Negative *K*-Particle Elastic Scattering from Hydrogen*

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Three (K^-,p) scattering events have been found in following 560 cm of negative K-particle track in nuclear track emulsion. The masses of the negative K-particles as calculated from the ranges and angles of the secondaries are not inconsistent with the mass of the τ^+ particle. 1634 cm of track length from other experiments in which no (K^-,p) scatterings were observed have been added to the 560 cm of this experiment to give an elastic scattering cross section of 44 millibarns.

THREE negative K-particle—proton scattering events have been observed by following 560 cm of K^- track in Ilford G5 emulsion. 520 cm of track were followed in a stack of 112 pellicles each 6 in.×6 in.×600 microns, and 40 cm of track in a stack of 20 pellicles each 3 in.×6 in.×600 microns thick. The stacks were exposed in the K-particle beam[1] of the Berkeley bevatron and subtended a momentum interval from 270 to 380 Mev/c. The (K^-,p) scatterings are of interest as they give an estimate of the (K^-,p) elastic cross section and an independent measure of the mass of the negative K-particle. Two positive K-particle—proton scattering events have come to our attention[2]; to the best of our knowledge no (K^-,p) scattering events have been reported.

In event 64 the K^- suffered a deflection of 80° and the proton went forward at an angle of 33° to the incident K^--particle. The K^- came to rest after traversing 1.3 mm of emulsion and produced at its end a three-pronged star. The steep vertical angles of the proton and K^- and their short ranges after the scattering made identification by ionization or scattering difficult; however, scattering and ionization measurements made on the incident particle are consistent with a K-particle energy of 35 Mev, a value that was calculated from the ranges after the collision.

Event 65 is an example of a grazing collision in which the K^- was deviated by 15° and continued on for 51 mm before coming to rest with a ρ-type ending and an associated blob but no visible prongs. Scattering and ionization measurements *versus* range, both before and after scattering, each gave a mass value of approximately 1000 electron masses. The proton left the collision at an angle of 81°.

Event 113, which is shown in Fig. 1, is particularly interesting in that the K^-, after suffering a 101° deflection in the collision, continued on for 505 microns to end in a four-pronged star, one prong of which is apparently a hyperfragment.[3] Ionization measurements on the incident particle are consistent with a K-particle of an energy of 32 Mev as calculated from the ranges of the secondaries.

Some of the measurements of interest which were made on the three events are shown in Table I. The coplanarity is the angle between the incident K-track and the plane of the secondaries. The tilt is the angle in the unprocessed emulsion between the plane of the (K^-,p) scattering and the plane of the emulsion surface. θ_p and θ_K are, respectively, the angles of the proton and the scattered K-particle measured from the direction of the incident K-particle. R_p and R_K are the ranges of the proton and the K-particle after the scattering. The kinetic energy, T, of the incident K-particle when it struck the proton was obtained from the ranges of the scattered particles where a mass of 966 m_e was assumed for the K^-. The angle θ_K^*, in the center-of-mass system, between the scattered K-particle and the direction of the incident K-particle is shown in the last column.

Four independent measurements, θ_p, θ_K, R_p, and R_K, were obtained from each of the (K^-,p) scattering events. The data have been treated in seven ways to obtain the negative K-particle mass. The first four ways depend upon the fact that only three of the above four measurements, combined with energy and momentum conservation, are necessary to calculate the mass of the K^-. The fifth method makes use of the included angle between the scattered K-particle and the proton

TABLE I. Data on (K^-, p) scattering events.

Event No.	Coplanarity (deg)	Tilt (deg)	θ_p (deg)	θ_K (deg)	R_p	R_K	T_K (Mev)	θ_K^* (deg)
64	1.0±0.9	82	32.9±1.0	80.3±1.4	(2.29±0.04)mm	(1.27±0.05)mm	34.5	112
65	0.5±0.9	51	81.0±1.8	14.5±1.9	(117±2)μ	(51.4±1.0)mm	106.5	22
113	1.5±2.6	21	22.9±1.0	101.4±1.0	(2.71±0.05)mm	(505±10)μ	32.1	135

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Kerth, Stork, Birge, Haddock, and Whitehead, Phys. Rev. 99, 641(A) (1955).
[2] Chupp, Goldhaber, Goldhaber, Johnson, and Lannutti, Phys. Rev. 99, 1042 (1955). A second (K^+,p) scattering event has been found by these authors.
[3] The analysis of this hyperfragment has not been completed and will be reported in a later paper.

