PRODUCTION OF CHARGED HYPERONS BY 9-Bev PROTONS INTERACTING WITH PHOTOGRAPHIC EMULSION NUCLEI

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The angular distribution of $\pi^{\pm}$ mesons from decaying $\Sigma^{\pm}$ hyperons, produced by interaction of 9-Bev protons with emulsion nuclei, was investigated. An estimate is obtained of the charge composition of the hyperons. The value of the cross section for the production of charged hyperons on emulsion nuclei is estimated.

CONDITIONS OF THE EXPERIMENT

Two pellicle stacks measuring $10 \times 10 \times 6$ and $10 \times 15 \times 4$ cm (stacks 1 and 2 respectively), and made up of NIKFI type BR-400 emulsions were used. The stacks were exposed to the 9-Bev proton beam from the proton synchrotron of the High-Energy Laboratory. The purpose was to investigate, in particular, the angular distributions of the charged-hyperon decay products; principal attention was therefore paid to finding the hyperons by a method as free as possible from experimental sampling, and also to a careful identification of the observed decay events. In this connection, the search for hyperons was conducted by continuing the tracks in stars produced by primary protons. The particle-decay events in flight produced by one relativistic particle were registered. The cases thus obtained could be due to decay in flight of either $\Sigma^{\pm}$ hyperons or $K^{\pm}$ mesons, with the admixture of the latter being exceedingly insignificant, owing to the large difference between the lifetimes of these particles.

The final identification of the decaying particle was by measuring the multiple scattering and the ionization. The prongs, produced by the primary protons, which were to be continued satisfied certain energy and geometry conditions. These conditions, as well as the details of searching and identifying the hyperons decaying in flight by the scheme $\Sigma^{\pm} \rightarrow \pi^{\pm} + n$, are given in reference 1.

The entire procedure of finding and processing was the same for both stacks, except that in stack 1 primary stars with $N_h \geq 10$ were selected, while the selection in stack 2 was independent of the number of prongs in the stars. A total of 76 $\Sigma^{\pm} \rightarrow \pi^{\pm} + n$ decays in flight were found, of which 33 were in stack 1 and 43 in stack 2.*

*Deceased.

RESULTS

1. Angular distribution of the $\Sigma^{\pm}$-hyperon decay products. Solov'ev[2] emphasized the importance of investigating the longitudinal asymmetry in the angular distribution of the pions produced in the decay of hyperons. As was already reported in reference 1, we undertook to refine the data on the angular distribution of the $\pi^{\pm}$ mesons from the decay of $\Sigma^{\pm}$ hyperons. The resultant angular distribution in the hyperon rest system relative to its direction of motion is shown in Fig. 1.

If we approximate the distribution by the expression $1 + a \cos \theta^*$, then the coefficient of asymmetry is found to be

$$a \equiv \alpha \overline{P}_{\Sigma} = \frac{3}{N} \sum_{i=1}^{N} \cos \theta_i^* \pm \left(\frac{3 - a^2}{N}\right)^{1/2} = 0.03 \pm 0.2,$$

where α is the coefficient of asymmetry for complete polarization of the hyperons, $\overline{P}_{\Sigma}$ is the component of the vector of the average polarization of the Σ hyperon along the direction of its motion, θ_i^* is the angle between the direction of hyperon flight and the pion flight in the rest system of the hyperon, and N is the number of observed hyperons.

We also investigated the angular distribution of

*Stack 1 was scanned in the High-Energy Laboratory of the Joint Institute for Nuclear Research, while stack 2 was scanned in the Physics Institute of the Georgian Academy of Sciences, and at the Tbilisi State University.

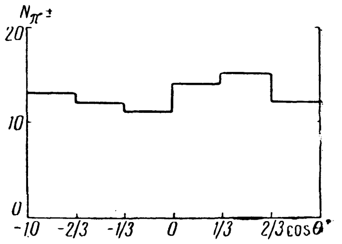

FIG. 1. Angular distribution of $\pi^\pm$ mesons in the rest system of the hyperon, relative to the direction of its motion.

