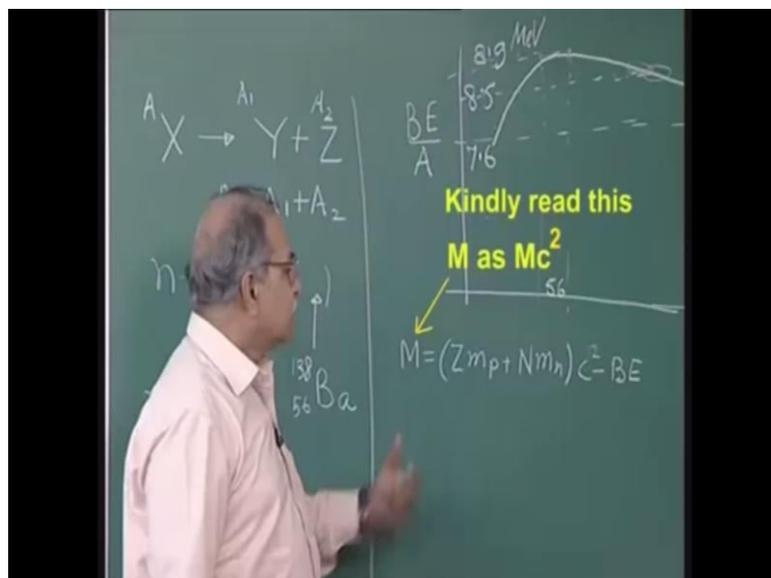


**Nuclear Physics Fundamentals and Application**  
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**Department of Physics**  
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**Lecture - 33**  
**Nuclear Fission basics**

So, today we start a very important nuclear reaction, that is nuclear fission and all our nuclear power plants run on this nuclear fission, which give us so much of energy, which we use fission is essentially breaking apart heavy nucleus in 2 roughly equal parts.

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So, if you have a nucleus some nucleus say X and then if it breaks in roughly two equal parts Y and Z and these are all. So, called heavy nuclei and middleweight nuclei. So, essentially a heavy nucleus breaks into two middleweight nuclei, this process is known as fission or this reaction nuclear reaction is known as fission reaction. Now, historically neutron was discovered 1932's. And then lots of nuclear physics experiments started bombarding neutron on different materials with the idea, that new elements of higher a value will be produced. So, neutron going into the material, increasing the mass number by one and then, later on beta decay can convert and neutron into protons so that a in periodic table you get one higher element. So, this way perhaps transuranic elements can be obtained so that was the motivation. So, lots of experiments on neutron irradiating.

We are going on and that is when 1939's that and strassmann were doing this experiment irradiating uranium natural uranium sample with neutron and when they did that.

So, the product that was obtained that, they were chemist in fact and so chemical analysis was very strong. So, when that irradiate product was analyzed they found that, there is barium in this barium. Barium is something like 56 here and around 138 there are several 6 isotopes of barium which are stable. So, 138 is the most abundant one. So, starting with uranium, which has a natural uranium has as you know uranium 235,92 and uranium 238 92. So, from here one is getting barium.

So, originally when they detected, this element they thought this is new transuranic element having properties similar, to barium but, then later on they could detect that, it is not something which is similar to barium itself and then, they found let me other elements in this irradiate uranium so that means from this 238 or 235 you are getting these medium waves nuclei of something like 130, 140 type of thing so that was the starting of nuclear fission experiments and immediately the explanation came in terms of this nucleus as dropped and then, that drop when some energy is given to and that drop place in two parts. So, those explanations came in the that same year 1939's and later on bore miller developed theory in terms of deformation, we will discuss all that things.

Now, if I understand it from this binding energy diagram, you remember binding energy of nuclei if I plot binding energy per nucleon, that is binding energy divided by mass number and mass number on this side, we had done it earlier in the initial set up lectures. So, with some irregularities here not very smooth but, then it rises and then, it goes through a maximum and then slowly decreases like this. So, this is how the binding energy per nucleon curve goes. This will be somewhere around let say 200 240 like that, this maximum this is the most stable region this is somewhere around 50 to 60 56 iron.

So, iron, cobalt and zinc these are the most stable part highest binding energy here and then the lighter elements you again you have a smaller binding energy per nucleon. So, in fission, the initial nucleus this X nucleus, it is somewhere sitting here. So, this heavy nucleus somewhere sitting here and then, it is placing two parts and when it is splits the mass number will become roughly half. So, it will come somewhere here. So, from this portions you are getting two nuclei in this portion, if you look at numbers here, this number binding energy per nucleon this number is around let us say something like 7.6

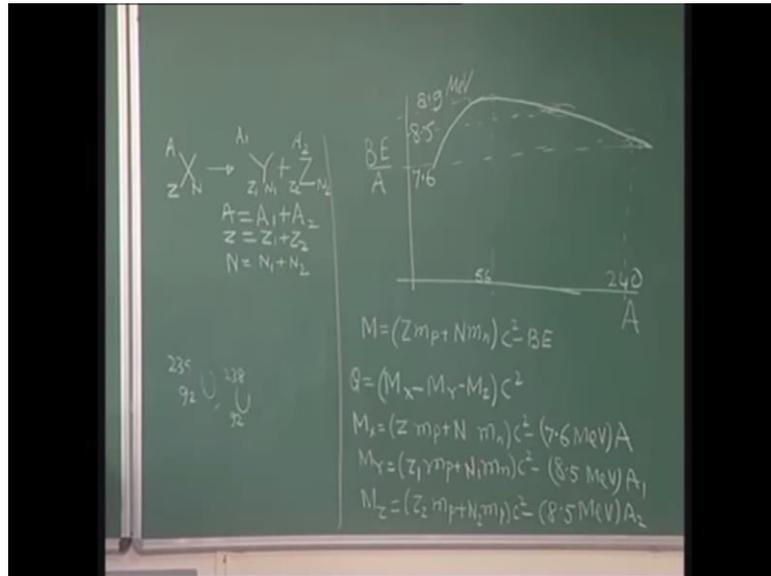
M e V's per nucleon and here if you look at half of it somewhere here, this will be around say 8.5.

