FIZIKA, 4 (1972) 87—95

PRODUCTION OF HYPERNUCLEI BY 1.5 GeV/c K^- MESON INTERACTIONS WITH LIGHT NUCLEI (^{12}C, ^{14}N, ^{16}O) IN NUCLEAR EMULSION

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Received 26 December 1971

Abstract: In nuclear emulsion, exposed to 1.5 GeV/c K^- mesons, the interactions on light and heavy nuclei have been investigated. Values for the percentage of K^- interactions on light and heavy nuclei, for both track scanned and area scanned stars, have been found to be in agreement with the calculated results obtained from »transparent nucleus« theory. Percentage of the hypernuclei produced on light nuclei is estimated to be $1.1 \pm 0.25\%$. Analysis of parent stars has been carried out and mechanism of the formation of hypernuclei is discussed.

1. Introduction

Investigations on K^- interactions and the hypernuclear production have so far been carried out mainly with nuclear emulsions. Since nuclear emulsion are composed of the heavy (Ag, Br) and the light (C, N, O) nuclei, the hypernuclei discussed in these studies were produced both on heavy as well as on light nuclei.

From a study of K^- interactions at rest Lemonne et al.[1] have shown that multinucleon K^- interactions on light nuclei are not responsible for a large number of hypernuclei. From 300 MeV/c K^- meson interactions Abeledo et al.[2] concluded that mesonic hypernuclei come mainly from light nuclei. From similar studies at higher energies[3, 4, 5] it has been shown that range of mesonic hypernuclei in emulsion increases with increasing K^- momenta. The latest and a very detailed account of the hypernuclei originating from 1.5 GeV/c K^- meson interactions was given by Cuevas et al.[6]. From this work, which refers to all the previous data, similar kind of conclusions can be drawn.

From all these studies it becomes evident that while the data about K^- interactions with heavy nuclei are extensive, the available data for K^- interaction with light nuclei are meagre. The reasons may be:

— the yield for light nuclear interactions which is too low, and
— the difficulty in selecting light nuclear interactions on the basis of production star analysis.

To carry out a careful analysis of hypernuclei from C, N and O, we tried to classify the interactions with greater accuracy. Our criterion was checked by application to the parent stars and comparing the results with those computed by the application of the »transparent nucleus« theory. Production rate of hypernuclei produced on light nuclei was estimated keeping in view the conclusions drawn from the identification of hypernuclei. Production rate of hypernuclei has been found and mechanism of their formation has been discussed.

2. *Experimental techniques and results*

Exposure and beam composition. A stack of Ilford G5 emulsion pellicles, exposed to a separated beam of 1.5 GeV/c K^- meson at CERN PS, was used. The beam composition was $2.7\,K^- : 0.4\,\pi^- : 0.6\,\mu^-$[7].

Mean free path. Scanning along the track of incident K^- mesons, we followed 92.16 meters of path. A total of 239 events were collected as given in Table 1.

Table 1

Path length (m)	Stars with $N_h \geq 1$	Zero Prong	One light prong $\theta > 5°$	One light prong $\theta \leq 5°$	Total
92.16	213	8	6	12	239

Absorption mean free path was therefore found to be

$$\lambda = 41.9^{+1.4}_{-1.8} \text{ cm.}$$

Applying correction against π^- contamination in the beam, the corrected value came out to be

$$\lambda_{K^-} = 42.9^{+2.0}_{-2.2} \text{ cm.}$$

This figure was in agreement with that found by Cuevas et al.[6]. Value of the π^- mean free path was taken from Ronne and Danielson[8].

Percentage of heavy and light nuclear interactions.

a) Track scanned stars: Prongs of the track scanned stars were classified as black, grey, or relativistic applying a criterion based on the grain density values[9]. The criterion to analyse the interactions was as follows:

Heavy nuclei (Ag, Br)

— $N_h > 7$, where N_h gives the total number of black and grey prongs,
— $N_h \leqslant 7$ and a recoil with range < 5 microns,
— $N_h \leqslant 7$, total charge of black and grey prongs $\sum_{i=1}^{n} Z_i > 7$.

Light nuclei (^{12}C, ^{14}N, ^{16}O)

— $N_h \leqslant 7$, no recoil of range $R < 5$ microns, total charge $\sum_{i=1}^{n} Z_i \leqslant 7$. Charge for black prongs was found by track width measurement[10], while for grey prongs it was always taken to be unit.

