PRODUCTION OF $\Lambda^0(\Sigma^0)$ HYPERONS AND K^0 MESONS IN π^-p INTERACTIONS AT 6.8 ± 0.6 Bev/c

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Processes involving the production of $\Lambda^0(\Sigma^0)$ hyperons and K^0 mesons in π^-p collisions were studied for 6.8 Bev/c π^- mesons. The cross section for the production of $\Lambda^0(\Sigma^0)$ and K^0 particles, the ratio between the Y^0K and $K\bar{K}$ pair production cross sections, the mean multiplicity of charged particles, the c.m.s. angular and momentum distributions of Λ^0 and K^0 particles, and the transverse momentum distributions for Λ^0 and K^0 particles have been obtained.

PROCESSES involving the production of $\Lambda^0(\Sigma^0)$ hyperons and K^0 mesons in π^-p collisions have been studied recently[1] only close to the threshold 0.9 — 1.4 Bev/c.

In order to elucidate the structure of the nucleon and the character of elementary particle interactions, it is necessary to obtain experimental data at higher energies. We have studied processes involving the production of $\Lambda^0(\Sigma^0)$ hyperons and K^0 mesons in collisions between 6.8 ± 0.6 Bev/c negative π mesons and protons with the aid of a 24-liter propane (C_3H_8) bubble chamber in a constant magnetic field of 13,700 oe. The experimental arrangement has been described by Wang Kang-Chang et al.[2]

METHOD OF ANALYSIS AND SELECTION OF π^-p INTERACTIONS

The bubble-chamber pictures were taken with a stereoscopic camera using "Russar-plazmat" objectives with a focal length of 67 mm. The photographic film was pressed against a plane-parallel glass on which crosses were engraved (straight lines intersecting at an angle of 90°). The objectives were adjusted so that their optical axes were parallel and passed through the points of intersection of the straight lines on the glass. The stereophotographic base, determined by the distance between the crosses, was equal to 300 mm. The scale of the photograph for the median plane of the bubble chamber was 1 : 10. The camera was mounted on the upper plate of the chamber and was in a fixed position during the chamber operation.

The photographs were scanned by different persons two or three times through stereoscopic viewers and reprojectors. The efficiency of observing V^0 particles was 91% in double scanning and 96% in triple scanning. A total of 14,000 photographs were scanned. The Λ^0 and K^0 particles were considered to be produced in π^-p interactions if they satisfied the following conditions: 1) short black tracks, characteristic of the disintegration products of carbon, were not observed in the stars to which the Λ^0 and K^0 particles belong, 2) the resultant charge of all secondary particles was zero, 3) no more than one baryon (Λ^0, $\Sigma^\pm$, p) was observed in the star, 4) the c.m.s. momentum of the Λ^0 and K^0 particles did not exceed the maximum values possible in the production of Λ^0 and K^0 particles in collisions between π^- mesons and free protons.

The background of Λ^0 and K^0 particles produced in collisions with quasi-free protons was estimated from the number of Λ^0 and K^0 particles produced in collisions with quasi-free neutrons. For this purpose, we counted the cases of Λ^0- and K^0-particle production in π^-n interactions on the scanned photographs. We found that the number of π^-n interactions was 20% of the π^-p interactions satisfying criteria 1 — 4. Assuming that the production cross sections for Λ^0 and K^0 particles on quasi-free neutrons and protons of carbon are the same, we found that 20% of the π^-p interactions (criteria 1 — 4) were due to interactions between π^- mesons and quasi-free protons of carbon.

The events found in the scanning were analyzed and 233 of them satisfied all of the aforementioned criteria. We measured the events on UIM-21 microscopes by measuring the coordinates of corresponding points on both stereo frames. The space coordinates, angles, and momenta were calculated on a Ural electronic computer. The geometrical reconstruction of the track in space was calculated by the method of least squares. The curvature of the track was approximated by a parabola. The nonhomogeneity of the magnetic field over the bubble-chamber volume did not exceed ± 3%.

Owing to multiple scattering, the error in determining the momenta of relativistic particle tracks was, on the average, 13% for a track length of about 10 cm.

The kinematical relations between the angles of flight and the momenta of the decay products were used to identify the Λ^0 and K^0 particles. This made it possible to determine the Λ^0- and K^0-particle momenta to an accuracy of $\leq 10\%$.