And of course, the maximum is here, which will be around 8.9, this is the all in mega electron volts. So, first look at the rest masses and the energies if you have heavy nucleus in this range and if you look for a reaction of this type where, this X goes into 1 X and Z to nuclei of roughly equal masses then, what is the Q value? Q value positive or Q value negative? Rest mass decreases in this reaction or rest mass increases in this reaction. So, very simple to calculate if I take the first nucleus here of mass numbers say A and this mass number A 1 and this is mass number A 2. From this diagram, you can write the binding energy and remember mass of a nucleus is Z times m p plus N times m n c square minus the binding energy.

So, the binding energy increases mass decreases A1. So, the Q value is mass of this X nucleus and minus mass of this Y nucleus and minus mass of this Z nucleus times C square. So, this is Q value is how much if you have a reaction? How much rest mass decreases in that reaction? So, that is the Q that is the energy at made available. So, rest mass is gone down so that much energy has been made available that is Q value, initial mass minus final mass times C square.

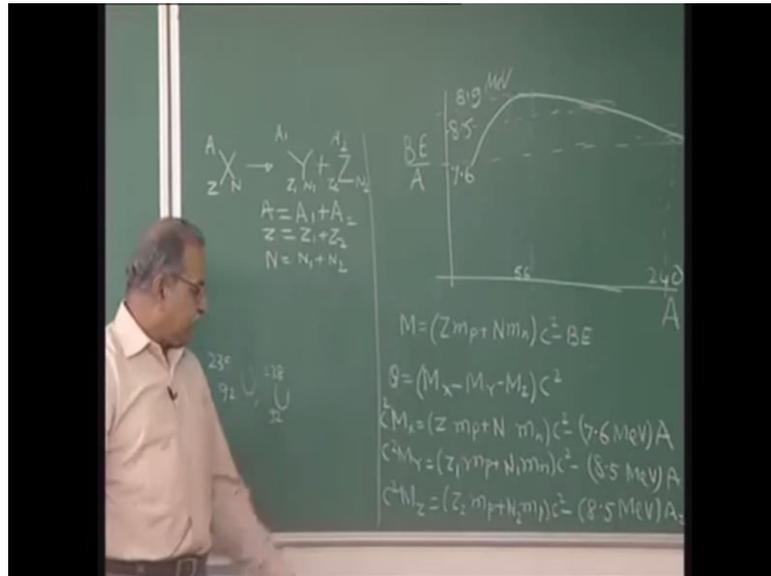
So, this you can write your M X is Z 1 times mass of proton plus N 1 times mass of neutrons and then, C square and minus binding energy and binding energy of this X nucleus capital A here and this is binding energy per nucleon. So, this will be if I take this value here 7.6. So, it 7.6 and multiplied M e V and multiplied by A. A 1 this binding energy per nucleon is 7.6 M e V and there are capital A nucleons. So, the binding energy is this much and this proton mass separately, plus neutrons mass separately minus the binding energy that is this M X then M Y similarly, you can write M Y is equal to Z 2 or let me write this as 1 and this as 2 and this is without subscript. So, let me write this as just Z and N for the first nucleus.

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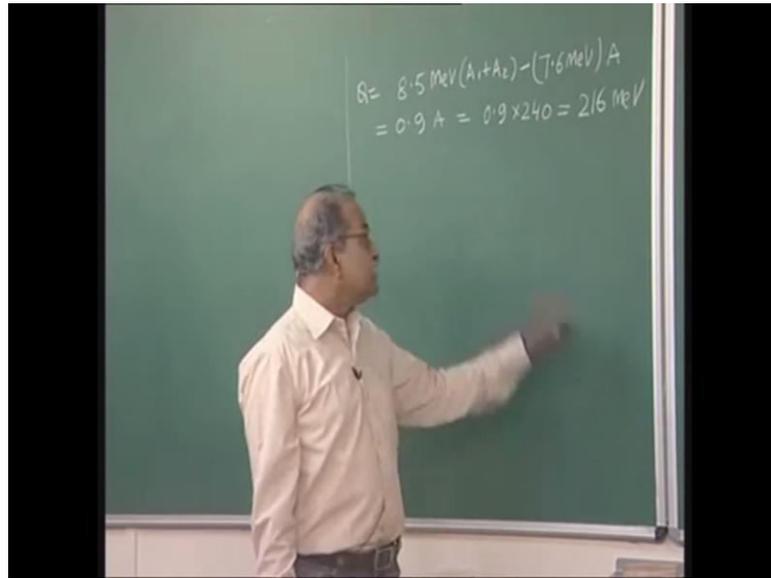
So, this is Z and this is N and this is Z 1 and this is N 1 and this is Z 2 and this is N 2. So, A is A 1 plus ((Refer Time: 10:07)) Z is Z 1 plus Z 2 and N is N 1 plus N 2. So, Y this nucleus so, it will be Z 2 times m p and plus N 1 times m n C square and minus. Now, this Y and Z roughly equal masses. So, it is half of it will come here and here, the binding energy per nucleon is 8.5 M e V. So, it minus 8.5 M e V times A 1, it has A 1 nucleons. So, 8.5 M e V times even and similarly, M Z you can write. So, M Z is equal to Z 2 m p plus N 2 C square and minus since, we assume that, they are of the same order the masses are of the same order. So, both of them are somewhere here. So, this also is 8.5 A 2, now you can work out this Q value, and the Q value will be this.

