appears to be more symmetrical when induced by helium ions than by protons of the same energy. It has already been pointed out that a large relative yield of Ag^{111} is accentuated at higher nuclear excitation; large relative yields of Zr^{97} and Ba^{139} are indicative of relatively low-energy fission. High-energy helium ions are thus more effective in causing nuclear excitation than are protons of the same energy. Deuterons again appear to occupy an intermediate situation. One may, from the values in Table II, estimate roughly that helium ions of 150-Mev energy induce about the same distribution of the fission products Zr^{97}, Ag^{111}, and Ba^{139} as do protons of about 300 Mev.

ACKNOWLEDGMENTS

We wish to thank Mr. James T. Vale and the crew of the 184-inch cyclotron of the University of California Radiation Laboratory for the bombardments which made this work possible. Thanks are also due Miss M. Gallagher for technical assistance.

PHYSICAL REVIEW VOLUME 94, NUMBER 5 JUNE 1, 1954

K-Meson and Hyperon Decays*

PAUL H. BARRETT†
Cornell University, Ithaca, New York
(Received Februrary 18, 1954)

A stack of 400μ Ilford G-5 nuclear emulsion surrounded by 5.5 cm of brass was flown at 85 000 feet for 10 hours at $\lambda=41°$N. While scanning 409 cm^2 of these emulsions the decay of seven K particles and one τ meson have been observed. A hyperon produced in a star is seen to decay into an L meson. For the decay scheme $Y^{\pm}\rightarrow\pi^{\pm}+n+Q$ this event gives $Q=(48\pm20)$ Mev. A heavy nuclear fragment ($Z\sim5$) from an eight-prong star decays into Li^8, a proton, and a particle that is probably a deuteron. An event has been observed that could be interpreted as an example of the decay of a τ meson by the decay scheme $\tau^+\rightarrow\pi^+ +2\pi^0$.

INTRODUCTION

DURING the last three years a large number of observations have been reported on the decay at rest in photographic emulsions and cloud chambers of charged heavy mesons (K mesons) and there have been reports of unstable particles (hyperons)[1] and nuclear fragments[2] more massive than the proton.

Further examples of the masses and modes of decay of these particles have been obtained from a stack of 400μ Ilford G-5 nuclear emulsions which was surrounded by 5.5 cm of brass and flown at 85 000 feet for 10 hours by a high-altitude balloon. The balloon was launched on July 18, 1952 from Holloman Air Force Base, New Mexico (geomagnetic latitude 41°N).

In a systematic scanning of 409 cm^2 of emulsion the decay of seven K particles, one τ meson, one hyperon, and one heavy nuclear fragment have been identified. A heavy particle is observed to stop in the emulsion and decay into a π meson which is identified by the characteristic π-μ-e decay in the emulsion.

CHARGED *K* MESONS

The results of the measurements on seven K particles are shown in Table I. K-1 to K-6 were found in scanning 370 cm^2 of emulsion that was inside the brass and K-7 was found during the scanning of 39 cm^2 of emulsion that was outside but near the brass. The masses of the K particles are determined from range-scattering measurements. g^* is the ratio of the grain density to the plateau grain density.

The event K-2 is consistent with being the decay of a χ meson ($\chi\rightarrow\pi+$neutral particle). The value of $p\beta$ for the secondary of K-2 agrees well with the value $p\beta=179\pm7$ Mev/c obtained by the Bristol group.[3]

The emulsions used in this experiment had glass backing and were placed emulsion-to-emulsion. Events K-4 and K-5 were traced from one emulsion to the next; however, there was a gap between the exit point in one emulsion and the entrance point of the next. This could have been due to two causes: (a) a gap between the emulsions in the vicinity of the tracks due to the emulsion surface being uneven; (b) removal of a surface layer of emulsion in processing. As the relative contributions of (a) and (b) are unknown and thus the correction to the range in going from one emulsion to the other, only the result of the mass measurement in the emulsion containing the decay is given. The mass values in parentheses are from scattering and grain

