POLARIZATION OF HIGH ENERGY μ^+ MESONS IN COSMIC RAYS

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The polarization of 2 Bev cosmic ray μ mesons has been measured to be $P = 0.23 \pm 0.12$, which indicates that in the upper layers of the atmosphere most μ mesons come from the decay of π mesons. Our data show that the number of μ mesons from $K_{\mu 2}$ decays can be no greater than 15% of the total number of μ mesons.

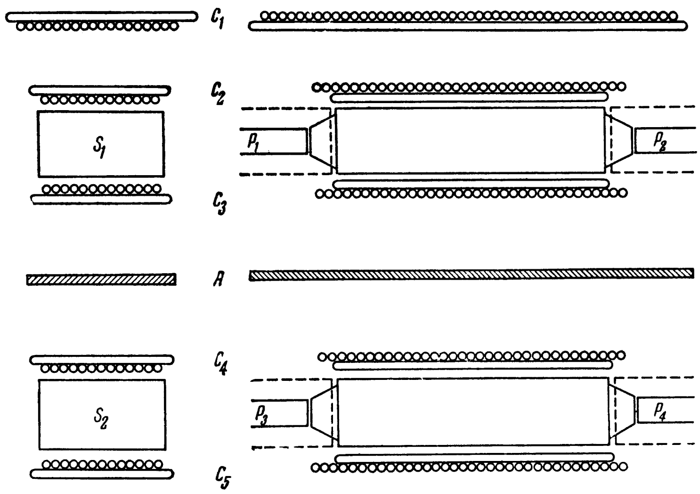
IN previous investigations[1,2] which have been carried out in our laboratory on the composition of cosmic rays, differential spectra for μ^+ and μ^- mesons have been obtained which show that for momenta $p \gtrsim 2$ Bev/c the ratio of the number of positive μ mesons to negative ones is about 1.3.

The papers mentioned above discuss one possible mechanism which could lead to such a surplus of positive μ mesons. Gol'dman has suggested another,[3] that the surplus might be due to $K^+_{\mu 2} \to \mu^+$ decays. The purpose of this paper is to report an experimental check on this hypothesis. In order to do this it is enough to measure the asymmetry in $\mu^+ \to e^+$ decays. It is well known that parity non-conservation leads to an asymmetry in the angular distribution of decay products from a polarized particle.[4] The degree of asymmetry depends on the degree of polarization of the initial particle and is a maximum for polarization equal to one.[5,6] Assuming that the whole current of μ^+ mesons results from the two decays $\pi^+ \to \mu^+$ and $K^+_{\mu 2} \to \mu^+$, in our case we will have a mixture of μ^+ mesons with various degrees of polarization. According to data in the literature,[3,7,8] the polarization of μ^+ mesons from the first decay is about 25%, while that from the second decay is $\sim 90\%$. This allows one to infer the relative weights of the two decays from a measurement of the average polarization of the μ^+ meson current.

To study 2 Bev μ mesons at the surface of the earth, we made our measurements 5 m below the surface. At this depth, a detector counting the particles stopping in a copper plate sees mostly μ mesons from the upper layers of the atmosphere.[9]

EXPERIMENTAL ARRANGEMENT

The figure shows a schematic diagram of the experiment. $C_1 - C_5$ are rows of Geiger-Müller



Arrangement of experiment to measure polarization of μ^+ mesons.

counters. Each row has two layers of counters, each of diameter 1 cm, the axes of the two sets being perpendicular, so that the place where a particle crosses the plane of the counters could be found. S_1 and S_2 are scintillation counters $400 \times 150 \times 100$ mm^3 and filled with a solution of p-terphenyl (2 g/l) and αNPO (0.05 g/l) in benzene. Each scintillator fed two photomultipliers (P_1, P_2) and (P_3, P_4), so that it did not matter where along the length of the scintillator the light flash occurred.

The μ^+ mesons were absorbed in a copper plate A with dimensions $600 \times 200 \times 10$ mm^3, and placed between the two scintillation counters.

