Nuclear Physics Fundamentals and Application

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Lecture - 19
Shell Model Contd…

We saw that a if you add this spin orbit interaction in dot s term on harmonic oscillator single particle nuclear potential, you will be produce all the magic numbers. So, far as these shell closures are concerned magic numbers are concerned, it does not matter whether you take informative square well potential or this harmonic oscillation potential or a finite square well potential with everything, you can get those magic numbers. But the values of energy the separation between different energy levels for example or sometimes the order of energy levels inside a sub shell, that is a function of a what kind of potential you chose. So, for any realistic calculations people choose more realistic potentials. So, as compared to infinite square well potential for harmonic oscillator potential.

Finite potential, finite square well potential is more realistic, because as we discussed earlier, you can take out a neutron or a proton from the nucleus, whereas these infinite potentials do not allow you to do that, then the sharp change in potential as in infinite square well potentials, suddenly it becomes 0, after some or equal to capital R. So, then also a little bit of unrealistic. So, people add on it some kind of rounding of at the edge, finite square well potential, but there is some kind of rounding at the edge to make it more realistic. The one which is which suits every all these discussions is it is would section potential right, it is would section potential.

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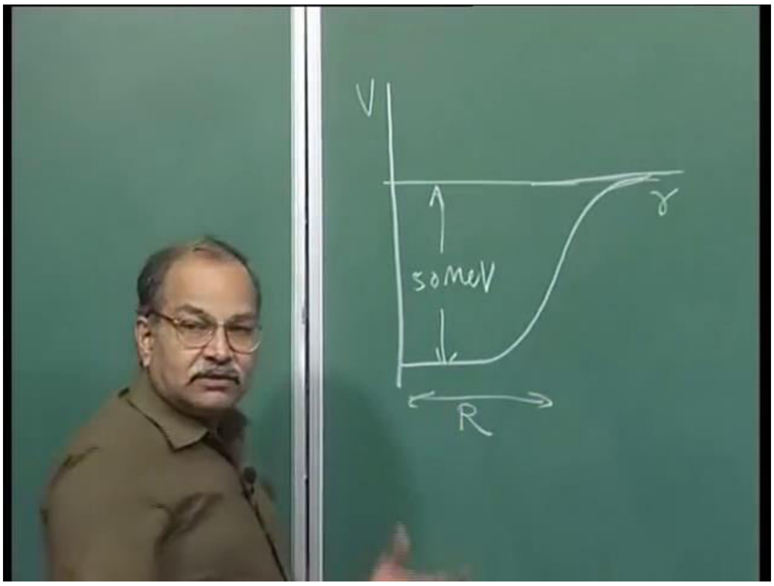

The shape is something of this type. So, more sharp edges and no infinite potentials v is a function of r is this would section potential, that is taken in most in many of the calculations, as the basic single particle neutral potential and on this on add l dot s ten with appropriate strength to get all those energy levels. So, I will show you on the screen how this varies how this differs from harmonic oscillator energy levels or if you use those harmonic oscillator energy levels and then apply L dot S on it. You do get some energy levels. And if you use this type of wood section, normally this is around 50 m e v depth and this r, becomes the size of the nucleus and this how it tails of that is a right. So, how these energies levels compare with the harmonic oscillator energy levels.

Students: Why is it called wood saxon?

Those are persons, those are scientists, who had a come out with this kind of potentials. So, the name is there to give them credit, that these are the persons who had simple say miller joules potentials. They were scientists who came up with this potential that look use these potential and you get the desired results. We, I will just go to the screen and you see how the these energy levels differ from on how do they compare from this right.

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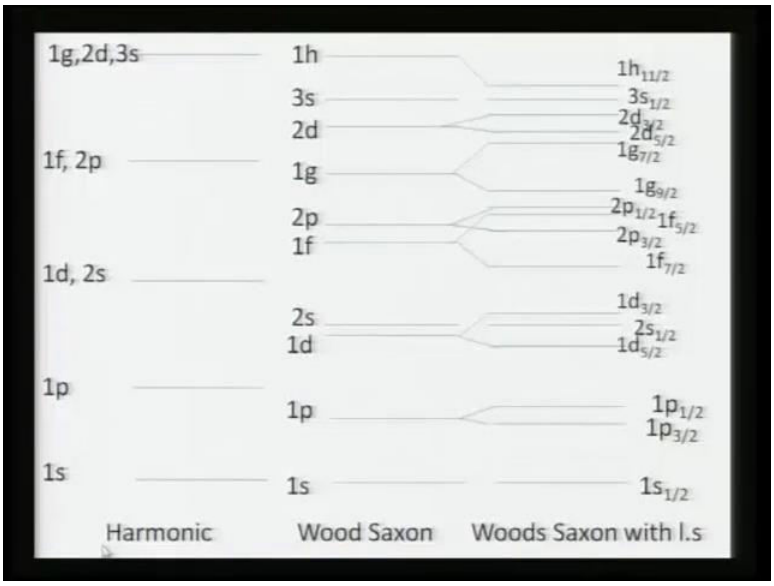

So, these are the harmonic oscillator potentials or with the harmonic oscillator potentials, these are the energy levels, this you remember.

Students: No sir.

