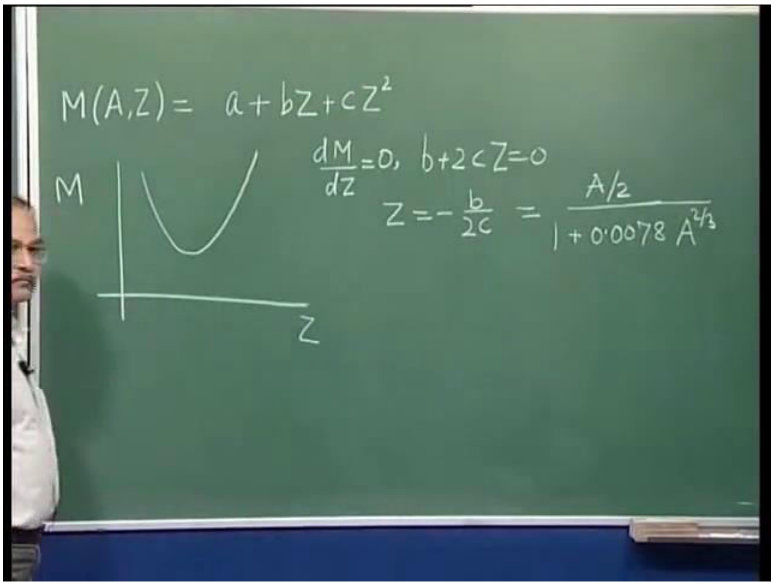
Nuclear Physics Fundamentals and Application
Prof. H. C. Verma
Department of Physics
Indian Institute of Technology, Kanpur

Lecture - 8
Semi empirical Mass Formula Cont.

So, what we are doing? We are essentially looking at, that nuclear stability and the proton, neutron composition for a particular A, which gives rise to a stable nucleus or nearly stable nucleus and so on. We are doing this, using semi empirical mass formula. That semi empirical mass formula is semi empirical, because it is taking a some logics, some arguments from the structure, developing some kind of theory, some kind of justification is there. But the same time finally, there are open parameters and those parameters are fixed by the experimental data. Therefore, it is semi empirical mass formula.

(Refer Slide Time: 01:12)



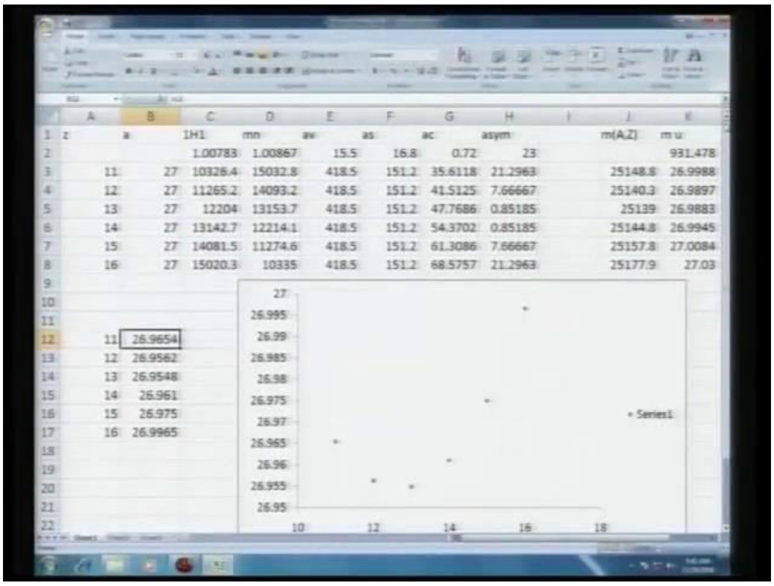
Now, if you remember, last time we discussed, that if you write mass of a nucleus with A, total number of nucleons and Z protons, as a function of Z and as a function of A. And, we are actually looking at, as a function of Z for a fixed A. So, that means Z changes, M changes, A remains the same. So, that turned out to be a function of Z, a quadratic function of Z. You can write, that as something like a term which does not contain Z, then a term which is proportional to Z and another term which is proportional to Z square. It is a quadratic expression. This, come from the coulomb term. You will have Z, Z minus 1. So, that will give you Z square and that will also give you Z.

Then, you will have asymmetry term, which will be A minus 2 Z whole square. So, that also gives you these terms. When, you do a minus 2 Z whole square you also get a term, which is independent of Z. Then, from the mass of the Z protons, mass of the Z neutrons, from there also you get this dependence. Now, this is a quadratic equation and if you plot this as a function of Z, it will be something like a parabola. So, if you plot, say Z this side and mass this side, mass is a function of Z this side, it will be a parabola and it will have one minimum and where that minimum will be, when d M by d Z is 0.

That means b plus 2 c Z is equal to 0. That means Z is equal to minus b by 2 c. This b and c they are in terms of those parameters, this volume parameter a v, a s, a c, a same and also mass of the neutron and mass of hydrogen atom or protons, though all those things will be there in this a, b, c , but here this will be minimum. In fact, we had calculated it and it turned out to be something like A by 2 and then 1 plus, what it was? 0.0078 and then A power 2 by 3.

