Cosmic Ray Muons

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Introduction

You may find it amusing that, every second, you are bombarded many hundreds of times by an ephemeral elementary particle. The particles pass through you, painlessly, at speeds close to that of light. These ``muons,’’ are similar to the familiar electron that is the basis of electricity. Both particles have the same electric charge but a muon is about 210 times more massive than an electron. Intuitively, you can think of a muon as a heavy electron, although there are important differences between the two so you shouldn’t think of a muon as *exactly* like a heavy electron. For instance, a muon spontaneously decays into electron and a neutrino while an electron doesn’t decay at all.

The muons are the end result of a chain of processes. The muons are a portion of the decay products of a non-elementary particle composed of a quark and an anti-quark. The muon’s parent particle, a “pion,” lives only a short time, about 26 nanoseconds, and is itself produced by collisions between protons of extraterrestrial origin and protons in the Earth’s atmosphere. The extraterrestrial protons, called “cosmic rays,” are accelerated to speeds very close to that of light by a mechanism not yet fully understood and then collide with essentially stationary atmospheric protons, producing several pions in the process. So, the picture we have is, a very fast proton from outside the earth strikes a stationary proton in the atmosphere and produces several pions that travel downward toward the Earth’s surface. Each of these pions then quickly decays into a muon (and a neutrino). The muons then arrive at the Earth’s surface.

Because the original extraterrestrial proton is very fast and much more massive than either a pion or a muon, both pions and muons move with speeds close to that of light. You might suspect then that special relativity will be somehow important. You are correct. The high speeds of the muons will cause their lifetimes to be lengthened or “dilated.” A muon’s lifetime observed by us on earth is much longer than the lifetime of someone riding along atop the muon. Were this not true, we would observe much fewer muons than we actually do.

How do we detect the passage of muons since we have lived a happy life so far without even suspecting that we are being pierced every second by hundreds of these discreet muons? Your previous laboratory exercise with a simulation of the CLEO experiment provided you some experience identifying particles by examining their interaction with matter. If you recall, you examined how muons, electrons and photons behaved in matter and what clues they left about their identity. We will do something similar here except we won't use a simulation. We will observe the effects of the passage of muons through matter directly!

Actually, when I say we will "directly" observe the muons I am exaggerating a bit, but only a bit. When the muons pass through matter, they ionize the atoms and molecules that comprise the matter and produce free electrons. These electrons are quite energetic and can travel some centimeters before they are captured again. It is the motion of these electrons that we will observe. And how will we do this since electrons have no known size and are therefore a bit difficult to see with our own eyes? We will need to use a particle detector that will respond to the electrons' motions. This detector is an airtight, transparent box filled with an alcohol vapor. The bottom of the box is chilled to the temperature of "dry ice" (frozen carbon dioxide) while the top of the box is not chilled at all. The result of this arrangement is that the chilled alcohol vapor will condense around the trail of a charged particle that passes through it. The condensation will look like a thin, wispy white thread when light is shined onto the vapor. The condensation traces the path of the ionized electrons as they travel away from the point of ionization. In essence, the electrons will produce small alcohol cloud chambers. Hence the detector is called a "cloud chamber."

Procedure

Verify that you can actually see the thread-like clouds of condensation called "tracks." You should stand on the side of the chamber opposite the lamp and your head should be at about 45 degrees to an imaginary line drawn from the lamp to the chamber. Look down at the bottom of the chamber since the sensitive volume of the chamber is the chilled portion.

Q1. Sketch the shapes of some representative tracks.

Q2. What is the length, in centimeters, of the longest tracks that you see?

Q3. Are most of the tracks horizontal, vertical, or roughly half-and-half?

Q4. About how many tracks per second do you see? Use your head to estimate this number. For example, look at only a fraction of the chamber, count for some amount of time, and then enlarge your answer sensibly to account for the fact that you were only examining a fraction of the chamber.

Q5. Introduce the "alpha" source into the chamber. The instructor will show you how. Alpha particles are helium nuclei and are produced by the decay of some of the atoms in the wire tip. What do these tracks look like? Sketch them. Pay attention to the width and length of the tracks. How do alpha tracks differ in shape from electron tracks?

Q6. Remove the alpha source. Now look for tracks that have shapes like alpha particles. How often do you see them (e.g., 1 per minute, 2 per day, etc.)? The alpha particles come from the decay of radon gas atoms in the air and radon itself comes from the decay of radium atoms that occur naturally in the earth's soil.

Muons from the Cosmos

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Abstract

Q1.

Q2.

Q3.

Q4.

Q5.

Q6.

Conclusion