it is one gamma ray will come to the ground state but that emission is in all directions so, most of it is going in different directions. In this detector, how many gamma rays I am counting as a function of time and therefore, as a function of velocity what we will find that when the velocity is match this number will go down. Because gamma rays are getting absorbed here and for other velocities where, the energies are different the energy of this gamma ray and the energy level difference in this absorber when they are different most of the gamma ray will be transmitted and you will have a higher count here.

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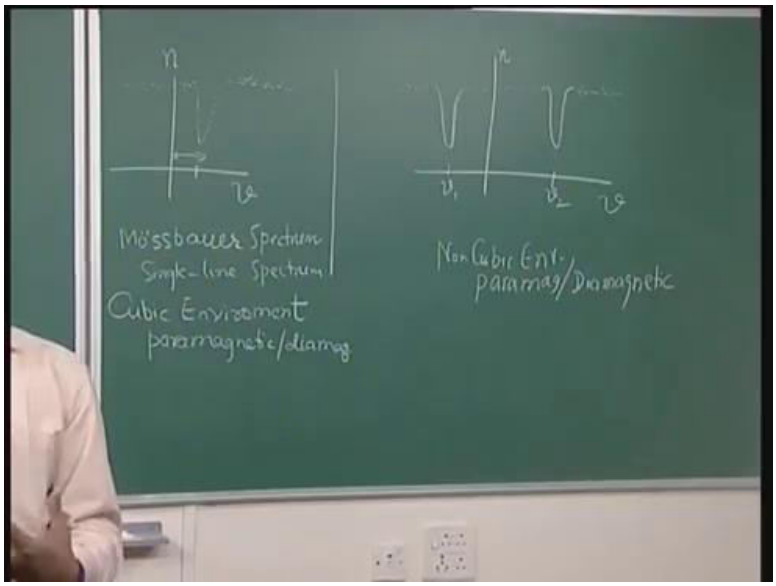

So, if I plot, if this is the velocity and if this is the count as a function of velocity what I will find that at a certain velocity all of sudden my counts are less so, I am having counts like this these many count here here here and all of sudden I will find that my counts are going down. And, again it increases so number of gamma rays at that particular velocity this is what we are plotting here which is coming from that detector the electronics is there to do all these things and we get this kind of curve. And, then, from this velocity at what velocity I am getting this absorption maximum absorption I can how much was the shift here as compared to this rhodium cobalt source this is known as Mossbauer spectrum. The shift is because of the interaction of electrons with the nucleus so, if I know this velocity where deep comes I know the shift and from there I information about electron density inside this nuclear and specially s electron because they overlap with nucleus maximum.

Similarly, you can think of a situation type of situation FeSiO 4 I told where the energies are split so, think of solid in which this first excited state is split in two parts. That happens, when the solid is non ferromagnetic as well as non cubic; when the crystal structure is non cubic and there is no ferromagnetic anti ferromagnetic coupling it is paramagnetic or magnetic in those kinds of situations that first excited state splits in two parts, ground state does not split. So, in that kind of situation you have this is source these are the energy levels for source E 1, E 2 you can say and for absorber you have iron 57 energy levels here, and then here. This is, I equal to half and this is I equal to 3

by 2 m I plus minus 3 by 2 are at one place plus minus half are at different place which is upper which is lower depends on the solid.

So, this is situation then this is a E 1 prime and here it has split as well as shifted. So, this is let us say E 2 prime 1 and E 2 prime 2. So, gamma ray is coming with this energy and here this gamma ray will falls on the iron 57 sitting in the ground state and tries to take it either to this level or to this level. It can go from here; it can go here, as well as it can go here. So, there are 2 different energies at which this a resonance will take place; if incoming energies equal to this much then also there is a level there and the probability of this gamma ray getting absorbed it will increase and if there is if the energy is equal to this then also it will increase. So, the gamma ray which is coming from the source which is Doppler shifted, the energy is Doppler shifted because of this vibration; so at two different velocity v 1 and v 2 you will have resonance. When the gamma ray energy after Doppler shift becomes equal to this difference here and v 2 where the gamma ray energy after Doppler shift becomes equal to this one.

So, what kind of spectrum it will be there? The spectrum will be something of this sort; you will have all these counts are coming and then, suddenly you find that there is a deep and then again you have more number of counts and then at some place some other place, some other velocity you can fine a dip this is velocity here and this n here. This is v 1 and this is v 2; so, this is Mossbauer spectrum; this is when you have normally, this is one line, single line spectrum cubic environment paramagnetic or diamagnetic. Here, it is non cubic environment and again paramagnetic, diamagnetic substance and the third is when you have a ferromagnetic or anti ferromagnetic coupling in the solid. If you have domains if the magnetic moments are aligned in that case I said the level, the ground state splits in 2 parts and excited state splits in 4 parts. Iron foil is an example, just simple iron foil.

