Department of Physics, Indiana University (HOM 12/14/98)

Cosmic Rays

Goal: Experimental study of cosmic rays. The lifetime of the μ meson

Equipment: Set of organic scintillation detectors, ^{22}Na source, fast electronics, fast oscilloscope, multi-channel analyzer.

Fast atomic particles are moving through interstellar space. The earth is thus under a constant bombardment by protons, and, to a lesser degree, by light nuclei (see ref. [RPP98], fig.20.1). The average energy of these particles of in the order of 1 GeV, but can range to energies higher than those that can be produced by accelerators. When the particles make contact with the upper atmosphere, they start to undergo nuclear reactions with the air. Almost none of them reach the surface of the earth. However, the products of these reactions can survive.

In high-energy collisions in the atmosphere, pions are produced in abundance. Pions have a mean life of only 26 ns (at the speed of light, they travel only about 8m, see table 1). When they decay, they produce a muon (μ) and a neutrino. The charged muons lose energy in the atmosphere (for energy loss and range of particles, see fig. 1), but an initial energy of about 1 GeV is enough to reach the surface of the earth.

The muon is also unstable, decaying into an electron and two neutrinos with a mean life of about 2 μs. Thus, it seems that the muons should decay before they reach the surface. However, according to special relativity, seen from an earth-bound observer, the muon clock run slow by a factor of $\gamma=(1-\beta^2)^{-½}$, where $\beta=v/c$ is the velocity of the μ. For a 2 GeV muon, for instance, $\gamma=20$, and in $20\cdot 2$ μs such a muon travels about 12 km, plenty far enough to reach the surface.

Thus, what remains of the interstellar cosmic rays at the earth's surface are mainly muons (see fig.2). Their energy distribution ranges from zero to many tens of GeV (see ref. [RPP98], fig.20.4). Their flux depends on the angle of incidence. Because of the deflection of charged particles in the earth's magnetic field, there is a slight east-west dependence, too.

The muon flux is hardly affected by the walls of a building, and we have these particles at our disposition to carry out experiments with them in our laboratory. As a rule of thumb, the flux in the vertical direction for a given accepted angular range (solid angle in sr) is about 10^{-2} cm^{-2} s^{-1} sr^{-1}.

The Lifetime of the Muon

In order to determine the lifetime τ of the muons, we capture them, one by one, and measure how long they live. In order to detect an incoming μ, we set up a telescope of fast scintillator detectors and require them to fire in coincidence. The last of the detectors in the telescope has a relatively large volume. We are interested only in the μ's that stop in that detector. When the stopped

μ decays, it generates another pulse. We determine the time t between that pulse and the time of arrival of the muon and order these measurements according to t, resulting in a measurement of

$$n(t) = n_0 \, e^{-t/\tau} \, , \qquad \textbf{(1)}$$

from which we determine τ. Unfortunately, most of the muons that get delivered are too energetic to be stopped in our apparatus (only the low-energy end of the spectrum is useful). Thus, the event rate for this experiment is very low (about a pulse every 5 min). For a stopping detector of a thickness d (in g/cm^2), and the geometry of our telescope, we can estimate the stop rate with another convenient rule of thumb which tells us that the expected flux of muons that stop per g/cm^2 is 10^{-6} cm^{-2} s^{-1} sr^{-1} (g/cm^2)$^{-1}$.

References

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(General introduction into cosmic rays)

[HAL70] R.E Hall, D.A. Lind and R.A. Ristinen, Am. J. Phys. **38**, 1196 (1970)
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