the pions relative to the plane of creation of the Σ hyperons. The normal to the plane of creation was determined by the vector product $[\mathbf{p} \times \mathbf{\Sigma}]$ where $\mathbf{p}$ and $\mathbf{\Sigma}$ are unit vectors in the direction of motion of the proton beam and the hyperon respectively, and the "upward" and "downward" directions relative to this plane were determined from the sign of the mixed product $[\mathbf{p} \times \mathbf{\Sigma}] \cdot \pi$. The coefficient of asymmetry of this distribution is

$$b = 2\,(N_{\rm up} - N_{\rm down}) / (N_{\rm up} + N_{\rm down}) = 0.36 \pm 0.22.$$

2. Angular and energy distributions of the $\Sigma^\pm$ hyperons. Two corrections were introduced in the angular and energy distributions of the $\Sigma^\pm$ hyperons. The first took into account the hyperons that decayed beyond the potential range. This correction amounts to approximately 16% of the observed number of hyperons. The second correction is purely geometric, and is connected with the circumstance that not all the hyperons traveling in the forward hemisphere relative to the motion of the beam proton have been registered, but only those for which the dip angle did not exceed 7.5° (reference 1).

Figure 2 shows the resultant angular distribution of $\Sigma^\pm$ hyperons with allowance for the corrections. As can be seen from the distribution, it can apparently be assumed that practically all the hyperons produced by interactions of 9-Bev protons with the emulsion nuclei are emitted in the forward hemisphere. Then, taking the foregoing corrections into account, the total number of hyperons is 488.

Figure 3 shows the total energy spectrum of charged hyperons. We see that the spectrum has a maximum and a sufficiently sharp fall-off towards higher energies. In addition, there are no hyperons with energies greater than 290 Mev, although hyperons with energies 410 — 420 Mev could have been registered according to the search rules applied in the present investigation. It is not excluded that these peculiarities of the spectrum are due to the fact that the produced hyperons interact effectively with the nucleons contained in the parent nucleus.

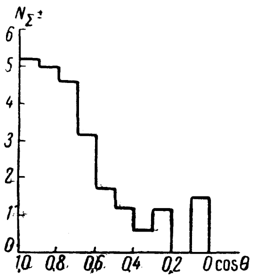

FIG. 2. Angular distribution of $\Sigma^\pm$ hyperons. The number of hyperons is given in arbitrary units.

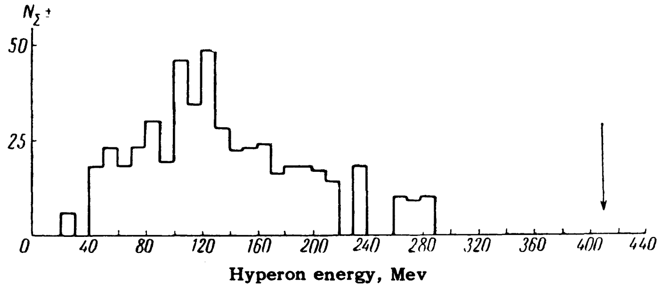

FIG. 3. Experimental energy spectrum of charged hyperons. The arrow indicates the upper limit of the hyperon energy which could still be registered.

Figure 4 shows the limiting curves for angles and the kinetic energy of the Σ hyperons produced in the reactions

$$p + N \rightarrow \Sigma + K + N, \qquad (1)$$
$$\pi + N \rightarrow \Sigma + K, \qquad (2)$$

calculated with allowance for the intranuclear motion of the nucleons. The possible generation of a certain number of additional pions in reactions (1) and (2) can cause only a narrowing of the limiting curves, which in this case will be completely located inside the corresponding curves of Fig. 4. The limiting curve of reaction (2) was calculated for an 8-Bev pion, corresponding to the maximum energy possible for pions generated by 9-Bev pro-

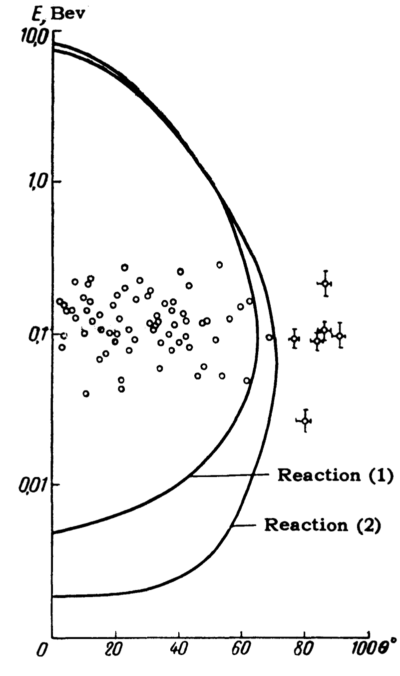

FIG. 4. Limiting curves for the angles of emission of hyperons in a laboratory system of coordinates, θ, and of the kinetic energy E of the Σ hyperons, produced in reactions (1) and (2).