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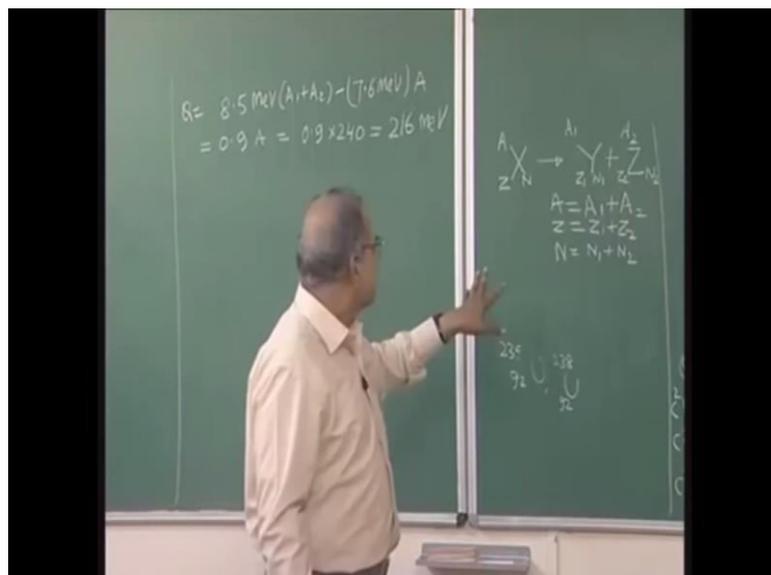
Q value will be  $M_X C^2$  and minus  $M_Y C^2$  and minus  $M_Z C^2$ . So, we need subtract this part, this proton mass part and neutron mass part that we cancel out, because Z is equal to  $Z_1$  plus  $Z_2$ . So, when you subtract this  $M_Y C^2$  and  $M_Z C^2$  from  $M_X C^2$  this part we all cancel out and then, you will have this one minus this one. So, these 2 will become positive and this will remain negative. So, it is 8.5 MeV common  $A_1$  plus  $A_2$ . So, this I have written the these last 2 terms, this minus has become positive, because I am subtracting these two quantities from this first one. So, these are positive 8.5 MeV into  $A_1$  plus  $A_2$  and minus 7.6 MeV into A.

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And A equal to A 1 plus A 2. So, it is just 0.9 times A and if you take A to be around 240 it is 0.9 into 240 and how much is that is to 216 M e V positive. So, the rest mass decreases and therefore, energetically it is favorable system normally tries to go into that minimum rest mass energy and if this nucleus splits in 2 parts, roughly equal parts the rest mass is decreasing and therefore, this reaction is energetically favorable and not only favorable, it yields about 216 mega electron volts of energy.

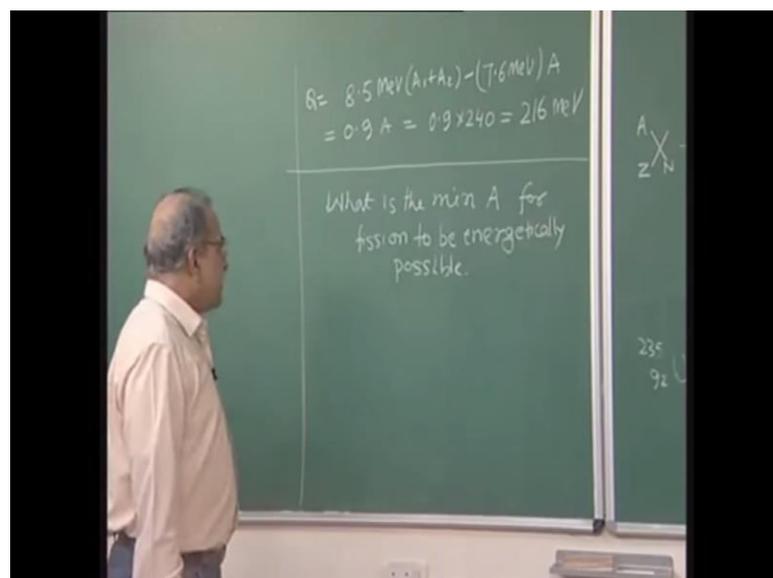
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If this reaction does take place if this X goes into Y plus Z, where is this 216 MeV gone the rest mass energy here is more and it has decreased in this reaction. So, the rest mass of energy is less here, the remaining 216 MeV where will it go primarily it will go into the kinetic energy of so called fission fragments. This reaction is fission reaction and these two product nuclei are called fission fragments. So, when these two are created, they move in opposite directions with certain kinetic energy and most of the 216 MeV is in that kinetic energy, there are some more things come out gamma rays, neutrons this and that the kinetic energy will talk about this later. So, this much of energy is realized

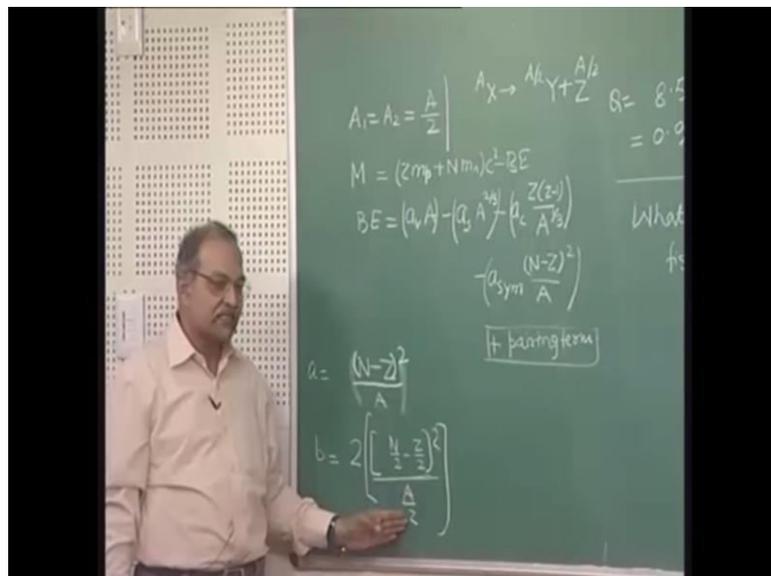
So, what is this minimum value of A where, this fission is energetically favorable for 240, we have seen that, yes it is favorable. So, we can work out using semi empirical mass formula, roughly I can see it here, this is around say 56 or. So, if the starting point is double of this then, it will still land up this side and landing this side means the binding energy per nucleon increases and that is how from 7.6 it increase to 8.5 and therefore, you got that difference 0.9 times A as the decrease in rest mass energy. So, as long as, the split nuclei are on the right side of this maximum, you will gain energy and this reaction will be energetically favorable but, if i started with a nucleus here and the split parts goes this side then one has to see which rest mass is less and with which rest mass is more simple calculation can be made using semi empirical mass formula.