GEOMETRICAL CORRECTION

The effective region for the production and observation of Λ^0 and K^0 particles in the chamber is less than the geometrical dimensions of the chamber ($55 \times 28 \times 14$ cm) and depends on the lifetime of the particles and their velocity.

The effective region was determined experimentally. To do this, we plotted the distribution of cases of Λ^0- and K^0-particle production in the chamber. It turned out that the distribution coincided with the distribution of primary beam tracks in the following intervals: on the x axis — from 4 to 22 cm, on the z axis — from 3 to 9 cm.* If we take the direction of the primary particle beam as the positive direction and measure y from the middle of the chamber, then 90% of all cases of Λ^0- and K^0-particle production are located in the interval between − 24 and + 14 cm. Of the 233 events, 209 lie in the effective region. It turned out that the effective regions for Λ^0 and K^0 particles practically coincide. The difference in the lifetimes is offset by the larger velocities of the K^0 mesons, which leads to a greater relativistic increase in their lifetimes, so that the K^0 lifetime becomes comparable with the lifetime of the Λ^0 particles.

In order to take into account Λ^0 and K^0 particles that decay outside the chamber, and also the difference in the probabilities of recording Λ^0 and K^0 particles emitted in the vertical and horizontal planes, we introduced a correction W_1 for the probability of Λ^0 and K^0 decay outside the chamber and a correction W_2 for the loss of Λ^0 and K^0 particles due to large azimuthal angles.

1. The probability of Λ^0 and K^0 decay within the boundaries of the chamber is determined from the well-known law $1 - \exp(-l/l_0)$, where $l_0 = \beta c \gamma \tau_0$ is the mean range and l is the potential range. By potential range we mean the distance from the point of production to the boundary of the effective region for the observation of decay. The dimensions of this region depend on the minimum length necessary for the momentum measurement of the decay products. This length was 4 cm in our experiment. Using the known values of the Λ^0- and K^0-particle lifetimes,[3] we calculated the probability f_i of observing decay in our chamber for each case. The mean values of f_i were 84% and 78% for the observation of Λ^0 and K^0 particles, respectively, and 65% and 63% for the observation of $\Lambda^0 K^0$ and $K^0 \overline{K}^0$ pairs, respectively. The reciprocal of the probability of observing decay in the chamber gives the correction W_1.

2. The chamber depth was less than its width and the probability of observing Λ^0 and K^0 particles produced in the chamber and emitted at large azimuthal angles was therefore less than that for observing Λ^0 and K^0 particles emitted at small azimuthal angles. This is what is known as the bias for unfavorable azimuthal angles Φ. We plotted the Φ distribution for Λ^0 and K^0 particles. It was found that the correction for Λ^0 decays was $W_2 = 1.48 \pm 0.1$ and $W_2 = 1.13 \pm 0.03$ for K^0 decays.

PRODUCTION CROSS SECTION FOR $\Lambda^0(\Sigma^0)$ AND K^0 PARTICLES

In this work, we did not set the task of estimating the fraction of Λ^0 hyperons resulting from the decay of Σ^0 particles for the total number of observed Λ^0 hyperons. Since only 11% of the γ quanta were converted into electron-positron pairs in our chamber, the decay of the Σ^0 hyperons into Λ^0 particles and γ quanta at practically the very point of production did not permit us to distinguish Λ^0 particles resulting from the decay of Σ^0 particles by the γ quanta. From Table I it is seen that at our energy some charged particles (n_s) are produced together with the neutral strange particles. These are mostly $\pi^{\pm}$ mesons. The mean number of charged particles accompanying the production of Λ^0 and K^0 particles is 2.5 ± 0.1. $K^{\pm}$ mesons are also present among the charged particles.

*x is the chamber width, y is the chamber length along the beam, and z is the depth coordinate.

Table I

Identified particles	Number of charged particles, n_s				
	0	2	4	6	Total
$\Lambda^0 + K^0$	2	8	3	0	13
Λ^0	6	47	17	3	73
$K^0 + \overline{K}^0$	0	5	1	0	6
K^0	16	62	26	3	107
Λ^0 or K^0	2	6	2	0	10
Total	26 12.5%	128 61.6%	49 23%	6 2.9%	209 100%