So, there it is minimum. So, it will be minimum there. Then, it will be something like this, a parabola. This, function you can always plot, this is an algebraic function you can always plot, but when you talk of real nuclei, Z will vary only in steps of one. So, you will have a point here, then you will have a point here, you will have a point here, you will have a point here and so on. This, minimum may not fall right at the integral value, but then this integral value is, what decides the nucleus, what decide the most stable nucleus for which the mass is minimum. So, I will show you a plot, which we have actually calculated on, excel sheet and how it looks? How this plot looks, using those parameters? So, let me go to the excel sheet and then show you the actual graph, that comes out from this semi empirical mass formula, for one or two cases.

(Refer Slide Time: 04:59)



So, look at this excel sheet. Can you see that? It is readable? Now, in this first column we have written here z and then a. This, z is your proton number. Below that you can see this 11, 12. You can see that, 11 here, then 12 here, 13 here, 14 and so on. These are the z values. Then, you have these a values. You have z values, you have a values. Then, this one, this cell. Can you see that? This cell is mass of the hydrogen atom, 1.00783. In what units? Kilogram? No, then, atomic mass unit, you, right. In, the next column, here you have mass of neutron. Next column is a v; that constant in the semi empirical mass formula, you have the first term, volume term a v times a. So, 15.5 m e v is the value of a v.

Then, you have a s; the surface term ,that is 16.8 m e v. Then, you have this coulomb term, 0.72 m e v. This, asymmetry term, which is 23. This, particular, on this particular sheet, I am working with odd a nucleus. Therefore, there I have not written that pairing term. Now, you have the formula and that formula has been calculated in the second, this third row here. This is z times mass of hydrogen. Then, you have this mass, n times mass of neutron in m e v’s, right? Then, you have this, a v times. What? A.

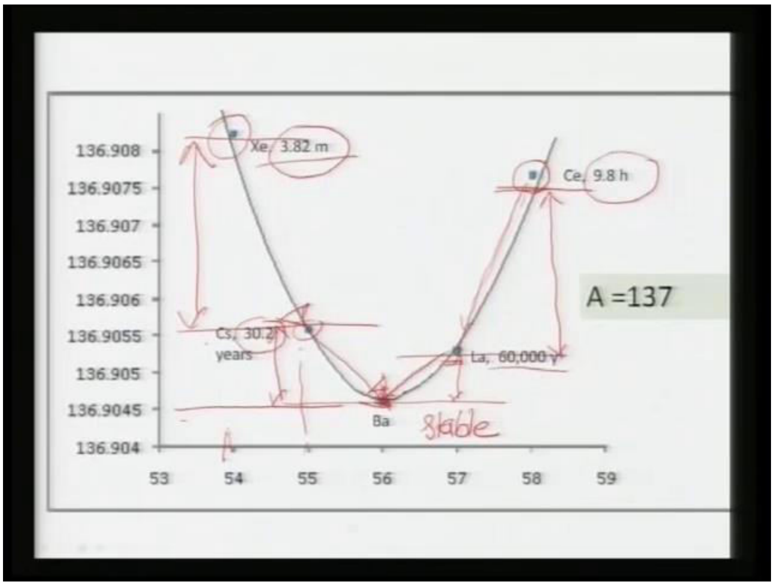
So, here is the A, 27. So, that is a v times capital A. This is for a s times capital A to the power 2 by 3. If, you can see this top bar, you can see that 2 by 3 appearing somewhere here. Can you see that? Next term is this a c. So, this is 0.72 that a c and then into z z minus 1 upon a to the power 1 by 3. Yes, that is there. Then, this is similarly asymmetry term, a minus 2 z whole square divided by a into this asymmetry. Then, all these things added, gives you here in m e v's. This is in mega electron volts that I have calculated. All your a v, a s, these things are in mega electron volts.

So, this is mega electron volts and then converted into mu, right? So, this way you can calculate for any given z and a on this excel sheet. Given, any z and a, you can get the mass of that nucleus as predicted by this semi empirical mass formula. Once, this excel sheet is created, you just have to write the value of z and a and the thing is recalculated by itself. Suppose, I say that I want it for 37. This is 37. So, I have put 37. The moment I put 37, the entire thing is recalculated and you get a value of this mass, as calculated by this semi empirical binding formula.

You change this 37 to something else, 57. So, this is 57. Of course, z also correspondingly should change so, with 57, let us say Iron. Iron is how much, tell me? Iron is how much? z is equal to 26, right, so 26. Now, I have 26 here and 57 here. So, this is iron 57. Then, the mass is calculated to be this much 56.9711, atomic mass units, u .So, this how things can be calculated very easily, once you have created those formulas on excel sheet.

So, coming back to that 27. Here, it is 27. So, 27, let us say. Then, here it is, how much it was? With 27, how many protons you would like to put? Start with 11. You get all the values and the graph is also is there. Can you see the graph? Does it look like a parabola? So, once you have created all this excel sheet, you just have to give the value of z and a and the rest is calculated there itself. So, where is the minimum? z is equal to? Can you read the graph? The minimum corresponds to 13. z is equal to 13. So, if a is 27 at z is equal to 13, you will have minimum. So, now I will show you some pre calculations I have already done some calculations and those graphs are already plotted, that I will show you.