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So, the question is what is the minimum A for this reaction fission to be energetically possible? Remember, I am talking of rest mass energies in ground state. No external energy given if external energy is to be given than anything can be broken but, just because of the difference in the rest masses which system, whether the initial big nucleus or the pair of fission fragments, which is having lower rest mass energy that we are looking at. So, no external energy involved. So, if I use this, semi empirical mass formula, we have to look at various contributions to this mass. Because, we will be looking at this Q value, whether this Q is positive or Q is negative. So, all these masses are involved and therefore, the binding energies are involved.

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Now, if you compare these two, let us take the case of say symmetric fission A 1 is equal to A 2 and that is A by 2. Let us consider this situation where, the nucleus is the split into equal parts although in the normal fission reactions. The probability of this symmetric fission is less than the a symmetric fission where, little bit difference is there in the 2 masses but, it is still let us calculate for this. Now, in the semi empirical mass formula you remember the mass is of course, mass of a nucleus is that Z times m n that is written there N times, Z times m p N times m n C square minus binding energy And this binding energy is a v times A this is the volume term. We had done it in the beginning and then minus surface term a s A two-third and then, a coulomb term minus a c Z Z minus 1 over A power one-third and then, there was an a symmetry term a sym N minus Z square divided by A and pairing term. Now, pairing term we will forget, this is when you have

even A nucleus or odd A nucleus odd odd nucleus or even even nucleus or even odd odd even nucleus, that has its own differences in binding energy but, that we will forget here, we will assume that everything is even even the original nucleus as well as the fission fragments.

So, this we just neglect this, in other terms this volume term this is a  $v$  times number of nucleons. So, if the number of nucleons its same initial side and on the final side it is the splitting but, the total number of the nucleons remains same. So, a  $v$  times capital A, that will remain the same before the event it is a  $v$  times capital A and after the event you have 2 nuclei A by 2 and A by two. So, a  $v$  times A by two plus a  $v$  times A by two. So, that will again become a  $v$  times A so that volume term in binding energy it is same in the 2 situations.

So, you have this A X going to A by 2 Y and again A by 2 Y and if this some difference in proton, neutron you can call it Z. So, X going into Y plus Z that is the name of the nucleus not the proton number. So, this total A remains the same on the 2 sides therefore, this volume term remains the same, what happens to the surface term if you have one nucleus assume it to be spherical? So, you have one nucleus and you have surface and if this is sphere is broken into smaller spheres, the surface area will increase and therefore, the surface energy will increase. So, this term, the surface energy this is going to increase and the coulomb term here, this coulomb term if you are separating it out your making it two.

So, essentially you are increasing the separation between protons on the average. So, if everything all protons are in one sphere and then, you split that and make it two spheres, two different spheres at the end of it. The coulomb potential energy is going to decrease. So, the surface term in the binding energy and the coulomb term in the binding energy, they are competing with the in splitting, the surface energy is increasing. So, the rest mass energy will increase corresponding to that, the coulomb energy is decreasing. So, the rest mass energy will decrease, because of that. So, there is a competition between the two. What happens to this symmetric? symmetry this energy N and Z are unequal, because of that you can work it out and you can see that this also remains unchanged. So, initially it was  $N - Z$  by  $A$  square, this was the initial term. So, let me call it just some  $a$  and the after this split you have two of them.

So, 2 times and N becomes N by 2 and Z becomes Z by 2 square of this of it, how do I write this? A should be outside. So, this bracket is smaller like this. So, this is square here and then divided by A by 2. So, for each fragment the a symmetry energy will be minus a sym and multiplied by N by 2 minus Z by 2 square by A by 2, whereas in the beginning it was N minus Z square by A multiplied by that A symmetry N that coefficient N minus and those things and these 2 happen to be equal, because this 2 and this 2 will become 4 and that will cancel this 4 and these 2 will be equal so that symmetry energy or a symmetry energy whatever, you call N Z are not equal therefore, there is a energy difference so that also remains the same in the initial nucleus and the two fragments. So, it is only the competition between the surface energy and the coulomb energy.

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$$\begin{aligned}
 Mc^2 &= M_0c^2 + A - \left( -a_s A^{2/3} - a_c \frac{Z^2}{A^{1/3}} \right) \\
 2M_1c^2 &= M_0c^2 + A \\
 &\quad - 2 \left[ -a_s (A/2)^{2/3} - a_c \frac{(Z/2)^2}{(A/2)^{1/3}} \right] \\
 Q &= Mc^2 - 2M_1c^2 \\
 &= a_s \left[ A^{2/3} - 2(A/2)^{2/3} \right] + a_c \left[ \frac{Z^2}{A^{1/3}} - 2 \frac{(Z/2)^2}{(A/2)^{1/3}} \right]
 \end{aligned}$$

So, you can work out what happens to the total mass? let me write mass time c square, some M naught c square and and some constant. So, all these terms which are constant, the symmetry energy the volume energy these are constant are here and that Z protons are there N neutrons are there, that is there and minus binding energy and from the binding energy those constant terms I have already written. So, here it is minus a s and then, A to the power two-third and minus a c and then, Z let me write it Z square divided by A to the power one-third. For these fission reactions, Z is more than 50 or so Z minus 1 can be written as Z 2 fragments M 1 and M 2 they are equal. So, double of that, that is the final rest mass energy and that will be this part will remain as such, because same

number of neutrons M number of protons, the volume term and asymmetry there equal and these two will become. So, this whole thing multiplied by 2 and then, this will be minus a s and this will be A by 2 to the power two-third and minus a c Z by 2 square and divided by A by 2 to the power one-third.