We recorded neutral strange particles which were produced in the following reactions:

$$\pi^- + p \to \Lambda^0 + K^0 + n\pi \quad (1)$$

$$\pi^- + p \to \Sigma^0 + K^0 + n\pi \quad (2)$$

$$\pi^- + p \to \Lambda^0 + K^+ + n\pi \quad (3)$$

$$\pi^- + p \to \Sigma^0 + K^+ + n\pi \quad (4)$$

$$\pi^- + p \to K^0 + \overline{K}^0 + N + n\pi \quad (5)$$

$$\pi^- + p \to K^0 + K^- + N + n\pi \quad (6)$$

$$\pi^- + p \to \overline{K}^0 + K^+ + N + n\pi \quad (7)$$

The following reactions with the production of K^0 mesons are also possible at our energy:

$$\pi^- + p \to \Sigma^{\mp} + K^0 + n\pi \quad (8,9)$$

$$\pi^- + p \to \Xi^- + K^0 + K^+ + n\pi \quad (10)$$

$$\pi^- + p \to \Xi^0 + K^0 + K^0 + n\pi \quad (11)$$

For the present, our problem did not involve the study of reactions (8) and (9)* The K^0-meson background from these reactions was negligible in our statistics: $\Sigma^\pm$ hyperons have a characteristic decay pattern, a short lifetime, and, consequently, can be reliably recorded and well separated from the reactions (1) — (7); $\Xi^{0,-}$ hyperons have a very small production cross section in the π^-p interaction.†

Ionization measurements for momenta > 1.2 Bev/c do not give a reliable separation of π^+ mesons and protons, not to mention the separation of $\pi^\pm$ and $K^\pm$ mesons. The fraction of Λ^0 hyperons produced in reactions (3) and (4), and the fraction of K^0 and $\overline{K}^0$ mesons produced in reactions (6) and (7) were estimated in the following way. We knew the fraction of Λ^0 and K^0 particles decaying into neutral particles, and also the fraction of long-lived K^0 mesons (K_2^0). Then, from the numbers of Λ^0K^0 pairs ($n_{\Lambda^0K^0}$) and $K^0\overline{K}^0$ pairs ($n_{K^0\overline{K}^0}$) that were found, we determined the true number of the pairs $N_{\Lambda^0K^0}$ and $N_{K^0\overline{K}^0}$:

$$N_{\Lambda^0K^0_1} = n_{\Lambda^0K^0_1}/(1-f_{\Lambda^0})(1-f_{K^0}),$$

$$N_{K^0\overline{K}^0} = n_{K^0\overline{K}^0}/(1-f_{\overline{K}^0})(1-f_{K^0}),$$

where f_{Λ^0} is the fraction of Λ^0 particles decaying into a neutron and π^0 meson ($f_{\Lambda^0} = 0.33$), f_{K^0} is the fraction of K^0 mesons decaying into two π^0 mesons plus the fraction of long-lived K^0 mesons [$f_{K^0} = 0.63$ (reference 4)].

Owing to the decay of K^0 mesons into neutral particles and the presence of K_2^0 mesons, part of the Λ^0K^0 pairs were recorded as single Λ^0 particles. The number of such cases is n′ $= N_{\Lambda^0K^0}f_{K^0}(1 - f_{\Lambda^0})$. We subtract n′ from the total number of single Λ^0 particles found after the corrections W_1 and W_2. The difference can be considered to represent production of a Λ^0 hyperon in reactions (3) and (4). A similar calculation was carried out for K^0 mesons.

We were thus able to estimate the probability of reactions (1), (2), (3), and (4), as well as (5), (6), and (7). For simplicity, we use the notation:

$$\sigma(Y^0K^0) = \sigma(1) + \sigma(2), \qquad \sigma(Y^0K^+) = \sigma(3) + \sigma(4),$$

$$\sigma(K^0\overline{K}^0) = \sigma(5), \qquad \sigma(K^0K^-) = \sigma(6), \qquad \sigma(\overline{K}^0K^+) = \sigma(7),$$

$$\sigma(Y^0K^{0,+}) = \sigma(Y^0K^0) + \sigma(Y^0K^+),$$

$$\sigma(K^0, \overline{K}) = \sigma(K^0\overline{K}^0) + \sigma(K^0K^-) + \sigma(\overline{K}^0K^+).$$

We performed a special examination of our material with a view to observing conversion γ quanta from π^0-meson decay. From an examination of 228 cases with the production of neutral strange particles, it turned out that electron-positron pairs from conversion γ quanta were associated with primary stars in 32 cases (14%).