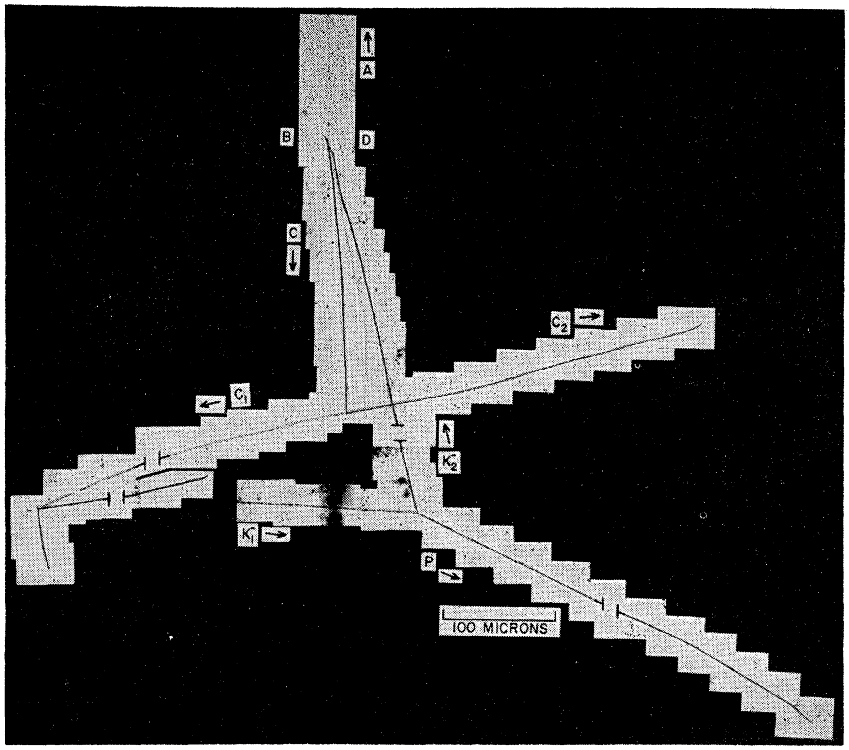

FIG. 1. A photomicrograph of event 113 in which a negative K-particle (K_1^-) is scattered from a proton (p) and continues on (K_2^-) to end in a 4-prong star. Prong (A) is a light meson which leaves the emulsion stack; (B) and (D) are short and unidentifiable; and (C) is a hyperfragment.[3]

and is consequently independent of the direction of the incident K^-. The sixth method uses all four measurements and only conservation of momentum transverse to the incident K-particle in the plane of the scattering. This calculation gives the mass of the K particle leaving the reaction and is independent of the mass of the incident particle. The last method uses all four measurements, the conservation of momentum parallel to the incident K-particle, and energy conservation. These resulting seven mass values with standard deviations are shown for each event in Table II. It is emphasized that the different methods of calculating the masses are not independent and that the best measure of the K-particle mass for each event is the mass with the smallest error.[4] The nature of event 65, for which the transfer of longitudinal momentum to the proton was small, was such that only the transverse momentum method and the method using θ_K, R_p, and R_K gave sufficient accuracy to calculate a meaningful mass.

In these three events one cannot rule out completely the possibility that the K-particle collided with a proton on the periphery of a nucleus. However, the following conditions which are necessary for scattering from a free proton are met by these events: (1) There were no recoils, blobs or electrons at the scattering point. (2) The three tracks were coplanar within experimental errors. (3) The masses obtained by the different methods

TABLE II. Calculated masses in units of the electron's mass for three negative K-particles.

Method	Event No. 64	Event No. 65	Event No. 113
1. θ_K, R_p, R_K	1008±26	980±220	993±11
2. θ_p, R_p, R_K	1011±40	···	997±42
3. θ_p, θ_K, R_K	1006±61	···	988±60
4. θ_p, θ_K, R_p	1006±61	···	988±60
5. Included angle, R_p, R_K	1009±29	···	994±14
6. Transverse momentum	1013±48	1000±220	998±67
7. Longitudinal momentum and energy conservation	1006±38	···	992±23

[4] The errors shown were compounded from range straggling and an estimate of our ability to measure the space angles between tracks. The masses were most sensitive to the space angles for which it was difficult to make accurate estimates of the errors. Consequently the deviations of the masses from $966m_e$ are not considered significant.