So that is this final rest mass energy and if you subtract, find the rest mass energy from the initial rest mass energy you get that Q value and that should be positive if it is to be energetically favorable. So, you can work out the Q value, M c square and minus 2 times M 1 c square, you can just write this minus this. So, you will have a s A to the power two-third and minus A by 2 to the power two-third. So, and double of that remember so that is the first term and the second term is similarly, plus a c Z square divided by A to the power one-third minus 2 times and then, Z by 2 square and divided by A by 2 to the power one-third.

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$$a_s \left[ A^{2/3} - 2(A/2)^{2/3} \right] + a_c \left[ \frac{Z^2}{A^{1/3}} - 2 \frac{(Z/2)^2}{(A/2)^{1/3}} \right] > 0$$

for spontaneous fission

$$a_s = 16.4 \text{ MeV}$$

$$a_c = 0.72 \text{ MeV}$$

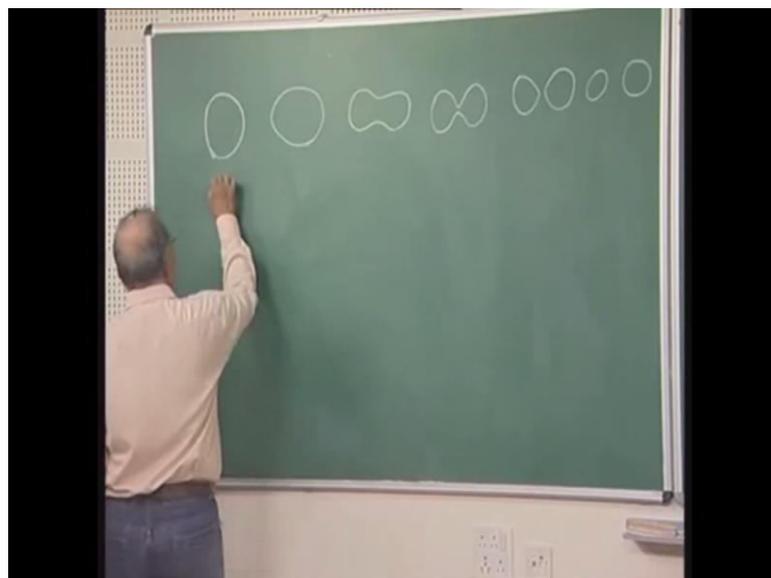
$$A > 100$$

So, this quantity should be positive for fission to be for this particular reaction energetically favorable. Now, you can put the values of a s and a c and that gives a condition just on Z square by A and then, one can see for any given nucleus if you want to check whether it should fission or not energetically. So, you can just put Z and A in this equation and work out whether this q value is positive or negative And it turns out from this, that if a is somewhere greater than 100 around, it is energetically possible anything with a value greater than 100 should fission and reduced its energy but, we very

well know that, we have so many nuclei with a greater than 100 at least up to uranium 230 238 is uranium 235 and 238 and beyond also there are so many nuclei above this A equal to 100 mark, which in general are very stable, they are there and they do not fission by themselves so that was a question a hard question that if energy can be reduced by breaking this nucleus in two parts without giving any extra energy then, how come these nuclei still exist? Why do not they fission and reduce their rest mass energy? And that once again using semi mass formulae Bohr and Wheeler was able to tell why it is.

So, one has to understand the mechanism of this fission, how this fission proceeds? And Bohr and Wheeler gave this theory, very good theory which explains almost all features but, fails at certain places and that mechanism that was suggested again based on liquid drop model. This nucleus is considered as spherical or nearly spherical drop in the beginning and then, before breaking in two parts it must go through that intermediate deformation process.

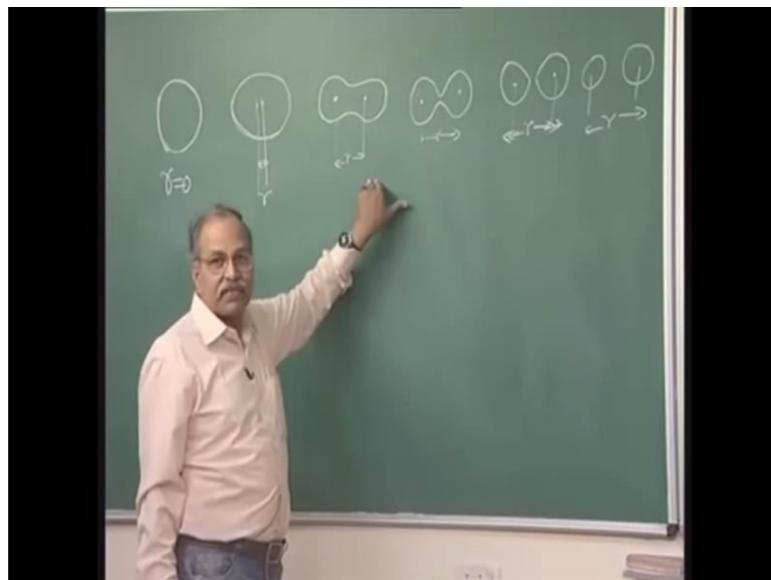
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So, the idea was that start with this spherical nucleus or nearly spherical nucleus and then, because of something some energy deposition or something if it starts deforming and finally, it breaks. It has to go through those intermediate process and. So, this will become something like an ellipsoid of the same volume, because nucleus is incompressible alright. The nuclear volume density is fixed remain same. So, the same volume is now, in this shape and then, if remember it has to split. So, the next phase

would be something like this always volume should be same. So, the drawing should be made accordingly and then, further deformation we take it like this and then, the two parts will just separate out and finally, they will go, they are all positively charge, they will go away from each other. So, Bohr and Wheeler took some deformation parameters and roughly speaking deformation parameter could be think of this whole thing as two loops, two masses and the centers of that separation between them, that you can take as deformation parameter. So, if you have one single sphere, that means the two parts are all occupying that same volume and that the deformation parameter is zero.