Observed rate of K^- interactions on light and heavy nuclei was thus found to be 34.4% and 65.5% respectively. Making corrections for the background due to elastic scattering, for K^- interactions on free proton among small stars ($N_h \leqslant 2$), and making a check on the charge of grey prongs the corrected rate was found as 23.7 ± 1.8% for C, N, O and 76.3 ± 2.6% for Ag, Br nuclei.

b) Area Scanned stars: A total of 7750 stars were located when searching areas of 5 pellicles in a systematic manner. It was found that 15.6% of the events were due to C, N, O and 84.4% due to Ag, Br nuclei. Percentage of the light nuclear interactions in this case was lower because of the loss of small stars. Comparing N_h distribution of light nuclear stars from both kind of scannings we estimated that 25% of light nuclear interactions with $N_h \leqslant 4$ were overlooked in the area scanning. Loss of the events with $N_h > 4$ was considered as negligible[11]. Applying this correction, true percentage was found as 18.9 ± 2.0% for light and 81.1 ± 2.9% for heavy nuclear interactions.

Optical model analysis. The following formulae based on »transparent nucleus« theory of Fernbach[12] were used to compute the absorption cross section for K^- interactions

$$\sigma = \pi R^2 \left[1 - \frac{\{1 - (1 + 2\,KR)\, e^{-2KR}\}}{\pi K^2 R^2} \right],$$

where $K = \frac{3}{4\pi R^3} \left[Z\, \sigma_{K^-p} + (A - Z)\, \sigma_{K^-n} \right]$

is the absorption coefficient for the incident particle in nuclear matter, A is atomic weight, Z is atomic number, σ_{K^-p} absorption cross section for K^- — free proton and σ_{K^-n} absorption cross section for K^- — free neutron interactions.

Nuclear radius was taken to be $R = r_0 A^{1/3}$ cm, where $r_0 = 1.3$ fm was assumed to be more or less the same for all nuclei.

Utilizing experimental value of the absorption mean free path $\lambda_{k^-} = 42.9^{+2.0}_{-2.2}$ cm, and using relation $\lambda_k = 1/\sum_{i=1}^{n} n_i \sigma_i$, a value $K = 2.26 \cdot 10^{12}\ \mathrm{cm}^{-1}$ was fitted. Composition of emulsion was given by Bonetti et al.[13]. Percentage of interaction on various nuclei was found as follows:
on Ag, Br 76.9%, on C, N, O 20.6% and on H (free proton) 2.5%. Results are summarized in Table 2.

Table 2

No	Technique	Ag, Br	C, N, O
1	Track Scanning	76.3 ± 2.6%	23.7 ± 1.8%
2	Area Scanning	81.1 ± 2.9%	18.9 ± 2.0%
3	Optical Model	76.9 ± 0.5%	20.6 ± 0.4%

Upper and lower limits in case (1) and (2) were calculated taking into account the number of uncertain events and the statistical errors.

3. *Analysis of hypernuclei*

Production rate. A total of 24943 K^- interactions were located in nuclear emulsions by area scanning. Each grey and black prong was followed in the original plate until it came to rest, left the plate or made a secondary star. All the secondary stars were recorded and then examined for the following possibilities:[14]

— capture of slow negative particles,
— interactions in flight of secondary particles,
— elastic scattering, and
— decay of secondary particles.

Total of 810 hypernuclei were finally separated. Observed rate of hypernuclei (from Ag, Br, C, N, O) from all the interactions was therefore 3.25 ± ± 0.06%, which agrees with the one found by Cuevas et al.[6].

Observed and corrected rate of hypernuclei from ^{12}C, ^{14}N, ^{16}O. Classification of the K^- interactions on light and heavy nuclei was based on the criterion given in Chapater 2. The hypernuclear track was considered as a black prong emitted from the primary star. Decision about the charge of hypernuclei was made by:

— width measurements of the hypernuclear track if its range was longer than 20 micron and dip less than 30°,

— considering the possibility that Λ° was bound to a nucleus with $Z < 7$; for this purpose range of hypernucleus or the presence of a short, so called, low barrier track[1] was taken into account,

— kinematical analysis of the decay products[15], taking binding energy value for Λ° hyperon from the data on mesonic hypernuclei[16].