(Refer Slide Time: 10:36)



Now, look at this graph. This is constructed for A equal to 137 and then z, I have calculated for 54. So, this is 54, this point you can see this point here. This point is, this corresponds to z is equal to 54 and A is equal to 137. z is equal to 54, Xenon. The name of the element is decided by the number of the protons. So, you have this Xenon, z is 54 and A is 137 and this point, as calculated, mass as calculated by semi empirical mass formula that falls here. Then, you have next Cesium, which has z is equal to 55. So, as calculated by semi empirical mass formula using all those a v, a s, ((Refer Time: 11.31)) and so on, you get the mass lower here.

Then, you have z is equal to 56. This is Barium. So, that mass comes out to be even smaller. But then if you go for one more z; z is equal to 57, which is Lanthanum, and then you get a higher mass, which is here. If, you go even further, z is equal to 58, then you get a point here. This line I have just drawn through all these five points. So, it is some kind of hand fitting of this data and therefore, you can see some variation here. But they are falling on a parabola. They look like, it looks like a parabola. So, which of these isobars? These are isobars, because A, it is same for all of them. So, which of these isobars is most stable?

The mass energy is minimum, for Barium. So, if mass energy is minimum, that is the most stable nucleus. So, if you look for all the nuclei, that can be formed with A equal to 137, you will find that this Barium here, this Barium has minimum mass energy and therefore, this is stable. This is not radioactive. This will not decay. If, it decays, by say, neutron going into proton, then you will reach Lanthanum, which has higher mass energy. So, by itself it will not do that. Similarly, if a proton goes into neutron, then you will get this Cesium here, one less proton. Again, mass is higher, mass energy is higher. So, by itself it will not do that. So, this is stable. But then Lanthanum; if Lanthanum is there, z is equal to 57 and if this z equal to 57 can become z is equal to 56, by decreasing one proton, keeping A 137, you will have a deduction in mass energy.

So, mass energy will be reduced and it will happy to do that. So, this will be radioactive and it should convert its proton into a neutron. So, it should be something like a beta plus decay. I will talk about that. Similarly, if you go for yet another value, they say, here A is equal to 137 and z is equal to 58. Here, the mass is very high, on this diagram. So, it can reduce its mass by changing a proton to neutron and coming from here to here. Similarly, this can come from here to here and then sit quite comfortably.

On the left side, if you see z is equal to 55, this is Cesium here. If, this z is equal to 55, may become z is equal to 56. How can that be? How can you increase the value of z? By, decreasing the value of n. That, means a neutron converts into proton, the beta minus decay. So, this will come here. So, this should be beta minus active, radioactive and it should be beta minus decay to this. Similarly, here Xenon mass is high. This is, z is equal to 54, so if this can come here, z is equal to 55, the mass will be decreased. Hence, it can come through that beta minus decay. Here, this will come, beta minus decay here. So, finally, anything on this parabola will finally, settle for Barium.

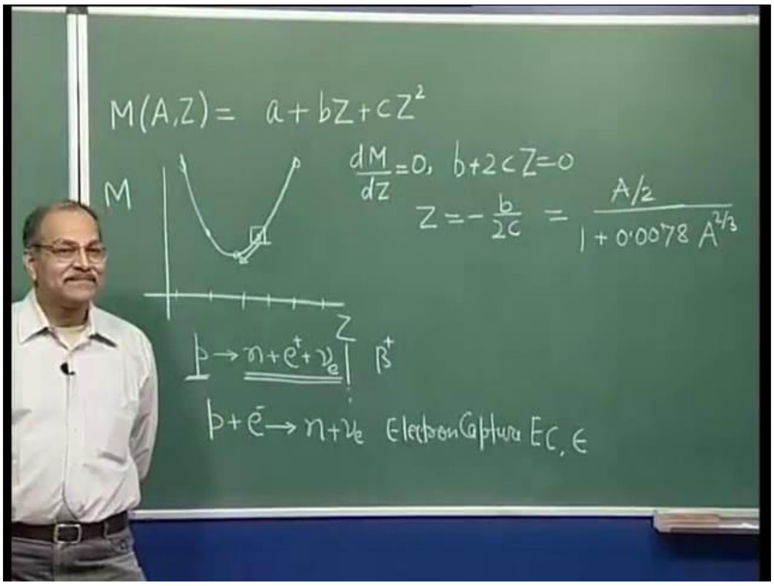
Before I leave this slide, look at one more thing. These are the half lives written here. Lanthanum, it can decay to Barium; proton number is reduced, so one proton going to neutron and the half life of that, just look at it, this is 60000 years. This can also go for a similar decay; z can decrease by one unit from 58 to 57. So, proton can decrease, proton can convert into neutron, so beta plus decay, but here the half life is 9.8 hours. Now, come to the left side of this parabola. Cesium, which is here, z is equal to 55. This is radioactive, but the half life is 30.2 years. Look at this Xenon, this is also radioactive. It can also decay to; Xenon can decay to Cesium and same, beta minus decay. But here the half life is 3.82 minutes.

So, closer to that stable isotope, the half life is large. Farther away from this isotope, stable isotope, farther away, the half life is less. So, it looks like this is of course stable, and all the others are unstable. Then, the one which is close to this stable is less unstable, it stays for long time, 60000 years or 30 years and so on and with the nuclei, which are away father away from this stable nucleus, they are more unstable. You can think of some degree of instability. How unstable it is? So, half life is large, that means it is less unstable and half life is small, it decays quickly. So, it is more unstable and you can also see the mass difference.

