Nuclear physics fundamentals and application
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Lecture - 16
Theories of nuclear forces

So, we were talking of the peak in scattering cross section in a scattering when you have angles much greater than 90 degrees around say 180 degrees. So, back ward peak and the kind of energy is that were used in this in that experiment will suggest that the scattering or the deflection of the particle should be hardly few degrees. So, forward peak is or close to 0 degree peak is well expected but, a peak of around 180 degrees total back a scattering that is difficult to understand. And as we discussed the explanation is much easier and elegant.

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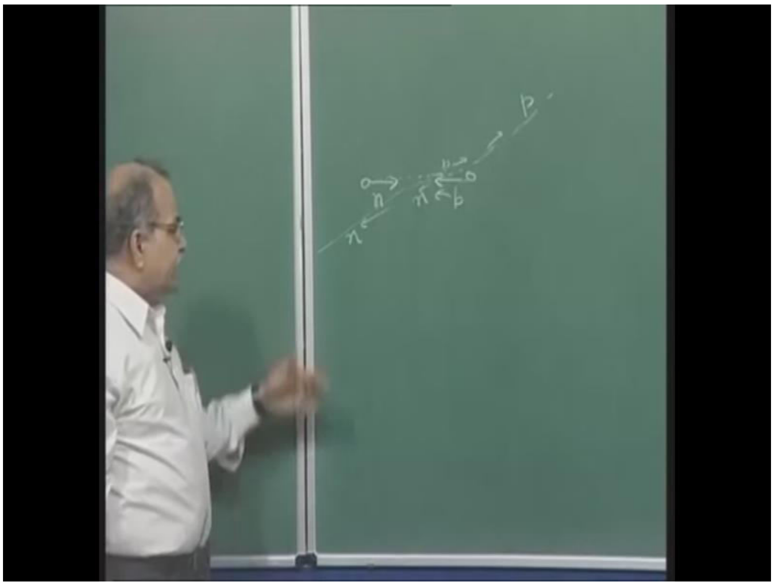

If we are shown that the particles inter change their nature. So, if centre of mass frame this is neutron and this is proton and the because of scattering it goes in this direction and because of scattering it goes in this direction. So, only a small deflection in the path but, then if this b during the inter action if this becomes n neutron. So, you get neutron this side and this neutron during the interaction if this becomes proton than you see proton this side. And it will appear to the experimentalist as if the scattering is through well large angles around 180 degrees. If protons are going this way protons are coming this way if neutrons are going this way neutrons are going returning this way. Now, this kind of exchange of neutron and proton, the character of the particle is possible, if you take the exchange particle charged exchange particle in to the consideration.

So, from here one can talk of the basic nature of 4 says interactions which is in contemn theory mediate by contused particles and from there one can reach or one can understand this kind of conversions. The most familiar case that you have is electromagnetic interactions and you remember in the school days we say that.

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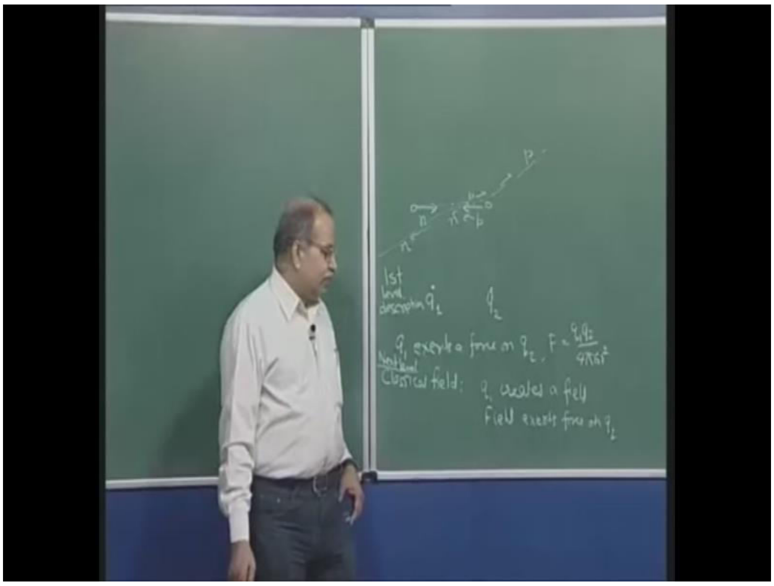

If there is a charge q 1 and if there is a charge q 2 than q 1 exerts a force on q 2. So, this is our say first introduction or first level description. Then, we say that q 1 exerts an force on q 2, q 2 exerts a force on q 1 and the force the magnitude of before is q 1 q 2 by 4 pi epsilon naught r square and so on. But, then has our understanding of nature increases our tools are more sharpened. We say that no this action at the distance picture is not good it is not consistent with any of the ((Refer Time: 03.56)) theories.

And the things so that, second level thing comes were we introduce field, classical field. So, that is our next level right second level. Next level description classical fields we say that q 1 creates a field and field exerts force on q 2. So, q 1 creates a field so you make it a 2 stay process q 1 creates a field and then q 2 is placed in that field that is why it takes variances force.

So, the interaction is through this field it is not a direct interaction, interaction is through this field. So, that is the next level of understanding and here this classical field is continuous in all those things. And then even further when you go next level. So, these are like 2 dynamics when you talk in terms of fields classical fields that is classical electro dynamics. And next level when you bring in contemn nature into picture and you talk of quantum electro dynamics; then you say that this field is not continuous, it has to be quantised the field has to be quantised. Any energy transfer has to be in units of certain minimum package.

So, that contestation field is talked in terms of quantised units and there comes photons. The field is described in terms of this quantised photons and interaction between q 1 and q 1 is through is exchange of, what we call virtual photons. So, the interaction is in terms of exchange of photon. It is photons are the mediator of this electromagnetic interactions you say that q 1 emits photons and those photons are absorbed by q 2, q 2 emits photons those photons are absorbed by q 1. And these photons which are used in this interaction they are called virtual photons in the sense that they are not experimentally observable.

We do not observe those photons as we observed the photons coming from this tube light. The light is coming from this bulb and we can observe that light we can measure the intensity; we can calculate the number of photons and all those things. These photons exist for very short time and we do not observe them, they only take part in these interactions. Now, if we do the same thing to our nucleon interactions.