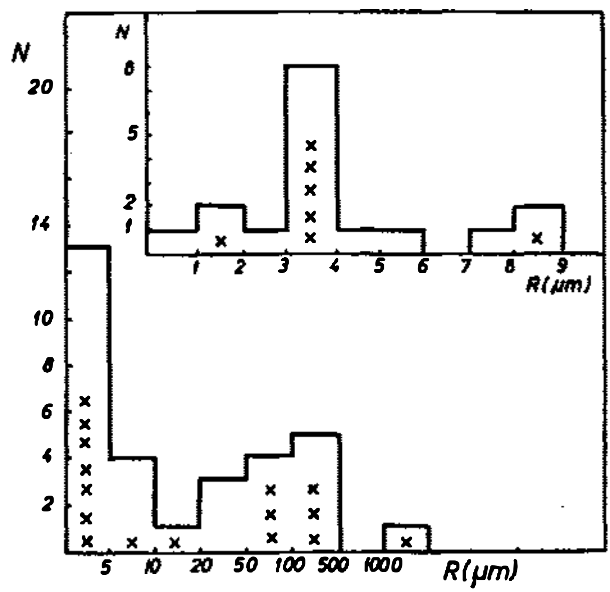

Fig. 1. Range distribution of hypernuclei, events indicated by X correspond to identified hypernuclei which led us to a decision about charge Z.

Kinematical analysis of the hypernuclei indicated that presence of a recoil among the products of the decay star did not necessarily mean that the interaction had taken place on a heavy nucleus. Proof came from five non-mesonic hypernuclei with range $R = 3$ micron, which when identified by kinematical analysis, were found to possess charge $Z = 2$ or 3 (Fig. 1). Therefore, while classifying unidentified hypernuclei with range $R < 5$ microns, with respect to the K^- interactions on light nuclei, the hypernuclear charge was taken as $Z \geqslant 2$.

34^{+6}_{-3} hypernuclei were found to be emitted from light emulsion nuclei. Total error in this estimate could be up to 25% on account of the large statistical fluctuations due to a low yield for K^- interactions on light nuclei, and because of the difficulties in finding the percentage of K^- interactions on light nuclei. Some of the events, which satisfied our criterion, might be possessing invisible recoil in the primary star. Such events must have been produced on heavy nuclei, just as the stars with a recoil could be the interactions on light nuclei. In addition, it must be mentioned that total charge can also be 8, if it happens that the interaction takes place on ^{16}O emitting odd number of charge pions. Therefore by taking $Z \leqslant 7$ we might have lost some of the light nuclear events. On the other hand, in view of the uncertainties in Z-measurement, some of the heavy nuclear stars might have also been regarded as the

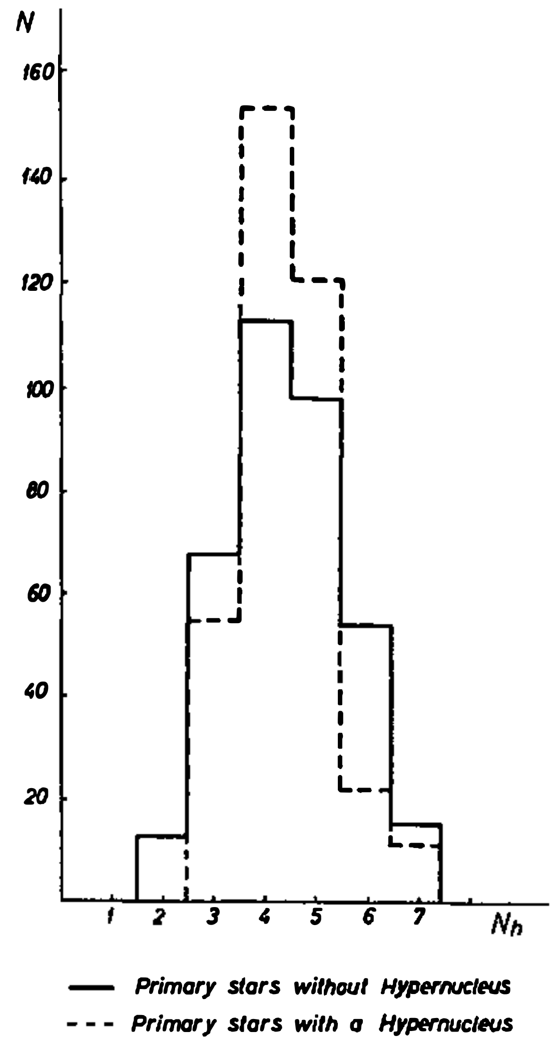

Fig. 2. Heavy prong number (N_h) distribution of primary stars, ——— 362 interactions where hypernucleus was not emitted, — — — — — interactions which gave rise to hypernuclei as well, normalized for same number of events (hypernuclear track was included as a black prong).

light nuclear events. All these effects seem to cancel and therefore the proportion of interactions on heavy and light nuclei remains unaffected. We think, however, that all these possibilities are covered in 25% error.