In order to determine the total cross section for the production of $\Lambda^0(\Sigma^0)$ and K^0 particles, we considered 7000 photographs, none of which contained more than 15 — 20 primary π^- mesons. The number of π^- mesons was counted independently by two observers. The primary particle flux was not counted on each photograph, but on every tenth frame. The difference in the number of tracks in the results of the two observers was 0.6% for about 100,000 π^- mesons. As was indicated above, the efficiency of double scanning was 91% and that of triple scanning 96%. In the determination of the total number of cases of $\Lambda^0(\Sigma^0)$- and K^0-particle production, apart from the corrections W_1 and W_2 connected with the geometrical parameters of the chamber, we introduced a correction for the neutral decay scheme of the K_1^0 particles and for long-lived K_2^0 mesons. Table II shows the results for the different reactions after all corrections have been taken into account.

*These reactions are studied in a separate work.

†The Ξ^- production cross section at this energy is $3.6^{+2.5}_{-2.1}$ μb/nucleon.

Table II

Reactions	(1) + (2)	(3) + (4)	(5)	(6) + (7)
Number of cases after all corrections	136±38	107±33	89±36	264±54

The total cross section for the production of $\Lambda^0(\Sigma^0)$ and K^0 particles on free protons after all the enumerated corrections and after the π^- meson contamination and scanning efficiency have been taken into account is equal to 2.0 ± 0.35 mb, where

$$\sigma(Y^0K^{0,+}) = 0.8 \pm 0.25 \text{ mb}, \quad \sigma(K^0K) = 1.2 \pm 0.3 \text{ mb},$$
$$R \equiv \sigma(Y^0K^{0,+})/\sigma(K^0K) = 0.7 \pm 0.2.$$

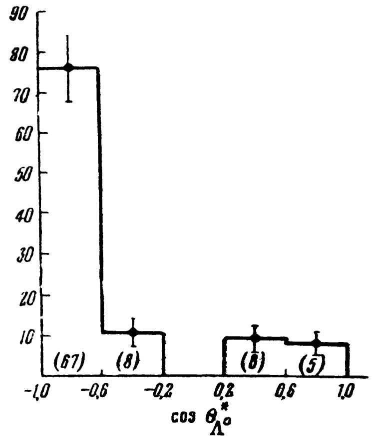

FIG. 2. C.m.s. angular distribution of Λ^0 hyperons (the number of cases is shown in parentheses).

Λ^0- AND K^0-PARTICLE MOMENTUM AND ANGULAR DISTRIBUTIONS

In constructing the angular and momentum distributions, we took into account only the correction W_1, since the correction for Φ made no essential contribution to the character of the distributions.

Figure 1a shows the momentum distribution of the Λ^0 hyperons. In Fig. 1b, the momentum spectra of Λ^0 hyperons emitted forward and backward in the c.m.s. are compared. It is seen that the momentum of Λ^0 particles emitted backward in the c.m.s. extends from zero to 1.6 Bev/c, while for Λ^0 hyperons emitted forward, the spectrum breaks off close to 1 Bev/c.

Figure 2 shows the Λ^0-hyperon angular distribution. The character of this distribution does not depend on the multiplicity of particles produced together with the Λ^0 hyperon; the Λ^0 hyperons are emitted mainly forward.

Figure 3 shows the K^0-meson momentum distributions. It is seen from Fig. 3b that the momentum spectrum of K^0 mesons emitted forward is almost the same as for K^0 mesons emitted backward.

If the angular distribution for Λ^0 hyperons does not depend on the charged-particle multiplicity n_s, then the picture for K^0 mesons is basically changed. Figure 4a shows the K^0-meson angular distribution for $n_s \leq 2$ and Fig. 4b, for $n_s \geq 4$. For cases of low multiplicity ($n_s \leq 2$), more K^0 mesons are emitted forward than backward: $n_{forward}/n_{backward} = 2.0 \pm 0.4$. For cases of high multiplicity ($n_s = 4, 6$), the angular distribution is practically isotropic, within limits of the small statistics.

Figures 5 and 6 show the angular and momentum distributions of π^- mesons for ordinary mul-

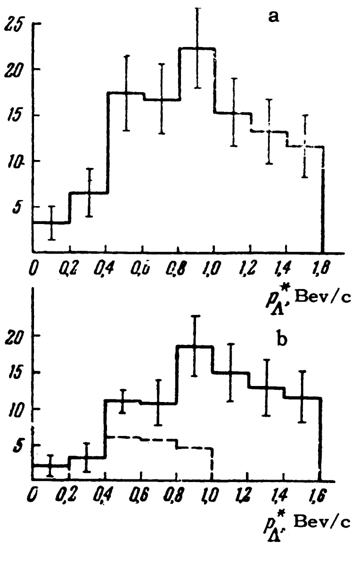

FIG. 1 C.m.s. momentum distribution of Λ^0 hyperons: a – total spectrum, b – Λ^0 hyperons emitted backward (solid line) and forward (dotted line) in the c.m.s.