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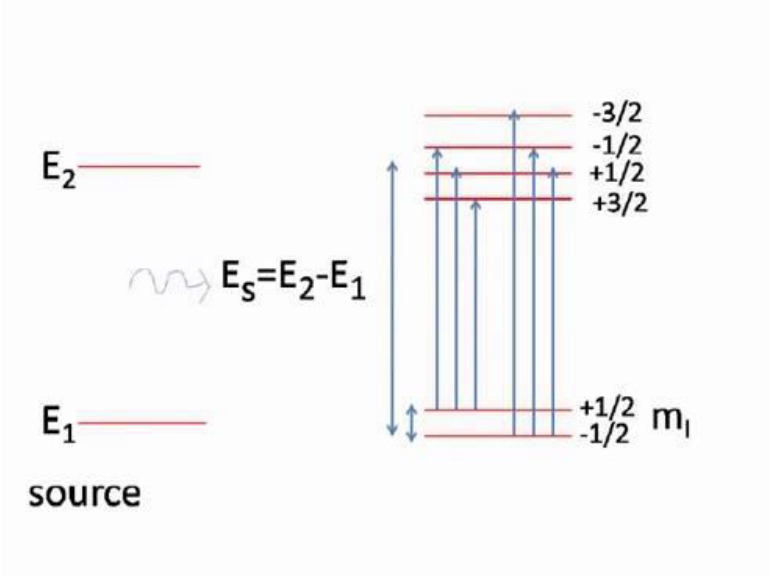

So, the source a single line source E 1 here E 2 here giving a gamma ray e s equal to E 2 minus E 1 there is a catch here and in the absorber you have two levels appearing corresponding to the ground state. This is say minus half and this is plus half; I am talking of m of I and the first excited state is split in 4 parts and m of I say minus 3 by 2 here and minus half here and plus half here and plus three by two here. And, this iron nucleus it sitting in the ground state some of the nuclei in this lower one some of them in the this, this plus half state. All right, they all ground state at such this difference is only 10 to the power minus 8 electron volts remember this difference is 14.4 kilo electron volts. They can go from any of these 2 to any of these 4 or going what we call selection roles that delta of m should not exceed 1 the absolute value of delta m it should not change by more than 1 this way or that way.

So, from plus half it cannot go to minus 3 by 2 for example, from plus half it can go to minus half delta m equal to 1 from plus half it can go to plus half then from plus half it can go to 3 by 2, alright. Delta m is from half it is going to minus half change of 1 unit zero unit and 1 unit on the other side. Similarly, from minus half it can go to minus 3 by 2 from minus half it can go to minus half and from minus half it can go to plus half. Delta m changing by 1 unit it cannot go from minus half to plus 3 half because here, it will be changing by 2 units. So, there are 6 possible translations and therefore, there are 6 different velocities; where will be high and Mossbauer spectrum if you look for such a system that will look something like this.

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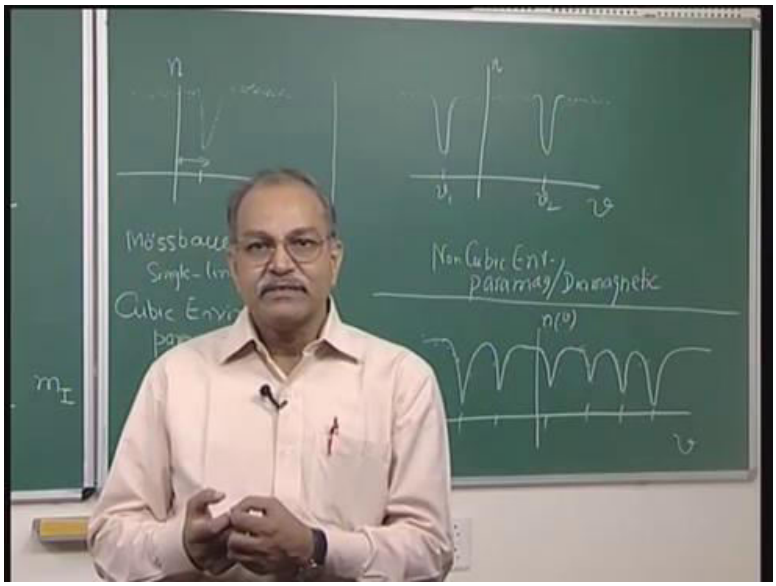

So, at 6 places so that lets say 1 here then 2, 3, 4, 5 and 6 you will get 6 line pattern; your count will be distributed around this. So, you will have a 6 line pattern if your system is ferromagnetic or anti ferromagnetic.