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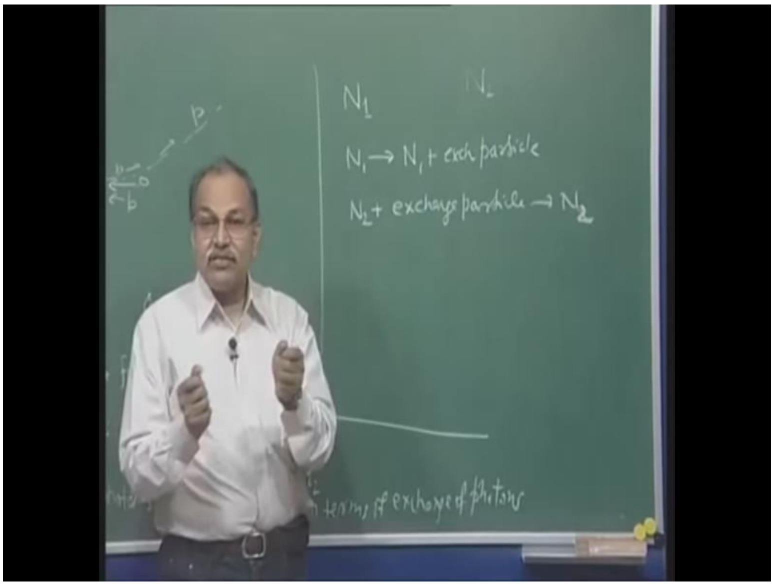

So, we have a nucleon call it N 1. I have a nucleon call it N 2 just like a q 1 and q 2. So, we have 2 nucleons here and the if the field if the interaction is mediated by such virtual particles then this N 1 should emit some particle that exchange particle and this N 2 should absorbed that exchange particle. So, n 2 absorbs that particle. So, that is how the interaction will go. Now, what kind of particle? Is this photon was no charge and no rest mass and so on. This particle can have charge can have mass. Can have charge if I remember our experiment if neutron is to be converted into proton and proton is to be converted in to neutron. That can happen only if this exchange particle has got charged right. So, it can also have mass because the mass is related to range of interaction because if you consider this type model this type of mechanism for interaction.

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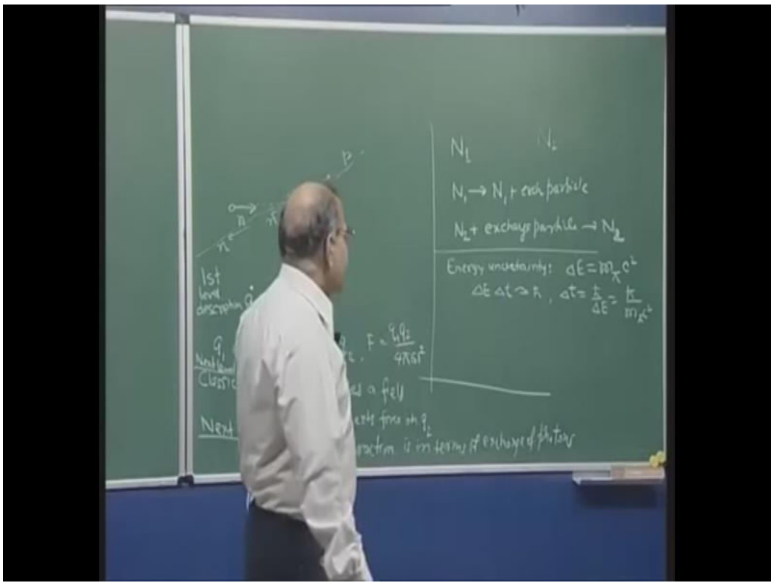

Then crucially Energy uncertainty comes in to picture. If a non zero rest mass particle is emitted from a proton. And this protons still remains proton or becomes neutrons, mass wise is the same. So, if a particle exchange particle is virtual exchange particle is emitted and this nucleons still remains a nucleon. So, that means that extra energy has created which is the mass energy of the exchange particle and similarly, if this particle gets absorbed into another nuclear and even after that nucleon remains nucleon 938 M e V remains 938 M e V so that, means the energy of that virtual part which is absorbed it appears nowhere.

So, apparently energy conservation is violated. First you have created a particle a without talking energy from nucleon, nucleon is still nucleon proton and neutron is still 938 M e V and then you have created a particle. And then that energy that m c square that exchange particle rest mass energy that got absorbed in to another nucleon and still its energy did not increase. So, it appears there energy and certainty and that is of this type mass of let me put this pi here. ((Refer time: 10:46))

You know why I am putting pi here? This is the kind of uncertainty but, than the uncertainty principal is allows this. You can have this kind of situations, where energy appears to been created out of nothing or energy have appears to get lost in nothing. So, those kind of ((Refer Time: 11.17)) are allowed by the theory by the central theme of the theory. The quantum theory is one of the very central idea of quantum theory is uncertain the principal but, then this is allowed provided this violation this energy in certainty last for a very short time delta t which is related to this delta e to that famous relation delta e delta t is h cross or h. So, in that case this delta t should be h cross divided by e, h cross divided by m pi e square. So, these particles can be created or absorbed and they should exist to mediate the interaction between this 2 nucleon, only for a time which is given by a relation of this type.

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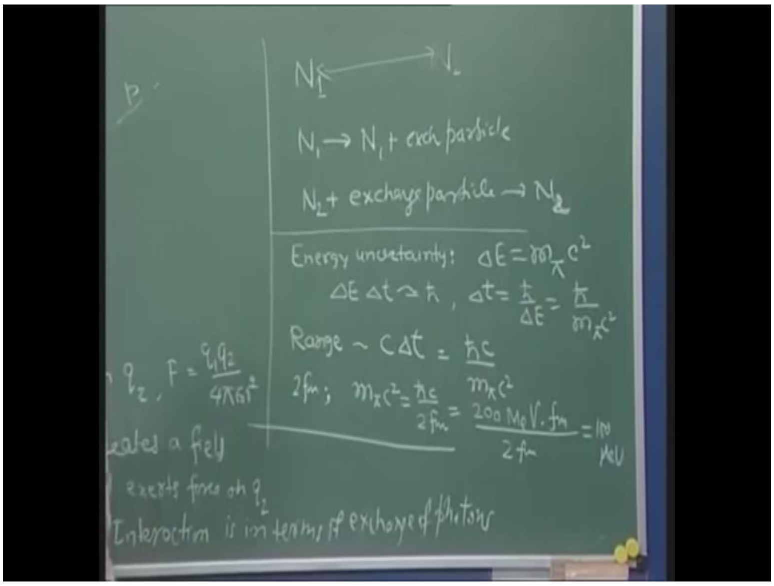

And therefore, the range that means this 2 particles are this much far away and if the part if this exchange part has to go from here to here should get emitted here and should get absorbed here or should get emitted and should get absorbed here. The particle has to travel this length and even if the speed of the particle is close to c. This range of interaction can be, should be less than or of the order of c times delta t. Cannot exceed this if this particles are too far away, then the virtual particles emitted here will only be absorbed by the same particle those virtual particles not reach there. But, they can exist only for this much of time, because they are when they are created they are getting absorbed there is an uncertainty of this order in the energy. And therefore, they can exist for this much time and so if this distance between this 2 nucleons is more than c times delta t. This exchange mechanism will not give any force interaction between these two. So, the range is related to the mass.

So, this is equal to h cross c divided by m pi c square. From here you can find what should be the rest mass? Because the range more or less in ((Refer Time: 14.07)) it is around 1, 2 femtometers as the range. So, if you 2 femtometers for examples, then m pi c square is h cross c divided by 2 femtometers. And how much is the h cross c? h cross c is something like 200 mega electron volt, h cross c f m, h c you must be remembering 1,2,4,0 1240 12 40 e v nm or e v fm. We call it electron volt nanometer or call it mega electron volt femtometer. The same 1240 comes divided by 2 pi, 2 pi is around 6.28 also, it would be 200 M e V femtometer 2 femtometer so 100 M e V.

