Nuclear and Particle Physics

Prof. P Poulose
Department of Physics
Indian Institute of Technology, Guwahati

Module – 04
Radioactive Decays
Lecture – 02
Alpha decay

Today, we will discuss the radioactivity case we will continue our discussion on this, and today we will focus on the alpha decay, alpha decay as we mentioned in the last lecture is when a nucleus say x with atomic number.

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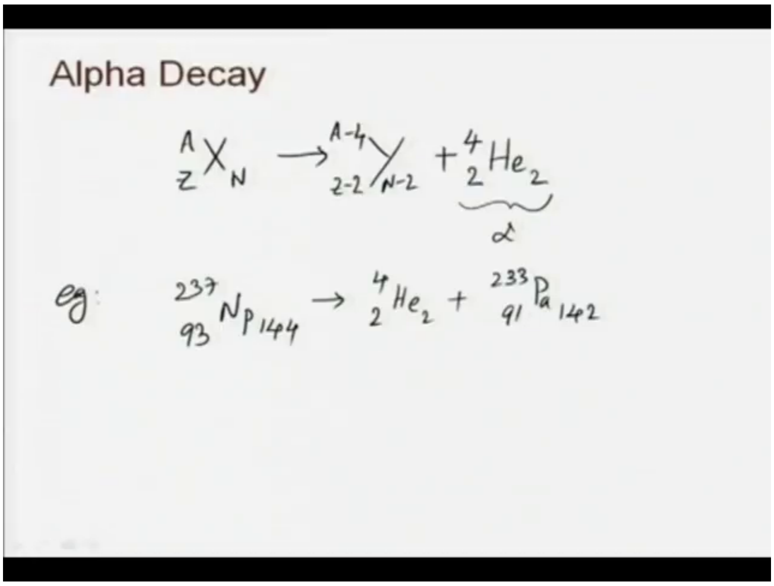

Alpha Decay

$${}^{A}_{Z}X_{N} \longrightarrow {}^{A-4}_{Z-2}Y_{N-2} + \underbrace{{}^{4}_{2}He_{2}}_{\alpha}$$

eg: $${}^{237}_{93}Np_{144} \rightarrow {}^{4}_{2}He_{2} + {}^{233}_{91}Pa_{142}$$

So, the mass number a and atomic number z, and neutron number n which is equal to a minus z, goes to a decays to another nucleus let us denote it by y, and an alpha particle which is essentially helium nucleus which has 2 protons, 2 neutrons and 4 mass number 4, and this will say that the nucleus y will half mass number a minus 4, atomic number z minus 2 and neutron n minus 2.

This helium nucleus is basically called to alpha particle it has 2 positive charge, because we are only looking in the nucleus of this thing we are talking about the nuclear is it is not the helium atom it is a helium nucleus. So, it is it has a 2-positive charge, an example is neptunium with a 93 protons and 144 neutrons. So, our notation in this discussion is the center, center we have the we represent the atomic nucleus the letters representing the nucleus and then on the left-hand side lower left-hand side, we have the z value the number of protons lower right-hand side we have the number of neutrons, and mass number a that number of protons plus number of neutrons on the top left side.

So, that is now 93 plus 14 is 237 this alpha decays 2. So, this is alpha decays 2 palladium and 91 142, and mass number therefore, is 233 this is an example, not all the nuclei alpha decays. So, we can ask the question why they do not all of them or we can ask why some of them decay through alpha emission, one thing that we had to consider is the kinematics, which means energy and momentum conservation in this case engine.

So, let us look at the kinematics as our next topic.

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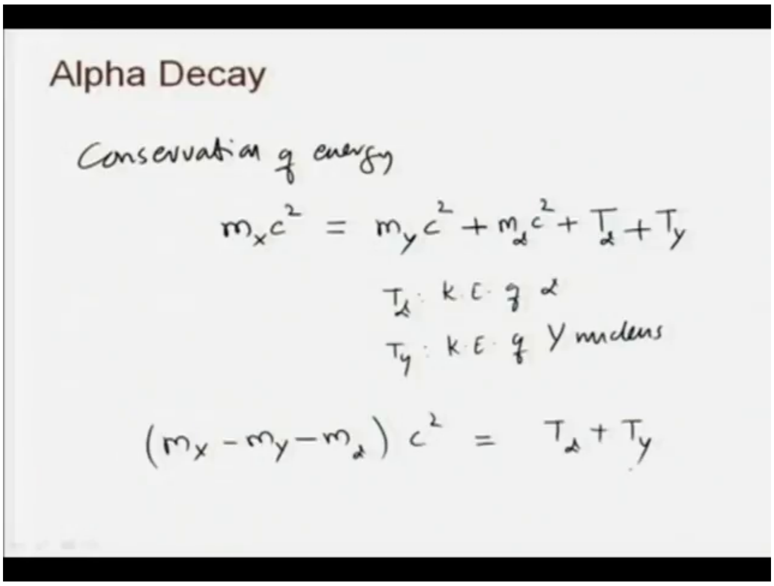

Alpha Decay

Conservation of energy

$$m_x c^2 = m_y c^2 + m_\alpha c^2 + T_\alpha + T_y$$

T_α : K.E. of α

T_y : K.E. of Y nucleus

$$(m_x - m_y - m_\alpha)\, c^2 = T_\alpha + T_y$$

So, conservation of energy says that, initially we had the nucleus x which has an energy equivalent of mass mx, let us say this denote the mass of the nucleus x as mx. So, the energy equivalent of that is mxc square according to einsteins relation, this is and let us say we are in a frame or we are actually we take this nuclei x, keep it in the laboratory with respect to as it is rest it is at rest.

So, it is at rest therefore, there is no kinetic energy to it. So, the only energy that it has is due to the mass which is a mxc square, and this should be equal to the total energy of the products or after the decay. So, after the decay we have nucleus y, which let us say has mass my and the energy equivalent to that a here mx my c square, then we have the alpha particle m alpha c square is the energy, and then in general they will have kinetic energy, say they will be moving out with some kinetic energy they will be in motion when the alpha particle is emitted it emits, with some kinetic energy it is emitted with some kinetic energy.