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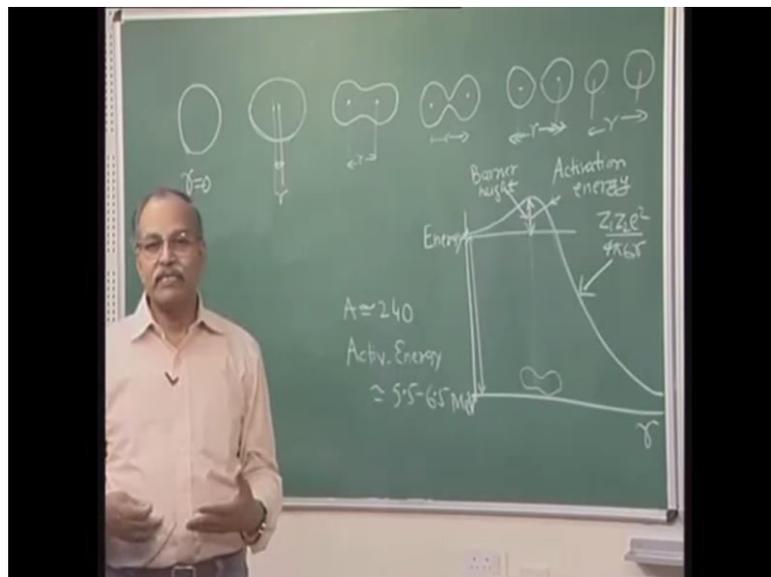
So, here that deformation parameter if I write it is as  $r$ , that  $r$  is 0 and here you can say that. Now, if you think of two parts, one part it centered here, one part is centered here. So, one part is like this and one part is like this. So, slight shifting so, this  $r$  parameter is small and is this is that  $r$  parameter here, this slope is somewhere here and this slope is somewhere here. So, the  $r$  parameter has the deformation is increased. So, this is  $r$  similarly, here this is  $r$ . So, it is increasing alright. So, this is how quantitatively define how much deformation is there in the intermediate states?

And then, for each shape for each deformation what should be the energy? the calculation are not easy but, what should be the energy, using semi empirical mass formula? For example, what we need is surface energy. So, how much is the surface area of that deformed nucleus at each stage as a function of  $r$ ? Similarly, coulomb energy, if

this these protons are now, distributed in this deformed dumbbell shape, what is the coulomb energy? So, this is how all these things were calculated and then, from that what is the total energy coulomb energy plus surface energy?

So, what is the total energy again? There is a competition between coulomb energy and surface energy, the surface energies increasing and coulomb energies decreasing. So, there is a competition so, what happens? when both things are taken into account for different values of capital A, you get different kinds of this energy versus r dependence. So, in this vicinity of interest where, initial A value is around 240 or so.

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The shape turns out to be something of the sort. So, on the horizontal axis, we are showing this deformation parameter and here we are showing that energy and 0 of energy is taken when, these two fragments are well separated. So, the coulomb energy is also 0, they are well separated. So, once they are well separated and the distance between these two fragments is large, there is no nuclear interaction. So, this portion here is essentially that coulomb part  $Z_1, Z_2 e^2$  square over  $4 \pi \epsilon_0$  naught r and with respect to this 0, where the 2 fragments are very widely separated calling that as 0. When it was one single nucleus, the rest mass energy was higher if I consider that A equal to 240 it is something like 216 MeV higher, that is this value here, 0 deformation alright. So, this is that Q value of that reaction and intermediate between this value and this value

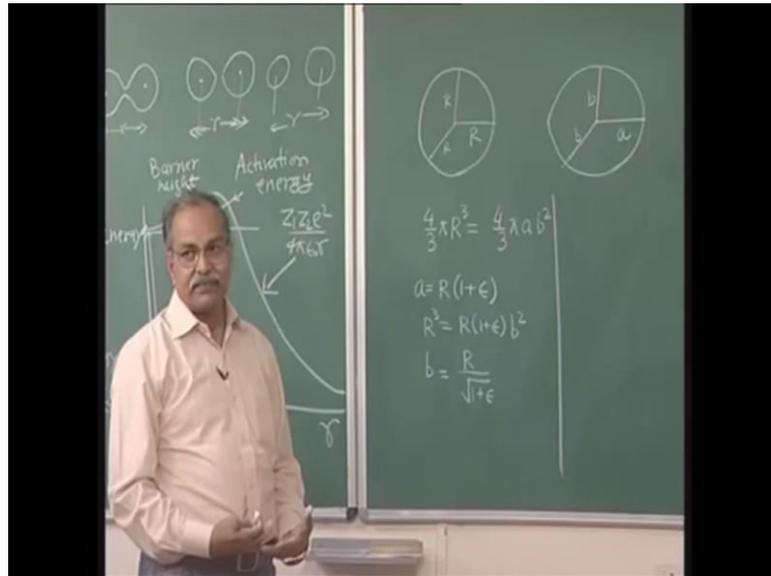
as the deformation starts, the energy increases and then, it goes through a maximum and after that it decreases and finally, a just goes as  $1/r$  dependence.