---

* Supported in part by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission. Part of the data analysis was done at Syracuse University and was supported by a grant from the Research Corporation.
† Now at Syracuse University, Syracuse, New York.
[1] Levi-Setti, Peters, and Ceccarelli, Cosmic-Ray Conference, Bagnères, 1953 (unpublished).
[2] M. Danysz and J. Pniewski, Phil. Mag. 44, 348 (1953); Tidman, Davis, Herz, and Tennent, Phil. Mag. 44, 350 (1953); J. Crussard and D. Morellet, Compt. rend. 236, 64 (1953).
[3] M. Menon and C. O'Ceallaigh, Cosmic-Ray Conference, Bagnères, 1953 (unpublished).

TABLE I. Results of measurements on K mesons. The masses of the primaries were computed from range-scattering measurements except for those shown in parentheses which were computed from grain density and scattering measurements. g^* is the ratio of the grain density of the track to the plateau grain density.

	Primary		Secondary			
	Range (μ)	Mass (m_e)	Length (μ)	$p\beta$ (Mev/c)	g^*	Mass (m_e)
K-1	5000	1020 ± 140	200	...	1.12 ± 0.11	...
K-2	520	...	4700	172 ± 26	1.07 ± 0.03	280 ± 50
K-3	120	...	2500	24.5 ± 2.5	2.75 ± 0.08	191 ± 30
K-4	11 300	1000^{+260}_{-190} (1080 ± 150)	130	...	~1	...
K-5	10 400	1190 ± 400 (1030 ± 250)	340	...	1.15 ± 0.40	...
K-6	1700	1000	250	...	1.56 ± 0.14	...
K-7	440	...	640	111 ± 35	$1.1\ \pm0.1$	190 ± 60

density measurements near the points where the particles first entered the emulsion. K-3, K-6, and K-7 are consistent with being examples of the decay of κ mesons ($\kappa\rightarrow\mu+2$ neutral particles) and K-1, K-4, and K-5 could be either κ's of χ's.

Ritson[4] has measured the masses of K-1 and K-4 by the method of gap-density *versus* range and has obtained the values $(1020\pm100)m_e$ and $(870\pm100)m_e$, respectively.

One example of a τ meson stopping and decaying in the emulsion has been identified. The three secondaries are coplanar within 2°. From grain density and scattering measurements they are all consistent with being π mesons and it is not likely that they are μ mesons though this possibility cannot be excluded. Their observed track lengths in the emulsion are 310μ, 2300μ, and 315μ, and the sum of their momenta is zero within the statistical errors of the measurements.

PRODUCTION AND DECAY OF A HYPERON

Originating from a star $(20+19p)$ (Fig. 1), a track of about five times minimum ionization goes a distance of 795μ (Track A) and then appears to decay at a right angle into a charged particle (Track B) and one or more neutral particles. The result of measurements on these tracks is given in Table II. The mass determination is from grain density-scattering measurements. The particle producing Track A had a velocity $\beta=0.20$ and lived $(1.3\pm0.1)\times10^{-11}$ sec. If Track B is assumed to be a π meson it has an energy of (59 ± 15) Mev. If a two-body decay is assumed with the neutral secondary being a neutron and Track B a π meson, then $Q=(72\pm20)$ Mev and $M=(2260\pm40)m_e$.

TABLE II. Results of measurements on the tracks shown in Fig. 1. The masses are computed from grain density and scattering measurements. See Table I for explanation of g^*.

Track	g^*	$p\beta$ (Mev/c)	Mass (m_e)	Length (μ)
A	5.0 ± 0.1	113 ± 35	2500 ± 900	800
B	1.6 ± 0.1	100 ± 25	300 ± 75	900
C	6.0 ± 0.1	55 ± 8	proton	2360

[4] D. M. Ritson, Phys. Rev. **91**, 1572 (1953).