So, let us denote the kinetic energy of alpha particle by t alpha, and the kinetic energy of the product daughter nucleus as y Ty. So, this are the kinetic energy of. So, T alpha is the kinetic energy of alpha particle, and Ty is the kinetic energy of y nucleus all right. So now, this equation energy conservation equation says that I can take all the masses to one side, and then write it as mx minus my all right let me denote the y by capital y I have been doing that, my minus m alpha times c square is equal to sum of the kinetic energies T alpha plus Ty fine all right.

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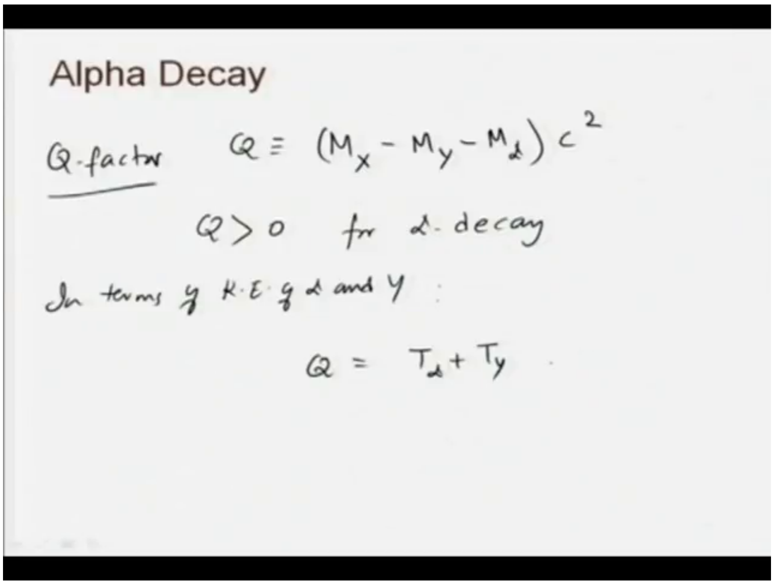

Alpha Decay

Q-factor $Q \equiv (M_X - M_Y - M_\alpha) c^2$

$Q > 0$ for α-decay

In terms of K·E of α and Y :

$Q = T_\alpha + T_Y$

Now, let us look at the left-hand side of this, which is m x minus m y minus m alpha, in general for any such decays in particular we are talking about the alpha decay. So, there are 2 particles or nuclei in the product final state. So, in general this energy the Q is if it is going to more than 2 also this kind of relation is valid, just that we have to consider all such finite state products. If my is larger than or my plus m alpha is larger than mx, this quantity will be negative what does that mean? This means that the energy due to the masses of these particles in the initial state mx is smaller compared to the energy due to this mass in the final stage, due to the mass of the products in the final stage.

This says that kinematically this will not be possible, I mean such a decay will not be possible energetically all right. So, if we step back at the earlier equation a m x c square is equal to m yc square plus m alpha c square plus T alpha plus ty, it says that if my plus m alpha is larger than mx, since T alpha and Ty which are the kinetic energies are always positive, kinetic energy is always positive therefore, the right-hand side will be larger than the left-hand side if my plus m alpha is larger than mx.

So, Q will tell us whether the sign of Q will tell us, whether kinematically this particular decay is allowed or not. So, it is only possible for a heavier nucleus to decay into a lighter nucleus, even when the sum of the masses of the lighter nucleus my plus, the sum of the mass of the alpha particle should be smaller than mx for this decay to happen. So, this because of the earlier relation energy conservation relation this is the kind of a definition of what is called a Q that I have written down we will call this the Q factor.

So, for a decay to happen Q factor should be negative a positive, Q should be larger than 0 for alpha decay, in this case and in general for any other decay. Now in terms of kinetic energies of alpha and y, we have Q equal to T alpha plus Ty that is good. So, that is one thing that is one relation we know Q is equal to T alpha plus Ty.

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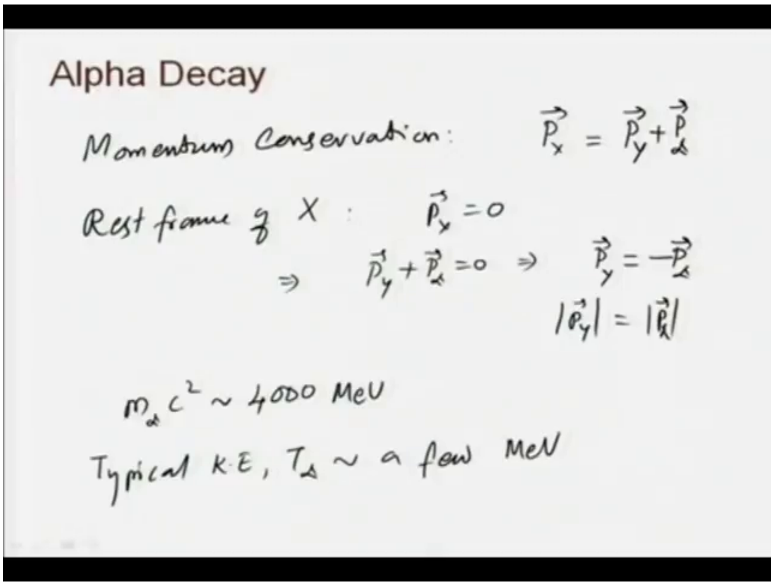

Alpha Decay

Momentum Conservation: $\vec{P}_x = \vec{P}_y + \vec{P}_\alpha$

Rest frame of X : $\vec{P}_x = 0$

$\Rightarrow \vec{P}_y + \vec{P}_\alpha = 0 \Rightarrow \vec{P}_y = -\vec{P}_\alpha$

$|\vec{P}_y| = |\vec{P}_\alpha|$

$m_\alpha c^2 \sim 4000$ MeV

Typical K.E, $T_\alpha \sim$ a few MeV

Now, let us look at the momentum conservation. Momentum conservation means the initial momentum px, let me denote it by the vector p x, momentum is a vector quantity px equal to p y plus p alpha sum of the momenta, 3 momenta we are talking about the normal momentum.

So, px equal to Py plus p alpha, now let us as I said we usually work in the rest frame of x, which means the x nuclei at are at rest when they are at rest momentum is equal to 0 so, px is equal to 0, which in then tells us that Py plus p alpha equal to 0, or that will tell you that px is sorry p y is equal to minus p alpha. So, p alpha is emitted in one direction it has some momentum, that should be equal and opposite to the recoil Py momentum, in particular the magnitude of the momenta are equal the directions are opposite.

