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PRODUCTION OF FAST NUCLEI OF A = 3 TOGETHER WITH A HYPERNUCLEUS BY 1.5 GeV/c K^- MESONS*

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Abstract: In this work an analysis has been made of the production of helium nuclei and tritons of energy greater than 70 MeV in events with a hyperfragment due to 1.5 GeV/c K^- mesons. The results of measurements of the helium nuclei show that the nuclei are predominantly ^{3}He. From the production characteristics of ^{3}He nuclei and tritons it follows that their production mechanisms are the same. It is shown that the nuclei most likely arise from the absorption of secondary π mesons and of the primary K^- meson in ^{4}He-clusters present at the surface of the nucleus.

1. Introduction

The former results on investigation of the production of high-energy particles of $Z = 2$ and tritons in the interaction of cosmic rays[1, 2], fast protons[3, 4, 5] and π mesons[6, 7, 8] with heavy nuclei show that they most likely arise from the interaction of the primary particle or cascade nucleons or from the absorption of secondary π mesons in nucleon clusters near the nuclear surface.

In this work we have analyzed the production of ^{3}He nuclei and tritons of energy greater than 70 MeV together with a hyperfragment induced by 1.5 GeV/c K^- mesons on heavy nuclei in nuclear emulsion. In these events the process of interaction of K^- mesons with nucleons in the nucleus gives rise to a Λ hyperon, which is emitted in the form of hyperfragment and n π-mesons where $n = 1, 2, 3$.

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2. *Experimental method and results*

Details concerning the emulsion stack, scanning and criterion for selection of events with a hyperfragment have been given earlier[9]. We have analyzed 500 events with a hyperfragment. About 95% of these events are due to the interaction of K^- mesons with heavy nuclei in nuclear emulsion (Ag, Br). All tracks in these events were traced up to the point of stopping or to the point of outlet from the stack. By the δ-electron method[10] we selected events in which $Z = 2$ nuclei of range longer than 2000 μm (this range corresponds to an energy of 71 MeV for ^{3}He) are emitted. We found (4.6 ± 0.6)% of events in which $Z = 2$ nuclei of energy greater than 70 MeV are emitted. The constant sagitta method was used to determine the ratio of ^{3}He to ^{4}He amongst particles of $Z = 2$. The results obtained show that the nuclei of $Z = 2$ are predominantly ^{3}He and that the percentage of ^{4}He amongst them is lower than 20%.

For the identification of tritons of energy greater than 70 MeV we used the gap, scattering and constant sagitta methods. Data on the use of the methods

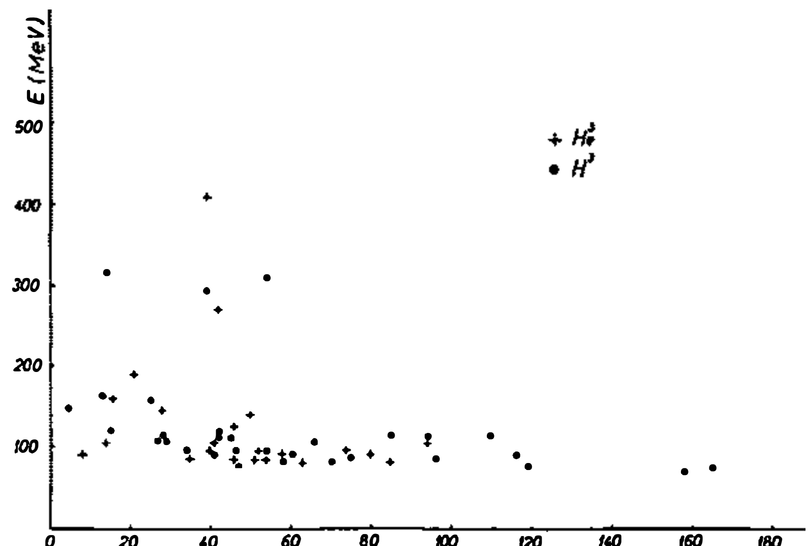

Fig. 1. Dependence of the energy of ^{3}He nuclei and tritons on the emission angle measured with respect to the incident direction of the primary K^- meson.

for track identification have been given earlier[11]. Using these methods we found that a triton of energy greater than 70 MeV was emitted in (9.1 ± 1.0)% of the events analyzed.