If the mass is only slightly reduced, it is nearly stable or less unstable. Therefore, the lifetime is larger, longer. Whereas, if mass can reduce by a much larger quantity, then it is highly unstable and the lifetime will be smaller. On the other side also you can see, look at this cesium here. If, the cesium goes to barium, then how much is the mass reduction? This is the mass reduction, when cesium goes to barium. When xenon goes to cesium, the mass reduction is much larger. You see the lifetime is 3.82 minutes. If, the mass difference is very large, lifetime is small, 3.82 minutes.

Here, cesium; where the mass reduction is smaller, you have lifetime 30 to 30.2 years. So, lifetime is related to how much energy, mass energy is reduced, when the decay takes place. So, I am coming to the board and I will come back to this excel sheet once again, with even number of A. So, it was this type of graph on that sheet, you have seen this type of graph. So, you have some element somewhere here, which will correspond to the minimum value of a mass, the Z corresponding to minimum value of mass. So, it will be here. Then, you had something here, you had something here, you had something here, you had something here, like that.

(Refer Slide Time: 19:48)



This side, what kind of decay is this? Beta plus or beta minus? Z is decreasing, so proton number is decreasing. Therefore, neutron number is increasing, because this is for a fixed a. So, that means a proton is converting into neutron. So, proton can convert into neutron and what other particles are created? A positron and a neutrino, this is called electron neutrino. You have three types of neutrino. We will talk more about this, later in this course. You have three types of neutrinos and their anti neutrinos. So, total six. So, this is called electron neutrino, or sometimes people write e here, to say that this is electron variety, in that electron family.

We will talk about these neutrinos much later and here it is positron. Positron, you must be familiar with. Positron is anti particle of electron. So, you have same mass and same spin and many other things also same, maybe we will talk about that. Charge is positive, equal in magnitude, one electronic charge, but positive. So, that is positron. This positron is created, when a proton converts itself into a neutron. Now, tell me if I write this, what is the mass here? How does this mass, compare with the mass here? Mass energy on the left hand side and mass energy on the right hand side, which is greater, right hand side is greater. Neutron is already heavier than proton.

Then, you have on top of it positron and this neutrino will also take some energy. So, the mass energy, if you see, neutron and positron, this mass energy is going to be larger than the mass energy of the proton. Then, how can proton decay into this? If, the mass energy is increasing, then how will this beta plus decay take place? A free proton will not go through this, but if this proton is part of a nucleus, look at this. This nucleus. This nucleus has some 55 or 56 protons and some 80 years neutrons. So, it is a part of that nucleus.

Student: Sir, whether neutrino has mass?

This is a very interesting thing, whether neutrino has a mass or not? Your question is very nice question. Whether, neutrino has a mass or not? This, debate is almost settled very recently, although researches are still on. People had always thought about this question, what is the rest mass of neutrino? Is it 0, or it is non 0? So, experiments were done and people were putting upper limits, that if there is a rest mass, it is less than, these many electron volts, or these many kilo electron volts, or these many atomic mass units and so on.

So, experiments where to put that upper limit. It has to be less than that. But whether it is exactly 0? Or, there is some value? That, upper limit, people were trying to reduce, but then the experiments in the last decade, they have thrown new light on it. Now, almost conclusively it can be said that, yes, it has a small rest mass. We will talk more about that when we come to that chapter of neutrino. But whatever that will be a good that is going to be very small. That, mass energy m c square, will be in electron volts only. Here, it is 511 Kilo electron Volts. Electron rest mass energy, positron rest mass energy is 511 Kilo electron Volts.

This is something like 938, 939 mega electron volts, the neutron mass energy and the proton mass energy. So, I was addressing the question, that if this right side is more? Mass energy on the right side is more, and mass energy the left side is less, then how can by itself, without pumping more energy from outside, a proton can ever go into this mode of decay? This mode of conversion, so the answer is yes, if it is just one proton, then no. But if it is a part of a nucleus, the total mass energy is to be seen, not mass energy of one proton. Total mass of the nucleus is to be seen. That total mass energy of the nucleus not only depends on the mass of protons and neutrons only.

It also depends on that coulomb interaction, it also depends on that surface part, volume part, this part, that part, asymmetry, many things. So, it is possible, that even though proton converts into a neutron by increasing the mass and creating a positron, again increasing the mass, but then other things are bringing it down; all that whatever pairing, or asymmetry, or coulomb, or this and that, those whole interaction, that whole interaction will bring the total mass. So, that is what is meant by this parabola. Mass of this Z is more and mass of this Z is less, where A is same. So, if a proton has converted into neutron, still the mass of the nucleus has come down.