So, this is fine and now let us we will now derive some relation between these kinetic energy of the alpha particle emitted, and the masses and the Q factor etcetera, for that let us see whether we need to actually consider we can consider this non related in this as a non-relativistic relation, or we want to consider the relativistic effects also, when do we actually consider the need to consider the relativistic effect, we need to look at the relativistic effect if we the particle is moving with large speed, large velocity, which means it has large momentum, large momentum compared to the mass of particle mass is not really directly so, we have to convert this into the comparable quantities equivalent quantities.

It is the energy equivalent in both cases we can consider, energy due to motion is kinetic energy and energy due to it is mass is the mass equivalent of energy equivalent of mass mc square. So, we can look at, what is the alpha particles? The energy equal to it is mass m alpha square, and we know it is mass is it has 4 it is almost 4 or about 4 atomic units one atomic unit is about 1000 mev slightly less than that something like 931 mev. So, let us consider approximately as 1000.

So, this has alpha particle has 4 atomic mass unit therefore, the energy equivalent of that is about 4000 mev, and typical kinetic energy of alpha particle t alpha, is about a few mevs, now this is what we have to compare against each other, m alpha c square compared to T alpha is very, very large something like 4000 times or maybe thousand times larger than t alpha. So, therefore, for all practical purposes we can say that, a non-relativistic approximation is very good, this will tell us that we can actually work in a non-relativistic approximation.

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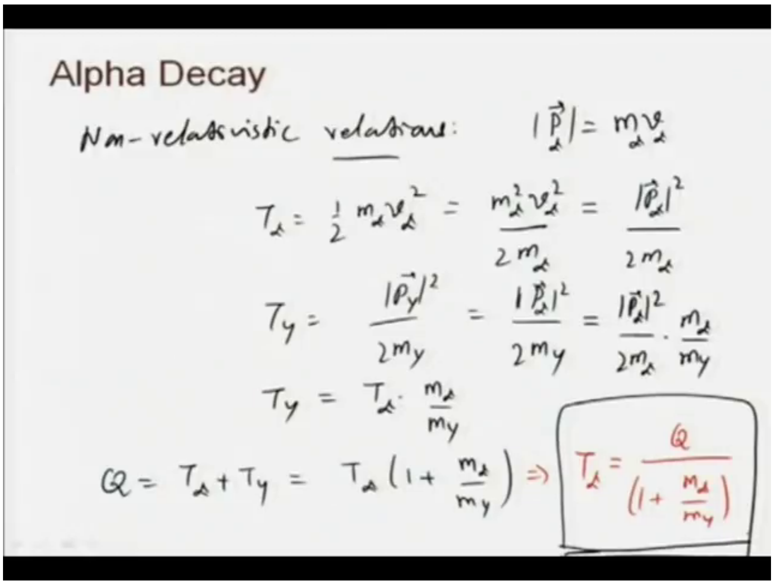

Alpha Decay

Non-relativistic relations: $|\vec{p}_\alpha| = m_\alpha v_\alpha$

$$T_\alpha = \frac{1}{2} m_\alpha v_\alpha^2 = \frac{m_\alpha^2 v_\alpha^2}{2m_\alpha} = \frac{|\vec{p}_\alpha|^2}{2m_\alpha}$$

$$T_y = \frac{|\vec{p}_y|^2}{2m_y} = \frac{|\vec{p}_\alpha|^2}{2m_y} = \frac{|\vec{p}_\alpha|^2}{2m_\alpha} \cdot \frac{m_\alpha}{m_y}$$

$$T_y = T_\alpha \cdot \frac{m_\alpha}{m_y}$$

$$Q = T_\alpha + T_y = T_\alpha \left(1 + \frac{m_\alpha}{m_y}\right) \Rightarrow \boxed{T_\alpha = \frac{Q}{\left(1 + \frac{m_\alpha}{m_y}\right)}}$$

So, we will be working with non-relativistic relation, in this p is equal to m times velocity. So, say particularly p alpha is m alpha v alpha, and kinetic energy T alpha is half m alpha v alpha square is equal to, m alpha square v alpha square divided by 2 m alpha, I have multiplied and divided by alpha m alpha. So, this numerator is nothing but p alpha square divided by 2 m alpha, now similarly Ty is equal to p y square divided by 2 my, but we already saw that Py the magnitude of Py is equal to p alpha, which means the numerator I can replace by p alpha square denominator is still 2 my, and this is nothing but, p alpha square divided by let me write it as 2 m alpha instead of 2 my in the denominator, but then I had to make up for that by multiplying by an m alpha and dividing by my.

So now this is like 2 factors the first factor p alpha square over 2 m alpha is equal to, T alpha kinetic energy of T alpha particle. So, kinetic energy of daughter nucleus y is equal to kinetic energy of the alpha particle, times the ratio of the masses ma m alpha and my now Q factor Q is equal to T alpha plus ty, is equal to T alpha into 1 plus m alpha over my. Very good now I can actually invert this and then write it as, T alpha equal to Q divided by 1 plus m alpha divided by my, fine this is one relation that we get between alpha the kinetic energy of the alpha particle, and the Q value of the reaction, and the mass ratios that is a useful relation.

So, given Q m alpha and my are known usually, we will be able to predict find out, what the kinetic energy of the alpha particle is? So, the kinetic energy of the alpha particle is fixed in a particular reaction, we will be able to compute the value of the kinetic energy of the alpha particle coming out of a particular decay, there is only one value that we can assign to this one, now as an aside I should say that in an actual alpha reaction, the daughter nucleus there is a possibility of decaying through alpha by I mean into daughter nucleus which is at either ground state or an excited state etcetera.

So, there will be a usually depending on what the energy states of the daughter nucleus is, we will have different Q values and therefore, a different kinetic energies for the alpha particles. So, we will find usually in the alpha decay some primary I mean alpha particle with a law with kinetic some kinetic energy, which some different kinetic energies I mean let me say that again, in a usual case of alpha decay we will find alpha particles with slightly differing kinetic energies, because the daughter particle can be in different energy states and therefore, the Q reactor the Q value of the reaction can be different for this, anyway we will mention some of this at the towards the end of today's discussion.

So, let me take this and consider some other approximation.