tons, and emitted in the direction of the beam.*

Among the 76 hyperons shown in Fig. 4, six cases have been noticed which did not fall within the 3-fold error limits into the region bounded by the limit curves. It is natural to assume that these hyperons were initially produced in reactions (1) and (2), but upon further passage through the parent nucleus they experienced a nuclear interaction. Nor is it excluded that they were formed in an interaction between a primary proton and a nuclear tunnel.

3. Signs of Σ hyperons and the cross section for the creation of charged hyperons. The statistical estimate of the ratio of the number of positive to negative hyperons was obtained from a comparison of the times of flight of all the observed hyperons, from the point of their production to the point of decay, with the average time of flight expected at the given differential range under the assumption that all the observed hyperons are Σ^+ or Σ^- hyperons.

In the calculation of the average value of the time of flight of each hyperon, in the two variants indicated above, the average lifetimes with Σ^+ and Σ^- hyperons were taken to be respectively 0.75×10^{-10} sec, and 1.59×10^{-10} sec.[3] The fraction of Σ^+ hyperons was found to be 0.62 ± 0.07. If one considers that the ratio of the decay frequencies of Σ^+ hyperons along the two possible channels is unity, we obtain for the ratio of the positive to negative hyperons

$$N_{\Sigma^+}/N_{\Sigma^-} = 3.2 \pm 1.0.$$

An estimate of the cross section for the generation of the hyperons was made separately for stacks 1 and 2. Necessary information concerning the mean free path for the interaction of the 9-Bev protons with the emulsion nuclei, on the percentage of interactions of the 9-Bev protons with the light and heavy nuclei of the emulsion, and on the elementary composition of the emulsion used to calculate the cross section were taken from references 4 — 6. The following values for the cross section σ_g for the generation of charged hyperons in interactions between the primary protons and emulsion nuclei (stack 2), and heavy emulsion nuclei (stack 1) respectively were obtained:

$$\sigma_g^{\text{e.nuc.}}(\Sigma^\pm) = 4.2 \pm 0.9 \text{ mb}, \quad \sigma_g^{\text{h.nuc.}}(\Sigma^\pm) = 3.7 \pm 0.9 \text{ mb},$$

It is easy to show from general considerations of isotopic invariance that in the interaction of primary protons with nuclei having zero isotopic spin, the number of produced charged Σ is twice the number of neutral Σ hyperons. The emulsion nuclei satisfy in practice these conditions. Therefore

$$\sigma_g^{\text{e.nuc.}}(\Sigma^{\pm,0}) = 6.3 \pm 1.4 \text{ mb}, \quad \sigma_g^{\text{h.nuc.}}(\Sigma^{\pm,0}) = 5.6 \pm 1.4 \text{ mb}.$$

4. Additional remarks. In this investigation we traced all the black and grey prongs in 76 stars, in which Σ hyperons decaying by the scheme $\Sigma^\pm \to \pi^\pm + n$ were observed. As a result we found four cases of paired production of a Σ^+ and K^+ meson, two cases of paired production of K^+ and K^- mesons, and a case of production of two hyperons in a single star. A star of the type (17 + 7p) contained two "grey" particles decaying in flight per relativistic particle. The values of the masses of these particles, obtained from the results of measurement of multiple scattering and ionization, were found to be

$$m_1 = (1.78 \pm 0.45)\, m_p, \quad m_2 > (1.91 \pm 0.44)\, m_p.$$

Assuming that both particles are hyperons, it must be admitted that this star contained also neutral or charged K mesons, which were not observed.

In addition, in the continuation of the selected prongs we observed one case of annihilation of an antiproton in flight. The range of the antiproton from the parent star to the point of annihilation was 17.4 mm. The kinetic energy of the antiproton at the point of annihilation was $A_{\text{kin}}(\bar{p}) = 92 \pm 15$ Mev. The annihilation star contains 9 "black" and "grey" particles, and one relativistic particle.

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*It should be noted that as the energy of the incoming pion is decreased, the region covered by the limiting curve becomes narrower.

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