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63

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THE SCATTERING OF MU MESONS IN BERYLLIUM

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We investigated the scattering of μ mesons in beryllium plates. The momenta of the μ mesons were in the range (130 ± 16) Mev/c. The observed angular distribution agrees within statistical error with the distribution to be expected from a Coulomb interaction between the μ mesons and the atoms of the material.

1. INTRODUCTION

THERE is reliable evidence for the absence of a non-Coulomb interaction between μ mesons and nucleons. It is to be expected, then, that the scattering of μ mesons in matter should be explicable in terms of electromagnetic interactions between the μ mesons and atoms. This question has been investigated experimentally for various momenta of of the μ mesons, and most of the results indicate there are more scattering events than would be expected on the basis of a nuclear model in which the nuclear charge is uniformly distributed in a sphere of finite radius $(R = 1.2 \times 10^{-13} A^{1/3}\,\text{cm.})$.

According to the latest data from the Manchester group,[1] in the momentum range 600 Mev/c to 100 Bev/c, the experimental distribution of μ mesons scattered from lead differs significantly from what would be expected from a nucleus of finite size, and agrees better with what would be expected from a point nucleus. One might try to explain the increase in the anomalous scattering at high energies by the absorption, in the nucleus, of virtual photons accompanying the moving μ meson. Such calculations have been carried out by Fowler.[2] According to Fowler's data, the anomalous scattering is small or entirely absent at momenta less than 270 Mev/c. The scattering cross section is proportional to A^2 and at large angles is such that the probability of a single scattering with a large momentum transfer is comparable with the corresponding quantity for a point nucleus. It is not yet possible to make a quantitative comparison between Fowler's calculations and the experimental data.

At small momenta, about 100 Mev/c, Alikhanov and Eliseev obtained evidence for anomalous scattering in graphite.[3] The anomalous cross section was about $5 \times 10^{-27}\,\text{cm}^2/\text{nucleon}$ and decreased with increasing energy. Alikhanian and Kirillov-Ugriumov studied the scattering of μ mesons with sharply defined momenta from copper and found an anomalous cross section of about $10^{-27}\,cm^2$/nucleon. These results cannot be explained by Fowler's mechanism.

We investigated the scattering of cosmic ray μ mesons having a momentum of 130 Mev/c from beryllium. In thin films of light elements, the Coulomb-scattering background is relatively small, so that if there is any anomalous scattering due to a non-Coulomb interaction, one would expect it to show up most clearly in such an experiment.

2. DESCRIPTION OF THE APPARATUS

A schematic diagram of the apparatus is shown in Fig. 1. The large rectangular cloud chamber was triggered by the counter telescope, three rows of which were in coincidence, while the last row was in anticoincidence. We considered the scattering of only those particles which stopped in the two centimeters of lead between the last row of coincidence counters and the row of anticoincidence counters. In order to obtain reliable results, it is very important that the counters, especially those in anticoincidence, be stable. Each counter had its own power supply, and their operation was checked daily. 100 cm of lead were placed above the cloud chamber in order to filter out electrons, protons and π mesons.

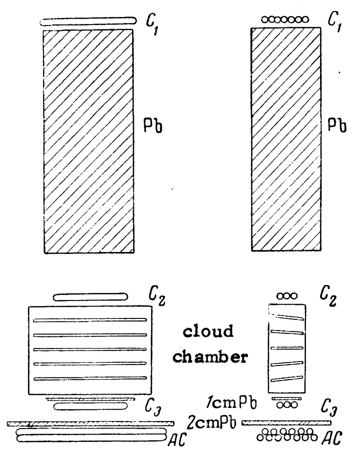

FIG. 1. Schematic diagram of the apparatus. C_1, C_2, C_3 – rows of coincidence counters. AC – row of anticoincidence counters.

The μ mesons were scattered in five beryllium plates one centimeter thick placed in the cloud chamber. The working volume of the cloud chamber was $(40 \times 55 \times 14)\ cm^3$, and it was usually operated at a pressure of 0.5 atmos. The cloud chamber was made of aluminum and was illuminated from the sides by two bype IFP-1500 flash bulbs. The stereoscopic pictures were taken 115 cm away. There was negligible error introduced into the measurements of angles by the photography. The expansion was spark-actuated. Spark valves have much less inertia than electromagnetic ones and are more stable over long periods of operation. To minimize track distortion, the cloud chamber was placed in a thermally insulated box which was temperature controlled to 0.5°C.

