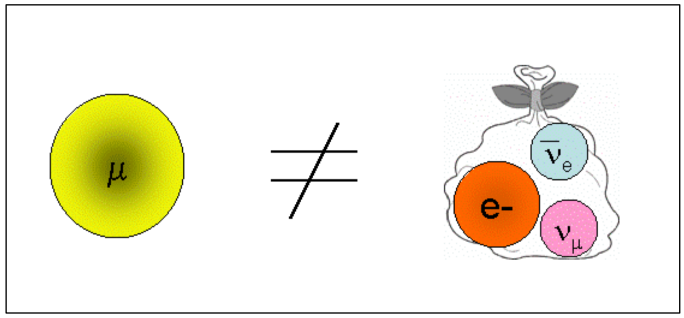
<u>What is a Muon?</u>

A muon is a type of subatomic particle. The name is pronounced “myoo-on,” and comes from the Greek letter μ, which we spell “mu” and pronounce “myoo.” A muon is a type of particle very much like an electron. In fact, it is exactly the same as an electron – except heavier. The mass of a muon is 207 times the mass of an electron. You can remember or look up (or take our word for it) that the mass of a proton, by contrast, is about 1,800 times the mass of an electron. So a muon has all the properties of an electron, but is more similar in mass to the big clunkiness (in relative terms) of a proton or other nuclear particle.



A muon, however, is not made up of any other particles. It is not a bag of electrons or of anything else, but appears to be its own *elementary* or *fundamental* particle. It’s just a heavier version of an ordinary electron. If the existence of the muon seems strange and unnecessary to you, you are in good company. The world-famous physicist I. I. Rabi, when first told of the discovery of the muon, said in response, “Who ordered *that*?”

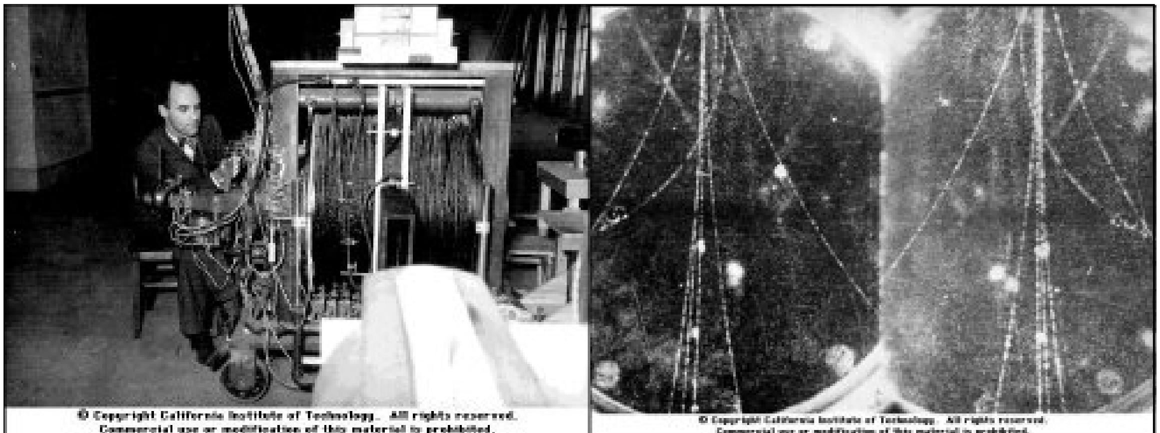
There’s a good reason why the muon is such an unfamiliar particle: muons are radioactive, and they decay with a half-life of 1.52 *microseconds*. That’s 1.52 x 10^{-6} seconds, or 1.52 millionths of a second. Not 5,700 years, like ^{14}C, but 1.52 millionths of a second! Muons don’t stick around long enough for anything ordinary to be made out of them. [This may be a good time to review a few units of time we will be using later on. A microsecond is one millionth of a second, which can be written as 0.000001s or 10^{-6}s. When times get even shorter than this, we turn to the *nanosecond*, which is one billionth of a second, or 10^{-9}s. The nanosecond is denoted by “ns.” We use the Greek letter μ as the abbreviation for micro, so “microsecond” is denoted by “μs.” The use of μ as an abbreviation here is <u>not</u> directly related to the fact that μ also forms the symbol and the name for the muon particle we are studying.]

A muon decays into an electron and two neutrinos (the neutrinos are very hard to detect):

$$\mu \rightarrow \mathbf{e+}\ \bar{\nu}_e + \nu_\mu \qquad \text{(muon} \rightarrow \text{electron + electron antineutrino + muon neutrino)}$$

How and when did scientists first notice such funny, short-lived particles in the first place? The muon was discovered in 1936 by Carl Anderson, a physicist at Caltech. By the way, shortly before this, in 1932-33, Anderson had discovered another unusual particle called the *positron*. The positron, which is exactly like an electron but with positive instead of negative electric charge, is sometimes called an *antielectron* and was the first-discovered member of a whole category of particles known as *antimatter*. Carl Anderson won the Nobel Prize in 1936 for the discovery of antimatter. In fact, he shared that year's Nobel Prize with Victor Hess, the original discoverer of cosmic rays.

Anderson discovered the existence of positrons and muons by very similar methods. He studied tracks made by various cosmic ray particles in an apparatus called a cloud chamber, under the influence of an applied magnetic field. If you have taken physics and have studied magnetic forces, you will know that a charged particle curves its path when it is influenced by a magnetic field. The direction of the curve tells whether a particle has positive or negative charge, and the radius of curvature tells the *charge-to-mass ratio* or Z/m for the particle. The muon was discovered when Anderson found particle tracks just like an electron but with Z/m 207 times smaller; the positron was discovered when Anderson found particle tracks just like an electron but curving in the wrong direction.



Left: Carl Anderson working on his cloud chamber. Right: A cloud chamber photograph of a cosmic ray min-shower, in which electrons and positrons curve in opposite directions.

The first paper to describe the muon's radioactive decay was published in the journal *Nature* in 1940, by a pair of scientists named Williams and Roberts. Very soon after, in 1941, the muon half-life was measured by Rasetti and co-workers and found to be $t_{1/2} = 1.5 \pm 0.3\ \mu s$. We will be measuring the muon half-life in our own experiment. We'll see if our results match Rasetti's from 1941!

To make the story just a little bit stranger, fast-forward to 1975. In 1975 scientists discovered a particle exactly like the electron and the muon… only heavier. This extra-heavy electron was called the tau lepton (symbol "τ", pronounced t-"ow!"). The tau decays to a muon, and has a half-life even shorter than the muon's. Observations of tau leptons are still rather rare, but stray muons turn out to be so common in cosmic rays that many physicists consider them more of a nuisance than anything else! That's fortunate for us, as it gives us a free, reliable source of muons for the half-life measurement we will perform.