The fraction of K^0 decaying by the $\pi^+ + \pi^-$ mode was taken to be 0.34 ± 0.02.[3]

The $K_1{}^0$ mean life obtained from these events is $(0.87 \pm 0.13)\times 10^{-10}$ sec, in agreement with other experiments.[4]

Figure 1 shows the cross section as a function of K^- laboratory momentum. The solid curve represents the charge-exchange cross section as evaluated from the S-wave, zero-effective-range approximation,[5] which fits the data satisfactorily. The dashed curve is the charge-exchange cross section (with arbitrary ordinate) predicted by Pais[6] in his theory embodying opposite parities for charged and neutral K's. There is in this theory a free parameter λ which can range from -1 (the prediction of perturbation theory) to +1. We have plotted $\lambda = -1$ as being the theoretically simplest choice (it also fits the data best). It can be seen that our data are inadequate to distinguish between the two curves. Both curves have been modified to take into account the mass differences. For the effective-range theory this was done simply by the introduction of a factor $p_{\text{final}}/v_{\text{initial}}$ into the cross sections. These effects dominate near threshold and tend to obscure the swift p^2 rise which would otherwise be characteristic of the Pais theory.

Figure 2 shows the angular distribution as a function of momentum. The S-wave effective-range theory predicts, of course, isotropy. The dashed curve is the Pais prediction from $\lambda = -1$, $P_K = 180$ Mev/c. Chi-squared tests on the experimental angular distribution show a probability of about 5% associated with either the isotropic or Pais hypotheses.

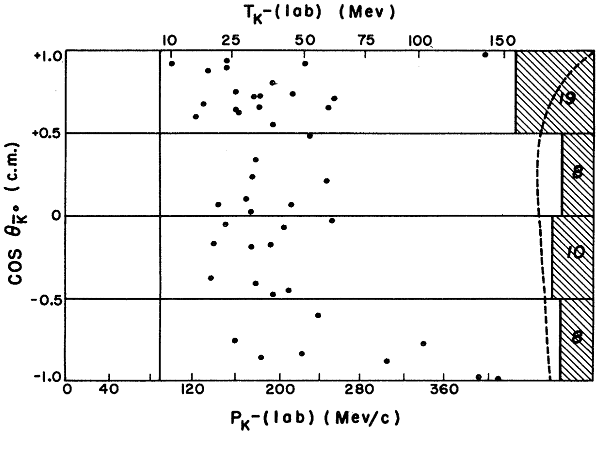

FIG. 2. Angular distribution of K^--hydrogen charge-exchange scattering vs K^- laboratory momentum. Each dot represents an event. A histogram appears at the right. The curve represents the prediction of the Pais theory for $\lambda = -1$ at a momentum of 180 Mev/c.

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[1] Preliminary cross sections for elastic scattering and hyperon production channels are given in the report of the 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN, Geneva, 1958), and in Bull. Am. Phys. Soc. Ser. II, 3, 336 and 363 (1958); 4, 24 (1959); data analysis is continuing. The electrostatically separated beam is described by Horwitz, Murray, Ross, and Tripp, University of California Radiation Laboratory Report UCRL-8629, June 1958 (unpublished).

[2] Rosenfeld, Solmitz, and Tripp, Phys. Rev. Lett. 2, 110 (1959); Crawford, Cresti, Good, Stevenson, and Ticho, Phys. Rev. Lett. 2, 112 (1959).

[3] Crawford, Cresti, Douglass, Good, Kalbfleisch, Stevenson, and Ticho, Phys. Rev. Lett. 2, 266 (1959).

[4] D. Glaser, 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN, Geneva, 1958), p. 272.

[5] Jackson, Ravenhall, and Wyld, Nuovo Cimento 10, 834 (1958). At the 1958 Geneva Conference, Dalitz[1] used this approximation to make an experimental fit, largely based on our very preliminary data. We have still not completed the analysis of all our data, but at present it appears that the cross sections for elastic scattering and charged Σ production are larger by about 25% and 15%, respectively, than the values used by Dalitz.

[6] A. Pais, Phys. Rev. 112, 624 (1958).