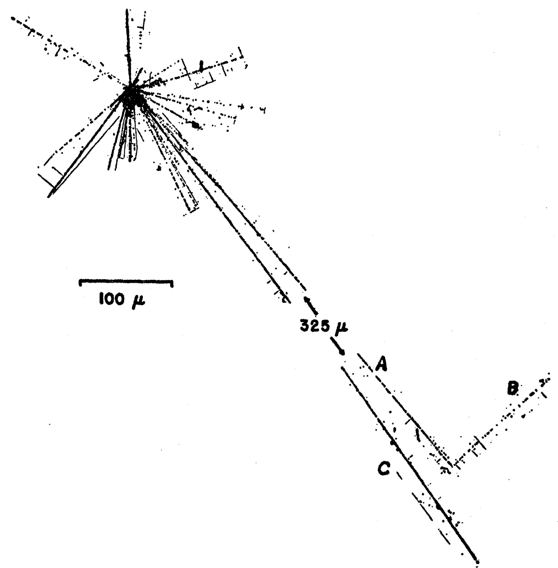

FIG. 1. Photomicrograph of a star in which one of the prongs (Track A) decays into a meson (Track B).

This event is similar to the case reported by Ceccarelli and Peters[1] which, in the new nomenclature of particles, is hypothesized as being the decay of a charged hyperon $(Y^{\pm}\rightarrow\pi^{\pm}+n+Q)$. Ceccarelli and Peters give for this reaction $Q=131\pm24$ Mev and $Q=135\pm35$ Mev, respectively.

From the nuclear interaction that was the origin of Track A there emerges another particle (Track C) that makes an angle of 3° with Track A. Track C leaves the emulsion after traversing 2360μ. Because of the high grain density of Track C an accurate density counting of grains cannot be performed; therefore, the mass determination of this particle is quite uncertain. However, its mass can be estimated to be about protonic. Since the measurements are not

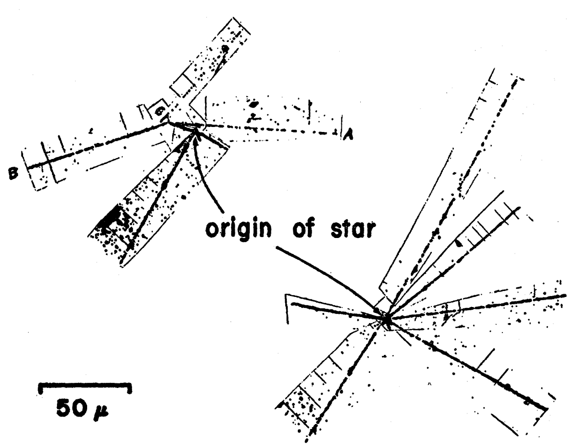

FIG. 2. Photomicrograph of an eight-prong star (one of the prongs might be the recoil nucleus). Seven of the prongs are shown in the lower right. The eighth prong is shown separately in the upper left along with several of the other prongs.

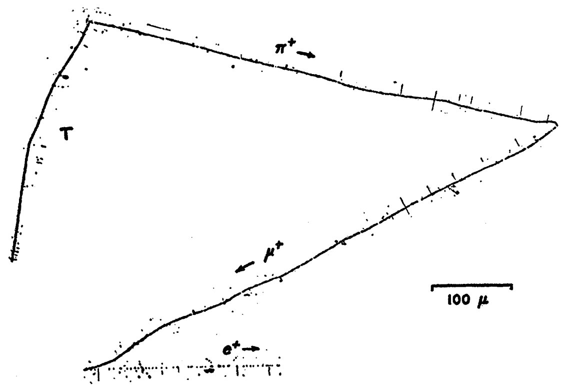

FIG. 3. Photomicrograph of a particle (Track T) decaying into a π^+ meson.

inconsistent with Tracks A and C having the same mass, it is thought worth while reporting this track as Tracks A and C could possibly be an example of the pair production of hyperons that has been suggested by Pais.[5]