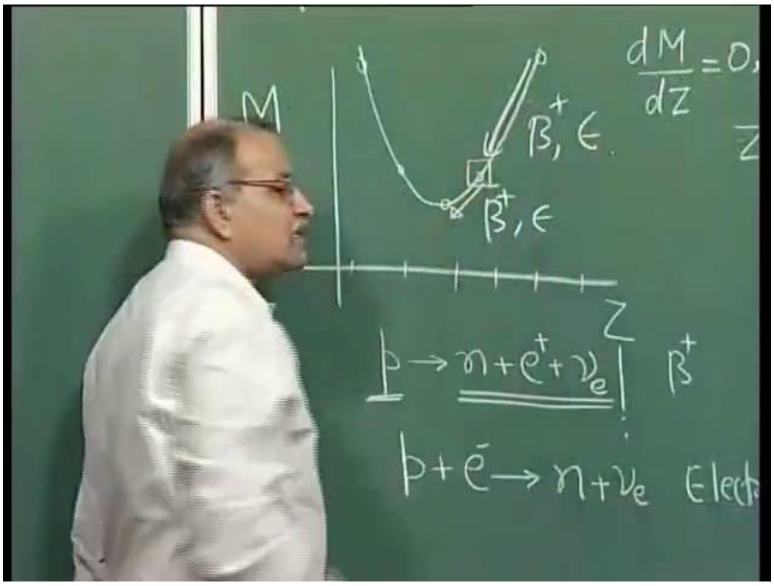
Another mode of this proton, converting into neutron, in a nucleus, the another possibility is, this proton captures an electron and then converts to neutron and this neutrino. So, this electron is now coming from outside. This electron was existing and this is now captured by this proton and it no more exists. So, this is also possible, because when you work with materials, then you do not really work with bare nuclei. You work with atoms. Any material you take in your hand that will have not only nuclei, but electrons.

1 s electron, then 2 s electron, then 2 p electron, 3 s electron and all those electrons. So, whatever experiment you do, you will put some targets; some solid, or some liquid, or some gas whatever, in whatever form you take that material. That material will be composed of atoms; you will have nuclei, you will have electrons. Now, one of these electrons, which are there in the atom, if that is captured by this nucleus and that electron gets absorbed into that proton and finally it no more exists, the electron no more exists, the proton has become neutron and the electron is gone forever. So, that is also possible. That process is written here, proton and electron making a neutron and neutrino.

This is known as electron capture E C. You will find in the books, E C. This, is written as beta plus and this is written as E C and sometimes the symbol epsilon is given for that. So, if somewhere some decay scheme, it is written E C or it is written epsilon, you understand that it is electron capture, which electron is likely to be captured, more likely to be captured? 1 s, 2 s, 2 p? Which electron is more likely to be captured? 1 s, because 1 s is closer to the nucleus as compared to 2 s, 2 p and so on. 1 s is closer to the nucleus. Now, compare 2 s and 2 p; 2 s and 2 p. 1 s is closer to the nucleus, than an equal to two. K shell and then L shell. L shell is larger, K shell is smaller.

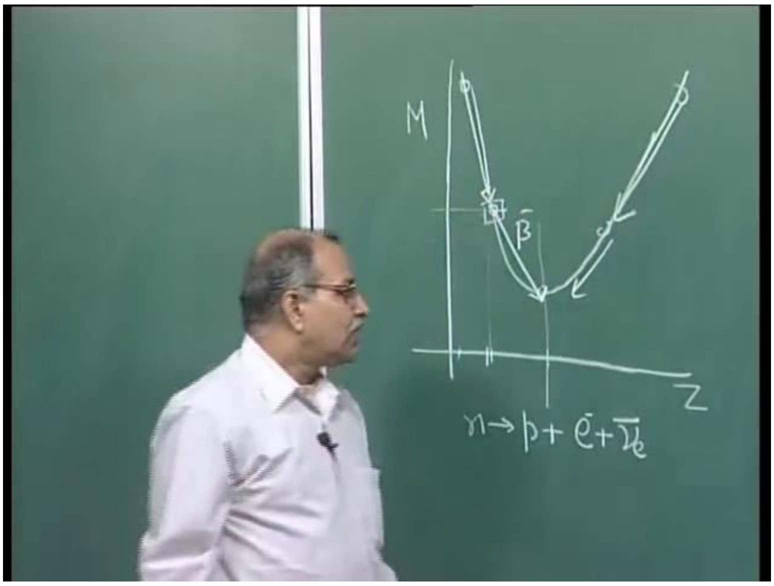
Now, compare 2 s and 2 p, which electron is more likely to be captured by the nucleus? 2 s, because if you look at the wave functions, we had talked little earlier. If you look at the wave functions, s electron wave functions are non zero at origin, p electron wave functions are 0 at origin. So, s electron will have overlapped with the nucleus. It is spending time inside the nucleus, s electron and therefore it is more likely to be captured. p electron is generally, outside the nucleus. The wave function is 0 there. At origin it is 0 there. So, 2 s electron is more likely to be captured than 2 p, whatever, once electron is captured, proton goes into neutron and this type of decay can take place.