1f then 1 p and 1 d 2 s together, we generate 1 f 2 p together 1 g 2 d 3 s together right, that you can write easily. This is how the wood saxon potential will look like. Now, compare 1 s 1 s are 1 at the same height 1 p has come down all right. Then 1 d and 2 s both have come down, this is a general feature from infinite potential, if you are coming to finite potential normally, here energy levels will come down in that that case. So, 1 d and 2 s are coming down by different amount. So, and therefore, the degeneration is left that.

Similarly, 1 f and 2 p they have come down by different amounts. So, 1 f has come down more 2 p has come down less and that degeneration is lifted then 1 g from that upper state has come down by quite some larger amount. So, that it is at that almost at the same level, where the original 1 f 2 p was there. Similarly, where 2 d 3 s, we have come down and the last line that, we are seen at the top is coming from 1 h.

Students: 1 h.

Next level was 1 h and then this 2 f 3 p those things were there that 1 h has come down insignificantly, and it is there. Now, if you add this spin orbit potential on this these levels see what happens. So, you have these wood saxon with l dot s term. So, 1 s becomes 1 s half, what you get half, the j value l and s, they have to combined and they have given as j. So, s state l is equal to 0 and spend is half j is half. So, it is l s half and this 1 p had split into parts p j equal to 3 by 2 that, we call P 3 half that has come down and 1 p half has gone up. So, this 1 p is split degeneration lift up.

Next one 2 s will not change, because if s is take that l dot s term is 0, that does not change. That does not split 1 d will split in 2 parts d 5 by 2 coming down and d 3 by 2 going up. Then here is 1 f in 2 p, so 1f split in 2 parts. The lowest 1 is f 7 by 2 and f 5 by 2 have gone up in 2 p also split in 2 parts 3 by 2 and half p 3 by 2 is coming between the 2 f states. So, 1 f has split in 2 parts 1 f 7 by 2 and 1 f 5by 2, 5 by 2 going up 7 by 2 coming down 2 p has also split in 2 parts p 3 half and p half and the structure, that we have drawn is the 2 p 3 half is coming between f 7 half and f 5 by 2, then you have 1 g.

So, 1 g will split and 1 g splits in 2 parts g 9 by 2 g 7 by 2 and 2 d on top of that, you have 2 d that will also slip split 3 s will not split and 2 d goes like this and then you have this 3 s coming. And then you have this 1 h coming from the top right. 1 h 11 by 2 coming from the top, these are the energy levels, if you use this woods saxon potential. The magic numbers are same shell closers are same place s half will have 2 occupancies 2 neutrons or 2 protons can go there.

So, 2 similarly, that p 3 half and p half that combined will give you the 6 and the next shell closer is 8 then 21 f 7 by 2 is stand alone. So, 8 8 nucleon can go there 8 nucleon of the same type 8 newtronce or 8 protons can go there. So, that shall closes 28 in after that the shall will close that g 9 by 2 that will be 50 and at h 11 by 2, that will be 82 and similarly, you can go up you will get that 126.

Now I will like you 2 practices writing these energy levels atleast up to say 50 nucleons that magic number 50. So, you will just to try to do that on bold, you can do in on your notebook. So, that whenever need rises, you can write this order of energy levels, these sub levels quickly. So, let us do this manually on the board. So, you can start with in the same fashion.

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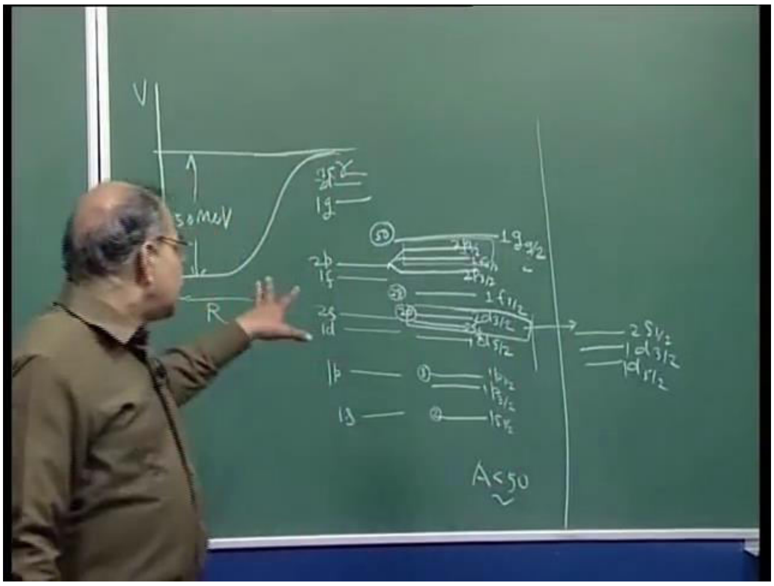

1 f and then 1 p like harmonicoslator and next one is 1 d and 2 s. So, 1 d will come down and 2 s will go will be slightly up they are split. Then 1 d and 2 s will be 1 f and f will be somewhere, 1 f and 2 p will be, slightly up 2 p somewhere here. So, you can write quickly, if it is harmonicoslator it is 1 s 1 p and then 1 d and 2 s together. So, you split down little bit and then next 1 will be 2 p and 1 f, so you split down.

