ANALYSIS OF STARS CONTAINING HYPERFRAGMENTS, PRODUCED IN EMULSION BY 9-BeV PROTONS

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A study was made of stars in emulsion, containing hypernuclei, produced by 9-BeV protons. Fast particles were identified and their momenta determined. The transverse momentum was found to equal 430 ± 140 MeV/c for K mesons and protons and 250 ± 150 MeV/c for π mesons. It has been concluded that Λ^0 particles are mainly produced in the $N + N \rightarrow N + \Lambda^0 + K$ reaction; that the Λ^0 particles move backwards in the c.m.s., and that the K meson and the nucleon may possibly form in the final state a bound system which subsequently decays.

IN the present article we report the results of a study of the angular and energy distributions of fast singly-charged particles in previously found 20 stars containing hyperfragments. [1]

The emulsion method, normally used to identify hypernuclei and to find their binding energy, can yield valuable information concerning the production mechanism of strange-particle pairs in nuclear matter and the interaction of unstable particles with each other and with nucleons during the hypernucleus production. In spite of the small number of events available, we find it possible to draw definite conclusions concerning the mechanism of hyperfragment production by protons on emulsion nuclei from the analysis of the primary stars in which the hypernuclei were produced.

It should be noted that the stars containing hyperfragments differ from both normal emulsion stars and from stars containing strange particles. Table I contains the comparative characteristics of the three types of emulsion stars produced in the irradiation by 9-BeV protons.

A comparison of the stars containing hypernuclei with the stars containing strange particles leads to the conclusion that the specific features of hyperfragment production are mainly reflected in the properties of fast particles. The number of such particles (with ionization $\leq 1.4\ g_{min}$) amounts to only half of the number of fast particles present in normal stars. One could attempt to explain this in the following way: Let us assume that the Λ^0 particles, which ultimately form the hyperfragment, are produced in nucleon-nucleon interactions inside the nucleus. As shown by a statistical calculation, [7] the main contribution is then due to the reaction $N + N \rightarrow N + K + \Lambda^0 + i\pi$ ($i = 0, 1, 2, 3$). In any mechanism of hypernucleus production, in order to combine with a fragment outside the parent nucleus, the Λ^0 particle must have small relative momentum, and since the energy of the fragment with which it combines is always very low, the Λ^0 particle must have very low energy in the laboratory system, as compared, let us say, with its energy in the c.m.s. of the colliding nucleons in the parent interaction. The remaining particles (N, K, or π) will, with a large probability, have a high energy, and can be considered as having an ionization $\leq 1.4\ g_{min}$. It is then easy to calculate the mean number of such particles per interaction, which is found to equal 2.0. Since the experimental

Table I

Type of disintegration	Mean number of particles: Fast	Mean number of particles: Slow	Bibliography
Normal stars	3.2±0.2	7.8±0.5	[2]
	3.4±0.1	8.3±0.5	[3]
Stars with strange particles	4.2±1.2	15.6±0.4	[4]
	4.3±0.6	13.7±1.9	[5]
Stars with hypernuclei	2.9±0.5	12.5±2.1	[6]
	1.6±0.3	14.0±1.4	Our data

value is even smaller, we can conclude that the contribution of particles of cascade origin to the number of fast particles in the stars containing hypernuclei is negligibly small. First of all, in such stars the intranuclear cascade is totally absorbed in the nucleus. This in turn explains the appearance of a large number of grey and black tracks in stars containing hyperfragments.

It remains for us to make one more remark.

At first sight, attention is drawn to the fact that the number of thin tracks in normal stars in emulsions irradiated by 9-BeV protons [8] is similar to that of fast particle tracks in our stars. If it is so, then the interpretation of the origin of the fast particles in the stars containing hyperfragments becomes ambiguous; the parent disintegrations in the case of hyperfragments apparently do not differ from the stars with usual fragments. The proposed mechanism of fast-particle production in stars containing hyperfragments could take place also in this case, but we should consider the possibility of a different mechanism, common to both fragmentation and hyperfragment production. The idea of fragmentation as of a process leading to the production of fragments and hyperfragments is attractive in itself. A more careful study shows, however, that the stars containing hyperfragments have different characteristics as compared with disintegrations containing normal fragments only.

Perfilov et al [8] regarded as thin all tracks of singly-charged particles with energy ≥ 1000 MeV for protons. To this energy corresponds an ionization $\leq 1.12\ g_{min}$. The fraction of particles in the ionization range $1.12-1.40\ g_{min}$, relative to all fast particles ($g \leq 1.40\ g_{min}$), can be estimated, say, from the shape of the π meson spectrum in the disintegration of emulsion nuclei by 9-BeV protons, [9] and amounts to about half of all particles.

The assumption about the predominant role of the $N + N \rightarrow N + K + \Lambda^0 + i\pi$ reaction in the first stage of the process of hypernucleus production leads to certain characteristic features of the ensemble of fast particles, which can be tested experimentally. First of all, let us compare the calculated and experimental multiplicity distributions of fast particles in stars containing hypernuclei. Such a comparison is given in Table II.