3. PARTICLE IDENTIFICATION, MEASUREMENT OF MU MESON SCATTERING ANGLES AND MOMENTA

The measurements on the scattering of μ mesons were carried out at sea level. It was estimated that the particle current getting through the meter-thick lead filter consisted almost entirely of μ mesons. No more than 0.1% of the particles we counted could have been π mesons. In 20% of the pictures, there were not one, but two or more particles travelling in the solid angle defined by the apparatus. One of these could have been a δ electron. In finding angular distributions, we did not use pictures containing several particles.

It will be shown below that the average mass of a single particle, as measured from its scattering and range, was 213 electron masses. The residual range of the μ meson was used to find its momentum. It was assumed that the scattering of the μ meson occurred in the middle of the beryllium plate and that the meson stopped in the lead filter between the third row of coincidence counters and the row of anticoincidence ones. In order to decrease the error of the momentum measurement, a lead slab one centimeter thick was placed above the third row of counters. The momentum of those μ mesons counted by this apparatus was (130 ± 16) Mev/c. In computing the range, we took into account the mean angle between the direction at which the μ meson entered the slab and the vertical.

The method described above is not suitable for obtaining the momentum of particles in the "hard" component, i.e., those particles which passed through all the rows of coincidence counters, but which did not stop in the filter and were not rejected by the row in anticoincidence. The number of "hard" particles was obtained by removing the filter over the row of anticoincidence counters. The counting rate decreased to 16% of what it was with the filter in place.

In obtaining the angular distributions, we used the projection of the scattering angle on the plane of the film. A special device was employed to measure the scattering angle. Repeated trials by various observers showed that the root mean square error in measuring angles was 20′.

4. RESULTS AND DISCUSSION

In all, 2250 scattering events of μ mesons on beryllium were observed. Not one of these had a scattering angle with a projection more than 6°. Subtracting the 16% of the events which corresponded to μ mesons of momentum more than 130 Mev/c, the upper limit on the cross section for the scattering of μ mesons with momentum (130 ± 16) Mev/c through angles greater than 6° was 4.5×10^{-28} cm^2/nucleon.

It is possible that some of the μ mesons which were scattered through large angles were not recorded in our apparatus. This would happen if the scattered meson missed the third row of coincidence counters. In particular, the probability of registering a 6° scattering event was 93%. The upper limit on the cross section includes appropriate corrections for this.

Errors in the measured angles could be introduced by gas movement in the cloud chamber, by the finite length of track, etc. In order to minimize such errors, the only cases used in calculating the angular distributions were those satisfying the following conditions: (1) the length of the visible part of the track was not less than 90% of the distance between plates in the cloud chamber; (2) between the plates, the deviation of the track from straightness was not more than half the thickness of the track; (3) the intercept of the track on the cloud chamber axis did not depart by more than 0.5 mm from the point where the scattered particle left the plate. These conditions eliminated cases where the measured angles could have been in error by about a degree, owing to distortions associated with the working of the cloud chamber. The above requirements were satisfied by 1429 scattering events.

Figure 2 shows the angular distribution for μ-meson scattering in each beryllium plate. The dotted curve shows the scattering to be expected from a point nucleus, assuming that all the particles considered were stopped in the filter above the row of anticoincidence counters. It appears that the number of particles scattered into angles between 0 and 1° is larger than predicted by theory. The solid line shows the distribution to be expected upon taking into account the fact that 16% of the μ mesons were "hard" mesons. This curve agrees satisfactorily with the observations at all angles.

In order to estimate the effect an admixture of fast μ mesons, or of other particles, would have on the results, it is interesting to compare the calculated mean-square deviation with the observed