Then putting that l dot s tern, this p, what will you do this p, you put in 2 parts p 3 by 2 down behalf of right. This p goes here then this d, you can this shell is closes at 2 and this is 6 of this closer at 8. next closer at 20 2 and 8 10 for 10 more with this d, what will happen d 3 by 2 will come down d 5 by 2 right, d 5 by 2 will come down and then d 3 by 2 will go up and this 2 s will be remain there. So, this 2 s will remain there, if you wish you can also write that n. Up to this part you can do that easily and how many what is the number of newtronce or protoconce that can be accommodated 6 plus 2 8 8 plus 4 12.

So, 8 plus 12 20 then f 7 by 2 will come down and that will be alone 1 f 7 by 2. So, that is next shell closer. And f by 2 will go up f by 2 f 5 by 2 go up and then this 2 p this 2 p 3 by 2 and 5 by 2 and how is that written, f comes between the 2 p levels. So, this 2 p let me write it slightly lower. So, that this 2 p when it is bits 1 level goes here and another level goes here. This is 2 p, this is 2 p 1 by 2 and this is 2 p 3 by 2 and this 1 is 1 f 5 by 2 in between. How many 4 plus 6 10 and plus 2 12 and this is how much 12 and 10 will come from 1 g, next 1 is 1 f 2 p 1 is 1 g 1 g will be there then 2 d will be there. And 3 s will be there and this 1 g will give you 1 g will come down and join here. 1 g 9 by 2 that makes it 12 plus 10 22 and 28 plus 20 is 50, you do not know to climb.

These levels that to first it is the half then p 3 or then p half and then d 5 by 2 then is a is almost impossible then crime all those things to remember all that author. But you construct them, if you remember the basics of how it is spitting n, how it is ordering from that basic construct basic knowledge, you can construct 8 in how much time, you will take from it is clean slate. If you have to write all these things, how much time will you take. Yes, how much time you will suppose, I will graph everything and ask you to write the levels, starting from scratch, how much time will you take.

Students: 5 minutes.

5 minutes.

Students: 2 minutes.

2 minutes.

Students: Maximum 2 minutes.

Maximum 2 minutes.

What you have to do, you have to first you imagine your harmonic oscillator potential 1 s 1 p 1 d 2 s 1 f 2 p and then the 1 g and 2 d and 3 s harmony that should take you some 30 seconds. Then write them separate them little bit in harmonic potential, you would have written these thing at 1 level. These 2 at 1 level, these 3 at 1 level, separate little bit and remember higher l value or lower n value that will come down.

So, separate that, writing this, this, this, this, this, this, and this 1 g at least 1 g should take about 30 seconds. And then you have to split 1 s will remain at such this will 3 by 2 coming down 1 by 2 going up d 5 by 2 coming down 3 by 2 going up and this s is in between where f comes down. And this is a you remember that, this is this close is up to next magic number 8. Next is 20 next is 28. So, this 8 will be alone and it is corresponding side by 2 will go up and this p will split into 2 parts and this f is signed with between t half and t 3 half and 1 g comes from here. And you reach this 50 magic number. So, now tell me how much time, you should will take 2 minutes or 1 minute.

Student: 1 minute

Yes it should be able to do it in 1 minute, whenever you need as is you can, you should be able to write it in 1 minute alright good.

Now, there are certain things about, this ordering, 1 is this nuclear potential depends little bit on the size of the nucleus. Because, more is the bigger is the size this potential that you have written will be wider. So, the basic features remains the same, but the values of energy will change. Values of energy will change and therefore, the separation between different energy levels that separation will also change, that depend on how big is the nucleus. And if the separation changes some times, it may also happen that 2 adjacent levels cross over. It may happen suppose, this separation is changing as a is increasing and so this separation is decreasing.

So, at certain instant it can cross over, it can interchange, that happens first here. This 2 s half and this 2 d half here, we have written 2 s half between the 2 d levels. This d level is splitting in 1 part here and another part here, 2 s is remaining here. Now around a equal to 50 or so this features. So, for this is for lower values A less than fifty, if a is larger and these, this section on this things, the order will remain the same this separation can change. But, order will remain the same.

But, this portion will become d 5 by 2 and then d 3 by 2 1 d 1 d and then 2 s half here. So, this order can change similarly. Here this order can change this order can change somewhere a greater than 60 70 and so on. So, just keep this in mind it is not a script order, but if you normally shell model is a used is quite successful for lighter nuclei and then in the middle heavy range also there are sections.

So, for lower lighter nuclei this is very good and if you are more than 50 more than 60 more than 100 at some places, you may get some cross overs. But the group will remain as it is it will not no level will leave it is own group and come join another group. So, the magic numbers will remain the same. So, that is 1, second thing is every separation between the energy levels, that decreases as this nucleon number, mass number A increases right. It comes from experiment essential. That last filled energy level, you can all it nuclear fermi level, last fill energy levels. That is a that does not vary much lighter nuclei, heavy nuclei, muddle weight nuclei that does not vary much varies within say 5 written middies of saw, similarly that depth of the potential.

That also remains almost the same. So, this total occupied energy difference the bottom and top that is of the same order of all nuclei and then if a is large then those who energy level should be there, if A is small then less number of energy levels are there, I am only talking of occupied energy levels. So, the highest occupied energy levels, if that remains almost at the similar, place and the lowest energy level, that remains roughly at the same place and then you are pushing 10 nucleons. So, you should have roughly 5 levels each one or yeah. In fact, nucleon means of protons and neutrons, when energy level will take 4 2 protons and 2 neutrons. So, you will have, but if u have say 200 nuclei nucleons and all those 200 are to be commutated.

