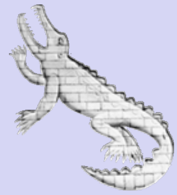
Cosmic Ray Detection

Cavendish Laboratory, HEP Group

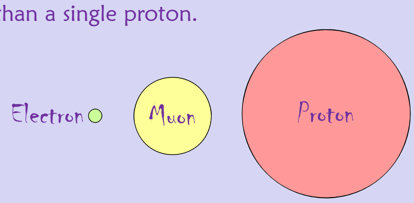


Muons

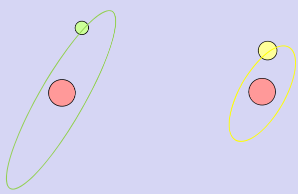
Muons are like heavy electrons.

They carry the same negative charge as an electron.

The muon is 200 times more massive than the electron and about 10 times less massive than a single proton.



It is even possible to create muonic atoms in the laboratory. A muonic atom is one that has at least one of the electrons orbiting around the nucleus replaced by a muon.



Unlike the electron, the muon is unstable and decays on average after 0.0000022 seconds.

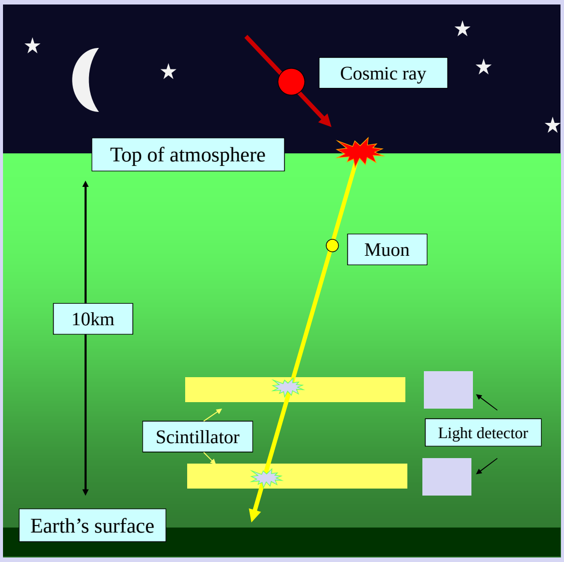
Cosmic rays

Most cosmic rays that arrive at the Earth are high energy protons coming from within our Galaxy.

When they smash into the top of the Earth's atmosphere a cascade of new particles is created.

Most of these particles are unstable and decay very quickly, losing energy as they do so, and they never reach the surface of the Earth.

Some particles live long enough and are travelling fast enough to reach the ground. These are mostly particles called muons. We can detect these with suitable apparatus.



Relativity

The average energy of a cosmic ray muon is around 4 GeV.

[1 GeV is the energy acquired by an electron when it is accelerated across a 1000000000 Volt gap.]

Einstein's formula $E=mc^2$ tells us how much energy corresponds to how much mass. With this formula, the mass of the muon is equivalent to about 0.1 GeV.

Because these cosmic ray muons have energy much greater than their mass energy we have to use Einstein's theory of relativity to describe their motion instead of using Newton's Laws.

4 GeV muons are travelling at 0.9997 times the speed of light and Newton's Law's would predict that they would decay after travelling only

$0.9997 \times 300000000 \times 0.0000022 = 660$ meters.

This is much less than the 10 km depth of the Earth's atmosphere.

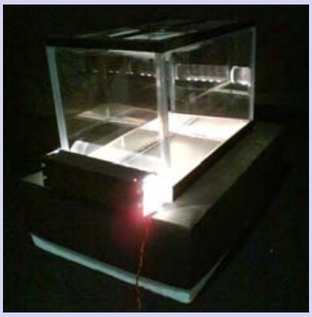
However Einstein's theory tells us that 4 GeV muons actually have a lifetime that is 40 times greater than stationary muons so they can travel 40 times further before they decay than is predicted by Newton's Laws.

So the observed number of cosmic ray muons that arrive at the ground provides strong evidence that Einstein's theory is correct.

The cloud chamber

A cloud chamber contains a supersaturated vapour (a gas that would prefer to turn into liquid but cannot because there is nothing for droplets to form around).

A charged particle passing through the supersaturated region disturbs the atoms and molecules along its path and seeds the formation of tiny droplets.



Our cloud chamber uses a tissue soaked in liquid isopropanol as a source of vapour.

The vapour falls towards a very cold plate at the bottom. The plate is kept very cold using solid carbon dioxide at -80°C in contact with the underside of the plate.

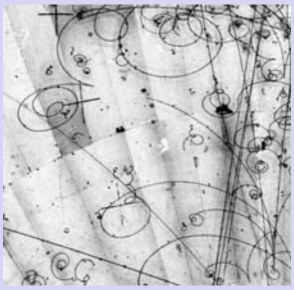
Just above the plate is a region that is the right temperature to make the vapour supersaturated.

The trails of droplets trace out the paths of charged particles from cosmic rays or radioactive sources naturally present in small quantities.

Particle detection

Muons and other fundamental particles are too small to see by the unaided eye.

We can trace the paths they follow by detecting how they disturb the material through which they travel - like footprints in the sand.



Charged particles like muons disturb the electrons and nuclei of atoms as they pass nearby and transfer a little of their energy as they do so.

This energy can be detected by converting it into other forms in various materials:

- Scintillators release the energy as light
- Solid state detectors convert the energy to electron-hole pairs
- Drift chambers detect the ionisation of a gas
- Bubble (photo) and cloud chambers detect ionisation by the seeding of bubbles or droplets

The spark chamber

In a spark chamber, the trail of ionisation left by a charged particle makes am electrically conductive path along which a visible spark will grow in a region of high electric field. This is similar to the way lightning forms.

Our spark chamber is made of several horizontal metal plates immersed in a mixture of Helium and Neon gas.

Alternate plates have several kilovolts applied with the remaining plates held at zero Volts. This provides the large electric field needed for a spark to form.

The electric field is not quite large enough for a spark to form without the help of the conductive ionisation trail of a charged particle. The spark therefore forms along the path of the particle.

The two nearly vertical sparks in the photo are due to two cosmic ray particles. The reddish colour of the sparks is characteristic of the atomic structure of the gas in the chamber.