

PROFESSOR: Welcome back to 8.20, special relativity. In the last section, we discussed that moving clocks tick differently than those which are at rest. And here, I would like to discuss real life example of this.

The muon is an elementary particle very similar to the electron. It's mass is about 200 times as heavy.

The muon was discovered in the 1930s by Anderson and Neddermeyer at Caltech. And it's really one of my favorite particles because you can-- they are abundant. There's many of them in cosmic air showers. You can study them, you can study their lifetime. You can even calculate the lifetime on a piece of paper.

So what Anderson and Neddermeyer did is they just basically went outside and discovered a particle which comes from the sky. And so they studied cosmic radiation. Muons are produced in cosmic air showers, and we look at one of those a little later.

Basically, protons hits the upper atmosphere, and in a shower of various particles, muons are being produced. And then those muons are not stable particles, but they are stable enough to reach us.

On average, if you hold out your hand right now, about one muon travels through your hand every second. How is this possible? So if you look at this muon, it gives you a little bit of particle physics explanation here.

Again, the muon is not a stable particle. They decay via the weak interaction. For those who are interested, this is a Feynman diagram for this decay.

The muon couples to the w , and as a result of the decay, you find an electron, an anti-electron neutrino, and the muon [INAUDIBLE]. The lifetime is about 2.2 microseconds-- 2.2 times 10^{-6} seconds.

And I just taught 8.701 which is introductory class into particle and nuclear physics, and the students calculated the lifetime of a muon in that class. So you can calculate this. And you need a few tools, but it's not that hard after all.

The average velocity of the muons when they're being produced is close to the speed of light, or 0.998 times the speed of light. And if you do a classical calculation, and you want to figure out how long do the muons on average live-- fly, you find that this is about 660 meters.

Now they are produced in the upper atmosphere, and nevertheless, we can find them down here on Earth. So something is not quite right. What is not quite right-- you can already assume-- is that the clock in the muon as observed by us ticks much, much slower than for the muon at rest. And so the lifetime of the muon of 2.2 microseconds is basically extended.

If you calculate this-- this is average velocity-- we find gamma factor of 15. Using the equation we-- [? of ?] time dilation, you just simply multiply 15 times 2.2 microseconds, and you find that muons, indeed, reach our hand on the surface of Earth.

This is a really fun example. Again, you can study those cosmic showers, those muons, and learn about the muons in very simple experiments. This picture here shows you one of those air shower formations. So the story is a little bit more complex.

As I explain, this is a spectacular air shower, or a picture of one, where you have an [INAUDIBLE] coming in at an energy of 10 to 15 electronvolts. And so even its lower energies show us look like the one here.

It produces, in collision with the atmosphere, many, many particles-- pions, protons, additional protons, neutrons, and pions again. And those pions then, they decay into muons. And this all happens in the upper atmosphere, but also in some cases, further down.

So here, we have seen now an example which you can actually see and observe in nature, where particles travel with high speed. And there are relativistic effects we can measure and observe.