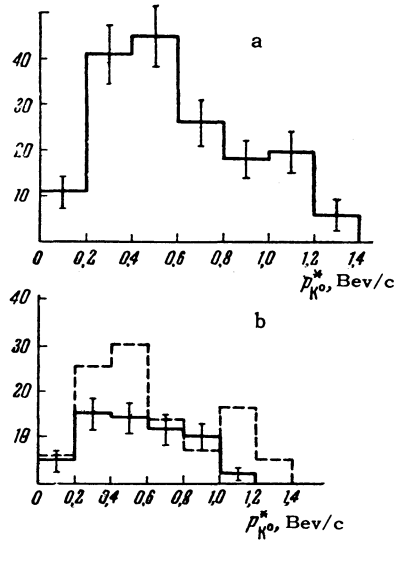

FIG. 3. C.m.s. momentum distribution of K^0 mesons: a – total spectrum, b – K^0 mesons emitted forward and backward in the c.m.s.

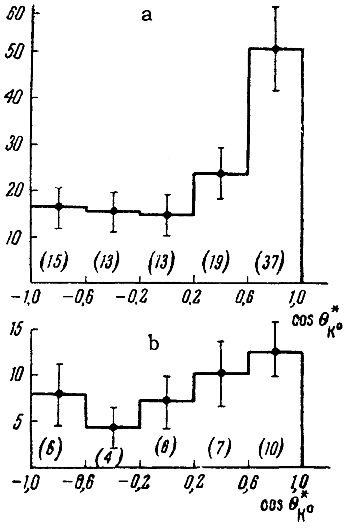

FIG. 4. C.m.s. angular distribution for K^0 mesons: a – $n_s \leqslant 2$, b – $n_s \geqslant 4$.

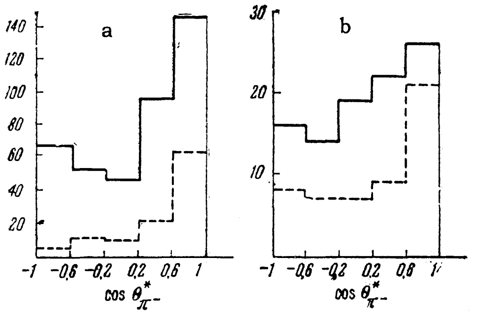

FIG. 5. C.m.s. angular distribution of π^- mesons: a – for ordinary multiple production of π^- mesons by π^- mesons, b – for π^- mesons produced together with Λ^0 hyperons. Solid line – $n_s = 2 + 4 + 6$; dotted line – $n_s = 2$.

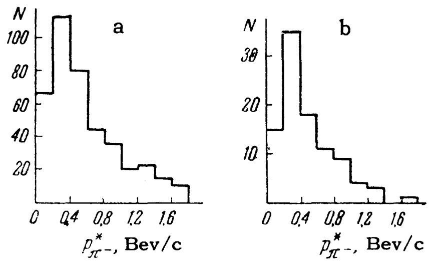

FIG. 6. C.m.s. momentum distribution of π^- mesons: a – for ordinary multiple production of π^- mesons by π^- mesons, b – for π^- mesons produced together with Λ^0 hyperons.

tiple production (a)[5] and of π^- mesons produced together with $\Lambda^0(\Sigma^0)$ hyperons (b). We compared only negative particles produced together with hyperons; this permits us to identify them uniquely as π^- mesons. In ordinary multiple production, negative particles are π^- mesons with a very large probability.

From a comparison of these distributions, it is seen that they are of the same nature.

The mean values of the transverse momenta of the Λ^0 and K^0 particles are equal to 388 ± 35 and 393 ± 35 Mev/c, respectively, i.e., they are equal within the limits of experimental error. The Λ^0-hyperon and K^0-meson transverse momentum distributions are shown in Fig. 7. The mean value of the transverse momenta does not depend on the multiplicity, as is readily seen from Table III.