So, this exchange particle should have mass something of this type about 100 M e V per c square divided by M e V by c square is the mass unit. So, it should be around 100 M e V by c square. Compare it to nucleon mass energy 938 M e V. ((Refer Time: 15.42)) that. So, proton or neutron the rest mass energy is around 938 939 M e V. So, this is a massive part this exchange part is a massive part is not small compared to nucleon, which is emitting it or which is absorbing it around 100 M e V. Now this virtual part are virtual in the sense that they exists for very short time and we are not absorbed them in real world. Otherwise they are not imaginary at such if a particle or certain properties is used here is created here and absorbed here.

Such an particles those properties must exist all with all conservation law and everything with the same properties. Like photons that we can absorb the photons, photons do exist they have some properties the virtual photons we do not observe but, the property of the virtual photon has the same property of this photon. If this photon does not have charge that photon also does not have charge. So, everything angular momentum ((Refer Time: 17.00)) everything. If photon exists than only you can have virtual photons there. So, do we have this type of particles and it terms that yes we do have and those particles are pions.

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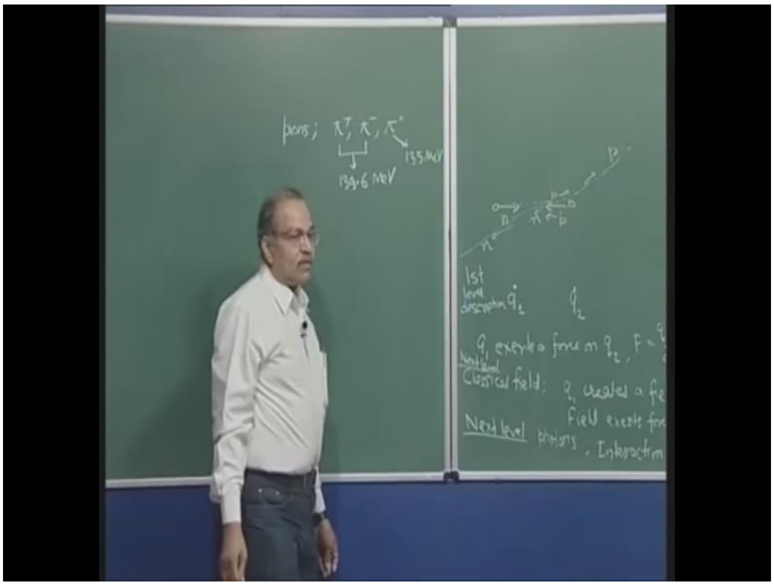

And there are 3 varieties of them pi plus pi minus and pi 0 neutral. The three verities of a pions, these are the particles which are absorbed in laboratories real particles real pions, which are created in atmosphere by those cosmic rays which also created in laboratory using unclear accelerator and nuclear reactions. So, this particle do exist and therefore, if they can exist with all quark ((Refer Time: 17.57)) quark and the quark in the structure and all laws of physics followed by these particles .Then you can have corresponding virtual pions. So, all these things are very well studied.

And this have mass around 139.6 mega electron volt rest mass energy or mass is this divided by c square. This has slightly smaller 1 mass 135 M e V. So, they are the right kind of particles which can meditate forces between the nucleons. You I must have told earlier, this force between nucleons is some kind of residual color force. Is the strong force we have strong force, weak force, electromagnetic force and gravitational force. The strong force is a where are quarks are interacting with the exchange of gluance and that is when that is because of the color charged carried by the quarks, just like electrical charge carried by the particles; the result in electromagnetic interaction in term in electromagnetic forces. Similarly, the color charges existing on these quarks that results in this strong forces. And each nucleon is color neutral nucleon is made with those colors quarks and the total color is 0.

So, just like 2 atoms with 0 charge each atom with 0 charge can combine to form molecule or can interact. Similarly, these nucleons, which have 0 color here, 0 color here but, still if they are close enough. So, that the distribution becomes important than you have some forces. Al right so this is about a pion exchange.

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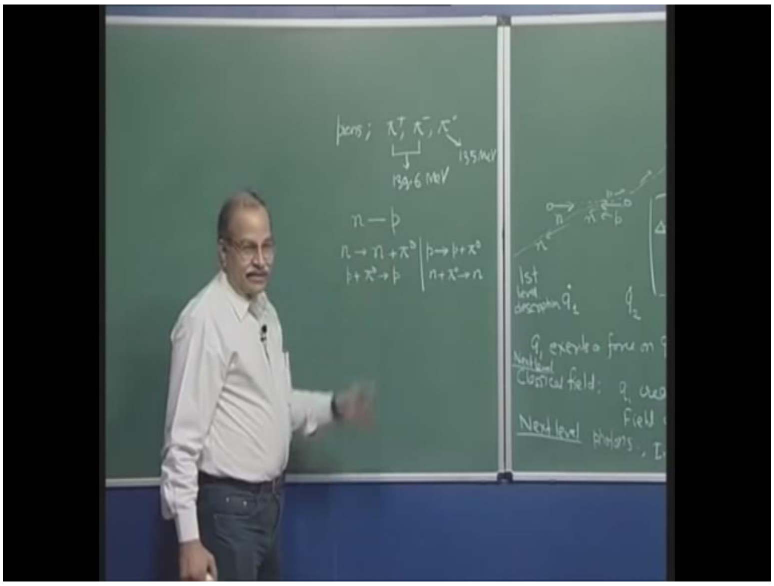

Now then you can have n p scat n p interaction can have the all kinds of varieties. This can emit. What can it emit? This can emit a neutral pions, n can emit neutral virtual pion and still remain neutral and this proton can absorb that and can still remain proton and similarly, this proton can emit this can this proton can emit neutral pion and still remain proton. And this neutron can absorb that pion and can still remain neutron. These are within that virtual processes so do not worry too much about the energy and certainty moment able certainty and all those things because they are for that flitting time. The time also you can estimate, if you estimate time from here if time you can estimate from this range itself.

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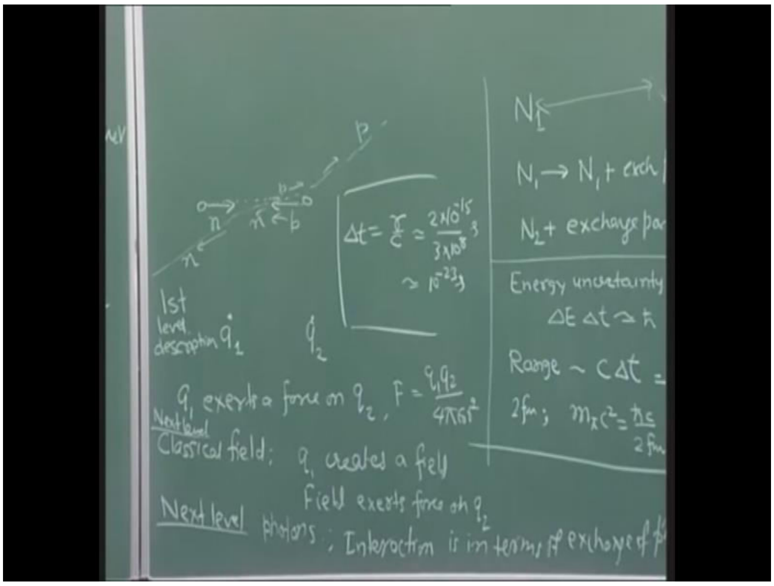

Time we say that it is range divide by c. That is how we to get and the range is something like 2 femtometres and c is 3 into 10 to the power of 8 meter per second.

