PRODUCTION OF STRANGE PARTICLES IN THE INTERACTION BETWEEN 9-Bev PROTONS AND EMULSION NUCLEI

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The frequency of production of strange particles by the collision of high energy protons with photoemulsion nuclei is examined.

A study of the dependence of the frequency of production of strange particles on the energy of the primary particles was undertaken in the laboratory of the Joint Institute for Nuclear Research. The preliminary results of this work are given below.

The emulsion stack, consisting of 100 pellicles of type BR-450, was bombarded with 9 Bev protons in the proton synchrotron of the Joint Institute for Nuclear Research. The volume of the emulsion chamber was $10 \times 10 \times 4.5$ cm. The pellicles are scanned by areas, and nuclear disintegrations caused by the primary protons are located. For the detection of hyperons and K mesons, one observed the tracks of singly-charged particles found among the disintegrations. The indicated tracks were traced up to their stopping point, decay, nuclear interaction, or exit from the chamber. The identification of strange particles was made by their characteristic appearance in decay and nuclear capture.

The comparatively small dimensions of the stack prevented the investigation of particles with long ranges outgoing at large dip angles.* To study high-speed particles the initial nuclear splittings were chosen near that edge of the stack which was turned toward the primary current. Secondary particles satisfying the following three conditions were traced:

(a) The outgoing particle is in the forward hemisphere. (This does not cause the loss of strange particles, because they, as will be later evident, are fundamentally outgoing in the forward direction.)

(b) The length of the horizontal component of the track in one pellicle is ≥ 3 mm, corresponding to a dip angle $\leq 7.5°$. (This condition also excludes a large quantity of slow protons and deuterons formed in the decay of excited nuclei.)

(c) The ionization is not less than 1.6 times the ionization of the primary proton. (From this, the velocity of the particle $\beta \leq 0.64$.)

When the above conditions are satisfied, the probability of recording the decay of a hyperon inside the stack is $\geq 85\%$. In such a manner, 1920 stars were got in thirty pellicles from the center part of the stack, and 670 tracks of secondary particles were traced. Six strange particles were found, three hyperons and three K^+ mesons. In addition, one ovserved in one case a sharp break (about 160°) in the track of a strongly ionized particle, which might have corresponded either to the large-angle scattering of a proton or to the decay of a hyperon to a proton. The absence of a change of ionization before and after the break and also the insufficient length of the track ($\sim 2200\,\mu$) prevented identifying the particle. The results of these tracings are the following:

Total number of measured prongs	670
Prongs without visible events at their ends	494
Strange particles	6
$\pi^\pm$ mesons	19
Number of secondary reactions*	53
Number of tracks leaving the stack	94

It can be seen that, on an average, one strange particle corresponds to 100 secondary particles. Just such a magnitude was got in the work of Edwards et al.[1] carried out with π^- mesons having energies ~ 4.5 Bev. In references 2 and 3, covering work done with cosmic rays, one strange particle appears, on an average, for every 250 or 300 ordinary particles. However, a rigorous

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*All the tracks of secondary particles were followed to their stopping place or exit from the stack. No strange particles were found in these cases.

comparison of the various results is not possible due to some differences in the conditions of examination and choice of the particles.

The large magnitude of the ratio of the number of strange particles to the number of $\pi^{\pm}$ mesons, $(N_{\Sigma,K}/N_{\pi^{\pm}}) \sim 1/3$, is remarkable. In an analogous work[3] the ratio $\sim 1/10$. It must be emphasized that these numbers refer only to the slow secondary particles outgoing in the forward direction.

For the evaluation of the cross section for production of slow strange particles by the photoemulsion nuclei, it is essential to know the cross section for star-formation and the frequency of appearance of strange particles, calculated for one star. In Fig. 1 the distribution of stars according to the number of black and gray prongs is depicted, both for stars found by track scanning (solid lines) and for those found by area scanning (dotted lines). The comparison of the solid and dotted histograms allows one to make a small correction, connected with the unobserved small-angle disintegrations, to the number of prongs. To determine the frequency of appearance of the strange particles, it is necessary to know the spatial distribution of particles having velocities $\beta \leq 0.64$ and a range, $l \geq 3$ mm. If we suppose that this is of the form $1 + a \cos \psi$, it follows from the experimental data that $a \sim 1$. Under these conditions the frequency of appearance of strange particles (for $\beta \leq 0.64$ and $l \geq 3$ mm) is about 0.042 per star. From the composition of elements in the NIKFI emulsion[4] and from the magnitude of the free range for the inelastic interaction of protons of energies ~ 9 Bev with photoemulsion nuclei, one gets a magnitude of ~ 460 millibarn for the star-formation cross section. This leads to the cross section for the production of slow strange particles, $\sigma_{\Sigma,K} \sim 20$ millibarn.