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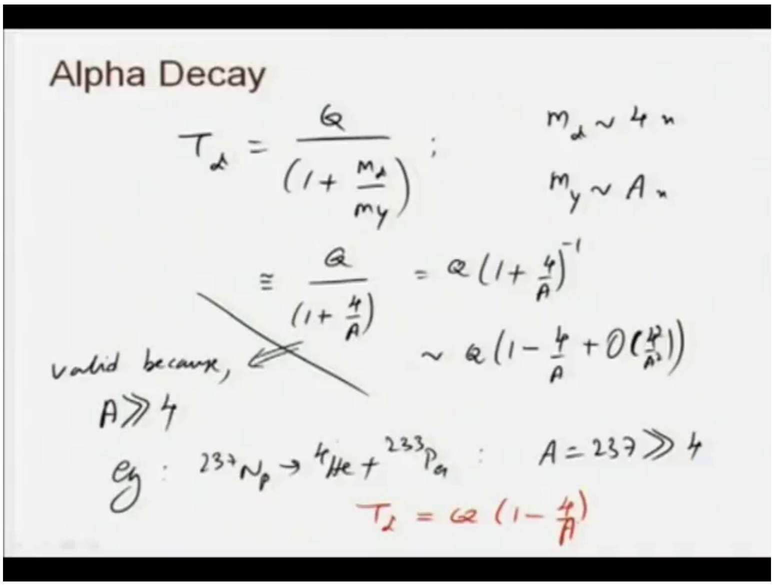

Alpha Decay

$$T_\alpha = \frac{Q}{\left(1 + \frac{m_\alpha}{m_Y}\right)} \; ; \qquad m_\alpha \sim 4u \qquad m_Y \sim Au$$

$$\cong \frac{Q}{\left(1 + \frac{4}{A}\right)} = Q\left(1 + \frac{4}{A}\right)^{-1}$$

$$\sim Q\left(1 - \frac{4}{A} + O\left(\frac{4^2}{A^2}\right)\right)$$

valid because,

$A \gg 4$

eg : $^{237}Np \rightarrow {}^{4}He + {}^{233}Pa$: $A = 237 \gg 4$

$$T_\alpha = Q\left(1 - \frac{4}{A}\right)$$

So, we have a T alpha equal to Q divided by 1 plus m alpha over my. Now if I approximate m alpha to 4 atomic units, and m y to a atomic units then this will give me T alpha equal to Q over 1 plus 4 by a, this is an approximation now I can invert this and write it as let me write it as Q 1 plus 4 over a times minus 1, and binomially expand it to get 1 minus 4 by a, plus higher order corrections order 4 by a square.

So, up to linear order a linear order in 4 by a we have, T alpha equal to Q times 1 minus 4 over a, right this is because usually a is much larger than 4, for example, valid because, for example, in our case of 237 neptunium going to 4 helium alpha particle plus 233 palladium we have a equal to, 237 which is certainly much larger than 4. So, we this approximation is quite valid there no problem. And so, let me write the kinetic energy therefore, in that t, let me use a different pen ink, kinetic energy t is equal to Q times 1 minus 4 by a all right.

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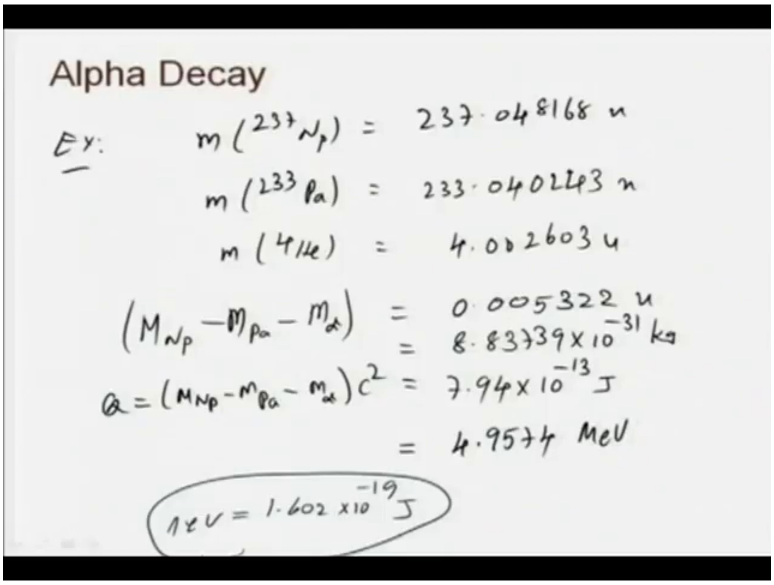

Alpha Decay

Ex:

$$m(^{237}Np) = 237.048168\ u$$

$$m(^{233}Pa) = 233.040243\ u$$

$$m(^{4}He) = 4.002603\ u$$

$$(M_{Np} - M_{Pa} - M_{\alpha}) = 0.005322\ u$$

$$= 8.83739 \times 10^{-31}\ kg$$

$$Q = (M_{Np} - M_{Pa} - M_{\alpha})c^2 = 7.94 \times 10^{-13}\ J$$

$$= 4.9574\ MeV$$

$$\boxed{1\,eV = 1.602 \times 10^{-19}\ J}$$

Now let us take an example, a consider the example that we have considered just now m of 237 in p is equal to 237.048168 atomic units, and mass of 233 pa is equal to 233.040243 units and mass of alpha particle is 4002603 units. So, the mass difference the mass of the neptunium minus, mass of palladium minus mass of alpha particle is equal to, you can find the difference between this and that turns out to be 0.005322 good.

So now Q is equal to MNp minus mpa minus m alpha c square, which turns out to be. So, converted into kilogram the earlier mass expression is better if you want to actually work in si units. So, let me write that down 8.83739 times 10 power minus 30 one kilogram, that is the mass difference, and this corresponds to times c square c is about 3 times 10 power 8 meter per second. So, almost c square is 9 times 10 power 16 meter per square per second square.

So, multiplying this with this 9 into 8 is 70 it turns out to be 7.94 into other decimal places, as well into 10 power minus 1 3 joules is that. So, it is this is equivalent to this is equivalent to 4.9574 mev, we can actually either we usually work in mev units rather than joules. So, basically, we will convert this into this. So, let me give you the conversion relation again, one electron volt is equal to 1.6 almost 602 into 10 power minus 19 joules.

So, this is the conversion relation. So, you can use this to convert this 7.94 into 10 power minus, 19 joules 2 mev, mev is mega electron volt which is 10 power 6 electron volt.