So, this is in seconds. So, this is 10 to the power minus 23 seconds. So, the processor are very small time so do not worry about how this reactions are energetically balanced and anything is like that. So, that is 1.

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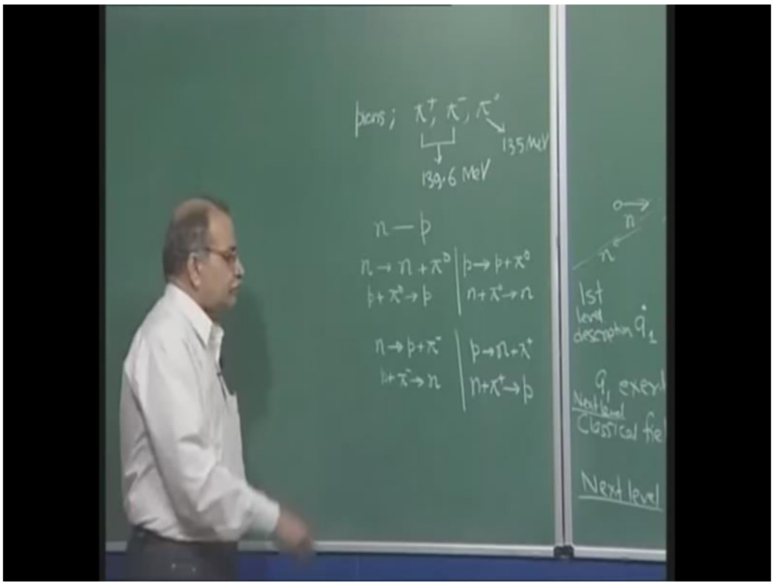

Yet another process is that, n can emit what negative pion the charge conservation should be should be there. So, n can emit a negative pion and convert itself into proton. The energy valuation is similar to neutron and proton has similar masses and this pion is has an extra mass. So, this is possible and then we can other this is n this is p, this p can absorb this pi minus to become neutron right. So, this proton becomes neutron this neutron becomes proton if there is a pi minus exchange. And then proton can do a similar thing, proton can convert itself to neutron by emitting pi plus and this neutron can absorb that pi plus and become proton. So, there are three varieties of a possibilities you can have this n p interaction can be mediated by all 3 kinds of pions. It can be mediated by neutral pion it can mediated by negative pion, it can be mediated by a positive pion.

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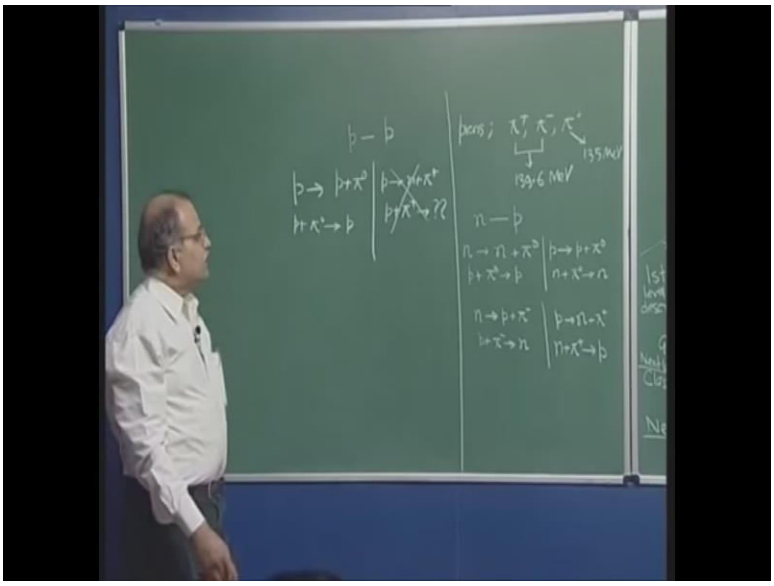

If you considered p p interaction, interaction between proton and a proton, what kind of exchange particle can mediate this? Out of the 3 pi 0 pi plus and pi minus. I am looking at interaction between 2 protons. So, what of this 3? Which pions can mediate this interaction between 1 proton and another proton like m p 1 side neutron other side proton. It was possible for the first particle to emit a neutral pion or a positive pion or a negative pion all 3 could go there and get absorbed right, these 3 equations, these 3 varieties.

So, this m p interaction can be mediated by positive pion by negative pion and can be mediated by neutral pion. In that same spirit if I have 2 proton sitting at some separation and say that this can this emits a particular pion and that pion get absorbed there. Fine 1 proton emits a particular pion and other proton absorbs it. What kind of pion that can be? pions yes neutral pion it has to be neutral pion nothing else ok.

P plus neutral pion p emits a neutral pion and still remain p and the other p absorbs that pion and still remain p. This the only possibility, if this p emits positive pion that is possible it can emit a positive pion and convert itself to n but, then this cannot be absorb by the second fine. So, this cannot be absorbed we do not have the particle of this nature 2 units of charges so on. You do not have any clue on like that. So, this is not possible similarly, pi minus is not possible so p p scattering of p p interaction can only be mediated by this neutral pion.

Whereas n p interaction can be mediated by all 3 of them there were small difference in the when you analysis scattering data n p data n p p data n p scattering data and p p scattering data with same energy similar energy and so on. Remove all that ((Refer Time: 26.39)) interaction effects so that, you are only looking at the nuclear interactions between proton and neutron proton. If you compare these 2; what is the strength of interaction? What is the strength with which it is scattering? Those parameters are there to compare scattering link and other things. So, if you compare how strong they are in interacting you find that when it comes to you compare this p p and this n p there is a slight difference, slight difference very close to each other but, there is a slight difference.