So, you should have 50 levels in that same range. So, that every separation between the energy levels, that is you are seen here. That is a function of capital A and as capital A will increase this whole thing will get squeezed. So, in the same height of the black board, you should be able to bring all those 1 26 and 184 all those things is compressed. The separation average separation between the energy levels decreases as capital A increases.

That is why in semi empirical mass formula, when we are writing that a symmetry n minus z, whole square divided by capital A. So, that is a because of this, the third thing is this proton, this these energy levels or this potential itself is some, what different for proton and neutron. Because, of limbic interaction, if you are writing for neutron is a single practical potential for all nucleons, we are saying that this is the potential and these are the energy levels. But, then that single particle, if it is neutron it is not experiencing any calamine direction, where as if it proton it is interacting with the rest of the nucleus through, coulomb potential also coulomb interacting also.

So, the potential it some would different for proton and for neutron in lighter nuclei, it does not matter much right. Light nuclei it does not matter much and the levels are same almost the same on the, but for middle weight or heavy weight. This coulomb interaction may become significant as compared to this nuclear potential depth, you remember the formula for a coulomb potential.

If you assume it will be a spherically charged system spherically, symmetric charge distribution z e z minus 1, you can say when the a flume potential can be written as or coulomb potential energy, can be written as some z e square 4 pie epsilon not capital R.

Capital R is this and then 3 by 2 minus 1 by 2 r by capital R square right. We have derived this, when we where considering the radius of the nucleus am initial lecture and how this electrostatic interaction between the nucleus and electron changes the energy and x-ray energy, alpha energy all those thing we discussed. So, we have derived this equation that time is class eleventh. So, columbic potential is like this.

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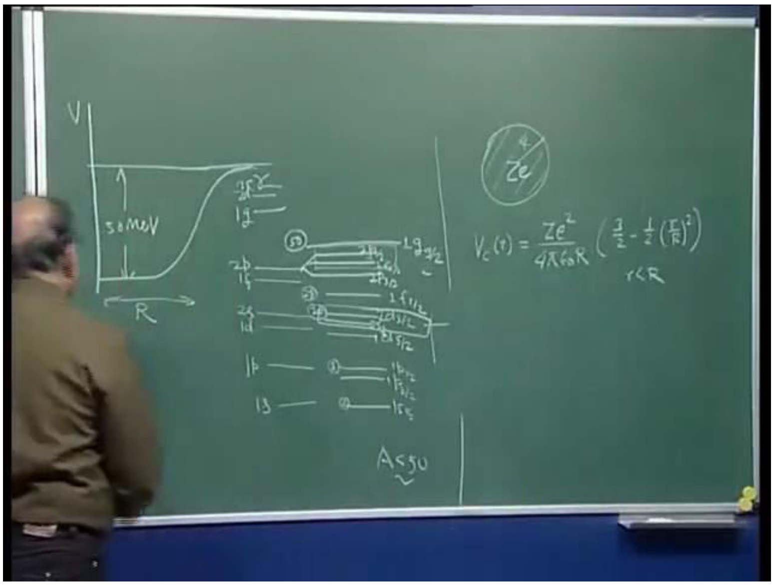

So, for low z if the you have light nuclei, z is low it does not matter, because this is quite high, but for middle n heavier nuclei it will matter. This is for r than r and r greater than r also, you have no electrostatic potential. Because it is long range force and that goes by 1 r, if you have z e or q charge in this sphere outside the potential will just go as 1 by r. So, your potential first thing it is lifted up, it is positive right. Proton and the rest of the nucleus. Both are positive charge. So, it is positive.

So, it will lift up at r equal to 0 small r equal to 0, it is 3 by 2 times of this much is added at r equal to capital R. This is 3 by 2 minus half is 1. So, this into 1 lifted. So, at the center it is lifted more, here it is lifted less. So, over all it is lifted and then you have 1 by r type fall. So, this is how the potential will modify for neutron potential is like this for proton potential is like this. So, if I drop both side by side.

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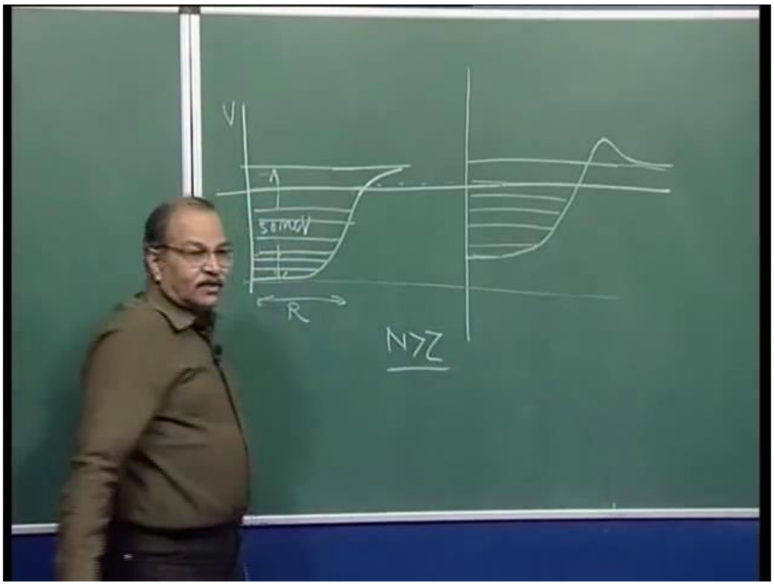