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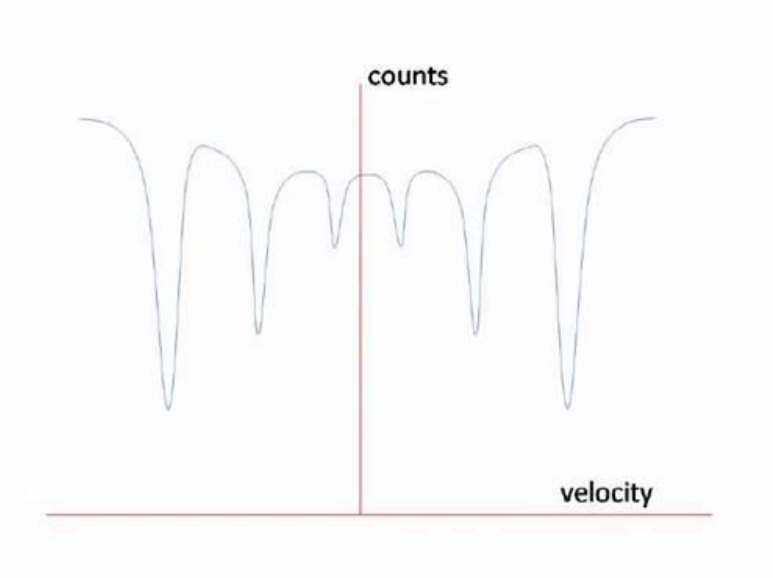

So, these are 6 different velocity whether is taking place and then, by measuring these intensities by measuring these splitting; these positions you know about the magnetic properties of this solid so you can have different kind of atomic environments. For example, magnetite you know in magnetite iron is placed in 2 different kinds of

environment in that crystal structure of magnetite. Some of the iron they are in a particular environment and others are in some different environment. So, that internal magnetic field is different for this group of iron and that group of iron; so, this group will give its own 6 line pattern and that will group will give its own 6 line pattern. So, they will be over lapping in some cases. You have this 2 line splitting of this type this is known as quadrupole splitting.

So, you can have quadrupole splitting together with the magnetic splitting; so all combinations are possible in the solid if iron is not having just one kind of environment then each competent will give its own Mossbauer spectra and the net result will be a this superposition. 4; so using computer programs one can get how many 6 line patterns are there, how many 2 lines patterns are there, how many single line pattern are there and what are the splitting; what are the intensity of these lines that the maximum absorption and so on.

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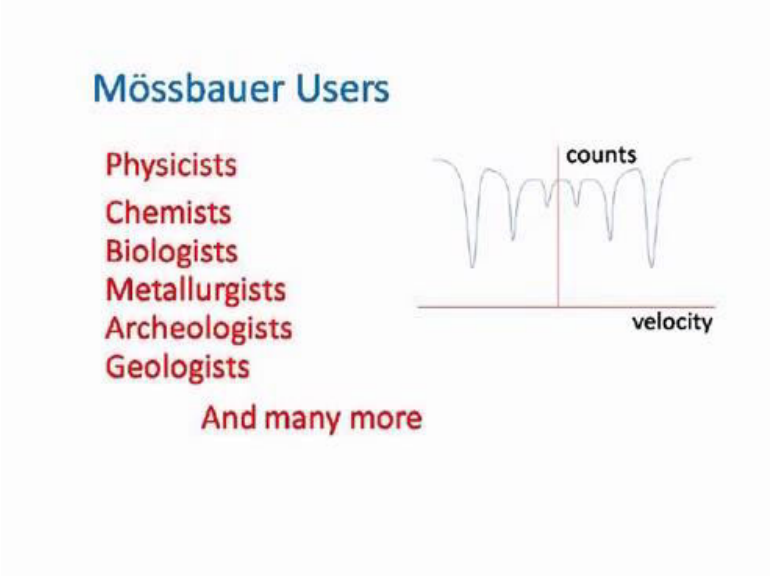

And, from there one can get lots of information about that structure. So, this is being used by chemistry people, this is being used by a metallurgists, this is being used by archeologists, all varieties of people use Mossbauer spectroscope which is based on some kind of a nuclear technique to do analysis of their samples. Repeatedly, I talk there is some catch in all these argument that I will be talking in the next lecture.