DECAY OF HEAVY NUCLEAR FRAGMENT

Figure 2 is a photomicrograph of an eight-prong star (one gray track and seven black tracks). The decay of one of the black tracks is shown in detail in the upper left of the figure. This prong appears to stop after traversing 27μ of emulsion. Its ionization is greater than that of an α particle of similar range and its charge is estimated as being from four to six. From the end of its range three charged particles originate. Tracks A and B leave the emulsion after track lengths of 300μ and 690μ, respectively. Track C has a length of 4μ and decays into two short heavy tracks and a light track which from its observed scattering is probably an electron. Track C is consistent with being a Li^8 nucleus ($Li^8 \rightarrow Be^8 + e^-$, $Be^8 \rightarrow 2He^4$), giving the characteristic "hammer" track upon decaying; however, other possibilities cannot be excluded. Track A is too short to get reliable scattering measurements but a rough estimate of its mass is $1500 \pm 500 m_e$. On the assumption that Track A is a proton the energy is about 50 Mev. The high grain density of Track B ($g^* \sim 8$) makes its identification uncertain but it is heavier than a proton. From scattering measurements the energy of this particle can be computed if its mass is assumed. Assuming an alpha particle or a deuteron the energies are (50 ± 10) Mev or (25 ± 5) Mev, respectively.

If Track B is assumed to be a deuteron there can be momentum balance within the accuracy of the measurements without requiring a neutral decay particle.

This event is similar to those reported by the Warsaw, Bristol, and Paris groups[2] and these unstable heavy fragments have been interpreted as containing a bound Λ^0 (or $V_1{}^0$ in the old notation) in place of a neutron. The bound Λ^0 can then disappear either by the normal decay $\Lambda^0 \rightarrow p + \pi^- + 37$ Mev or by interacting with other nucleons and changing into a nucleon with the release of about 178 Mev. This latter process has been called by Cheston and Primakoff[6] "nonmesonic decay."

Applying this hypothesis to the event reported above, we have, resulting from a high-energy nuclear interaction, a carbon or boron nucleus ($A = 11$ to 13) with a neutron replaced by a Λ^0. The Λ^0 undergoes a "nonmesonic decay" after about 10^{-12} sec leaving the nucleus highly excited. The nucleus breaks up with the emission of Li^8, a proton, a particle of $Z = 1$ or 2 and $A = 2$, 3, or 4, and one or more neutral particles.

π MESON FROM DECAY OF HEAVY PARTICLE

In Fig. 3 a photomicrograph shows the decay of a particle (Track T) into a π meson of range 536μ (4.3 Mev) which decays upon coming to rest into a μ meson (562μ) which in turn decays into an electron. The π meson is assumed positive as it is not captured by a nucleus. Track T enters the emulsion at the glass surface and has a track length in the emulsion of 320μ. Its mass can be only roughly estimated from inspection of its track and comparing it with the tracks of protons and mesons of similar range. Its mass is probably intermediate between those of the π meson and the proton.

This event could be an example of the decay of a positive τ meson by the alternate decay scheme suggested by Pais[5] $\tau^\pm \rightarrow \pi^\pm + 2\pi^0$. Other possible examples of this mode of decay of the τ meson have been observed by Crussard *et al.*[7] and Amaldi[8] and co-workers.

One more possible example of this type of decay has been found in these emulsions but the "τ meson" track is short (60μ) and the π meson (480μ) makes an angle of only 8° with the end of the "τ meson" track. The possibility that this event could be the scattering of a π meson cannot be ruled out.

ACKNOWLEDGMENTS

The author wishes to thank Mrs. Carol Sienko and Mrs. Gerry de Vesty who performed the exacting task of scanning the emulsions, and the personnel of the Aero-Medical Laboratory, Holloman Air Force Base for making the balloon flight possible.

[5] A. Pais, Phys. Rev. **86**, 663 (1952).

[6] W. Cheston and H. Primakoff, Phys. Rev. **92**, 1537 (1953).

[7] Crussard, Kaplon, Klarmann, and Noon, Phys. Rev. **93**, 253 (1954).

[8] Amaldi, Baroni, Castagnoli, Cortini, Franzinetti, and Manfredini (to be published).