Suppose this is the potential for neutron and then you can draw a similar thing here. This is 0 and this goes up, this was the original level and now this has been shifted up it goes up and it falls 1 by 1 type. The energy level starts here, if these are the energy level correspondingly, you will have energy levels here. But, these energy levels are missing am for neutron energy levels will starts here and here it will start here. So, that is one simple effect another effect, because of this lowering of this depth here spacing is little bit larger than this. And if the nucleons are to fill this these energy levels for bottom to keep the total energy of the nucleus minimum possible. So, neutrons and if neutrons and protons are allowed to interchange be technically.

So, the energy will be filled up to some level right. If that is the case you will have more neutrons and less number of protons, because top the energy should be same, if we are filling the higher levels then it should change through beta decay. And then fill that lower energy levels, if you have to keep the total energy of the nucleus minimum possible. So, protons and neutrons both should fill up to almost the same level poly exclusive for example, has to be obeyed up to same. Otherwise, if you have much more things there they can interchange between neutrons can go into proton or proton can go into neutron and this empty shells will be filled up.

And if is to be filled at the same level energy, same energy then the number of energy levels appear in here is less number of energy levels appearing here is more. That means, you will have more neutrons than protons n greater than z. So, this is 1 way to understand way in heavier nuclei, you have more neutrons than protons, for light nuclei coulomb interaction is not very effective. And therefore, the 2 potential and 2 schemes of energy levels are almost the same right.

And therefore, n is equal to z to keep that energy minimum n is equal is z. But, once this coulomb interaction becomes effective then to keep that to total energy minimum you must have larger number n neutrons than protons. These are some of the things, which i wanted to talk about that. Now, coming to connecting this whole model, this whole scheme to the miserable properties, the first thing, which the shell model can quite satisfactorily explain is spin and parity of nuclei with in ground state right. So, spin parity of nuclei in ground state.

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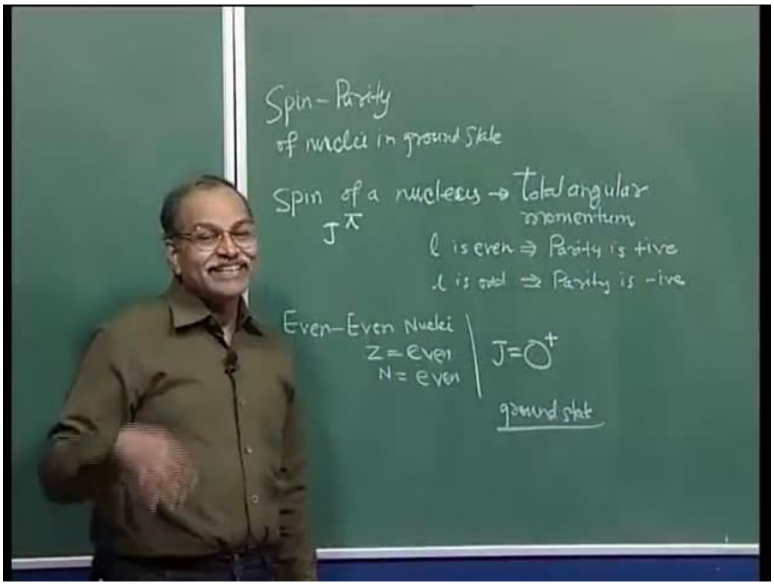

A spin when I say spin of a nucleus, what to I mean, this is total angular momentum remember. This is the terminology used in nuclear physics not in atomic physics, in atomic physics, we spin we by spin we understand spin angular momentum. But, in nuclear physics if i say spin of this nucleus, it is the total angular momentum not the spin angular momentum. So, that is the terminology used. So, when I say spin it is j, total j all orbital spin everything combine for the whole nucleus, this is the final j am and then parity pi, whether the space part of vary function is symmetric or any symmetric and this pie depends on l.

So, if l is even, we say that parity is positive, your space part of v function depend on this l and if l is odd, we see that parity is odd, we have discussed little bit of this while doing dethrones parity negative. So, as super script it is written plus or minus, if it is written plus, that means parity is positive. If it is written minus, parity is negative and j is the total spin.

So, first even nuclei when I write even even nuclei, what do I mean z is even and n is even, z is even and also n is even. These are called even even nuclei, now one assumption or consistence with the observation is that in particular energy level, where you have 2 neutrons and 2 protons going 1 with spin up and 1 with spin down. Because, all these levels which are drawn here. So, each will contain 2 contemn number n contemn number l contemn number j and n j right.

So, those 2 neutrons or 2 protons in that same level, they will pair up. And pair up means, if these 2 neutrons for example, p half in p half, we have 2 neutrons on s half, we have to neutrons or 2 protons or p 3 half, we have 4 counter states there, then 2 will pair up and 2 will pair up and when they pair up. They pair up to angular momentum 0 and magnetic moment 0 everything 0. So, we call it extreme single particle model well we say that all neutrons and protons, wherever possible. They will pair up pairing decreases there total energy.

