MARKUS KLUTE: Welcome back to 8.701. So in this video, we talk about stability and, the opposite of stability, the decays of nuclei. OK, so let's look at this diagram first, which shows the number of protons-- the number of protons and the number of neutrons here. And you find that the stable elements sit in this so-called Valley of Stability. So there's a certain part of our nuclei which are stable.

This valley follows directly out of the discussion of the binding energy, where you can calculate the optimal Z value such that the mass is minimal. It's about A half in this area here at low masses, and about 40% of A the higher part-- at high value of mass. We already discussed that the binding energy has this form here, with a maximum around the mass of iron, which is like somewhere here-- 50 some.

OK, so it's energetically favorable for some unstable nuclei to break apart in so-called fission processes. And it's also energetically favorable to fuse together to create energy. And we'll talk about the applications of those processes later on. But for now, we want to just look at a radioactive nuclide, which can decay in various ways.

And so the first, most prominent decays we want to discuss here-- and then we'll follow up a little later-- is an alpha decay, which is splitting up-- a mother particle splits up into daughter particle nuclei and helium-- which is an alpha particle-- or the emission of electrons, positrons, or the capture of electrons as well. It is also possible, but rather rare, that a nuclei just spits out a proton, or spits out a neutron. So this is possible, but it's rather rare.

All right, so let's look at the alpha decay first. As I said, we start from a rather large, heavy nuclei. And it seems possible for it to spit out helium or an alpha particle. So the first thing we want to-- the view we want to have here is of the potential in which the alpha particle sits. So the alpha particle sees a really deep well of the nuclear potential. And it also sees this boundary here, this barrier, of the Coulomb potential.

So for the alpha particle to be emitted, it needs to break through this Coulomb potential here. And you can calculate the likelihood using quantum mechanics-- the quantum tunneling likelihood-- in order to figure out how stable an individual particle is. Here, I just wanted to show you something. This plot here shows you the lifetime of an unstable nuclei, for various sorts, as a function of the energy.

And what you see here is it's very strong energy dependent. This is a logarithmic plot. And what you see is the lifetime seems to be rather, rather short when the emitted particle has a lot of energy. And that can be explained by this plot here very easily. In order for this particle-- the energy of this particle, when it goes here, is dependent on where this particle sits in this potential, right? So particles which sit at very high values here will have a high likelihood to tunnel through this barrier, and therefore a short lifetime. Hence, this particle has a lot of energy after it's been emitted. So we see lifetimes in the range of 10 nanoseconds to 10 to the 17 years for some examples. So there's this huge variation depending on where the alpha particle sits in this potential.

We can have a discussion of the energetics involved. And we use our very same formula for the binding energy. So you write this down here, including your helium here, and then just figuring out what are the contribution of the individual terms. And since we observe experimentally alpha decays only for heavy particles, in this discussion here, we can assume that Z is approximately 0.041 times the mass number. And so the energy of the emitted alpha particle for this to be able to occur has to be positive. And so we find this to be possible for A values starting from about 150. Experimentally, you observe this to start happening at about 200.

All right, the next thought we want to discuss is beta decay. So this is shown in this diagram here, where-- starting from carbon-14 decays, for example-- carbon-14, you will see this in the next recitation, is very useful probe in order to date living things, and date when they were not living anymore. And you will discuss why and how you can actually do this. But for now, carbon-14 can decay via beta decay. And what you find is nitrogen, an anti-electron, and an electron.

This is a beta decay, or beta minus decay. And using our particle physics discussion, we can easily understand this. The neutron is transformed into a proton via electroweak processes with a W. The electron comes out, the anti-neutrino comes out. And similarly, we can look at carbon-10 here. Into boron is a neutrino and a positron. And again here, we have a W plus in the decay.

So now, we can, again, use our binding energy in order to understand this. So what we want to do here, for constant mass numbers, you want to plot the binding energy for the individual atoms or nuclei. And so if you do this for odd A, those as where the pairing term doesn't contribute, you find this nice quadratic term. And you can find beta decays in each of those instances here.

For A even, you have the question whether or not Z is odd or N is odd-- oh sorry, Z and N are odd, or Z and N are even. So you have two quadratic functions here. And you find the beta decay between one and the other. And so that's interesting you find those decays chains, based on where you start in the chain, you have the possibility to go back and forth. And because of the even and odd pattern, the lifetime of the decay can vary quite tremendously between those individual states.

Last but not least, election capture-- if you have a very massive nuclei and atom, and the electrons-- you know, thinking about a cloud around this-- some of the electrons can come very, very close, and be captured into the nuclei. And you find this here. The time direction goes up, proton captures via the weak interaction. The electron becomes a neutron and emits a neutrino. And an example is the electron capture of krypton into boron.

All right, so we start to get some sort of understanding of nuclear decays. We find this Valley of Stability here. We find, in a large range for lower numbers of Z, beta decays. For higher numbers of Z, we find beta plus decays. And for very heavy nuclei, we find alpha decays. Proton decays, seen at the very boundary here, and nuclear fission processes where the nuclei spontaneously breaks up, we haven't discussed in detail. But you can think about them very similarly to the alpha decay.

As you already kind of probably saw from the discussion of the beta decay, it's possible to have rather long decay chains. So you start from radioactive nuclei, which then decays, and decays, and decays, and decays in those kind of chains. So this is two examples here-- the thorium chain and the uranium chain-- creating all kinds of other new elements. And on the uranium chain, it's very interesting to say uranium is part of our core. If you build a house and you build-- if you build-- the foundation is concrete, you probably have some uranium in there, which then, in this decay chain, generates radium. And therefore, if you build a house with concrete, you want to have a measure to get rid of the radium which is just floating around.

All right, so this is it for now. We continue the discussion with more detailed understanding, or detailed discussion, on how those decay processes are possible, and what we can learn from them.