(Refer Slide Time: 30:05)



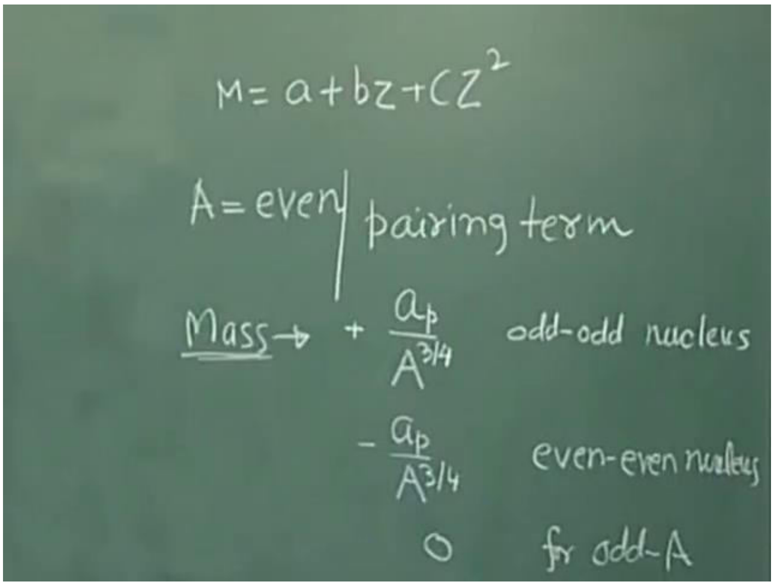
So, this could be beta plus or epsilon, this could be beta plus or epsilon.

(Refer Slide Time: 30:12)



So, this was for this side. Now, look at this side, from left of this stable thing. So, this particular nucleus has mass and it can reduce its mass and go here. What happens to Z ? Z increases. Z increases means a new proton has been created. That will come from neutron. So, this is beta minus, a neutron, becoming a proton. What will be emitted? electron and anti neutrino. So, inside the nucleus, one of the neutron can convert into proton. Electron will be created and new electron will take birth. This anti neutrino and then, this can come here, similarly this can come here. The lifetime is related to the mass difference, that I had shown you. If the mass difference is small, then lifetime is large and if the mass difference is large, lifetime is small. So, now look at the situation when A is even.

(Refer Slide Time: 31:50)



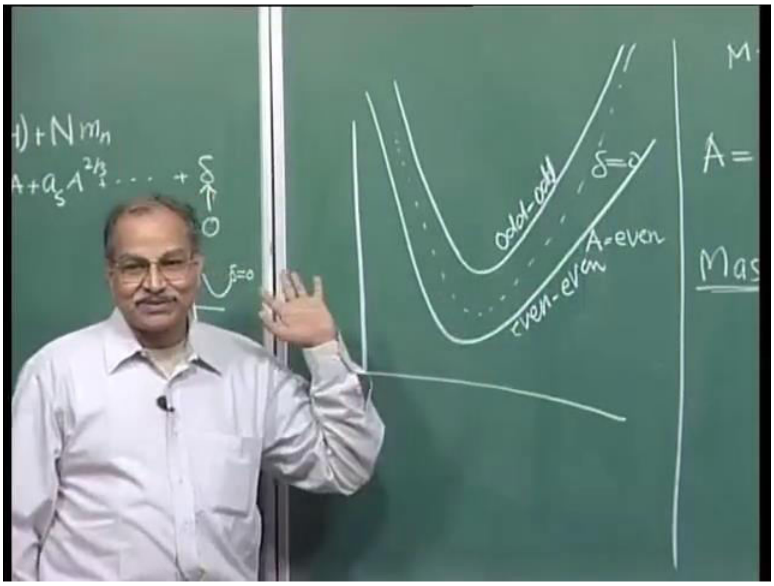
What is the difference in that semi mass, semi empirical mass formula? A equal to even and A equal to odd, what is the difference between that semi empirical mass formula? Which term? Delta, all other terms are same, A. Remember, A will be fixed. So, if I look at that expression of mass energy, as a function of Z for even number of nucleons, A, the difference will be in delta. That delta as such, does not depend on Z. Remember? That, delta, that extra term that we add, that we call pairing term. This is a p divided by A power 3 by 4. So, we add it, if it is odd-odd nucleus.

Remember, I am taking of mass. So, if it is odd-odd nucleus. Negative, that is what I am trying to explain. Yes, you are correct. It is negative for odd-odd, but that expression was for binding energy. So, binding energy reduces, if you have odd-odd it is less bound. Now, I am writing mass. So, if it is odd-odd, it is less bound, means its mass has gone up. The mass of the whole nucleus has gone up, as compared to, that delta equal to 0 situation. Less bound, less bound means mass has gone up. So, for binding energy when we write; a v into A minus a s into A 2 by 3 etcetera that time, yes. From, binding energy, if it is odd odd nucleus and pairing is not taking place for both of them, the binding energy is reduced.

Therefore, you subtract from binding energy this factor, so it is negative. For, even-even it is positive. But when you write an expression for mass; mass of a nucleus is, mass of z protons plus mass of neutrons minus the binding energy. So, in there, this will become plus. So, for mass expression all this parabola that I am drawing here is for mass. So, this is ,then it is minus a p over A 3 by 4, that is for even nucleus and 0 for odd A. So, on the face of it, it is A, that is appearing here the z is not appearing here. So, if I write the parabola M, as equal to a plus b z plus C Z square. Mass as a function of z and there is no z here. Should there be a change in the parabola, or is this same parabola that will come? Should there be a change because of this extra delta coming in? Suppose, I put A is equal to even, some 100 in that semi empirical mass formula and forget delta. Put delta equal to 0. Then I do put delta value, depending on whether it is odd-odd or even-even.