To estimate the loss of long range hypernuclei we checked all the secondaries in the plates next to the original one. For this purpose we followed all the prongs from 487 light nuclear stars up to the end. A single mesonic hypernucleus was detected which was produced by a secondary K^- meson. From the primary star characteristics (two more relativistic tracks, three grey prongs and two black prongs) it was obvious that secondary K^- meson was the result of quasielastic scattering within the nucleus. Loss of long range hypernuclei was therefore zero.

Assuming production rate of hypernuclei from pions to be negligible[17], corrected rate of hypernuclei from light nuclei per K^- star was found as $1.1 \pm 0.25\%$. This was in the limits of a rough estimate given by Cuevas et al.[6].

Mesonic and non-mesonic hypernuclei. Percentage of mesonic hypernuclei from all nuclei (Ag, Br, C, N, O) was found as 5.8%. On the other hand from light nuclei this percentage was 23.5%. This was in accordance with our expectations. Frequent emission of the mesonic hypernuclei from light nuclei can be explained in terms of their low potential well depth which makes the decay of Λ^0 hyperon into a proton and a pion possible.

Charge distribution of hypernuclei with $R < 5$ microns is given in Table 3.

Table 3

Z	1	2	3	4	< 5	Total
N	1	8	3	3	3	18

Products of the primary interactions. Normalized heavy prong number (N_h) distribution of the primary stars is given in Fig. 2, both for the cases where hypernuclei were not emitted as well as for those in which hypernuclei were produced. Mean multiplicity of the heavy prongs took the following values:

$\langle N_h \rangle = 4.5$ for the first group without hypernuclei,

$\langle N_h \rangle = 4.4$ for the second group where hypernuclei were produced.

From N_h distributions and the mean multiplicities we find that de-excitation mechanism of excited light nuclei is the same in both the cases. Therefore the pion emission from the parent stars can tell us about the origin of Λ^0 hyperons which are responsible for hypernuclear production.

All grey prongs with dip $< 45^\circ$ and relativistic tracks with dip $> 30^\circ$ could be identified applying the standard techniques[18, 19, 20]. For relativistic tracks, which left the stack, we applied the »ionization-scattering« method[21]. Results of the identification are given in Table 4.

Table 4

Number of stars				
without pions (π^0 events)	one pion	two pions	three pions	could not be identified
12	11	7	1	3

From identified pion tracks it was concluded that normalized grain density (g^*) of every fast pion was < 21 grain/100 microns. Therefore, every relativistic track, with $g^* < 20/100$ microns, was regarded as the pion track. Some other tracks, which were proved by the identification methods not to have been produced by proton or heavier particle, were also taken as the pion tracks (because the probability for K^- meson reemission was small).

Three π^+ mesons were found to be emitted from the primary stars. They ended in emulsion with their characteristic decay.

From Table 4 it is evident that emission of charge pions is frequent. By charge independence, considering the possible emission of neutral pions, we estimated that in 70% of the cases hypernucleus was produced from the interaction which gave $\Lambda^\circ\pi\pi$ in the final channel.

4. *Conclusion*

From a study of K^- interactions on light nuclei it has been found that percentage of produced hypernuclei is $1.1 \pm 0.25\%$. In about 70% of the cases Λ° hyperon is produced by the process which gives rise to a pion pair.

Acknowledgements

We would like to thank Mrs. N. Antanasijević and Mr. Dj. Levaja for careful measurements. Thanks are due to Mr. V. Gerc for calculations on IBM computer. We would like to thank Prof. E. H. S. Burhop for exposure of our stack. Our sincere gratitude goes to CERN PS staff and to Dr. J. Sacton for developing our emulsions.

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PRODUKCIJA HIPERJEZGARA IZAZVANA INTERAKCIJOM K^- MEZONA OD 1,5 Gev/c SA LAGANIM JEZGRAMA NUKLEARNE EMULZIJE (C, N, O)

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Sadržaj

Ispituju se interakcije K^- mezona od 1,5 Gev/c sa jezgrama nuklearne emulzije. Nađeni odnos vjerojatnosti interakcija na laganim (C, N, O) i teškim jezgrama ((Ag, Br) slaže se s vrijednošću dobivenom na osnovu teorije »transparentnog jezgra«. Određen je procenat produkcije hiperjezgara nastalih pri interakciji K^- mezona sa laganim jezgrama i iznosi $(1,1 \pm 0,25)$ %. Iz analize primarne interakcije diskutira se o mehanizmu produkcije hiperjezgra.