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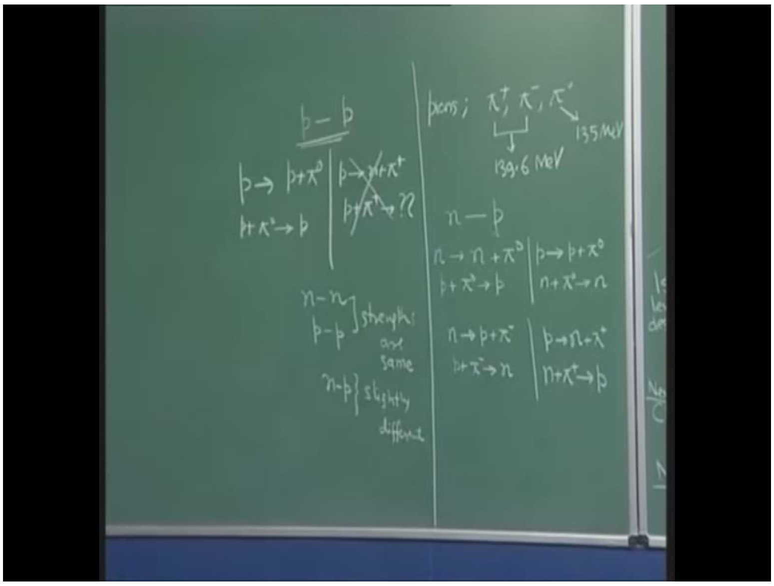

And if you analysis this n n n p p they are same the strength of this and this are same. Whereas that of n p slightly different. People give credit for that difference or responsibility for that difference to this difference in mass, slight difference in mass of neutral pion charged pions. These interactions can only go through neutral pions whereas these interactions can go through the neutral as well as the all three contribute.

So, slight difference comes from there. With this mechanism the potential are created the 2 approaches first which we described for quite some time was we have the experimental later and from those data and with some arguments you keep on constructing potentials with variable parameters so many parameters can adjust the value of the parameters. So, that you match with the data start with ((Refer Time: 29.58)) potential. What is the bases of starting with ((Refer Time: 29.04)) potential? Why not harmonic potential? Why not some other kind of potential? But, since the square potential square ((Refer Time: 29.14)) potential hard parameters like depth and width; we could play with those numbers and could adjust the numbers so that, the netron binding energy resulted from that.

That does not mean that, the interaction is described by square well potential. So, this type of approach where we just collect some potential with so many parameters which we can play with which we can vary. And then we fix the values of those parameters according to the data available so that, the numbers coming from here match with the experiment that is known as phenomenal logical approach. The potential is constructed that way are called phenomenal logical potentials. Whereas if you start with a mechanism that the interaction is generated in this particular way and from that mechanism you come out with a potential that can also have certain exist able parameters but, this shape of the potential is not arbitrary, the shape of the potential coming from the mechanism that more basic mechanism that you are contemplating. Now here is that kind of case where the interaction mechanism first laid down and from here theory is developed modules are developed to get to the potentials. So, you come in the year of 1934's 1935's and then came out with potentials with you called a ((Refer Time: 30.56)) potentials in or we call it.

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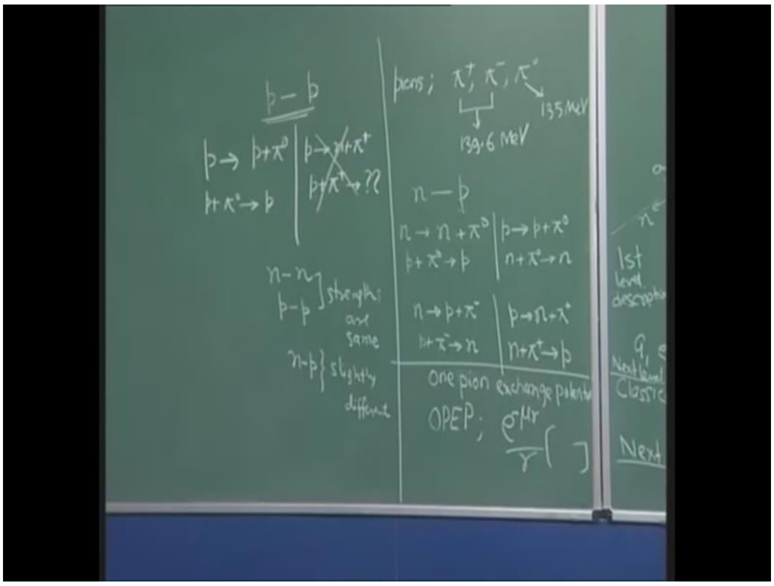

One exchange 1 pion exchange potentials, OPEP 1 pion exchange potentials. So, and the dominant part is e to the power mu r over r and many more things but, these are the dependence dominated by this. You have spin part, you have non central part those things are put but, the r dependent part comes out to be this exponentials. So, there is justification of the shape its coming because of this 1 pion exchange. You have a different branches or different germs of nuclear interactions here with this kind of energy of pions around 135 140 mega electron. We will have certain range which will come out around how much 2 femtometer we took than it was 100.

So, little less than that so that, so in this range which you can say for nuclear range this is almost near the end this virtual but, if you are looking at interaction at the separation of a 0.5 femtometers 0.4 femtometers like that much smaller separations. So, other may ((Refer Time: 32.43)) exist or other exchange particles exist with much higher energy that those can come in to picture. Pions are not only the exchange particles you have omega many other type of particles with higher energies. Since, they have higher energy that energy violation is larger and therefore, the range c delta t that they can cover smaller.

So, they will not take part into interaction, if the separation it say 1.5 femtometers or 1.7 femtometers because there life time or their existence time those higher mass particles their existence time is so small, they can let say they can travel only a distance of 0.4 femtometer. So, these mesons will not contribute in the interaction if the 2 nucleons are the separation of 1 femtometer or 2 femtometer. However 1.5 femtometers but, if nucleons are pushed at that small separation 0.4 femtometer 0.5 femtometer 0.3 femtometers than those mesons will also start interacting.

So, that the repulsive force for example, we talked of repulsive core and all those things that will not come from 1 pion exchange that will come from those higher order particles. So, one can have 2 pion exchange one can have omega mix on exchange and varieties of those things. So, this is one approach where 1 starts with more basic mechanism and comes out with potential. Yes the nuclear potentials between 2 nucleons that is all about that ok. So, this is about a force or interaction between 2 nucleon yes we talked about bound system of 2 nucleons that gave some information about the interaction. And we also talked about scattering between these 2 nucleons p p scattering or n p scattering n m scattering but, essentially it was 2 nucleons interacting with each other. Now if I look at a nucleolus apart from this deuteron all nuclei will have more than 2 nucleons helium 4 nucleons right similarly, iron 56 nucleons all packed in that nuclear radius nuclear volume.

So, if we try to look at the interactions between all those nucleons which are there in the nuclear that could be a very formal able task. With two nucleons we had so much of discussions and so much to understand and so many experiments so many theory and big expressions and non central part and central part and spin dependence and exchange and this and that just with 2 nucleons. Now if there are 10 nucleons 20 nucleons or 30 nucleons or 56 nucleons or 80 nucleons and if we try to look at the net interaction and the total energy and all those properties the magnetic moment or regular movement term in this. And then from the very basic nucleonic interactions it could be very difficult task and yet another complication is that in a nucleolus you have so called many body forces.