So, this is the kind of dependence of this energy, which includes surface energy as well as coulomb energy and this maximum, this value, the highest value of energy minus this 0 deformation energy, this is known as activation energy or barrier height. You can also call it barrier height is a potential barrier. So, the fission has to go through this potential barrier to really get to that fragment state. So, this barrier is the answer to the question that why, they do we have stable or very stable nuclei beyond that  $A$  greater than hundred? So, this extra energy when you have a nucleus in its ground state it has this much of energy if the nucleus is splits in two parts, it will have this much of energy.

So, the rest mass energy will be decreased but, the intermediate processes, the intermediate states, the intermediate deformed shapes of the nuclei will undergo through these energies and therefore, you have this barrier, the total available energies this much where as this barrier is to be surmounted. This extra energy is needed, this is activation energy or barrier height. This is perhaps somewhere around here, this means perhaps you have some kind of deformation in this state, if it is further deform the energy decreases but, in the beginning it is this. So, for different  $A$  value is this barrier height is different and for  $A$  equal to 240 or in that range of course, it will be a sensitive function of  $A$  somewhere around say 240 region, this activation energy or barrier height. It is something like say 5.5 MeV to 6.5 MeV something of this sort of this type.

So, this much of extra energy is needed and that is why, the probability is very small and that is why, we have almost stable nuclei but, if you look for much larger values of  $A$  then, there is no barrier in fact, this shape does not work in the from the very beginning has the nucleus start deformation. The energy start decreasing if that be the case then, for she will not have those nuclei, they will spontaneously fission. We can work out that condition also, where a small deformation triggers larger deformation, It is like unstable equilibrium of an object if you disturb it slightly, that triggers larger disturbance and it falls. So, similarly, if you consider very large nuclei and in spherical shape it will have some energy slightly deformed and the decrease in already starts right from there is does not increase and then, decrease in that cases you will not have any barrier.

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So, if you want to work out the conditions for that, you have to do little bit of geometry if you have sphere of radius say  $R$  and you deformed slightly in that ellipsoid shape the first stage let us say of this type. So, if you deform it here and if it takes a prolate type of ellipsoid shape then, this radius is larger and these radii are smaller the drawing does not suggest, that what does not matter this is  $b$  and this is the  $b$  and the volume should be same.

So, the volume here is four-third  $\pi R^3$  and the volume they are is four-third  $\pi a b^2$  square. So, the volume should be same, nuclear density it is same and if I write this  $a$  as  $R$  times  $1 + \epsilon$ , this radius is increased here is elongated and this is compress. So,  $b$  will decrease so, if I write this  $a$  as  $R$  times  $1 + \epsilon$ , I can put it here and see what is  $b$ ? So, you have  $R^3$  is equal to  $a b^2$  square, you have  $R$   $1 + \epsilon$  that is  $a$  and  $b^2$  square and from here you can work out what is  $b$ ? So,  $b$  will turn out to be  $R$  square and square root of that is this and this by  $1 + \epsilon$ .

So, if the volume is to be kept same and if this  $a$  is increased by  $1 + \epsilon$  factor then,  $b$  should decreased by  $1 + \epsilon$  by square root of  $1 + \epsilon$  with this geometry one can work out how much is the increase in surface area? And how much is the decrease in coulomb energy?

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$$S \Rightarrow S(1 + \frac{2}{5}\epsilon^2 + \dots)$$

$$a_s A^{2/3} \Rightarrow a_s A^{2/3} (1 + \frac{2}{5}\epsilon^2 + \dots)$$

$$a_c \frac{Z^2}{A^{1/3}} \Rightarrow a_c \frac{Z^2}{A^{1/3}} (1 - \frac{1}{5}\epsilon^2 + \dots)$$

$$\text{increase} \Rightarrow a_s A^{2/3} \frac{2}{5}\epsilon^2 - a_c \frac{Z^2}{A^{1/3}} \frac{1}{5}\epsilon^2$$

So, the surface area that becomes S into 1 plus two-fifth epsilon square up to order epsilon square. So, you have higher order terms that I am not writing so, the surface area becomes this much and therefore, if you look in terms of the surface energy so, a s A to the power two-third it will be multiplied by 1 plus two-fifth epsilon square the area is increased by this much now, coulomb energy once again 1 has to make a t d s calculation how much is coulomb energy, it will decrease the cost things are getting separated. So, it will decrease and this coulomb energy becomes a c times Z square by A one-third and then, 1 minus one-fifth epsilon square. So, the net increase should become negative if you do not want any barrier. So, net increase will be equal to a s capital A two-third times two-fifth epsilon square this is increase and then minus this a c Z square by A one-third and time one-fifth epsilon square.

So, the coulomb energy is decreased the surface energy is increased, we are writing the amount by which the service energy is increased minus the amount by which that coulomb energy is decrease. So, this is the net increase. Now, you can ask when you do not have any increase give a small deformation and the energy starts decreasing that will be the case if this quantity happens to be less than 0. So, even a small deformation decreases energy so, this is the condition and you can now, cancel that epsilon square other things and you can get a condition once again on Z square by A and this turns out to be using the same value of a s and a c.

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$$a_s A^{2/3} \frac{2}{5} \epsilon^2 - a_c \frac{Z^2}{A^{1/3}} \frac{1}{5} \epsilon^2 < 0$$
$$2a_s - \frac{Z^2}{A} a_c < 0$$
$$\frac{Z^2}{A} > \frac{2a_s}{a_c}$$