TABLE III. Comparison of measurements of the mass of negative K-particles.

Experiment	Method	K^- mass (m_e)
Hornbostel and Salant[a]	$H\rho$ and range	931±24
Chupp, Goldhaber, Goldhaber, and Webb[b]	Capture by proton in emulsion to give Σ^+ and π^-	≥966±6[e] ≥935±5[e]
Webb, Chupp, Goldhaber, and Goldhaber[c]	K^- to K^+ mass ratio obtained from ranges in emulsion for same $H\rho$.	963±12
Gilbert, Violet, and White[d]	Capture by C^{12} in emulsion	966±5

[a] J. Hornbostel and E. O. Salant, Phys. Rev. 98, 339 (1955).
[b] Chupp, Goldhaber, Goldhaber, and Webb, "Proceedings of the International Conference on Elementary Particles, Pisa, 1955," Nuovo cimento (to be published).
[c] Webb, Chupp, Goldhaber, and Goldhaber, Phys. Rev. 101, 1212 (1956).
[d] Gilbert, Violet, and White, Phys. Rev. 103, 248 (1956).
[e] The Σ in these events may decay in flight.

of calculation, which weight the four independent measurements differently, are all consistent with the same mass value for a given event. (4) The masses obtained are not inconsistent with other independent measurements of the negative K-particle mass. Table III lists some other measurements of the K^- mass. These masses, along with the masses from the three scattering events of this paper, are consistent with a mass of 966 electron masses,[5] the mass of the τ^+ particle. (5) Only on event 65 was it possible to make accurate ionization measurements on the K-track before and after the scattering. These measurements gave an energy change of $+5\pm10$ Mev which is inconsistent with a large energy loss at the point of scattering. It should also be noted that the 4-Mev proton from this event lies below the Coulomb barrier for the heavy elements in the emulsion.

Although the number of events is low, an estimate of the (K^-,p) elastic scattering cross section is of interest. Three scatterings in 560 cm of track analyzed in this experiment give a cross section of 170 millibarns. If additional length of track of other observers[6] is included in which no (K^-,p) scatterings were observed, a cross section of 44 millibarns is obtained. This is in agreement with a geometric cross section for the (K^-,p) interaction. The ratio of the (K^-,p) cross section to the (K^+,p) cross section ($\sim$15 millibarns)[7] is about 3 and is in agreement with the ratio of the cross sections for the K^- and K^+ interactions with nuclei in emulsion.

We wish to thank Irene Brown who found the three events, A. J. Oliver for processing the emulsion, and Dr. E. Lofgren and the Bevatron crew for their cooperation in the emulsion exposure.

[5] R. Haddock, Phys. Rev. **100**, 1803 (A) (1955).

[6] Webb, Chupp, Goldhaber, and Goldhaber, 630 cm (to be published); J. Hornbostel and E. O. Salant, 136 cm, Phys. Rev. **102**, 502 (1956); D. M. Fournet and M. Widgoff, 868 cm Phys. Rev. **102**, 929 (1956).

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

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Properties of Heavy Unstable Particles Produced by 1.3-Bev π^- Mesons*

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A propane bubble chamber has been exposed to a π^- beam of 1.3-Bev kinetic energy. The reactions

$$\pi^-+p\to\Sigma^-+K^+,$$
$$\pi^-+p\to\Lambda^0+\theta^0,$$
$$\pi^-+p\to\Sigma^0+\theta^0,$$

can be experimentally distinguished from carbon events. Results based on the first 55 such events are presented. The center-of-mass production distribution of the Σ^- is peaked forward, that of the Λ^0 backward. No large anisotropies in the angular correlation of production and decay were found, so that we have no evidence for spin in excess of $\frac{1}{2}$ for any of the three particles: Σ^-, Λ^0, or θ^0. A study of the relative abundance of single and double V production indicates that both Λ^0 and θ^0 have either long-lived "states" or neutral decay modes. A statistical analysis gives $\bar{\alpha}_{\Lambda 0}=0.3_{-0.12}^{+0.15}$, $\bar{\alpha}_{\theta 0}=0.3_{-0.12}^{+0.19}$, for the normal charged decay probabilities ($\Lambda^0\to\pi^-+p$; $\theta^0\to\pi^++\pi^-$) of the Λ^0 and θ^0, respectively. One event was analyzed to obtain the energy released in Σ^- decay. $\Sigma^-\to\pi^-+n+Q$; $Q=118\pm2.6$ Mev. The Σ^- lifetime on the basis of 16 decays is $(1.4_{-0.5}^{+1.6})\times10^{-10}$ sec.