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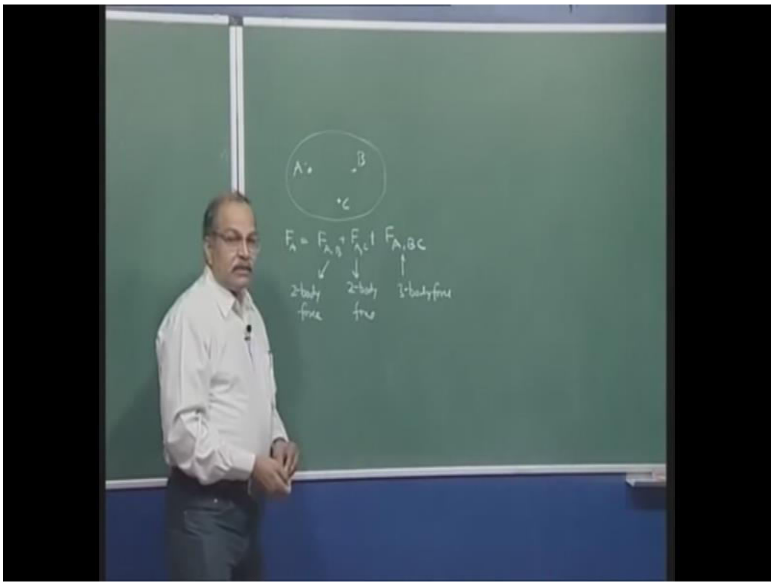

Coming into picture that means many body forces means suppose we have 3 nucleons 1 here 1 here 1 here this is named a this is named b this is named c and you say that force on a you do not talk in terms of 4. We talk in some potential but, anyway I am not going to do any mathematics qualitative only. So, force on a is because of b and because of c normally this is how we think on a if a and b are there alone b exacts force on a a exacts force on b if a and c are alone existing alone then c will exert force on a and a will exerts force on c. If both of them are here then net force on this is force from b plus force from c that is how we think but, in nuclear apart from there we have yet another term which is some extra something extra. If we have 3 nucleons together than there is something extra you can if you wish you can write b c. This is 3 body force. This is 2 body force.

So, how it is out of calculation lot of theory developed is multi body forces. It is not that since there are too many particles also I have 2 many pairs to consider for interaction if even more than that those pair wise interactions will come under 2 body forces but, you have 3 body forces may be 4 body forces. After relative importance will decrease most dominant will be 2 body forces and than 3 body and 4 body so that, means even if I am if I know this nucleon interaction potential very well. I will not be able to write the ((Refer Time: 39.17)) for the entire interaction inside the nucleolus because those 3 body 4 body will also be present so that, is yet another complication even this 2 body interactions. If you try to write for all pairs in the nucleolus and all that ((Refer Time: 39.36)) do you understand how big it will be? Similar is the situation in atomic physics of course, that three body things are not relevant not much significant there.

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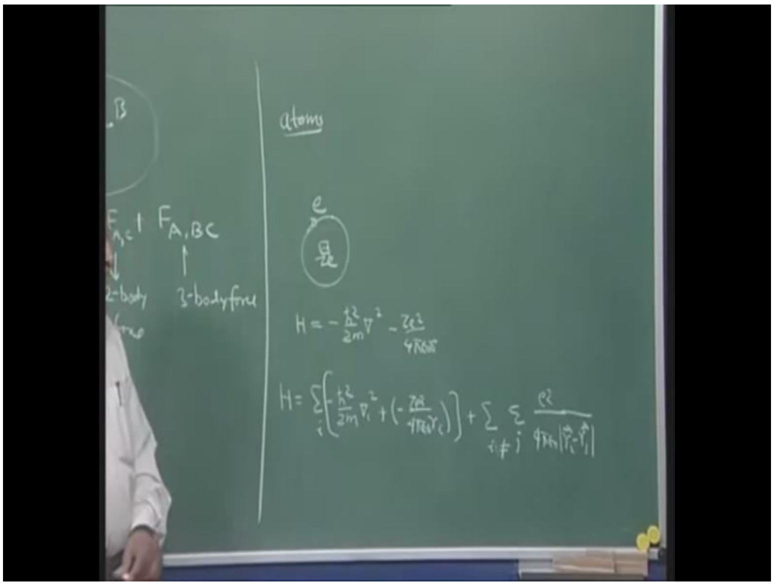

The simplest was hydrogen or hydrogen like where you only had 1 electron and 1 particle here z e and then the its simultaneous easy you write this just as h cross minus square by 2 m delta square and this potential energy between this and this correct. So, it is minus z e square over 4 pi epsilon r but, if you have multiple electron system than the hemultonion will have for each electron you will write kinetic energy term. For each electron you will write potential energy with the nucleolus. And on top of that we will also write the interaction between the electrons among the electrons them self submission over and submission over j and i naught equal to j, than it will be e square four pi epsilon naught mode of r i minus r i. So, the whole thing becomes very difficult to handle.

So, how does atomic physicist deal with the situation. They say that this entire atom is producing some kind of effective central potential for 1 electron to come. In the atom if you have z electrons 20 electrons or 16 electrons. So, that nucleus plus all these remaining electrons the all though the potential if you write the potential it will be weird thing but, one assumes that all this is equivalent to a central single central potential and you do not have to considered the coordinates of this electrons, coordinates of that electrons, coordinates of that electrons. And what kind of potential they are producing for the 1 electron? I have in mind all these things are replaced by 1 single potential origin and some kind of v as a function of r finish this v as a function of a r is not with this ((Refer Time: 42.46)) expression will be equivalent of all these things but, once you have that central potential. Then you solve just 1 equation not this.

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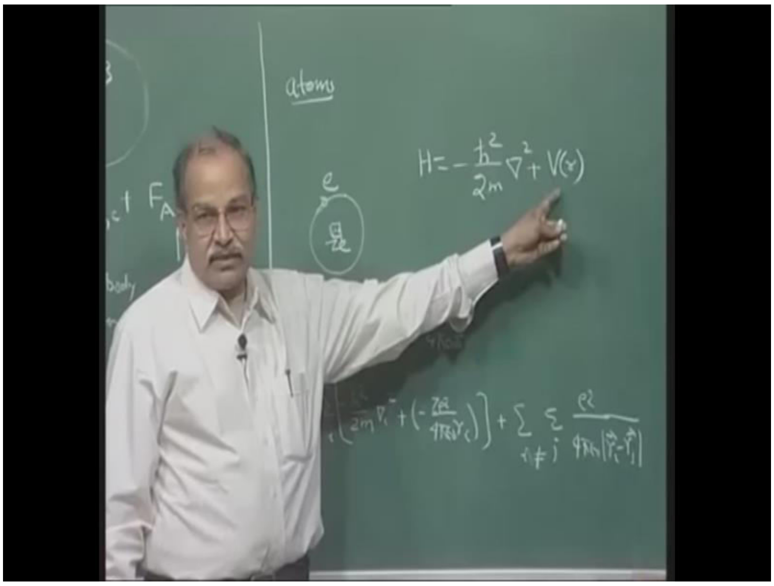

Equation like this, you consider 1 electron in this potential. This is that equivalent potential coming from electron and nucleus and everything. So, that what formula or expression is to be written that there is a separate story. But at the end of it is 1 single potential with 1 single co-ordinate coming in and this electron 1 electron I have in mind this is called single particle potential so that, 1 particle 1 electron I have in mind that will be at this position r and with this ((Refer Time: 43.40)) it will stop spreading the equations to get the energy possible energy of that electron and that is valid for all the electrons of the atom. All the 16 electrons of the atom for each 1 of them this same potential and same energy levels are available. So, when you do that what happens if it is a central potential and not columbic potential?