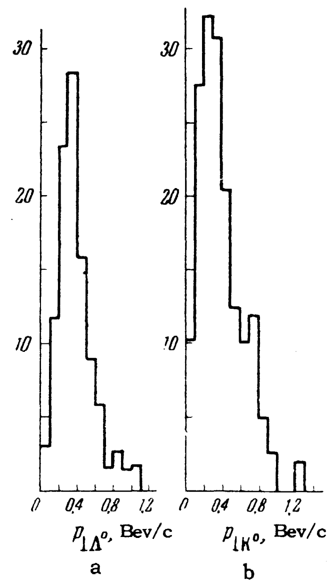

FIG. 7. Transverse momentum distribution: a – for Λ^0 hyperons, b – for K^0 mesons.

Table III

	Mean transverse momenta	
	Λ^0 particles, Mev/c	K^0 particles, Mev/c
$n_s \leqslant 2$	395±47	394±42
$n_s \geqslant 4$	367±60	386±66
$\bar{n}_s$	388±35	393±35

DISCUSSION OF EXPERIMENTAL RESULTS

1. Production cross section for $Y^0K^{0,+}$ and $K^0\bar{K}$ pairs. Our experimental results indicate that for a π^--meson energy of about 7 Bev, the production cross section for $K^0\bar{K}$ pairs is greater than the production cross section for $Y^0K^{0,+}$ pairs. The ratio of these cross sections has the value

$$R = \frac{\sigma(Y^0K^0) + \sigma(Y^0K^+)}{\sigma(K^0\bar{K}^0) + \sigma(K^0K^-) + \sigma(\bar{K}^0K^+)} = 0.7 \pm 0.2.$$

We studied only $K^0\bar{K}^0$, K^0K^-, and $\bar{K}^0K^+$ pairs. If we assume that at our energy the production cross section for charged K^+K^- pairs is the same as for $K^0\bar{K}^0$ pairs, then the ratio is reduced to 0.5:

$$R = \frac{\sigma(Y^0K^0) + \sigma(Y^0K^+)}{\sigma(K^0\bar{K}^0) + \sigma(K^0K^-) + \sigma(\bar{K}^0K^+) + \sigma(K^+K^-)} = 0.5 \pm 0.15.$$

The production cross section for Λ^0K^0 and Σ^0K^0 pairs close to the threshold was studied in detail. The total cross section for Y^0K^0 pairs has a maximum of 1.1 mb at 0.96 Bev and drops to 0.4 mb at 1.2 Bev, and then again increases to 0.6 mb at 1.3 Bev.[1]

We do not know how the cross section behaves after this. For a comparative estimate, we consider the work of Maenchen et al.,[6] where the multiple production of π^- mesons at an energy of ~ 5 Bev was studied. Among 106 π^-p interactions in a hydrogen diffusion cloud chamber, four cases of production of strange particles were observed, where one of these cases was identified as $\pi^- + p \rightarrow \Lambda^0 + K^+ + \pi^-$. This constitutes 4% of the total inelastic cross section. If we take a total inelastic cross section of 18 mb, as was done by Maenchen et al., then the production cross section for strange particles is 0.7 mb. Evidently, too much weight should not be attached to this result, but one may expect, after all corrections are taken into account, that the Y^0K pair production cross section will be of the order of 1 mb.

Comparison of the results of Maenchen et al.[6] with our result $\sigma(Y^0K) = 0.8 \pm 0.25$ mb indicates that the Y^0K-pair production cross section apparently remains almost constant with an increase in the π^- meson energy.

In calculations based on statistical theory[7] for the probability of the production of different pairs of strange particles, we obtain the following values relative to the total π^-p interaction cross sections: $w(\Lambda^0K) = 3.8\%$, $w(\Sigma K) = 6.8\%$, and $w(K\overline{K}) = 1.1\%$. If we take $\sigma(\Sigma^0K) = \frac{1}{3}\sigma(\Sigma K)$ and $\sigma(K^0\overline{K}) = \frac{3}{4}\sigma(K\overline{K})$, we obtain $\sigma(Y^0K) = 0.06\,\sigma_t$, or 1.5 mb; $\sigma(K^0\overline{K}) = 0.008\,\sigma_t$, or 0.2 mb.

We compare the ratios of the cross sections $\sigma(Y^0K)$ and $\sigma(K^0\overline{K})$ obtained experimentally with those calculated from statistical theory:

$$\sigma(Y^0K)_{\text{expt}}/\sigma(K^0\overline{K})_{\text{expt}} = 0.7,$$

$$\sigma(Y^0K)_{\text{theor}}/\sigma(K^0\overline{K})_{\text{theor}} = 7.5.$$

Comparison of our results with those calculated from statistical theory does not even give qualitative agreement.