Do I get the same parabola or do I get a different parabola? Will it be the same parabola? No, it will not. It will not, because that parabola, when you are drawing that parabola, a plus b z plus C Z square, a is also there. A term independent of that is also there. That also decides the parabola. That is going to change, whether I put delta equal to 0, or I put delta as equal to this, or I put delta as equal to this, the a will change. If, a changes, the parabola will change, so the z dependence is not here, the z dependence is here, z dependence is here, but that a will depend on this delta.

(Refer Slide Time: 36:56)

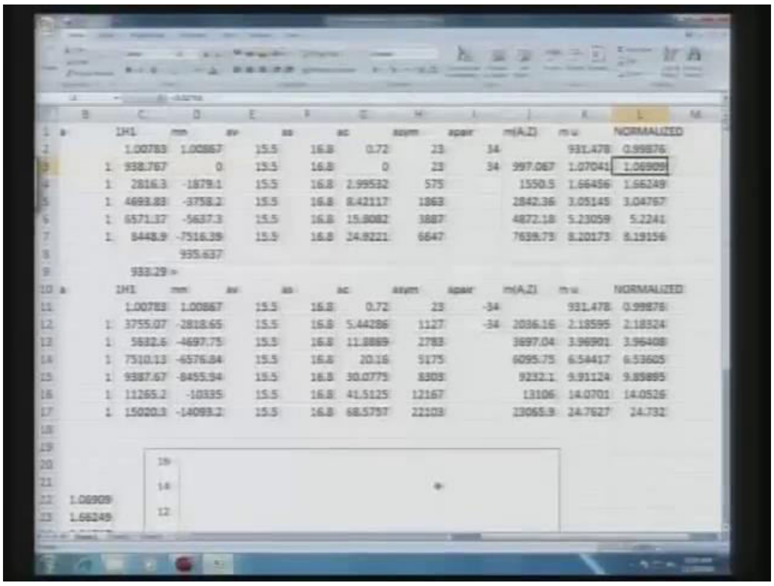


So, now suppose, I have this. If, I put delta equal to 0, suppose I get this parabola. Suppose, when I put delta equal to 0, there is some A, which is even. I put delta equal to 0, then you will get a definite parabola. Now, if I put this value, positive value, a is increased. This a here, if this a here, is increased, how will it look like on this diagram? The whole parabola will be shifted up. Where, everywhere all those other terms are there and this term is added, this a is increased. So, everywhere that y axis, y coordinate will increase. So, you will get a parabola of this type. If, this extra term added is positive. That means all those odd-odd nuclei corresponding to that A. The A, we have fixed. But with that same A, I have two varieties.

In one variety, as I change z, as I keep on changing z with one unit; you will get two varieties. One in which, proton number and neutron number are both even and other both odd. So, all those values, all those nuclei for which, Z is odd and therefore N is also odd, they will fall on this parabola. But then you also have nuclei, with the same value of A, where Z is even and N is even. When, I use that semi empirical mass formula to calculate mass and plot here, I will be using, this negative contribution here. This mass is decreased. If, Z is even, N is even, and then pairing will take place.

You do not have unpaired nucleons. So, the mass will go down, it will become more stable. So, if I add this term, as compared to this delta equal to 0 parabola, this parabola will be shifted down. So, all those even-even nuclei, with that same A will fall on another parabola, which should be like this. So, this is for odd odd and this is for even even. I have done these calculations for A equal to 128 on that excel sheet. I will just show you, how it appears?

(Refer Slide Time: 39:58)

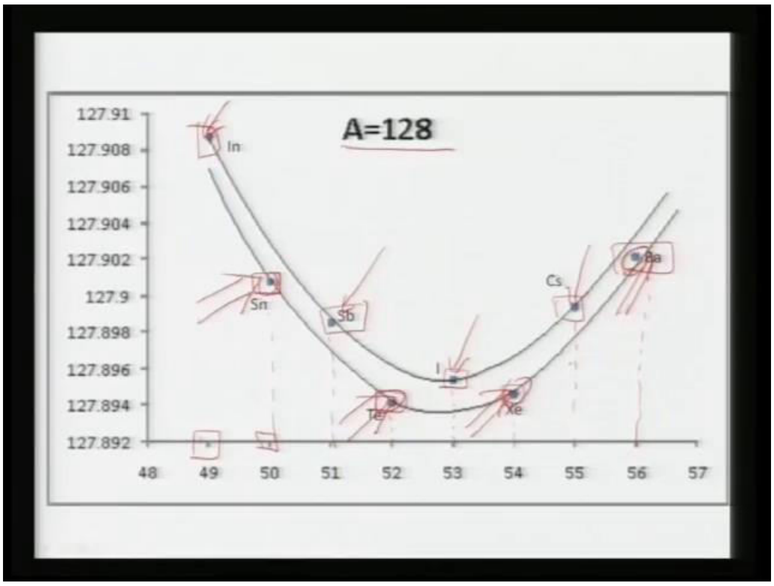


Now, even parabola the situation is slightly more interesting, as well as more involved also. See, it is the same excel sheet and you have those values. Those values one H one, mass, neutron mass, then you have this a v, a s, all that same sheet is there. Now, if I put, let us say Z and A. So, in place of A, let me write 128. In place of Z, let me start with some 54 or so. Now, you have masses here. See, in this first part, I am taking; Z is equal to 54, then 56, then 58, then 60 and then 62. Can you see that or should I enlarge more?