So, some kind of an addition to this potential. This potential tells that this is the energy, this is the energy, this is the energy on tomb of that we say that if neutrons 2 neutrons pair up. Pair up means, if they combine there angular momentum to 0 of these 2 0, j is 0 and m j is anyway 0. Those 2 only not of the hole minus then we say that, they have paired up and this pairing takes the energy down. So, as many pairs can form the energy of the nucleus is going down.

So, in extreme, what we call extreme single particle mortal, we say that neutrons and protons will pair up to the extent possible greatest extent possible right. If you have even even nucleus all the protons will pair up and all the neutrons will pair up. So, all the neutrons will pair up, all the protons have pair up. then the total angular momentum of the nucleus is also 0. Because, pair wise it is 0 0 plus 0 plus 0 plus 0. The whole thing is 0, it should be 0 15 should be 0 and since there are 2 of them.

So, whether it is l is equal to even or l equal to odd for each of the 2. The parity will become positive, if there are in say d phi by 2 state, so then for this neutron d for this neutron. So, plus parity combined parity is also plus. If they run 2 3 by 2 p l is equal to 1, but then. So, negative parity. So, negative parity of the first particle, negative parity of the second particle, total in the symmetric and anti-symmetric multiplied becomes symmetric. So, parity is positive. So, independent of what levels these pairs are occupying pair wise, the parity is positive. So, the entire nucleus that also will have positive parity 0 plus all even-even nuclei in there ground state remember will have is j totally. J is yeah.

That is terminology here guys terminology here, you must remember and the word nuclear spin is ment for the total angular momentum of the nucleus, so that the term the definition of the term nucleus spin right. Why that nomenclature has come that could be some historical reasons, that today we only knew our d s, if the nucleus is talking of nucleus spin, he must have talked about the total angular momentum right. So, all even-even nuclei in the ground state should have 0 plus spin parity according to the extreme single particle shell model and this comes out to be true in all experiments. So, that was about even-even, now let us come to what we call odd A.

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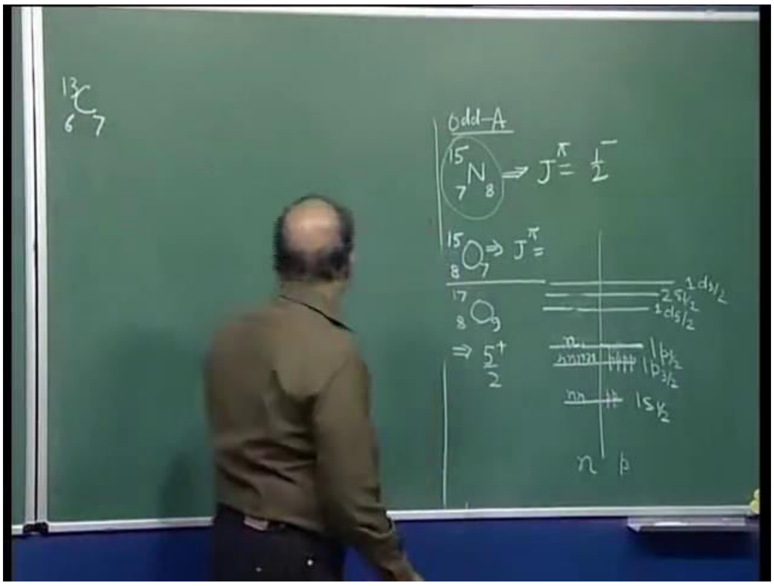

Odd A nuclei, either z is odd together with an even of l is odd together with z even. So, 1 is even 1 is odd. So, the total will be odd. And what are the third variety possible, even-

even then you had odd and the other possibilities odd odd. Both are odd the total is even both are odd, but very few odd odd nuclei stable nuclei exists right. Some 4 of them in the lighter 1's nitrogen 7 7 14, nitrogen 14 7 7 7 that is a stable element, and so on. So, bigger 1 bigger 1 itself 1 1

Students: Oxygen

Oxygen is 8 8 protons it is not it is not odd odd, oxygen means 8 protons, you can take different isotopes 16 oxygen 17 oxygen 15 oxygen. But that 8, you cannot change that 8 oxygen is always z equal to 8. So, z is even. So, odd A if you are discussed even-even and odd A, you have discussed almost all the nuclei barring, some 4 or 5 in odd A now here that you would not get extreme single particle, that is relevant here. Because, odd A means there is 1 neutron or 1 proton which does not have a chance for pairing, the total number is odd and for pair you need 2.

So, if there are 9 of them only 8 can pair up that 9 one has no chance of pairing up. So, the problem in the extreme single point of a model, we assume that the property of this nucleus is decided by that last nucleon only holding other, which had paired up will give you 0 0 spin 0, parity 0 angular momentum everything 0, 0 magnetic moment. Only that last unpaired nucleon will decide all those properties, that is extreme single particle model to some extent even this simplified model works and that we will see. Now, tell me some light odd A nucleus and we will look at the spin parity of that. So, give me 1 anyone.

Students: Nitrogen

Nitrogen odd A 7, you have to give 7 here and then you can get 8 here or you can give odd A 6, you can give 6 or you can give 8 or you can give 10 15. This will be odd A nucleus is it stable do not remember, I also do not remember, but let us just work on it if this is the nucleus for whatever time it is there. What would be the spin and parity in it is own ground state. So, let us draw those energy levels. So, tell me what is the lowest 1, 1 s half, next 1.