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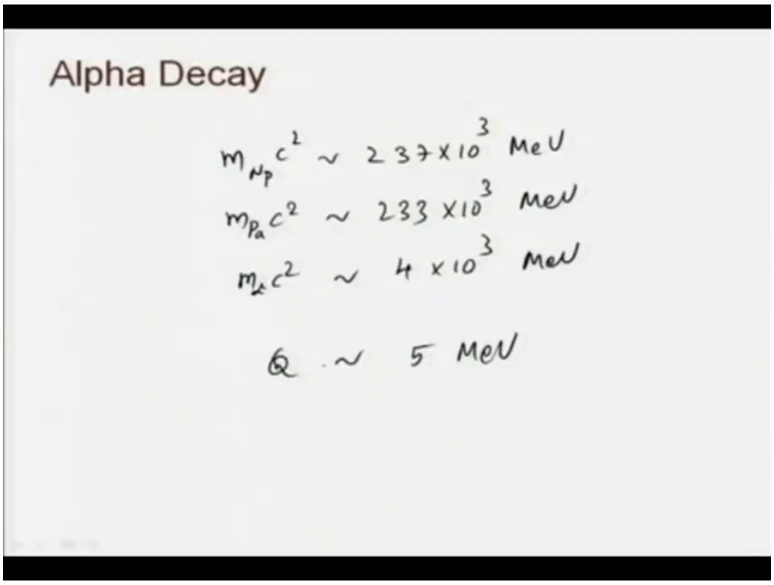

Alpha Decay

$m_{Np}c^2 \sim 237\times10^3$ MeV

$m_{Pa}c^2 \sim 233\times10^3$ MeV

$m_{\alpha}c^2 \sim 4\times10^3$ MeV

$Q \sim 5$ MeV

Now so, let me summarize this what we have we have MNp the energy equivalent, of that c square is almost 237 into 10 power 3 mev approximating each of the proton and neutron mass to or each atomic mass unit to 10 power 3 a mev, which is almost a good approximation.

But not exact m y the product the product here is pa c square is 233 times 10 power 3 mev, and m alpha c square, is 4 into 10 power 3 mev and Q factor is 5 mev. So, this is why we actually set and t q, is T alpha plus the sum of the kinetic energies. So, the sum of the kinetic energies is very small compared to the masses of the particles all right. So, the law the approximation that we worked with is quite all right.

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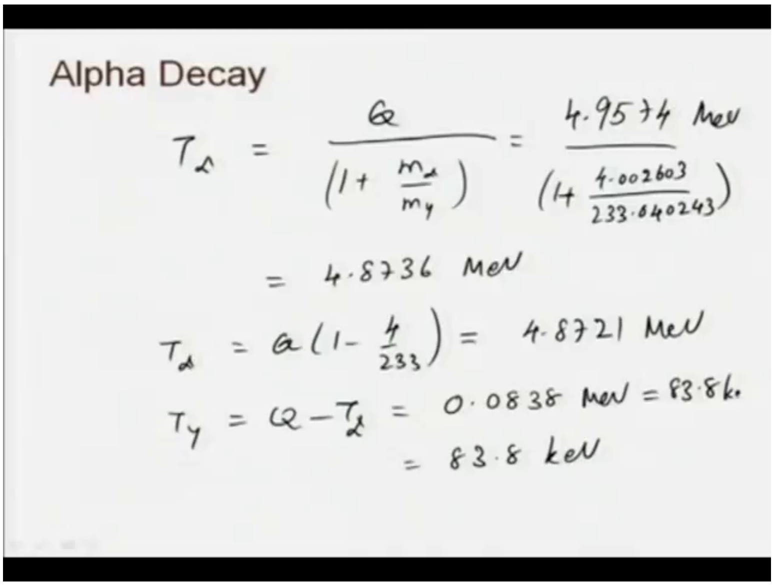

Alpha Decay

$$T_\alpha = \frac{Q}{\left(1+\frac{m_\alpha}{m_y}\right)} = \frac{4.9574\ \text{MeV}}{\left(1+\frac{4.002603}{233.040243}\right)}$$

$$= 4.8736\ \text{MeV}$$

$$T_\alpha = Q\left(1-\frac{4}{233}\right) = 4.8721\ \text{MeV}$$

$$T_y = Q - T_\alpha = 0.0838\ \text{MeV} = 83.8\text{k}.$$

$$= 83.8\ \text{keV}$$

Now, let us come to the kinetic energy of the particle alpha particle in this case, it is Q over 1 plus m alpha over my. So, let us use this relation. So, this turns out to be sorry Q is equal to 4.9574 mev, divided by 1 plus 4.002603 in atomic units divided by, 233.040243 which you can do the algebra is equal to 4.8736 if I have done it correctly, you check that out mev. Now the approximation that we used because 4 is much smaller than a, in this case 233 is Q times 1 minus 4 by 233, which is equal to again you do the algebra that is equal to 4.8721.

So, this is a very good approximation, in this case up to 2 decimal places it is it agrees, and the third decimal place it changes a little not much by one. So, this now let us look at what is the kinetic energy of the product particle the recoil kinetic energy, Q the Ty is equal to Q minus T alpha that is equal to point naught 838 mev. So, it is something like 84 kilo electron volt all right. So, this now therefore, we can see that most of the kinetic energy is most of the energy, the coming from the difference in the masses is carried taken away, by the kinetic energy of the alpha particle because it is light.