So, 54, 56, 58, 60 and 62 and the corresponding masses are calculated and they are here. These are the masses. Now, this thing, I have put a pair 34, that 34 a p. So, using this a p equal to 34, I have calculated the masses for Z is equal to 54, 56, 58, 60 and 62. Now, in the other part, other half you can see here, this a pair, the lower part a pair, here is minus 34. So, it the same formula copied, but a pair that constant is now minus 34. I am using this minus 34, to calculate the masses for Z is equal to 55, Z is equal to 57, Z is equal to 59, 61 and so on. These, are odd odd nuclei. The total A is 128, remember.

So, these are odd odd nuclei, these are the odd-odd nuclei. I am using, a pair is equal to minus 34.Whereas, these even even nuclei and I am calculating the mass using, a pair is equal to plus 34. You have to do that, you have to do that. Even even nuclei, you have to see, that they are paired and therefore the mass energy is decreased. Odd odd, it is the other way. So, all these things are taken care of. When everything is taken care of, then you get this final parabola. That, I will show you for A equal to 128, here it is.

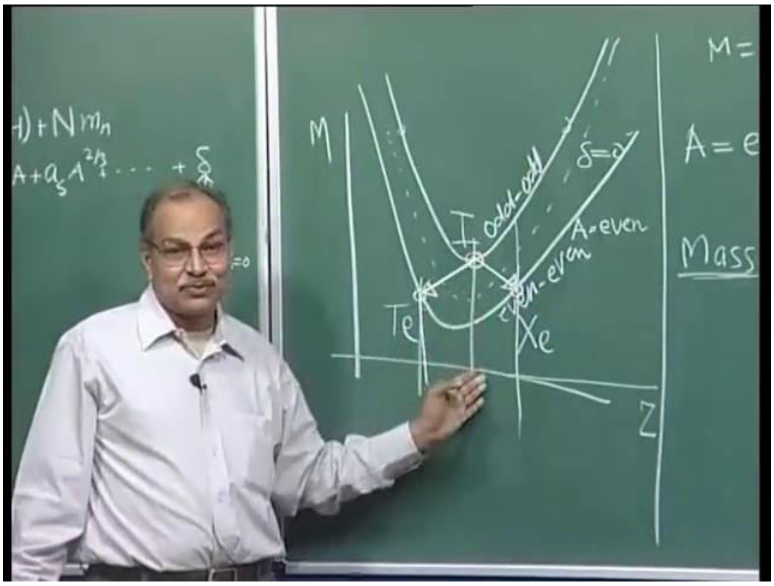
(Refer Slide Time: 43:14)



Look at this. This is the results that we calculated from excel. Those results are plotted here and it is shown to you. This is A equal to 128 and Z is equal to 49. Z is equal to 49, is this point, Indium. Z is equal to 49 is Indium. Z is equal to 50, is tin. This is tin, is equal to, Z is equal to 50. Look at this 50 here, Tin. 51 is antimony. 52 is tellurium, and then 53 is indium. All these are numbers that I have gotten from that excel calculation. 54 is Xenon, 55 is the cesium and this is barium here, 56. If you look at all these points together, they do not lie on one parabola. But if you look the odd one separately, this is the odd one, this is odd one, then this is odd one, this is odd one. They, lie on one parabola, which is shifted up.

The even-even, 50 here it is, 50, 52, 54, 56, this point, this point, this point, this point, they lie on another parabola, which is shifted down. So, even-even will shift down, odd-odd will shift up. For, the same value of A, you will have, these two parabolas coming together. Now, just watch, that I will draw this schematically on the board and we will discuss the decays. So, tellurium here, xenon here and iodine here and other things, just keep in your mind. So, you have this type of situation. It is already there.

(Refer Slide Time: 45:28)



So, you have Z on this side and mass on this side. You had an element here, you had an element here, you had elements somewhere here, and then other things. What was this? iodine. What was this? Tellurium and what was this? Xenon and other things. Now, if you look for, where are the stable nuclei? Remember, for odd A case, we had one minimum on the parabola. Whatever, was lying close to that, minimum of the parabola was the stable one and from one, side it was beta plus, and from one side, it was beta minus. Now, if you look at this diagram, what can happen? This is one Z, this is next Z and this is next Z. Look at these three, and specially look at this one.

This can go to this, lowering the mass and this can also go to this, lowering the mass. The difference of Z here to here, is two units. Z increases by one unit, Z increases by another unit. So, tellurium to xenon, or xenon to tellurium, is very difficult. It is not beta plus, it is not beta minus. Z is increasing by two, if you go from, here to here, or Z is decreasing by two, if you go from, here to here. So, all those double beta decays possible, but almost very, very small probability, so both of them are stable. This one and this one, both of them are stable, even if there is a slight mass difference. So, for even A nuclei, you can have two stable isotopes.

For, odd A nuclei, you had one stable isotope. Anything, on this side, will decay to this. Anything, on that side, will decay to it. But here you can have more than one stable isotope. In fact, you can have three stable isotopes also. You can have a situation in which, there is only one isotope stable. That is also possible. This is one case, 128, I have shown you, where we have two stable isotopes, tellurium and xenon. So, next lecture we will talk more about this, even A things. How you can get three stable isotopes? Or how you can get one stable isotope in this case?