Interactions of K^--Mesons in Nuclear Emulsion*

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THE mean free path for nuclear interaction of negative K-mesons in emulsion has been measured and the types of interactions which occur have been found to be consistent with the conservation of strangeness, as required by the Pais and Gell-Mann schemes, among others.[1]

A stack of 95 pellicles of Ilford G5 emulsions, each 3 in.$\times$5 in.$\times$600μ, was exposed in a focused K^--beam of the Berkeley Bevatron. The particles entering the stack were those emitted from a copper target at right angles to the 6.2-Bev proton beam. A magnetic analyzer allowed only particles with momentum of 400 Mev/c to enter the emulsions. The K-meson interactions were found by "along-the-track" scanning beginning at about 5 cm residual range. In this technique, a track of the appropriate grain density for a K-meson having the beam momentum is followed until its end. This type of scanning introduces no bias in the type of interaction found. Following a total track length of 8.68 meters resulted in the finding of 137 capture stars of K^--mesons at rest, 23 interactions (other than scattering)[2] of K^--mesons in flight, and 6 decays in flight.[3] The observed track length of mesons which left the stack before interacting, about 5% of all the mesons followed, was included in the total. Since an interaction produced by a K-meson in flight in the last 2 mm of its range could not be distinguished from one produced at rest, this track length was omitted. The mesons that came to rest and produced zero-prong stars were distinguished from stopping protons by grain count *vs* residual range measurements. Interactions of K^--mesons in flight were distinguished from those of protons by grain count and multiple scattering measurements. From the number of interactions in flight—23 apparent absorption events and 1 nuclear scattering—the mean free path for K^--interaction is $(36.2_{-6.1}^{+9.2})$ cm,[4] in contrast to (95 ± 16) cm for interaction of K^+-mesons.[5] Table I indicates the variation of the mean free path with energy. For comparison, the mean free path corresponding to geometric cross section in emulsion is about 31 cm.

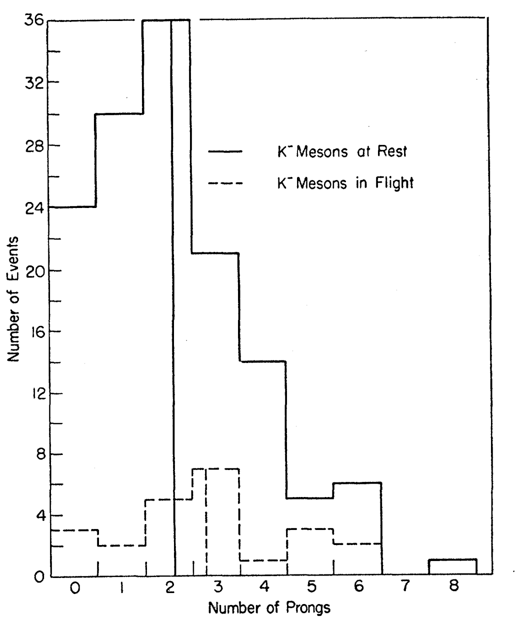

FIG. 1. Prong distribution of stars produced by K^--mesons.

TABLE I. Variation of mean free path with energy.

Energy region	0–50 Mev	50–100 Mev
No. of interactions	8	16
Total path length	214 cm	654 cm
Mean free path	26.7 cm	40.9 cm

Figure 1 shows the similarity of the prong distributions of the stars produced at rest (absorption stars) and in flight.[6] The average number of prongs per star for mesons at rest is 2.1 and for mesons in flight is 2.8. The possible shift toward higher prong number can probably be attributed to the kinetic energy of the mesons in flight.

Table II compares the types of events produced by K^--mesons at rest and in flight. The similarity indicates that the absorption process $K^-+\text{nucleon}\rightarrow\text{hyperon}+\pi$, which occurs for K^--mesons when they interact at rest,[7] also predominates when they interact in flight. However, the 23 absorptions probably include some charge exchange events. The possibility of charge exchange could be excluded in 16 of the cases.

In all the schemes that have been proposed to describe the behavior of K-mesons and hyperons,[1] these particles are assigned values of a quantum number (e.g., "strangeness") which is required to be

TABLE II. Comparison of events produced by K^--mesons at rest and in flight.

Class of event	Stars produced at rest	Stars produced in flight
Total number of events	137	23 (plus 1 nuclear scattering)
Stars with a charged π meson	32	3
Stars with a charged hyperon or hyperfragment[a]	16	5
Σ^+ decays at rest into π	3	1
Σ^+ decays at rest into a proton	1	0
$\Sigma^\pm$ decays in flight	4	1
Σ^- stars produced at rest or hyperfragment decays	8	3
Stars with a charged hyperon and a π meson	10	1

[a] In all the stars with no charged hyperon or hyperfragment, the visible energy release was low enough to be consistent with the emission of a neutral hyperon.

conserved in fast interactions. In the Pais and Gell-Mann formulation, for example, this quantum number has the value -1 for K^--mesons and hyperons, while for K^+-mesons its value is $+1$. Consequently, a K^--meson can be absorbed by a nucleon to produce a hyperon and a π meson, in a fast interaction, conserving strangeness, while a K^+-meson can undergo only scattering or charge exchange.