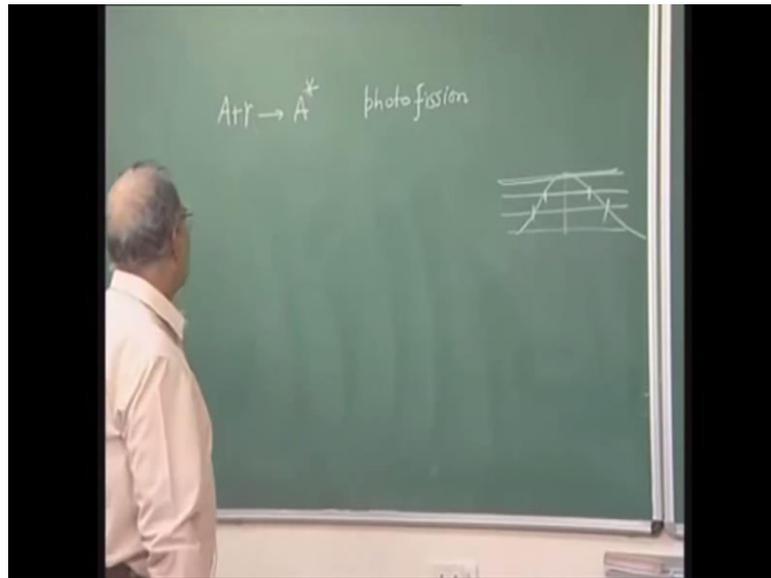
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$$\frac{Z^2}{A} > \frac{2a_s}{a_c} \quad a_s = 16.4 \text{ MeV}$$
$$a_c = 0.72 \text{ MeV}$$
$$\frac{Z^2}{A} > 47$$
$$Z = 0.4A, A > 300$$

a c 0.72 M e V and a s is 16.4 M e V Z square by A turns out to be around 47 and if you take Z equal to 0.4 times A for a rough calculation for uranium 238 this value is 0.38 or so, Z by A if you take this value, this relation will say that a roughly greater than 300. So, these calculation will suggest that if you have if you somehow create a nucleus with a greater than 300, it will immediately fission in two parts, because there is no potential barrier. So, this is all about the spontaneous fission or fission by itself and energies rest mass energies and so on. No external energies is given but, the fission that we are using most of the time for our power generation and in many other situations is induced fission

where, you have some kind of a stable are very stable kind of nucleus heavy nucleus and it is not going to fission anyway at such, because of that fission barrier but, then we put some energy into it, we pump some energy into it and that energy makes it capable of surmounting that fission barrier and when, that happens you call that as induced fission alright induced fission can be, because of any kind of nuclear reaction that we trigger we can also trigger it with just gamma photons.

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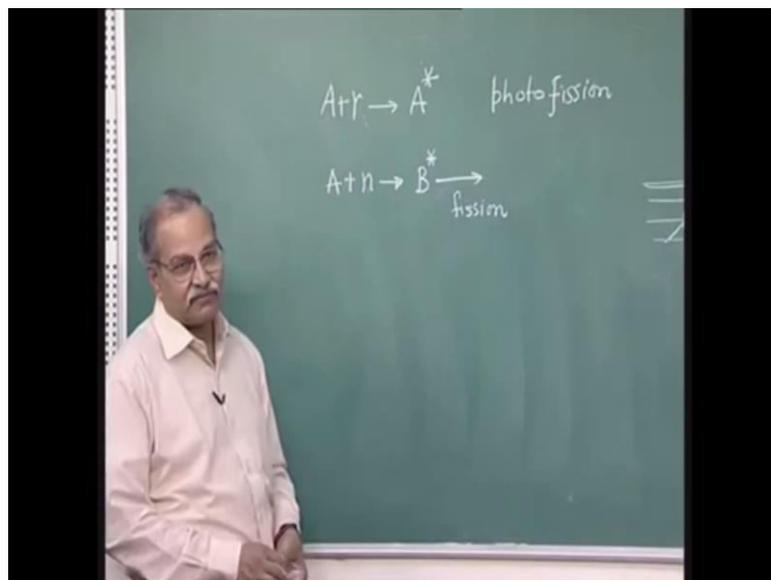


So, if we have a nucleus and if we put gamma photons on it. It can go to its excited state and depending on how much energy we have given to it it can surmount the barrier and then this can fission this is known as photo fission. So, fission by photons fission induced by photo fission in fact, this reaction is a very good reaction to experimentally measure the activation energy because there are no extra neutrons or nucleons we are putting in is the same nucleus we are not changing the nucleus only energies been deposited.

So, if we give a small amount of energy the barrier is not surmounted the fission probability is very small negligible and as you keep on increasing this gamma photons that fission cross section will increase exponentially barrier penetration no because that height to be penetrated and the width to be penetrated is a small remember you have this kind of barrier and this is that. So, if you put this much of energy this width is to be penetrated and if you put this much of energy then, this width is to be penetrated. So, width is decreasing as well as the height is decreasing and a probability of this reaction

goes up and once you have given this much of energy so that, the barrier is over, barrier is surmounted then, the fission cross section will suddenly rise many fold. So, by looking at the energy of the gamma photons required to trigger this fission with large cross section one can make calculations and work out from this experimental data is a actual activation energy. The actual height of the barrier and one can match with the model calculations say and all those things that is this. Similarly, you can have other particles going in A.

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and then, some other particles going in ((Refer Time: 47.49)) the most important one, which we will talk in detail is neutron. So, now, on the nucleus is different this nucleus is now, different call it be and that is in excited state, this is captured, this is absorbed so that becomes B star and this fissions, say compound nucleus type reaction. So, when this happens then depending on the Q value if the Q value is positive then, that energy is made available because if the rest mass energy goes down this side rest mass energy is more this side rest mass energies is less than that extra energy must be there in the nucleus somewhere and in this reaction you do not have much of kinetic energy involved.

If it has a kinetic energy n then, this will also have a kinetic energy to conserved the linear momentum but, then we had made calculations in previous lecture that, this kinetic energy will be much smaller. It will be smaller by a fraction of say this mass of this

neutron divide d by mass of this particle so that kinetic energy part is almost negligible. So, the entire that Q value and any kinetic energy which is there in this neutron becomes the energy above the rest mass energy or above the ground state and therefore, the total energy is the raised by that much and if that is enough to surmount the fission barrier the fission will take place if it is not then, that barrier penetration and low cross sections in all those things will happen. So, we will continue from here.