Each counter in the rows $C_1 - C_5$ fed a neon bulb which lit when a particle passed through the counter. Counts in the scintillation counters were registered in the same way. μ^+ meson decays were identified by delayed coincidences. Only those delayed coincidences were counted in which the time lag between the pulse from the initial μ^+ meson and the pulse due to the decay electron was

0.7 to 6 μsec. The scintillators S_1 and S_2 were periodically exchanged, and the counting system checked regularly. The background due to μ meson decays in the scintillators themselves was obtained from measurements with the copper plate removed and also the delayed coincidence circuit switched off. Each of the decay events observed was plotted on a scale drawing of the apparatus. From the constants of the hodoscope, the trajectory of the primary particle could be obtained, together with the place where the decay occurred, and the direction of travel of the decay electron checked. Such checks eliminated accidental coincidences and verified that the scintillation counter channels were working properly.

RESULTS

A total of 563 decays in copper were observed. In 298 of these the electron was ejected into the upper hemisphere, i.e., the pulses from both the initial μ meson and the decay product came from the upper scintillator. In the remaining 265 cases the decay electron was detected by the lower scintillator. The ratio of the number of electrons going up to those going down is thus $k = 1.12 \pm 0.06$. The uncertainty quoted is the probable error. This takes into account the fact that if the decay electron is ejected at a small angle with the direction of the primary particle, the efficiency of the Geiger counters in detecting one going up is different from the efficiency for one going down. In the first case, both particles can go through one and the same counter. To exclude such an asymmetry, we considered only cases where the secondary particle was counted $\gtrsim 2$ counters away. From the asymmetry we calculated the polarization of the μ^+ mesons, as in reference 10, and found

$$N = c\,[1 \pm 0.27 \xi P_1], \qquad (1)$$

where c is a constant, ξ is a parameter in the two-component neutrino theory, and P_1 is the degree of polarization of the μ mesons in the absorber.

To obtain the true polarization P of the μ mesons, it is necessary to take into account depolarization in the atmosphere and the layer of earth above the apparatus, and also the solid angle of the apparatus. Both effects together give a correction to P_1 of about 8%. The final expression for P is then

$$\frac{N_{\text{up}} + N_{\text{down}}}{2N_{\text{down}}} = \frac{1}{1 - 0.25\,\xi P}\,. \qquad (2)$$

Substituting the experimental values for N_{up} (the number of electrons ejected upward) and N_{down} (the number of electrons going downward) we get

$$\xi P = 0.23 \pm 0.12; \qquad (3)$$

Since $|\xi| \approx 1$, then P = 0.23. This is quite different from the result obtained by Dolgoshein and Luchkov,[12] who got $0.98^{+0.02}_{-0.32}$ for a kinetic energy of 1 Bev.* If this large polarization is due to $K_{\mu 2} \rightarrow \mu$ decays, then according to the data of Gol'dman,[3] not less than 60% of the total number of μ mesons at high altitudes must be due to such decays. Our result P = 0.23 agrees with that calculated on the assumption that the mesons come essentially only from $\pi^+ \rightarrow \mu^+$ decays and that the power of the π meson spectrum is $\gamma = 2.5$. Hence it follows that in the upper layers of the atmosphere, even though there are large numbers of energetic protons capable of giving $K^+_{\mu 2}$ mesons, $K^+_{\mu 2} \rightarrow \mu^+$ decays do not contribute significantly to the number of μ^+ mesons formed.

Lohrmann and Teucher[11] have used nuclear emulsions at an altitude of 30 km to measure the relative number of strange particles made in stars where the energy of the primary particle was $10^{12} - 10^{14}$ ev. According to their data, the number of charged K mesons, baryons and antibaryons is about 9^{+8}_{-6}% of the total number of secondary charged particles. The number of $K_{\mu 2}$ particles will be at least less than half the total number of strange particles. Hence, the number of $K_{\mu 2}$ particles will be about 5% of the number of charged π mesons.

Our measurements on the asymmetry in μ^+ meson decays under the earth have thus shown that the μ^+ mesons in cosmic rays come primarily from π^+ meson decays and only to an insignificant extent from decays of $K^+_{\mu 2}$ mesons.

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*At the 1959 International Conference on Cosmic Rays in Moscow, Johnson reported results on measurements of μ meson polarization at 540–593 Mev. He obtained 0.21 ± 0.03, which agrees well with our result. He notes that there was no significant contribution from $K_{\mu 2} \rightarrow \mu$ decays.

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