NUCLEAR INTERACTION OF A PROTON OF ABOUT 10^{15} ev PRODUCING AN ELECTRON-PHOTON CASCADE OF 2.4×10^{13} ev*

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In a stack of 22 liters of Ilford $G5$ emulsion flown by a Skyhook balloon for 13 hours above 110 000 feet from Brownwood, Texas, a nuclear interaction initiated by a proton of type $6+16_p$ was found. The angular distribution of the 16

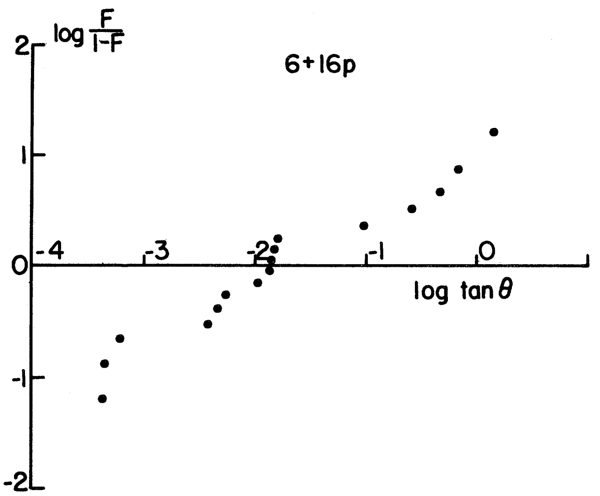

FIG. 1. Angular distribution of shower particles for primary event $6+16p$. F is the fraction of particles in the laboratory system found in a cone of half opening angle θ.

shower particles is shown in Fig. 1. It indicates that the primary energy is probably between 10^{14} and 10^{15} ev. Between the three innermost tracks of the forward cone, at a distance of about 4 mm from the origin, an unusually energetic electron-photon cascade is initiated which could be followed for 22.6 cm [=7.8 c.u. (cascade units)] in the stack. The longitudinal and the lateral development were investigated by drawing target diagrams of the electrons after 4, 5.6, and 7.1 c.u. The results are shown in Table I. The density $\Pi(r)$ of the electron tracks could be measured down to very small distances from the cascade axis ($\approx 10^{-5}$ radian). No evidence of a double or multiple core structure could be found. It may, therefore, be assumed that this cascade was started by one single high-energy π^0 decaying into γ-rays. This conclusion is further supported by the low meson multiplicity in the primary event which makes the probability of finding two high-energy π^0 mesons within the solid angle of 10^{-5} radian fairly small. Only one small secondary nuclear interaction of the shower particles was found. Its influence on the cascade is negligible. The cascade can, therefore, be regarded to be purely electromagnetic in nature. Hence a comparison with electromagnetic theory can be attempted. The longitudinal development was compared with approximation A of Rossi and Greisen.[1] The lowest energy E of the cascade electrons counted in this experiment was determined by multiple-scattering measurements. The extrapolation of the electron density distribution beyond the largest distances R quoted in Table I was carried out and corrected after Pinkau[2] and Eyges and Fernbach.[3] The longitudinal development is in good agreement with approximation A for a primary energy of 2.5×10^{13} ev for the π^0 which does not depend critically on the way the energy is shared by the four electrons. In Fig. 2 the integral number of electrons at 7.1 c.u. from the origin is plotted against the distance r from the cascade axis. Using the theoretical computation developed by Nishimura and Kamata[4] and calculations by Pinkau,[5] one obtains an energy of 2.4×10^{13} ev from Fig. 2 which is in satisfactory agreement with the estimate based on the longitudinal development mentioned previously.

Table I. Development of electron-photon cascade. t = distance from primary event in cascade units. N = number of tracks within distance R in microns from the axis of the cascade. γ = quantity defined by Eq. (1).

t	N	R	γ
4.0	1050	350	1.36±0.1
5.6	3560	550	1.29±0.1
7.1	6730	770	1.24±0.1

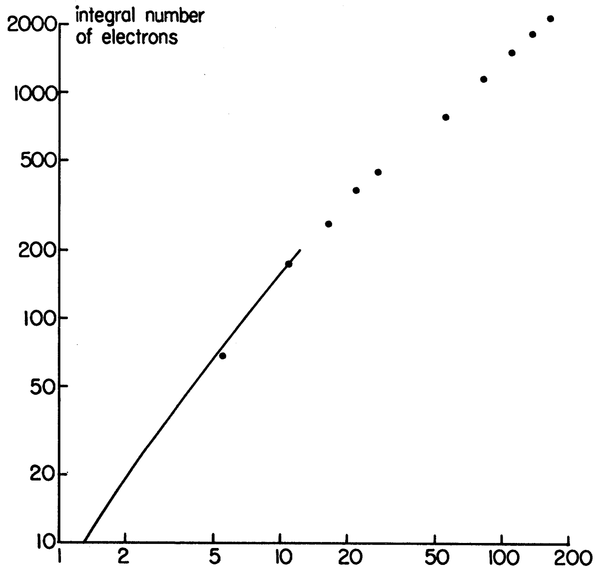

FIG. 2. Lateral distribution of electrons at a distance of 7.1 c.u. from the primary event. r = distance from cascade axis. ● = experimental results. Solid curve = distribution function calculated by Pinkau.[5]