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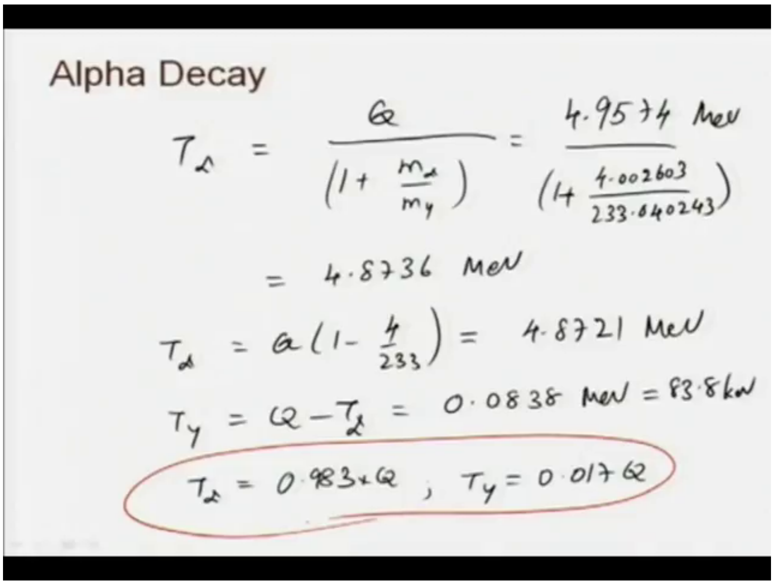

Alpha Decay

$$T_\alpha = \frac{Q}{\left(1+\frac{m_\alpha}{m_Y}\right)} = \frac{4.9574 \text{ MeV}}{\left(1+\frac{4.002603}{233.040243}\right)}$$

$$= 4.8736 \text{ MeV}$$

$$T_\alpha = Q\left(1-\frac{4}{233}\right) = 4.8721 \text{ MeV}$$

$$T_Y = Q - T_\alpha = 0.0838 \text{ MeV} = 83.8 \text{ keV}$$

$$\boxed{T_\alpha = 0.983 \times Q \,, \quad T_Y = 0.017\, Q}$$

So, we can write. In fact, as you find this out this relation again, T alpha is equal to 0.983 times Q in our case in our example, it is and t y is equal to point 017 Q all right. So, this says that more than 98 percent of Q available energy available for kinetic energy, is taken by the alpha particle. So, it is only 1.7 percentage of this which is given to the recoil that daughter nucleus all right. So now, let us come to leave the kinematics here, and then come to what causes or what may be the reason for this decay? Or rather let us let us discuss some theoretical model for this.

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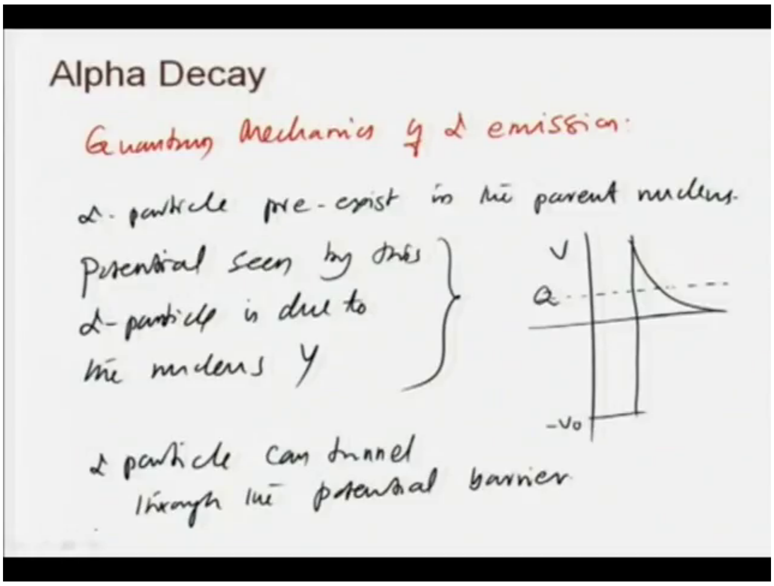

Alpha Decay

Quantum Mechanics of α emission:

α-particle pre-exist in the parent nucleus.

Potential seen by this α-particle is due to the nucleus Y

α particle can tunnel through the potential barrier

So, what is the quantum mechanics of alpha emission, one theory one today we can consider is to have an alpha particle in the nucleus preformed already existing, it is bound to it is there in the potential of the daughter nucleus. So, somewhat the kind of picture of the nucleus eggs, can be that there is a y kind of a nucleus, and it there is an alpha particle bound to this. So, there is an alpha particle which exists in the this one is a one kind of way to look at it, but actually we do not know what exactly is the situation in the small nucleus of the atoms therefore, this model may not have anything to do with the reality, but we can still take that as a kind of a toy model.

Some kind of a crude approximation of what may be happening or just as a mathematical model to understand, what can what may be happening and try to predict, whether the probability for decay etcetera can be computed using this model. So, that is what one can do. So, the there exists alpha particle, is exists preformed pre-exist in the nucleus, now this alpha particle sees the potential, and this alpha particle sees the potential due to the nucleus y, all right.

So, let us say like in our earlier case, let us consider some kind of a square well potential, remember this both of these are positively charged, and it is alpha particle has 4 protons in 2 protons in it, and y has a minus 2 protons in it not a minus z minus 2 protons in it. So, there will be some coulombic barrier to this. So, essentially we will have a an attractive strong potential between this, and then there is a coulomb positive coulomb potential repulsive potential, effectively the potential may look like this, all right and the 1 over r electric potential the coulombic potential, is actually repulsive and then therefore, there is a kind of a wedge like a feature for this potential, and suppose Q is the suppose our Q value is somewhere here, Q value for that particular reaction is here, somewhere here and 98 or more than 90 percent of the kinetic energy of the alpha particle is, sorry more than 90 percent of the Q value is the kinetic energy of alpha particle.

So, alpha particle we can say is has a kinetic energy more or less equal to Q almost q. So, that energy can be thought of as the energy of the alpha particle the quantum alpha particle, and then we will see that with that energy the alpha particle as a quantum particle, can penetrate this potential the wedge like potential right and come out of this. So, there is a particular there is a tunneling possibility there, and the probability for that tunneling to happen may be able to be may be able to compute using quantum mechanics, through quantum mechanics.

So, there is a tunneling probability, alpha particle can tunnel through the potential. So, this could be a possible model right and. In fact, people have worked on this, and then computed what kind of probability one can actually get, for particle decays a alpha particle decays for different nuclei, we will not go into the details of this calculation any further than this just mentioning that such kind of a model and possible mathematical explanation for the alpha particle decay is exists, and it is possible to compute the probability of decay.