Since the calculation was carried out assuming that the Λ^0 particle interacts strongly with nucleons and π mesons and is produced in the same effective volume, while the K mesons interact with nucleons and π mesons weaker and are produced in a different volume, the agreement between the calculated and experimental data confirms this assumption. We can thus state that the strength of the $\pi\Lambda^0$ interaction is of the same order of magnitude as that of the NN, πN, and NΛ^0 interactions.

Fast particles were identified by relative ionization and scattering measurements. We have measured the relative energy loss as a function of the quantity $p\beta c$ for the NIKFI-R emulsion (Fig. 1). The measurements were carried out using a MBI-8M microscope. False scattering and noise over the working cells were corrected for, having been determined by measuring the tracks of the primary beam particles in close vicinity to the tracks of the identified particles. The ionization due to fast particles relative to that of beam particles was determined by blob counting, using the same reference tracks. The measurements were carried out in a number of consecutive layers, until the particle was well identified.

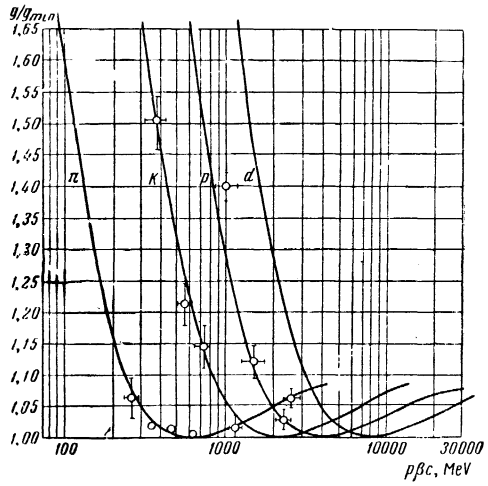

FIG. 1. Relative ionization energy loss as a function of $p\beta c$ for the NIKFI-R emulsion (experimental points corresponding to several particles are shown).

Table II

Type of disintegration	$n_s = 0$	$n_s = 1$	$n_s = 2$	$n_s = 3$	$n_s = 4$
Calculation	—	0.316	0.457	0.175	0.052
Experiment (our data)	0.15	0.35	0.30	0.15	0.05

The measurements enabled us to test other consequences of our assumptions concerning the first stage of the hypernucleus production process by 9-BeV protons. If the $N + N \rightarrow N + K + \Lambda^0 + i\pi$ reaction is really the one responsible for the production of the Λ^0 particle contained in the hypernucleus, all other particles are fast, and secondary effects essentially do not affect the composition and spectrum of fast particles, then a number of K^+ mesons will be present among the fast particles accompanying the hyperfragments, and the angular distribution of all fast particles in the c.m.s. of the two colliding nucleons should exhibit a maximum in the direction of motion of the incident particle. We have estimated the fraction of stars with hyperfragments containing K^+ mesons [7] to be ~ 0.6 of all stars with hypernuclei, and for our sample of stars this fraction is $0.1^{+0.2}_{-0.07}$ at a 5% confidence level. At present, we do not possess sufficient experimental material to discuss the reasons for this discrepancy.

The angular distribution of fast particles in our stars containing hypernuclei is shown in Fig. 2 in the c.m.s. of the two colliding nucleons. No particles going backward were found. Thus, we have to assume that in stars with hypernuclei, the Λ^0 particle produced in an nucleon-nucleon interaction moves backwards in the c.m.s. and, therefore, has a small energy in the l.s. This is one of the necessary conditions for the production of a hypernucleus.

We discuss now some characteristic features of the momentum distribution of fast particles in the investigated stars. We concentrated mainly on the mean value of the transverse momentum of the different particle groups. We found that the measured mean value of the transverse momentum of eleven π mesons was equal to 250 ± 150 MeV/c and of eight protons and three K^+ mesons to 430 ± 140 MeV/c.

In two cases the K^+-meson and proton momenta were measured in the same disintegration in which no other fast particle was present. The transverse momenta in these disintegrations were equal to 600 and 360 MeV/c for K^+ mesons, and to 300 and 390 MeV/c for protons. The equality of the transverse momenta of protons and K^+ mesons may indicate the existence of an intermediate (KN) compound which decays into a nucleon and a K meson.

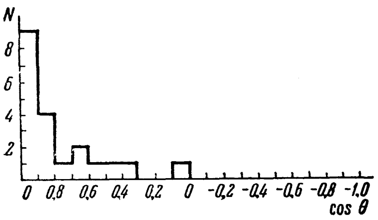

FIG. 2. Angular distribution of fast particles in stars containing hyperfragments produced by 9-BeV protons in the c.m.s. of the two nucleons.

In principle such a bound state could exist, [10] although no resonance in the K^+p scattering cross section has been observed.

The analysis of stars containing hyperfragments, produced in emulsion by 9-BeV protons, leads thus to the following conclusions concerning the first stage of the production mechanism of hypernuclei:

1. The incident nucleon interacts with a nucleon of the nuclear matter. This interaction involves the production of a Λ^0 particle and of a K meson. Other channels of Λ^0 particle production are not effective in the production of hypernuclei by protons with energy up to 9 BeV.

2. Bound states which decay into a nucleon and a K meson may occur among the products of the elementary interaction of nucleons in nuclear matter. [1]

3. It is probable that the production of stars containing hypernuclei is accompanied by a total absorption of the cascade particles, since the number of fast particles is twice as small as in normal stars, and more energy is transferred to the nucleus.

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