If we consider the Y^0 hyperon as a bound state KN (Goldhaber's scheme), then, as was shown by Markov,[8] the production cross section for $K\overline{K}$ pairs increases with the energy of the primary π^- meson. From this viewpoint, it would be of great interest to consider the behavior of the $K\overline{K}$-pair production cross section for π^- meson energies higher and lower than ours.

2. Mean multiplicity of charged particles. Apart from strange particles, several other charged and neutral particles are produced at 6.8 Bev. We shall compare the mean multiplicities for the production of strange particles and for ordinary multiple production of π mesons[5] at the same energy. The mean number of charged particles for multiple production of π mesons is $\overline{n}_s = 3.2 \pm 0.2$. In cases of strange-particle production, the observed mean number of charged particles is $\overline{n}_s = 2.5 \pm 0.1$.

Most of the charged particles are undoubtedly π mesons. Since part of the energy is expended on the production of strange-particle pairs, less energy remains for the production of π mesons. One may then expect that the number of π mesons produced together with strange particles is less than in the case of ordinary multiple production of π mesons. This is in agreement with our results. We have already mentioned above that 14% of the cases have a pair due to the conversion of γ quanta, while for multiple production of π mesons the γ-quanta stars constitute 21%. If it is assumed that the number of electron-positron pairs from conversion γ quanta is proportional to the number of π^0 mesons, then the ratio of the number of π^0 mesons with the production of strange particles to the number of π^0 mesons in ordinary multiple production is 2 : 3, while for charged particles, this ratio is not preserved.

If we take the ratio 2 : 3 for $\pi^\pm$ mesons too, then, in the case of the production of charged particles, the mean multiplicity of the charged particles should be $\overline{n}_s = 2.0$, i.e., 0.5 less than in ordinary $\pi^\pm$-meson production. This difference can be attributed to $K^\pm$ mesons accompanying the production of neutral strange particles.

In fact, if we estimate the fraction of charged K mesons by another method, we obtain the same results, namely, $\overline{n}_{K^\pm} = 0.5$. This was estimated on the basis of observed reactions, where we have taken into account: a) decays of Λ^0 and K^0 particles into neutral particles, b) decays outside the chamber volume.

We have omitted cases in which V^0 decays were not observed, as we considered these to be ordinary multiple production of π mesons. But since we already know the probability of Λ^0- and K^0-particle decay into charged particles

$$\eta_{\Lambda^0} = (1 - f_{\Lambda^0}), \qquad \eta_{K^0} = (1 - f_{K^0}),$$

then the probability of recording decays into charged particles

$$\eta'_{\Lambda^0} = (1/W_1W_2)_{\Lambda^0}, \qquad \eta'_{K^0} = (1/W_1W_2)_{K^0}$$

can be determined as follows:

$$\overline{n}_{K^\pm} = [\eta_{\Lambda^0}\eta'_{\Lambda^0}N_{\Lambda^0K^+} + \eta_{K^0}\eta'_{K^0}N_{K^0K^\mp}] \times [\eta_{\Lambda^0}\eta'_{\Lambda^0}N_{\Lambda^0K^+} + \eta_{K^0}\eta'_{K^0}N_{K^0K^\pm} + (\eta_{\Lambda^0}\eta'_{\Lambda^0} + \eta_{K^0}\eta'_{K^0})N_{\Lambda^0K^0} - n_{\Lambda^0K^0} + 2(\eta_{K_0}\eta'_{K^0}N_{K^0\overline{K}^0} - \tfrac{1}{2}n_{K^0\overline{K}^0})]^{-1} = 0.5 \pm 0.12,$$

where $N_{\Lambda^0K^+}$, $N_{K^0K^\pm}$, $N_{\Lambda^0K^0}$, and $N_{K^0\bar{K}^0}$ are taken from Table II and $n_{\Lambda^0K^0}$ and $n_{K^0\bar{K}^0}$ are the observed number of Λ^0K^0 and $K^0\bar{K}^0$ pairs.

3. Angular and momentum distributions. The angular distribution of Λ^0 hyperons produced in π^-p interactions close to the threshold has been studied in detail. An analysis of the S- and P-wave amplitudes has been made.[1]

Such an analysis cannot, of course, be made at 6.8 Bev. Only general ideas can be used to explain the angular distributions of the secondary particles.