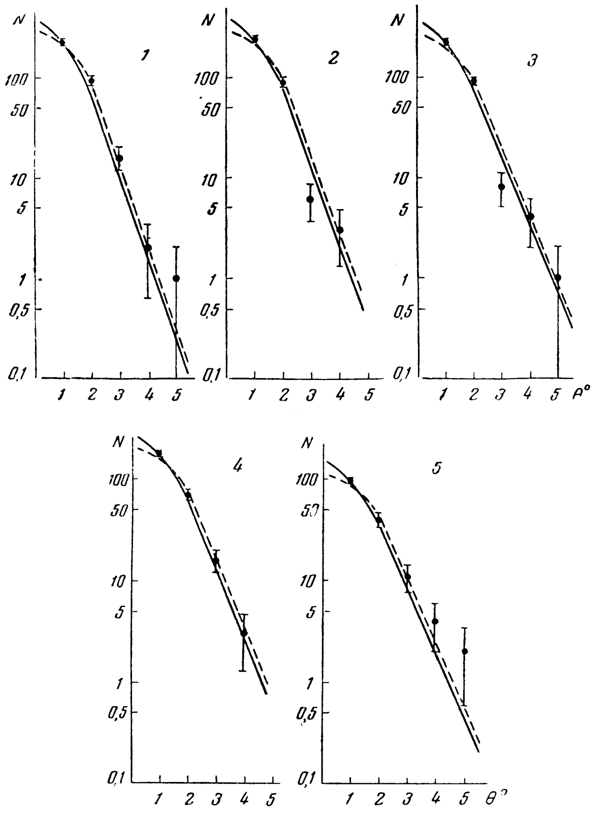

FIG. 2. Angular distributions for the scattering of μ mesons in beryllium plates 1–5. Dashed curve: scattering from a point nucleus, solid curve: expected scattering distribution, taking into account the 16% admixture of "hard" μ mesons. Mean momentum $\bar{p}$ is 140, 135, 131, 127 and 125 Mev/c for plates 1 to 5 respectively.

one. Such data are presented in the table. Knowing the momentum of the meson from its residual range, one can calculate the expected mean square deviation. Since an admixture of fast μ mesons would affect the scattering only at small angles (less than 1°), the data in the table indicate that they have little influence on the mean square deviation of the observed distribution. In particular, if the admixture of fast μ mesons were much greater than we have estimated, then we would not observe a decrease in the mean square deviation with increasing momentum. Analysis shows that the error in measuring angles near the edge of the cloud chamber is somewhat greater than at the center.

Since the range and scattering angle of the particles we observed are known, our data can be used to find their mean mass. This turned out to be 213 ± 10 m_e. This confirms that our apparatus really did record μ mesons which stopped above the row of anticoincidence counters. Figure 3 shows shows the total differential cross section for the

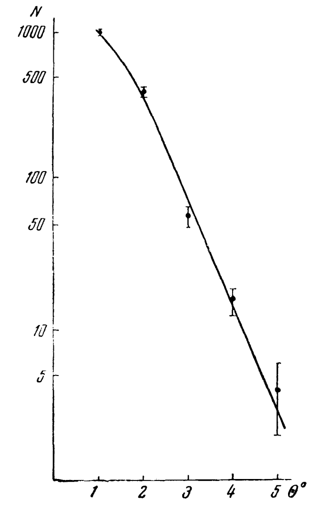

FIG. 3. The total differential cross section for the scattering of μ mesons with momentum (130 ± 16) Mev/c. The solid curve is a theoretical one, and is the sum of the distributions for each of the plates, taking into account the 16% admixture of "hard" μ mesons.

scattering of μ mesons with momentum (130 ± 16) Mev/c. The theoretical curve is the sum of the distributions for each plate, taking into account the 16% admixture of fast μ mesons. It is significant that this admixture has no effect on the scattering through angles greater than 1°. The agreement between the experimental and theoretical angular distributions (estimated by the χ^2 criterion to be 60%) indicates that μ mesons with momentum 130 Mev/c are scattered in beryllium plates 1 cm thick as they should be from a purely Coulomb interaction between the μ mesons and the beryllium atoms.

Since the angles we measured are considerably smaller than λ/R_{Be}, the theoretical scattering from a point charge is practically identical with the scattering from a charge distributed over nuclear dimensions. It should be noted than an angular distribution computed from all 2250 cases observed, i.e., from all events within the solid angle of the apparatus, including those which did not satisfy the requirements imposed above, also agrees well with the calculated distribution. Thus,

Comparison of the calculated with the observed mean square deviations.

Plate number	1	2	3	4	5
$\overline{(p\beta)}$Mev/c^{-1}	110	106	102	99	96
$\sqrt{\overline{\theta^2}}\cdot 10^{-2}$, calculated	2.02	2.09	2.17	2.25	2.33
$\sqrt{\overline{\theta^2}}\cdot 10^{-2}$, observed	2,20	2,02	2,14	2.47	2,60

for example, the ratio of the number of particles scattered through 3° or more to the expected number is 86/95, while the figure for 4° is 23/18.

Before drawing a final conclusion on the anomalous scattering of μ mesons in this momentum range, it would be desirable to carry out measurements in other materials.

In conclusion, we should like to thank Prof. A. I. Alikhanian for his constant interest in the work and for his help in carrying out the analysis of results. We also would like to thank A. M. Rozhin, L. P. Morozov and S. S. Lomakin for their assistance in making the measurements and in treating the data.

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64