Students: 1 2.

3 by 2 next 1,next 1,1 d,next next all right this is enough. 2 parts are done, 1 for the proton, 1 for neutron. So, 8 protons 8 neutrons here, this 8 neutrons will go here right. Lowest energy of the nucleus, 7 protons where should they go 4 here p 3 by 2 4 here, so 2 plus 4 6 and 2 8, so 8 neutron are going here and then 7 protons 2 here, 4 here and 1 here. Alright according our model this gibbs is 0 spin 0 parity. This gibbs is 0 spin 0 parity, this gibb's is 0 spin and 0 parity 2 pairs.

And similarly this and similarly this, so the spin of the nuclease is same as the angular momentum of this part and that is half j equal to half. So, if capital J should be half in ground state capital J should be half. And since it is p state l is equal to 1, so the parity negative right. That is how we calculate take another example oxygen. Oxygen 15, oxygen 15, what do you expect tell me spin parity neutron proton different, now protons 8.

So, all these you will have a proton here and you will have a 1 neutron here. So, same half minus right, what about 17 oxygen. It protons 2 plus 4 6 plus 2 8 protons will be there, now 9 9 neutrons. So, 8 neutrons and 9th neutron must go here. So, 5 by 2 plus correct, it should be 5 by 2 plus the ground state spin parity should be by 2 plus 13 carbon.

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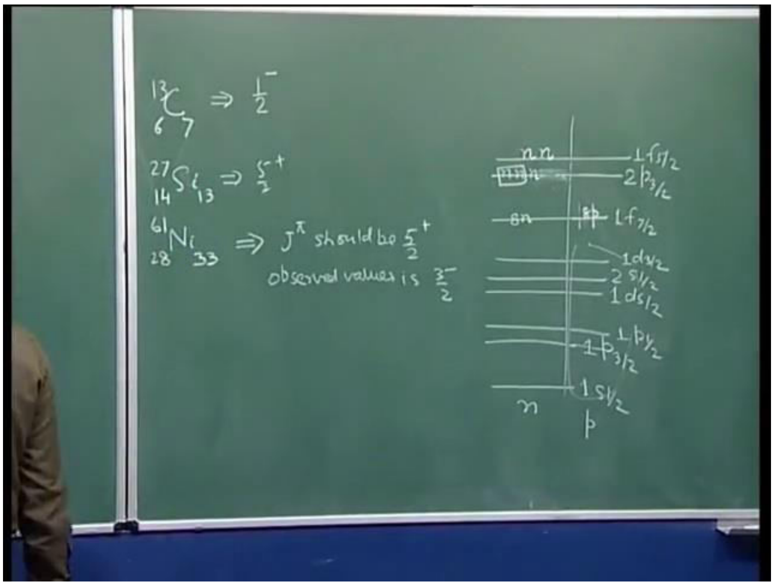

Carbon is z is equal to what, so n is equal to 7. So, z is equal to 6 4 plus 6 correct 6 here and this 1 is 7. So, 1 neutron will go here, correct 2 plus 4 plus 1 7 right. 7 neutrons, 7 neutrons and 6 protons. So, what should be the spin parity, half negative yes that is how you can calculate, in most of the cases, it comes out to be correct right. Most of the cases it comes out to be correct, you can take for example, 27 silicon, what is z for silicon. Silicon is very important element 14 14 13 right. So, 14 what 14 z z 14 2 plus 4 6 plus 2 8 and 6 14 n 13 so that means, what should be spin parity.

Students: 5 by 2 plus.

5 by 2 plus correct. So, it is 5 by 2 plus most of this odd a nuclei, you will find that single by article model prediction is correct. I gave you 1 exception also and that is nickel 61 nick for nickel z is 28. Iron, cobalt, nickel iron is z is equal to 26 then 27 and 28. So, nickel is 28 how much remains 33. Total is 61 correct. So, now, lets work it out let me draw the fresh diagram yeah, dictate me 1 s half tell me.

Students: 1 p 3 by 2.

1 p 3 by 2.

Students: 1 p 3 by 2.

1 p 3 by 2.

Students: 1 p half.

1 p half.

Students: 1 d 5 by 2.

1 d 5 by 2.

Students: 1 d 5 by 2.

1 d 5 by 2.

Students: 2 s half.

2 s half.

Students: 1 d 3 by 2.

1 d 3 by 2, 1 f 7 by 2,1 f seen by 2, next is,2 p 3 by 2. That is enough, 28 28 will come up to here right. So, this is which side I take proton which side neutron lets take this side neutron and this side proton. So, 28 up to here, this will be 28 remember 20 and this makes this 28, so everything up to here. So, fill proton everything is all this is fill that will make it 28.

And similarly 28 means all 3 how do I write 8 of them, 8 of them let me write 8 p all 8 protons are here, all 4 protons are here, all 2 protons are here, all 6 protons are here that will make it 28 correct up to her it is 28. So, up to here it is 28 neutrons, how many more are there. So, 1 2 3 4 5 ok, it cannot contain 5th. So, n here right. So, this the ground state should be the ground state, should be according to this calculation j pi, should be 5 by 2 minus. Now and the observed value is 3 by 2 minus, observed value is 3 by 2 minus ground state spin parity of 61 nickel is measured to be 3 by 2 minus.