From the angular distribution of single Λ^0 hyperons (Fig. 2), it is seen that they have a very strong tendency to be emitted backward in the c.m.s. Such an asymmetry can result from a background of interactions with quasi-free nucleons of carbon (in the propane molecule). In fact, even in the most unfavorable case, when the entire contamination from Λ^0 hyperons produced on quasi-free protons (about 20%) is subtracted from the distribution under the assumption that all Λ^0 are emitted backward, there still remains the asymmetry $n_{\Lambda^0 \text{forward}}/n_{\Lambda^0 \text{backward}} = 1:5$. This asymmetry was also observed in cases of Λ^0K^0 pairs. A similar result was obtained for protons in ordinary multiple production of mesons.[5,9]

Table IV

cos θ*	Λ^0K^0		$K^0\bar{K}^0$
	Λ^0	K^0	
1.0— 0.6	0.0	7.0	7.5
0.6— 0.2	5.3	0.0	4.0
0.2— —0.2	0.0	2.2	0.0
— 0.2—0.6	1.2	1.1	1.0
—0.6— —1.0	10.3	3.3	2.4

Table IV shows the c.m.s. angular distributions of Λ^0K^0 and $K^0\bar{K}^0$ pairs. Although the number of these pairs is small, the basic character of these distributions is evident: The Λ^0 hyperons are emitted backward, while the K^0 mesons are emitted forward, although this tendency is not so marked here. Owing to the poor statistics, we cannot consider the angular distribution of $K^0\bar{K}^0$ pairs in greater detail. It is seen from Fig. 4 that the K^0-meson angular distribution actually extends forward to an extent depending on the multiplicity of the secondary charged particles. When $n_s = 0$ or 2, it is not symmetric, and when $n_s = 4$ or 6, the distribution is practically isotropic.

In Figure 5b, the c.m.s. angular distribution is given for π^- mesons produced together with a Λ^0 hyperon. It is seen that the π^- mesons are emitted preferentially forward in the case of low multiplicity ($n_s = 2$). The ratio $n_{\pi^- \text{forward}}/n_{\pi^- \text{backward}}$ is 1.7 ± 0.5. When $n_s \geq 4$, the anisotropy in the distribution is less marked, although the statistics here are poor and it is not possible to make a quantitative estimate. A qualitative comparison of the distribution of π^- mesons produced together with Λ^0 hyperons indicates that they are of the same character. The behavior of the π^- mesons produced in both types of interactions is of the same character as the behavior of K^0 mesons.

Birger et al.,[5] Maenchen et al.,[6] and Belyakov et al.,[9] who studied multiple production in π^-p collisions, obtained similar results. It was established that the proton travels in the same direction as it did prior to the interaction, i.e., it travels backward in the c.m.s., while the π^- mesons are emitted forward in the case of low multiplicity and are distributed approximately isotropically as the multiplicity increases. The π^--meson momentum distributions in ordinary multiple production[5] and in production together with a Λ^0 hyperon are very similar. This is plainly seen from Fig. 6. On the basis of the similarity in the momentum and angular distributions, we can consider, as a first approximation, that the Λ^0 hyperon and nucleon (as baryons) are in one group and the K and π (as mesons) are in another group.

The character of the Λ^0-hyperon angular distribution is connected with the Λ^0 momentum distribution. Since a very small part of the Λ^0 hyperons are emitted forward, it may be expected that the probability of a large momentum transfer during the collision is small, i.e., the spectrum of Λ^0 hyperons emitted forward is soft. From Fig. 1a, it is seen that this is in agreement with our experimental results.

4. Transverse momenta. One of the interesting facts is, perhaps, that Λ^0 hyperons and nucleons in inelastic interactions without the production of strange particles have the same distributions and the same mean transverse momenta independently of the multiplicity. In references 5 and 9, the transverse momenta were measured for protons for various multiplicities. Within the limits of experimental error, the values of the transverse momenta coincide with our results.

The calculated rms transverse momentum for Λ^0 and K^0 particles is approximately equal to 400 Mev/c. Using the uncertainty relation $\Delta p \Delta r \geq \hbar$, we can estimate the radius of the region of interaction responsible for the production of strange particles: $\Delta r \geq \hbar/\Delta p \approx \hbar/3m_\pi c = 4 \times 10^{-14}$ cm.

It is interesting to note that the dimensions of the region of interaction in the case of strange-particle production and in ordinary multiple production almost coincide.

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