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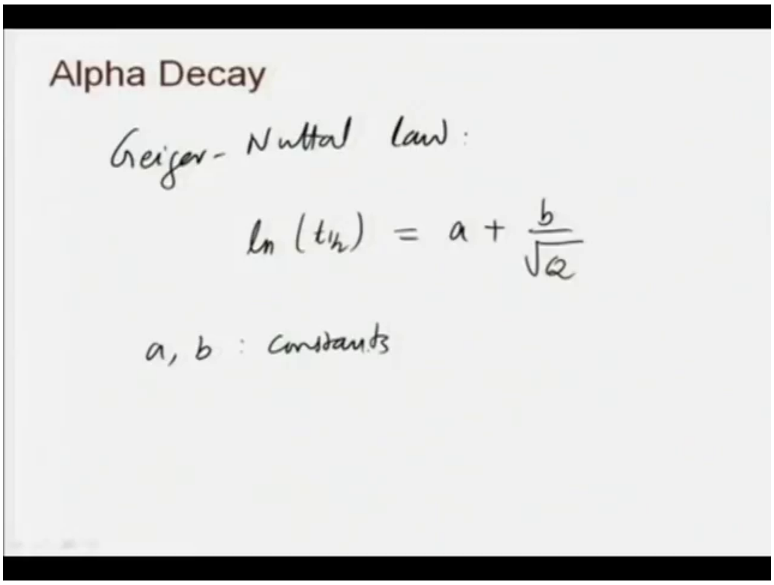

Alpha Decay

Geiger-Nuttal law :

$$\ln(t_{1/2}) = a + \frac{b}{\sqrt{Q}}$$

a, b : constants

Another relation that we will just state, but not discuss is the Geiger natal law of radioactive of alpha decay. It says that logarithm of half-life we saw in a as the last discussion, that half-life for any radioactive process or radioactive sample is proportional to inversely proportional to the probability of decay, in the larger the probability of decay half-life will be smaller it will decay faster. So, half-life will be smaller. So, there is a relation between the probabilities to decay, and the half-life and inverse relation. In fact, and this logarithm of half-life is equal to is related to the Q value of the reaction in this manner, where a and b are constants these constants may depend on z value for example, but they do not depend on the energy.

So, the energy dependency is through q, and this is the relation that holds in most of the reactions. So now, another feature is another a quantity.

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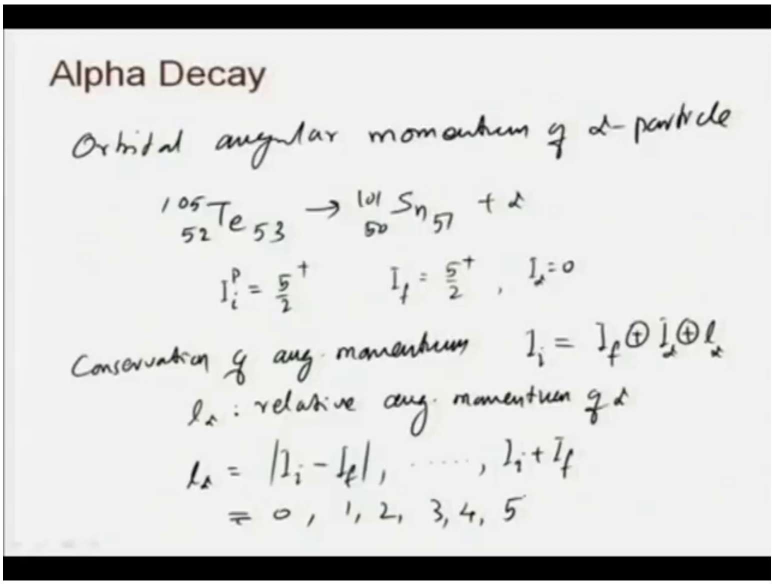

Alpha Decay

Orbital angular momentum of α-particle

$${}^{105}_{52}Te_{53} \rightarrow {}^{101}_{50}Sn_{57} + \alpha$$

$$I_i^P = \frac{5}{2}^+ \qquad I_f = \frac{5}{2}^+ , \quad I_\alpha = 0$$

Conservation of ang momentum $I_i = I_f \oplus I_\alpha \oplus l_\alpha$

l_α : relative ang. momentum of α

$$l_\alpha = |I_i - I_f| , \ \cdots\cdots , \ I_i + I_f$$

$$= 0 , 1, 2, 3, 4, 5$$

That we may look at is the angular momentum rather the orbital angular momentum, of alpha particle. So, the angular momentum of alpha particle let us consider an example to start with, let us say we consider tellurium 52 protons and 53 neutrons, totally 2 105 mass number, this is seen to go down to tin 50 one naught one. So, 50 one is the neutron number, and if plus alpha particle of course.

So, when we look at the i, the spin and the parity of the initial parent nucleus it is equal to 5 by 2 plus, and for the final daughter particle daughter nucleus it is again 5 by 2 plus, and experimentally I of alpha particle is equal to 0, now conservation of angular momentum will tell you that, t is not t i i is equal to if plus i alpha plus if there is any relative angular momentum, between alpha and the produced daughter particle in the rest frame of the parent nucleus. So, this plus I have written as plus inside the circle to remind us, that it is to be added according to angular momentum addition rules not like simple numbers.

So, l alpha is the relative angular momentum of alpha particle, i alpha vz is equal to 0. So, if you look at l alpha angular momentum addition rules will tell you that it is between i i minus i f modulus of that increase in one units and up to i i plus if, these are the possible values of l alpha we can measure i i the spin of the parent nucleus and it is given actually to be 5 by 2, then spin of the daughter is also 5 by 2 therefore, l alpha is 5 by 2 minus 5 by 2 is equal to 0. So, it is 0,1,2,3 or 4 or 5 these are the values all right.

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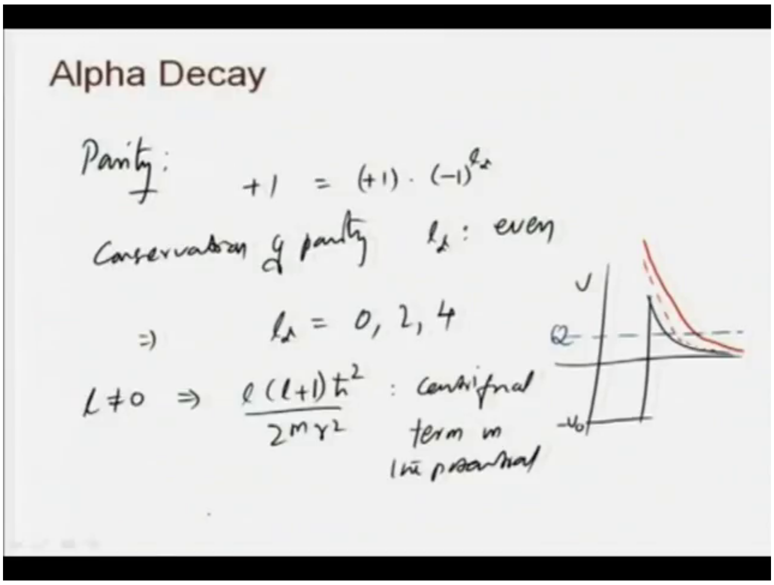