Besides the method described for distinguishing hyperons and heavy mesons, other events which could be strange particles are located in the area scanning: two-pronged stars, decays of various types and nuclear captures. The corresponding particles were traced in the reverse direction to find their parent disintegrations. In such a way 24 strange particles were found, a large part of which were formed in stars produced by primary protons. The collected data for all the strange particles found are given in Tables. I and II.

From the tables it follows that the majority of strange particles are outgoing in the direction of the forward hemisphere. We note also that all the π mesons formed in the decay of a Σ hyperon in flight are outgoing backwards in the center of mass system (except for hyperon No. 8, whose parent star was produced by a neutral particle).

Stars formed by primary protons and containing slow strange particles, found in the area search, have a somewhat increased number of gray and black prongs, N_h. In fact, for this group of stars we have $\langle N_h \rangle = (12.5 \pm 2.1)$ and $\langle n_s \rangle = (2.9 \pm 0.5)$; for the same time for ordinary stars, formed by primary protons, $\langle N_h \rangle = (8.3 \pm 0.5)$ and $\langle n_s \rangle = (3.4 \pm 0.1)$.[5] This fact evidently means that the production of hyperons and heavy mesons stems predominantly from the heavy nuclei of the photoemulsion. An analogous remark was made in a series of other papers (see, for example, reference 6).

In the stars containing strage particles, all the other prongs were also traced. The production of a second strange particle was observed in three cases, in one of which a pair of K mesons (K^+

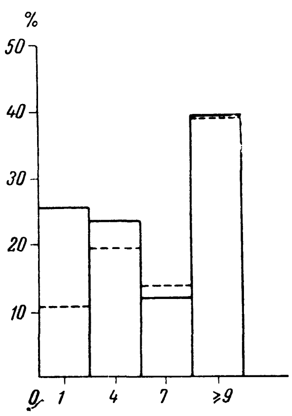

FIG. 1

TABLE I. Heavy mesons

No.	Particle	Type of parent star	Production angle of K meson, deg	K meson range, Mev	No.	Particle	Type of parent star	Production angle of K meson, deg	K meson range, Mev
1[1]	K^+	$5+3\ p$	54	14	10[3]	K^+	$11+0\ p^*$	—	21.8
2[2]	K^+	$22+3\ p$	8	56.6	11[4]	K^+	$6+1\ p$	49	57.1
3	K^+	$14+7\ p$	48	22.5	12	τ^+	$21+4\ p$	72	12.8
4	K^+	$4+4\ p$	41	4.4	13	τ^+	$21+0\ p$	44	30.7
5	K^+	$7+0\ n$	—	54	14[5]	K^-	$6+1\ p$	20	50.6
6[3]	K^+	$4+0\ p^*$	—	59	15	K^+	Entered the stack from below		
7	K^+	$6+5\ p$	86	50.4	16	K^+	Entered the stack from below		
8[3]	K^+	$3+0\ p^*$	—	17.3	17	K^+	Entered the stack from below		
9	K^+	$14+1\ p$	91	52.3					

[1]Formed in a pair with hyperon No. 4 (see Table II).
[2]Formed in a pair with hyperon No. 5 (see Table II).
[3]Stars with p* produced by secondary charged particles.
[4]Formed in a pair with K meson No. 14.
[5]The method adopted for the strange particle search does not guarantee that the ratio obtained for the number of K^+ and K^- mesons corresponds to reality.

TABLE II. Hyperons

Primary						Secondary		
No.	Particle	Type of parent star	Production angle, deg	Length of hyperon path, mm	Energy	Particle	Range, mm	Center of mass exit angle, deg
1	Σ^-	$4+3\,p$	42	53.2	217	π^-	15.3	168
2	$\Sigma^\pm$	$21+1\,p$	84	16.5	96	$\pi^\pm$	—	113
3	$\Sigma^\pm$	$18+5\,p$	89	0.80	~ 42	$\pi^\pm$	—	~ 121
4	Σ^+	$5+3\,p$	20	28.6	800	π^+	11.5	154
5	Σ^-	$22+3\,p$	29	16.8	115	π^-	33.2	155
6	$\Sigma^\pm$	$2+1\,p$	37	10.6	~ 67	$\pi^\pm$	—	~ 120
7	Σ^+	$12+4\,p$	91	4.4	37	$\pi^\pm$	—	51
8	$\Sigma^\pm$	$8+0\,n$	—	4.8	~ 55	π^+	—	~ 82
9	$\Sigma^\pm$	$15+6\,p$	47	4.5	~ 90	$\pi^\pm$	—	~ 102
10[1]	Λ^0	$18+2\,p$	3	0.164	140	—	—	—
11[2]	Λ^0	—	133	—	20	—	—	—
12[2]	Λ^0	—	152	—	36	—	—	—
13[2]	Λ^0	—	19	—	112	—	—	—
14[2]	Λ^0	—	77	—	35	—	—	—
15[3]	*Hf*	$11+4\,p$	90	0.020	—	—	—	—
16[4]	*Hf*	$22+3\,p$	63	0.284	—	—	—	—

[1]Decayed beside parent star.
[2]The production angle of the Λ^0 hyperon changed relative to the direction of the primary protons.
[3]Mesonic decay.
[4]Non-mesonic decay.

and K^-) was formed. In the other two, a hyperon and K^+ meson were found.