The radial density distribution of electrons at $t=4$, 5.6, and 7.1 c.u. was measured between $r=10\mu$ (3.5×10^{-4} c.u.) and the value R quoted in Table I. For each value of t the density distribution can be fitted by a power law:

$$\Pi(r)\propto r^{-\gamma}, \tag{1}$$

where γ is slowly increasing with r. The average exponent γ in the indicated interval is given in Table I. The measured values of γ are in agreement with the distribution functions close to the shower axis as calculated by Nishimura and Kamata,[4]

$$\Pi(E_0, r, t)\propto r^{s-2}, \tag{2}$$

with s defined by

$$\lambda_1'(s)t+\ln(E_0r/K)=0, \tag{3}$$

in the notation of Rossi and Greisen. Our measurements do not show any significant deviations from electromagnetic cascade theory at a primary energy of 2.5×10^{13} ev. Pomeranchuk[6] and Migdal[7] also obtained Eq. (2) from their theory. Their value of s is defined by

$$\lambda_1'(s)t+\ln(E_0/E)=0. \tag{4}$$

Our observations, however, are not in agreement with these results.[8]

One of the three innermost tracks in the forward cone undergoes a secondary interaction of type $4+29_p$ after 7.5 cm. Its energy can be estimated[9] from the angular distribution of the 29 shower particles to be 5×10^{11} ev using

$$\ln\gamma_C=-\frac{1}{n}\sum_{i=1}^{n}\ln\tan\theta_i+\ln C, \tag{5}$$

with $C=0.7$ as determined experimentally and discussed elsewhere.[10] Within a cone of half opening angle 1.7×10^{-3} rad from the axis, we found four high-energy electron pairs originating at distances less than 1 c.u. from the primary event. They are attributed to two π^0 mesons. Their energies can be estimated both from Pinkau's[5] method and from the angular separation of the pairs. One obtains for the π^0 mesons energies between 100 and 500 Bev. The energy of these π^0's and the secondary interaction are smaller by a factor of 50 to 100 compared with the π^0 starting the main cascade.

Assuming a primary energy of 5×10^{14} ev ($\gamma_C=500$), we would obtain for the high-energy π^0 meson in the center-of-mass system an energy of at least 25 Bev which is unusually high. Lowering the primary energy would even increase this value. An alternative explanation of the event would be a reaction of the kind.

$$p+\mathfrak{N}\rightarrow K+\Sigma^0+\mathfrak{N}+\pi+\pi+\ldots,$$

$$\Sigma^0\rightarrow\gamma+\Lambda^0,$$

where the primary proton emerges after the collision as a Σ^0 of very high energy. A lower limit for the primary energy under this assumption is 2×10^{14} ev. This explanation would avoid the very high energy of the π^0 meson in the center-of-mass system. Due to the very short lifetime of the Σ^0, it also offers a somewhat better explanation for the short distance between the primary event and the origin of the cascade.

This event seems to be the highest energy proton collision in nuclear emulsion which has been described so far, since all the other events known to us with energies greater than 10^{14} ev per nucleon were produced by α-particles.[11-13] It shows that the primary proton spectrum certainly extends to these very high energies.

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[1] B. Rossi and K. Greisen, Revs. Modern Phys. 13, 240 (1940).

[2] K. Pinkau, Nuovo cimento 3, 1285 (1956).

[3] L. L. Eyges and S. Fernbach, Phys. Rev. 82, 23 (1951).

[4] J. Nishimura and K. Kamata, Prog. Theor. Phys. Japan 7, 185 (1952); 5, 889 (1950).

[5] K. Pinkau, Phil. Mag. 2, 1389 (1957).

[6] I. Pomeranchuk, J. Phys. U.S.S.R. 8, 17 (1944).

[7] A. Migdal, J. Phys. U.S.S.R. 9, 183 (1945).

[8] For a possible explanation see Nishimura and Kamata.[4]

[9] Castagnoli, Cortini, Franzinetti, Manfredini, and Moreno, Nuovo cimento 10, 1539 (1953).

[10] Jain, Lohrmann, and Teucher (in press).

[11] Fowler, Freier, Lattes, and Ney, Suppl. Nuovo cimento 8, 725 (1958).

[12] Ciok, Danysz, Gierula, Jurak, Miesowicz, and Wolter, Nuovo cimento 6, 1409 (1957).

[13] E. Lohrmann and M. W. Teucher, Phys. Rev. 112, 587 (1958).

REMARK ON STRONG INTERACTIONS

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In a recent note of Pais,[1] the question has been raised as to the conservation of parity, P, in