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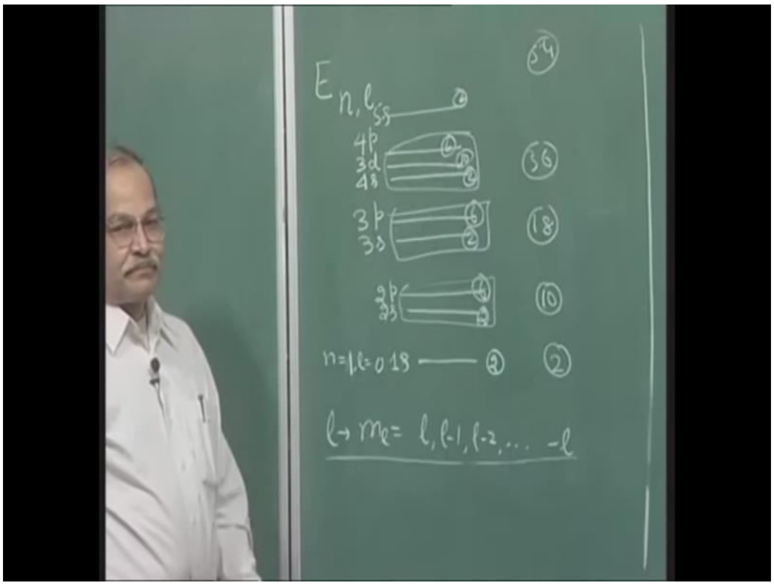

You will have energy pending on two parameters energy depending on n and energy depending on l. Orbital angular momentum quantum number, principal quantum number. And then you will have energies like 1 s that is n equal to 0 and l is equal to n equal to 1 and l is equal to 0 so that, this is 1 s than you will have 2 s. We will have 2 p right l is equal to 0 l equal to 2 p, then you will have 3 s you will have 3 p then the 4 s is somewhere here in general 3 d is slightly ever and then you have 4 p and then you have 5 s and so on. So, energy is different energy levels are appear for different n and l and it so happens that there are gaps in energy bigger gaps. Here also there is gap but, this is smaller gap here is a bigger gap here is a bigger gap.

So, these are called shells major shells. Now this is 1 shell this is another shell this is another shell this is another shell and so on. And these are energy levels they are non degenerate they are degenerate energy level 1 degeneracy comes from spin because the central potential that we solve that does not have spin in it. So, spin up spin down those energy will be same as long as this hamiltonious concerned. They may depend on the same energy they really depend on spin but, then you have to bring in extra terms l dot s or something.

So, the basic hamiltonion allows spin degeneracy and on top of that it will allow that l degeneracy because with any given l m l can be plus l l minus 1 l minus 2 up to minus l. So, that degeneracy is also there energy does not depend on m l it depends on l energy depends on l s and p their energies are different. So, it depends on l but, it does not depend on ml therefore, the same energy l is equal to 1 then m l equal to plus 1 ml equal to 0. They will appear at the same energy and then spin up and spin down. So, the total number of contemn state will be 2 here, will be 2 here, will be 6 here, will be 2 here, will be 6 here, will be 2 here, will be 10 here, will be 6 here and so on right. And then if you look at those gaps and call them as shells than this shell is at 2 and this shell is at 10. And cumulative ((Refer Time: 47.39)) this shell itself contains eight quantum levels quantum states at this 2 also.

So, you have ten and this is 1 shell this makes it 18 this is 1 shell and this makes it 36 and so on. Next will be 54 and so on. And these different shells with different energy with larger gaps in between that reflects in the periodicity of many of the properties in of atoms much before all these was there developed the periodic table concept was there because baa people has seen that periodicity in properties. So, and atomic weights not atomic numbers atomic weights with they have determine with the different elements and therefore, in terms in increasing order of atomics weights they had tried before this atomic number came into picture. So, some kind of periodic table was involving and finally, now we know that it is all if it is arranged with this atomic number very nice ((Refer Time: 49.00)) property has come in the groups in periods and so on.

So, that shall structure is now is very well established. Now look at your screen on the screen you should see the picture.

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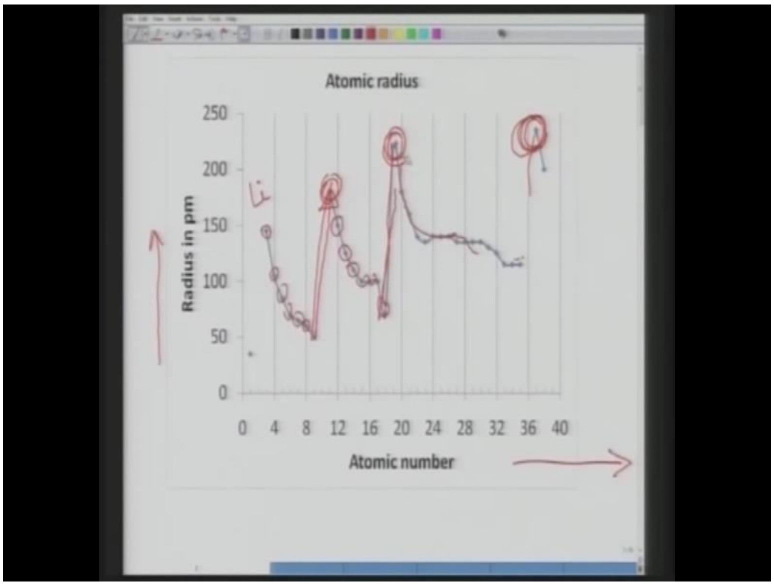

So, on this graph they have shown is a atomic number on this x axis and you can see 0,4,8,12 at this interval it is written this is scale on the y axis it radius atomic radius in Pico meters and this graph has been created in excel, very simple and this is vertical lines are added you can see it. Now see here, what happens? The atomic radius keeps decreasing it is here. This is 3 this is lithium this is z is equal to 3 lithium and then it decreases this is z is equal to 4, 5, 6 and so on. This is 8 next cell starts here and then all of sudden you see that data come from this radius and then again it decreases and when the next measure shell starts it increases again it decreases and then it goes and here it increases again right. The shell closes at different places and there it really gets up. Here this is 37 shell closes 36 and 37th. Once you go to 37 you can see it has gone up similarly, here you can see it is 19. So, shell closes at eighteen and as you go for 19th all of sudden atomic radius increases. This sudden change in atomic radius is one indication that somewhere you are having those different shells. I will show 1 more thing.