While K^--mesons can also undergo scattering and charge exchange, the present results indicate that absorption predominates strongly. The difference between K^- and K^+ interactions[5] with respect to both the size of the cross section[8] and the types of interaction are in excellent agreement with the requirement of conservation of strangeness in fast interactions.

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[1] M. Gell-Mann, Nuovo cimento (to be published); A. Pais, Physica **19**, 869 (1953); T. Nakano and K. Nishijiama, Progr. Theoret. Phys. (Japan) **10**, 581 (1954); M. Goldhaber, Phys. Rev. **101**, 1828 (1956). R. G. Sachs, Phys. Rev. **99**, 1576 (1955).

[2] Eighteen scattering events, at angles $>5°$, were observed. With account taken of the K^--meson energy at the point of scatter, most of these events are consistent with Coulomb scattering; only one is classified as a nuclear scattering.

[3] A value of the K^--meson lifetime will be reported separately.

[4] J. Hornbostel and E. O. Salant, Phys. Rev. **102**, 502 (1956) also give a value for the mean free path for K^--interaction, based on eight events.

[5] Lannutti, Chupp, Goldhaber, Goldhaber, Helmy, Iloff, Pevsner, and Ritson, Phys. Rev. **101**, 1617 (1956).

[6] In plotting the prong distributions, recoil tracks shorter than $\sim 5\mu$ were not included. Such recoil tracks were associated with about half of the "zero-prong" stars.

[7] Fry, Schneps, Snow, and Swami, Phys. Rev. **100**, 950 (1955) and Phys. Rev. **100**, 1448 (1955); J. Hornbostel and E. O. Salant, reference 4. Reports in Proceedings of the International Conference on Elementary Particles, Pisa, June, 1955, Nuovo cimento (to be published) by Chupp, Goldhaber, and Webb; Pevsner, Ritson, and Widgoff; Bacchella, di Corato, Ladu, Levi Setti, and Scarsi; Bristol-Padua group.

[8] K. A. Brueckner and A. Pais have independently pointed out that, if K^-- and K^+-interactions proceed in such a way as to conserve strangeness, the difference in size of their cross sections can be understood in terms of a simple perturbation theory.

Further Analysis of the Massachusetts Institute of Technology Antiproton Event*

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SOME time ago, the M.I.T. group published[1] a picture showing a heavy particle that came to rest in a $\frac{1}{2}$-inch thick brass plate of a multiplate cloud chamber, and gave rise to at least three photons with a total energy in excess of 1 Bev. The event could not be explained in terms of any experimentally known particle, but could be interpreted easily as the annihilation of an antiproton, or an antihyperon, whose existence was predicted by Dirac's theory. At that time, a unique identification was not possible because the primary mass and the secondary energy had not been determined with sufficient accuracy to rule out the possibility that the event represented the decay of a hitherto-unknown boson of mass considerably greater than that of the various heavy mesons.

Subsequently, however, Hazen[2] made a careful cloud-chamber study of showers produced in copper plates by electrons of known momentum. His results show that the total number of secondary electrons gives a good measurement of the primary energy in the region from 0.1 to 1 Bev, and that the fluctuations are not unduly large. Using the M.I.T. results, Hazen found that the total energy of the showers in the M.I.T. event was more than[3] 1630 Mev ($\pm 20\%$), which is in agreement with the original energy determination by DeStaebler. Hazen's results remove any doubt as to the evaluation of the secondary energy, and they provide a good estimate of the error.[4]

In addition, since our original measurements, photometric techniques for the determination of ionization in cloud-chamber tracks have been studied in detail.[5–7] In particular, a method has been developed for making ionization measurements in multiplate chambers.[7] Using ionization *vs* residual range, we have applied this method to determine the mass of the primary particle in the M.I.T. event. The application is particularly favorable in this case because five track segments of 13 cm total length were available in the central, uniformly illuminated region of the chamber. Furthermore, three proton tracks, two K-meson tracks, one π-meson track (all of known range), and several tracks of minimum ionizing particles were available for comparison in nearby pictures in the same chamber region. The ratio of the photometrically determined transmission of the unknown track to that of a comparison track is related to the ratio of their ionizations by a calibration curve obtained from measurements on a number of known particles of known residual range. This method, which will be described in detail elsewhere, gave for the rest energy of the primary particle a value of 823 ± 155 Mev, which is to be compared with the rest energy of the proton, 938 Mev. As a check, similar measurements were made on a statistically equivalent length of tracks made by stopping K-mesons, and the resulting rest energy, 488 ± 80 Mev, was in excellent agreement with the accepted value of 493 Mev (all errors are standard deviations).

The new measurements of the primary mass and the secondary energy make it appear very unlikely that