Alpha Decay

Parity:

$$+1 = (+1)\cdot(-1)^{l_\alpha}$$

Conservation of parity l_α : even

$$\Rightarrow \quad l_\alpha = 0, 2, 4$$

$$l \neq 0 \Rightarrow \frac{l(l+1)\hbar^2}{2mr^2}$$: Centrifugal term in the potential

So now let us look at the parity, parity no change in the parity, right the initial parity is plus 1. So, when I say no change, parity should be conserved. So, let us look at the conservation of the energy. So, plus 1 is the initial parity, and plus 1 is the parity of the daughter, and alpha particle parity is plus again, and there is parity due to the orbital angular momentum, which is minus 1 power l alpha. So, for conservation of parity, l alpha should be even therefore, that gives us in this particular example 0, 2, 4 as the 3 options right.

Now, let us look at what which of this whether we can make any statement about, which of these is more probable? When we have an a non-0 angular momentum then that adds a centrifugal term to the potential, you know this from say the discussion of hydrogen atom in quantum mechanics, even in the case of classical mechanics the central a central force motion of planetary motion etcetera, we have such centrifugal term, and this centrifugal term is l times l plus 1 h cross square divided by 2 m r square in the case of alpha particle quantum mechanics alpha particle.

And centri fugal potential term in the potential. So, the effect is that apart from the potential that we discussed earlier, we will have to add this centrifugal term which is basically a positive definite term. So, depending on what the l value is it is a 1, over r square potential. So, it will actually go like this and depending on what the other values are it will take some value as some shape, and some of these 2 will be bigger than or larger than the earlier case.

So, when we consider the Q a particular Q value we will see that, when l is not equal to 0, the particle will see a thicker potential that is from up to this red end, or the where the dashed line blue dashed line meets the red line, compared to the case when l equal to 0, which is the black line meeting the blue dashed color, black solid line that is certainly thinner compared to the l not equal to 0 case, which means that it has to penetrate through larger potential barrier or bigger potential barrier and therefore, it is probability tunneling probability will be smaller and therefore, the larger the l value the smaller the probability.

So, the probability will be smaller when we actually have larger l, which means that in this particular gauge case l equal to 0 is the most preferred value or the primary decay channel, and l equal to 2 and 4 maybe there. Now there is one point that I want to bring your attention to related to what we just discussed.

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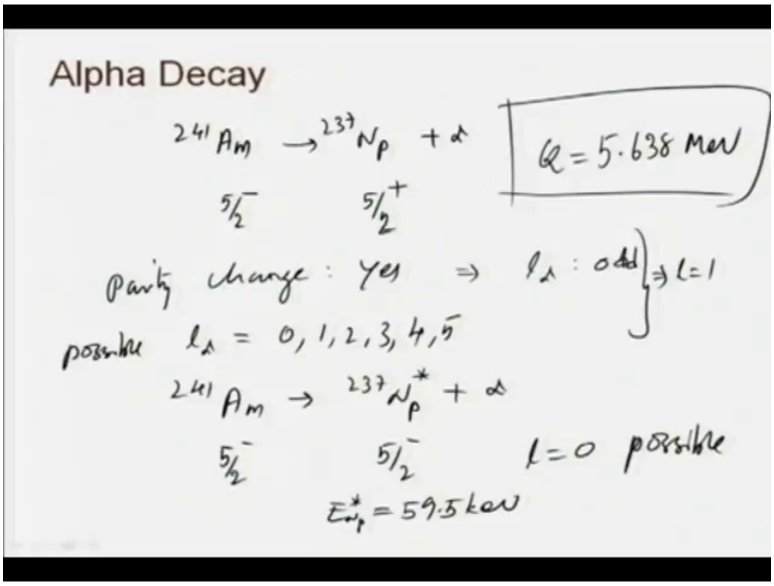

Alpha Decay

$^{241}Am \rightarrow {}^{237}Np + \alpha$

$\boxed{Q = 5.638\ MeV}$

$5/2^{-}$ $5/2^{+}$

Parity change : yes $\Rightarrow$ l_α : odd $\} \Rightarrow l=1$

possible $l_\alpha = 0, 1, 2, 3, 4, 5$

$^{241}Am \rightarrow {}^{237}Np^{*} + \alpha$

$5/2^{-}$ $5/2^{-}$ $l = 0$ possible

$E^{*}_{Np} = 59.5\ keV$

Consider americium 241 decay into neptunium 237, all right the I p of americium 241 is 5 by 2 plus and that of neptunium is also 5 by 2, sorry this americium it is 5 by 2 minus, and for neptunium it is 5 by 2 plus right.

Now, you can ask the question whether there is parity change, between the daughter and the parent nuclei parity change yes, that actually tells you that l alpha is odd, right should be odd, now let us look at what are the possible l alpha values possible l alpha 0 1 2 3 4 5, and this says that since parity change is occurring it should be l equal to one, now let us look at americium 241 going to 237 Np, but not to the ground state, this has a an Ip equal to 5 by 2 minus, all right and excited instead of going to the ground state, if it goes to the excited state of Np then it has Ip equal to minus 1.

So, l equal to 0 possible. So, this together will tell you l is equal to one, this l equal to 0. Possible and the excitation energy of Np in this case, is about 59.5 kilo electron volt which is small compared to the Q value, Q value of this reaction is 5.638 mev compared to this the excitation energy is very small, which actually means says that it will the americium 241 will prefer to actually decay to an excited state of neptunium, rather than to the ground state according to the analysis based on the angular momentum of the a parent and the product.

And it is indeed found that that is true, it is experimentally verified that this is also. So, so I mean based on these angular momentum analysis, we will certainly be able to understand some of the basic properties of this thing. So, what we discussed today is the kinematics, and angular momentum analysis of the alpha particle. So, and we will not go into the details of this. So now, your textbook actually deals with the alpha particle decay in slightly greater detail, you will also find other details in other references given.

So, we will stop our discussion on the alpha particle here.