I. INTRODUCTION

THE production of strange particles by high-energy mesons in hydrogen has been studied by Fowler, Shutt, Thorndike, and Whittemore[1] in a diffusion cloud chamber. It was this experiment which demonstrated that hyperons and K mesons are produced in accordance with the hypothesis of associated production.[2,3] A similar study, at lower energy, was made by Walker and Shephard.[4] In total, 14 events have been observed, 9 by the Brookhaven group at $\sim$1.5 Bev and 5 by the Wisconsin group at $\sim$1 Bev. We present here preliminary results from an exposure of a liquid propane bubble chamber to a 1.3-Bev (kinetic energy) π^- beam at Brookhaven.

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† On leave from CERN Laboratories, Geneva, Switzerland.

‡ National Science Foundation Fellow.

[1] Fowler, Shutt, Thorndike, and Whittemore, Phys. Rev. **98**, 121 (1954).

[2] M. Gell-Mann and A. Pais, *Proceedings of the Fifth Annual Rochester Conference on High Energy Physics, 1955* (Interscience Publishers, Inc., New York, 1955).

[3] T. Nakano and K. Nishijima, Progr. Theoret. Phys. Japan **10**, 581 (1953).

[4] W. Walker and W. Shephard, Phys. Rev. **101**, 1810 (1954).

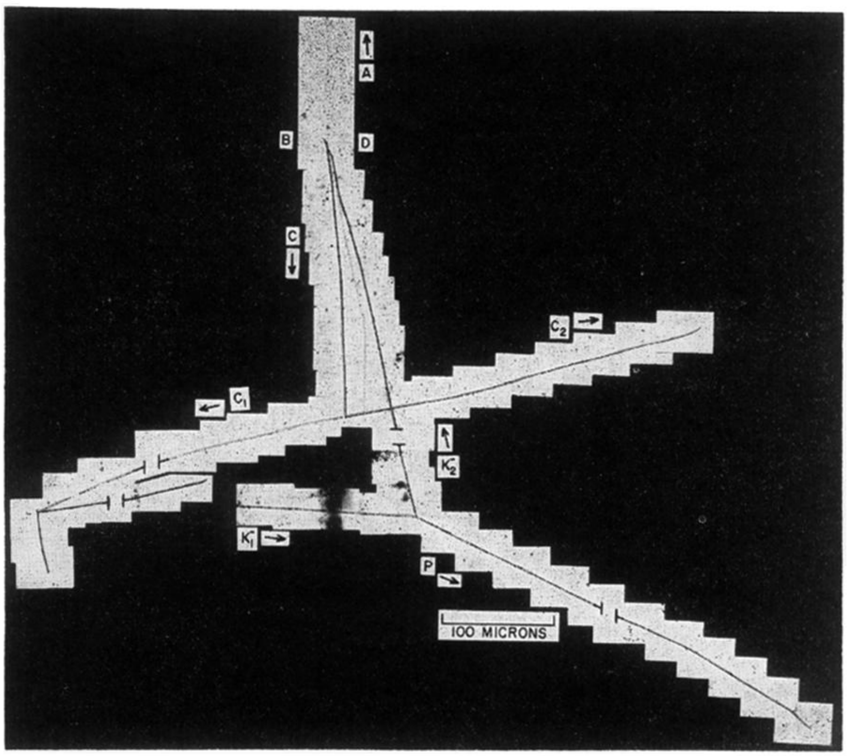

FIG. 1. A photomicrograph of event 113 in which a negative K-particle (K_1^-) is scattered from a proton (p) and continues on (K_2^-) to end in a 4-prong star. Prong (A) is a light meson which leaves the emulsion stack; (B) and (D) are short and unidentifiable; and (C) is a hyperfragment.[3]