The kinetic energies and production angles were measured for all Σ hyperons formed in stars produced by primary protons. The corresponding points are plotted in Fig. 2, which shows also the limiting curves for energies and angles of Σ hyperons formed in the reaction

$$P+N \rightarrow \Sigma + K + N. \quad (1)$$

The solid curve corresponds to a rigid target nucleus, the dotted one takes into account internal nuclear motion. The possibility of producing various numbers of π mesons in reaction (1) can be accounted for only by the restriction that limiting curves for such reactions must lie within the solid and dotted curves shown in Fig. 2. Therefore, the presence of the points distributed outside of the limiting curves shows that the production of the hyperons considered must be connected, at least partly, with reactions more complicated than reaction (1). Here two possibilities must be considered:

(a) The hyperons are possibly formed by some kind of secondary particle, for example, a π meson, in its interaction with nucleons of the parent nucleus (see, for example, reference 6).

(b) The hyperons are originally formed in a type (1) reaction but in their further passage through the parent nucleus they can experience interactions leading to changes of energy and direction of motion.

Apparently both these possibilities are realized.

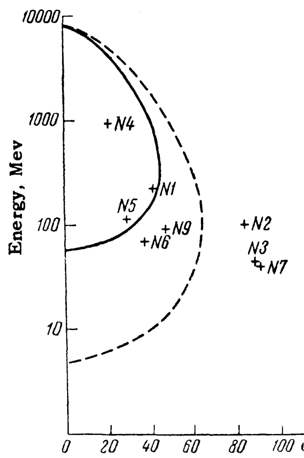

FIG. 2

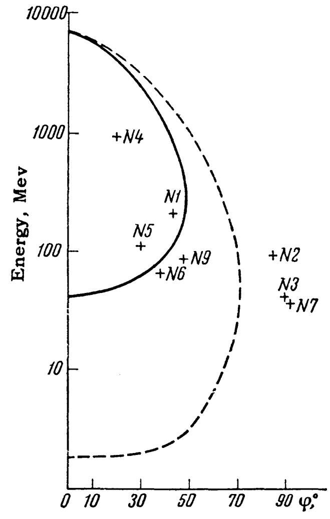

FIG. 3

Actually, a kinematic analysis shows that, taking into account the intranuclear motion of the target nucleon, both cases of pair production of a Σ hyperon and a K^+ meson agree with the scheme

$$\pi + N \rightarrow \Sigma + K. \quad (2)$$

On the other hand, it is apparently impossible to connect the formation of hyperons no. 2, 3 and 7 with reaction (2). In Fig. 3 the limiting curves for Σ's formed in reaction (2) are given. The solid line again corresponds to a rigid target nucleus, the dotted line includes intranuclear motion. The energy of the π meson chosen is 8 Bev, which corresponds to the maximum possible energy for

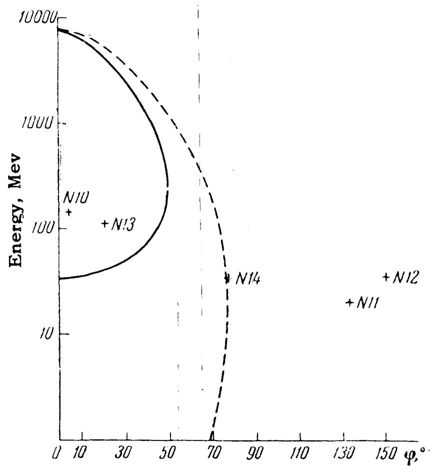

FIG. 4

π's produced by protons with E ~ 9 Bev.* The direction of production of the π is calculated as coinciding with the direction of motion of the primary proton (see reference 7). It follows from Fig. 3 that hyperons 2, 3 and 7 fall outside the region enclosed by the limiting curves. It is natural to suppose that they experienced interactions inside the parent nucleus.†

Analogous reasoning can be carried out for Λ particles, some of which are observed to be produced at such large angles as 133° and 152°. The corresponding data, together with their limiting curves, is shown in Fig. 4 for the reaction

$$P + N \rightarrow \Lambda^0 + K + N. \quad (3)$$

If we look at the reactions in which Λ^0 particles are formed through intermediate pions of high energy (close to 8 Bev), then even in this case the formation of Λ^0 particles 11 and 12 is kinematically impossible.

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*When the π-meson energy decreases, the regions enclosed by the limiting curves shrink. The same applies to the reactions of the type $\pi + N \rightarrow \Sigma + K + n\pi$.

†Of course, the formation of hyperons through the absorption of slow K^- mesons inside the parent nucleus is not excluded.

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