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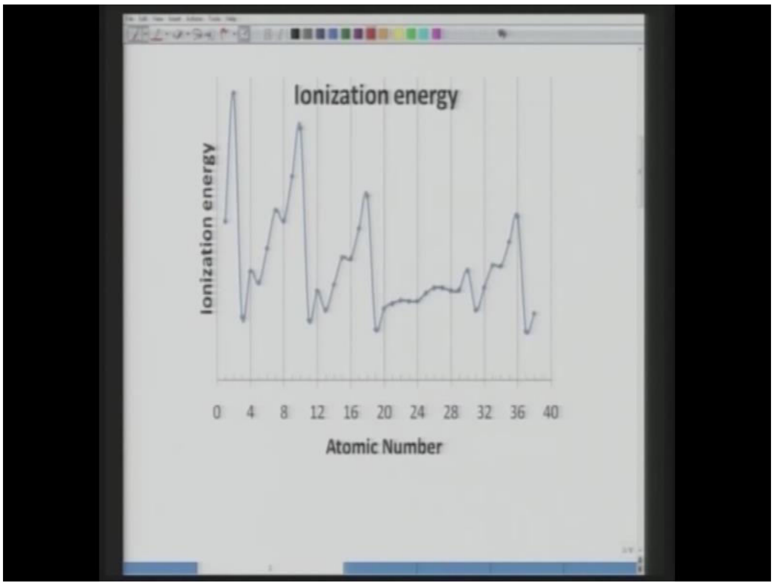

This is ionization energy, ionization energy is the energy that is needed to remove 1 electron is first ionization energy 1 electron from the atom so that, is an ionization energy and here also you will see here the ionization energy is very high. That means it is now difficult to remove that electron from the atom but, one more electron next element here all of a sudden here ionization energy drops.

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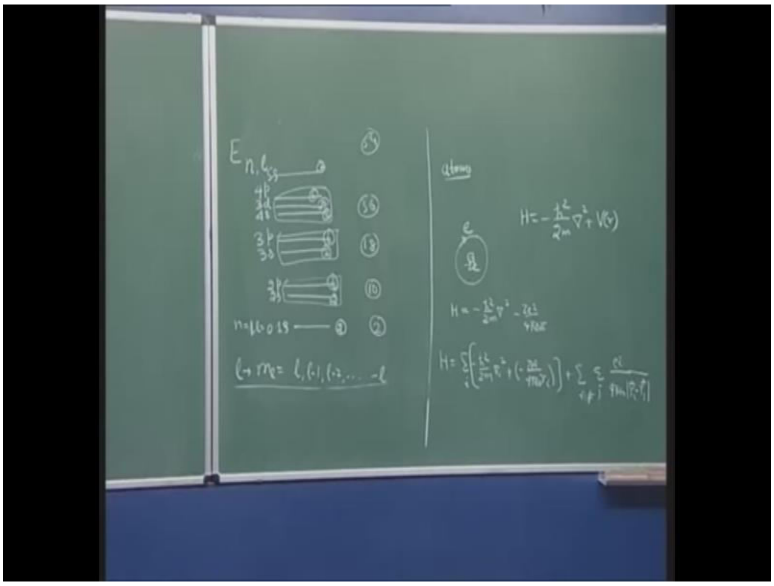

So, a new shell has started with this addition of 1 electron and therefore, it is so easy to take it out. So, ionization energy is much less so it is loosely bound its very small energy you can take it out. So but, then it goes up it reaches here this is 18 is a shell closer you can look at your board. 18 is a shell closer at 18; so, 18. If you have 18 electrons than the ionization energy is quite high but, if you have 19 electrons the ionization will all of sudden drops. So, that shows the shell structure if inside the shell if you look at inside the shell that means from here to here it is slowly increasing. And when you change the shell you are going from one shell to the other shell 18 to 19 than it suddenly it goes down than after 18. Then next shell closer is at 36 on the on the board we have seen that 36.

So, look at from 18 to 36 the ionization slowly increasing or decreasing or slowly changing but, as you go from 36 to 37 all of sudden the energy ionization energy goes down right. So, this kind of discreet changes this kind of sudden jumps in various properties they indicate that there is some kind of a shell structure where 1 shell closes than next shell starts and than that next shell keeps filling and once that shell is close then again next shell starts. And that change from the starting of a new shell that is marked by sudden change in properties right.

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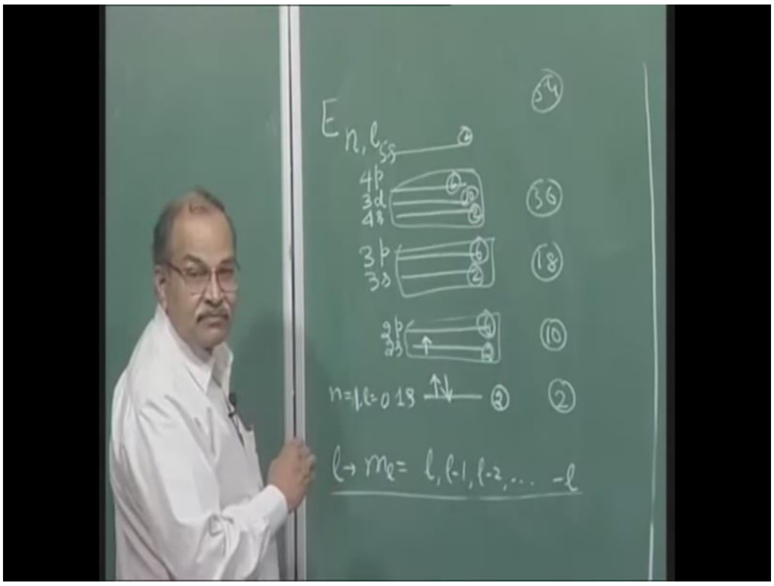

So, come to the board again this is a helium z is equal to 2 is helium very tight atom removing electron is not that easy but, once you go from helium to lead here that third electron can just come out easily. And similarly, next will be there at 10 in the periodic table 10, then 18 and then 36. These kind of different shells are there. And how do you make it? Just by saying that two electrons will come here 1 with spin 1 with spin down and any third electron must go here in that different shell. Why this third electron cannot be accommodated here? This is because they are foramens electrons are foramens no 2 foramens can occupy the same quantum state. That is why they have to go up. Now similar structure exists in nuclei also in nuclei also or what we can do? We can have and every kind of potential 1 particle potential single particle potential.

There are so many nucleons in the nucleus. Think that this whole nucleus is presenting to any 1 single nucleon the whole nucleon to any 1 single nucleon this whole reaming nucleus is presenting this potential same thing for all nucleon. So, this potential gets the energy levels and then fills the energy those quantum states from below and remembering that protons and neutrons are also foramens. So, quantum state can accommodate only 1 particle. So, all that polices and principles and then you come up with a similar cell structure. The first thing is if there are this kind of interaction that shell structure should be visible in experiments for example, nuclear radii you have seen on your screen you have seen atomic radii. How atomic radii change?

As number of electrons increases and goes from one shell to the next shell similarly, nuclear radii if there is a cell structure inside the nucleus than this nuclear radii should also have this kind of jumps sudden jumps or corresponding to ionization energy. Here you will have neutron separation energy or proton separation energy that should have this kind of sudden jumps at certain fixed numbers.

So, next lecture will look at the experimental some of the experimental data and see this if those data also just a cell type of structure inside the nucleus so that, similar atomic models. The method of atomic models can be implied there also and you will see that they do exist. And based on that they do that one developed to what we call nuclear shell model.