No no . So, that will be here, that will be here, know at since you have 61. This nucleons therefore, the order will change I told you, but that was here that was here not here. This order remains the same how can I get this 3 by 2 minus as the ground state can you see a 3 by 2 minus. In this scheme, where a and odd neutron should be there in this scheme to give you 3 by 2 minus. 2 p 3 by 2 here, 4 neutrons here, if you have 5 neutrons here, it will give you 3 by 2 minus.

But, 5 neutrons cannot common this is 3 by 2 only. If not 5 neutron 3 neutrons will also give you 3 by 2 minus. So, if this neutron is not here, and this neutron is here, and you have only 3 of them, that can give you 3 by 2 minus, but why should it go to a higher energy, when the lower energy is available. And the answer is that, if it is here it will be it will pair with this neutron, if it is here it will pair with this neutron. Now when 2 neutrons or 2 protons pair up energy of the nucleolus goes down, but by how much amount it is not fixed.

It depends on l. So, if 2 neutrons are getting paired up in p level. The pairing energy will be different, if they pair up in f level the pairing energy will be different and that pairing energy the amount by which the energy of nucleolus is reduced due to pairing is larger, if the pairing is made in a larger l state. So, turns out that if the pair is made here. The energy comes down by larger amount, then if the pair is made here, this is f l is larger here it is p l is smaller l is 1 here, l is 3 here.

So, if pairing is done in a higher l level that pairing energy is larger, so it. So, happens that difference in pairing energy compensates, more than compensates for this rise here. The energy is because of pairing energy is reduced by certain amount, here it is reduced by much larger amount. So, even if it has to go to a higher energy level that saving due to paring is more than, this going up and hence in ground a state it is n n n here, and n n here. So, that extreme single particle model is still working, we are only bases on that only, we can also explain this type of situation nickel 61 type of situation by taking proper care of pairing energy.

Students: Why we called only ground state.

We discuss ground state excited state also, you can discuss with this extreme single particle model for example, I give you the excited the state of let us say oxygen 17.

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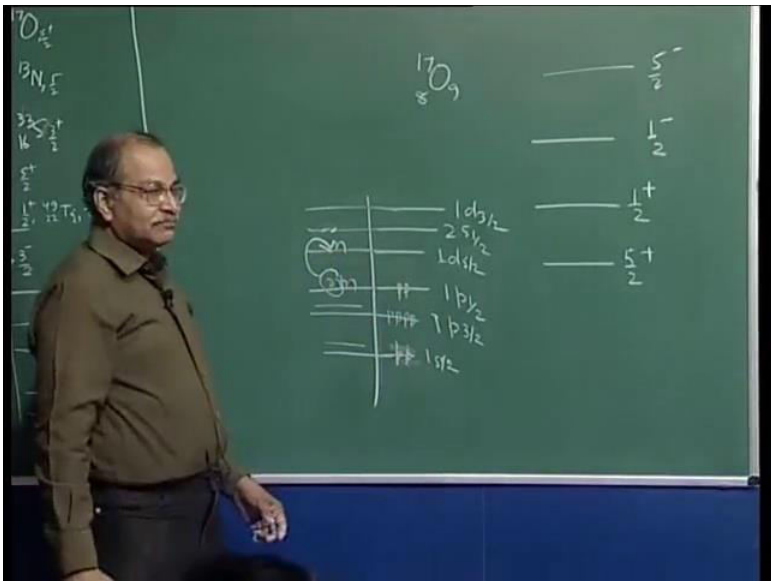

Oxygen 17 if ground state, I am telling you the observed values 5 by 2 plus then the next one is half plus this is the first excited state. And the next one is half minus and then you have 5 by 2 minus and so on. Now, look at this 17 O structure your 8 protons and 9 neutrons. So, protons will anyway form a close, shell we have minus half then you have 1 p 3 by 2 1 p half what is next. 1 d 5 by t, 1 d 5 by 2,2 s half,2 s half,1 d 3 by 2,1 d 3 by 2 enough, enough, enough protons we do not have to see look at the neutrons only. So, you have all these will be filled up to here it is 8 right. So, you will have protons and then protons and then protons. So, protons is anyway fill neutron talk of neutrons all right protons is also. So, neutrons up to here are all filled and a next 1 is here, 5 by 2 plus is ground state. Now if energy has to go upward this neutron should go here.

So, the first excited state will be obtained, if this neutron goes here and if this neutron goes here. It should be half plus and it is half plus. Next way is half minus, how can I get the second excited the state half minus. Next one is 3 by 2, if this neutron from here it goes here it will it should be 3 by 2 plus it is not it is half minus. The same story this can give you half minus. So, if this neutron one of these neutron goes here and pairs up.

Then you will get 1 by 2 minus. So, that is the second excited state for hence, this pair is broken and here, the pair is made this is p this is d. So, some energy saved, but this energy difference is larger say it has gone up. So, even excited the states also many of the excited the states also you can understand on this. So, we discussed ground state first and then excited states also many of the excited. The states of these at least this light nuclei can also be understood using single particle shell model right. So, the next property that we will discuss with this model is magnetic moment of the nucleus.