Fig. 1 shows the energy distribution of ^{3}He nuclei and tritons as a function of their emission angle in the laboratory system measured with respect to the incident direction of the primary K^- meson. Tritons are plotted in the figure without geometric correction. From the figure it can be seen that the degree of forward collimation increases with increasing kinetic energy of ^{3}He nuclei and tritons.

Fig. 2 shows the energy spectra of ^{3}He nuclei and tritons. We note that their energy spectra are similar and can be represented by the relation

$$N(E)\,dE = cE^{-a}\,dE.$$

The constant a was determined by the method of least squares to be $a = 2.13 \pm 0.50$. The value obtained for the constant a is in agreement, within the limits of error, with those obtained by other authors[1, 2]. From the given

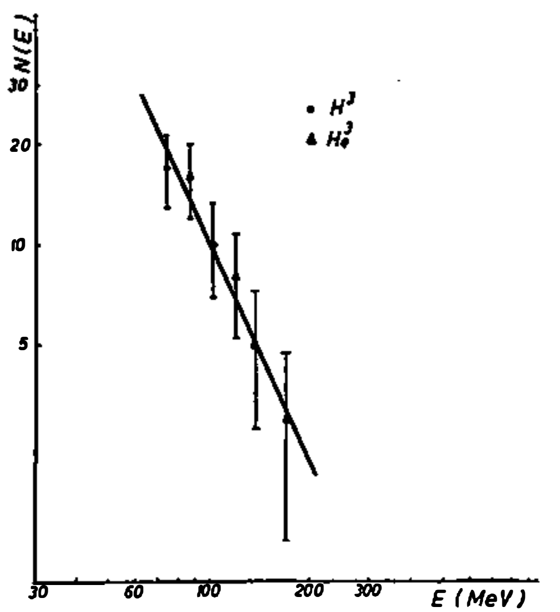

Fig. 2. Energy spectra of ^{3}He nuclei and tritons.

energy spectrum we can see that the energy of ^{3}He nuclei and tritons does not depend on the temperature of the nucleus.

Fig. 3 shows the angular distributions of the emitted ^{3}He nuclei and tritons relative to the incident direction of the primary K$^-$ meson. From the figure it can be seen that their distributions are similar.

Fig. 4 shows the distribution of stars with and without fast ^{3}He nuclei and tritons over the heavy-prong number N_h. The distributions of stars in which there are emitted ^{3}He nuclei and tritons are similar and shifted towards the higher values of N_h.

Since the above mentioned production characteristics of ^{3}He nuclei and tritons are similar, it is most likely that also their production mechanisms are the same.

Table 1 gives the mean values of relativistic (N_s), gray (N_g) and black (N_b) tracks for events in which ^{3}He nuclei and tritons are emitted in the energy intervals 70—100, 100—200 and higher than 200 MeV.

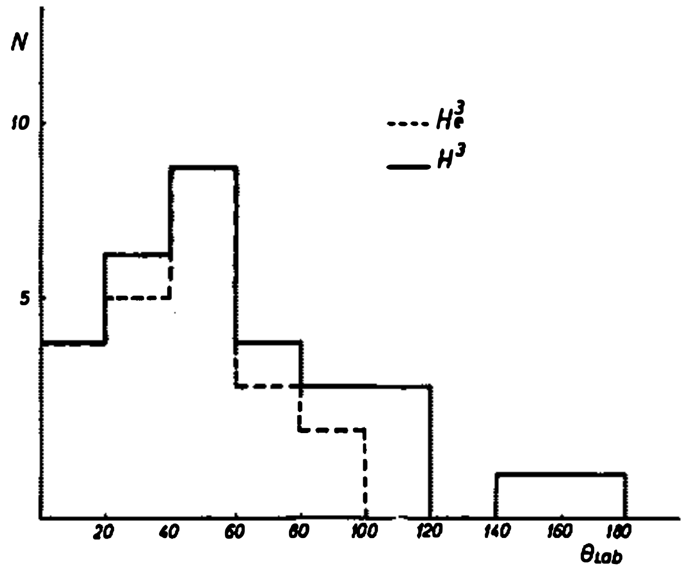

Fig. 3. Angular distribution of ^{3}He nuclei and tritons relative to the incident direction of the K⁻ meson.

Table 2 gives the percentages of the identified protons of energy greater than 100 MeV and of π mesons in events with and without fast nuclei of $A = 3$.

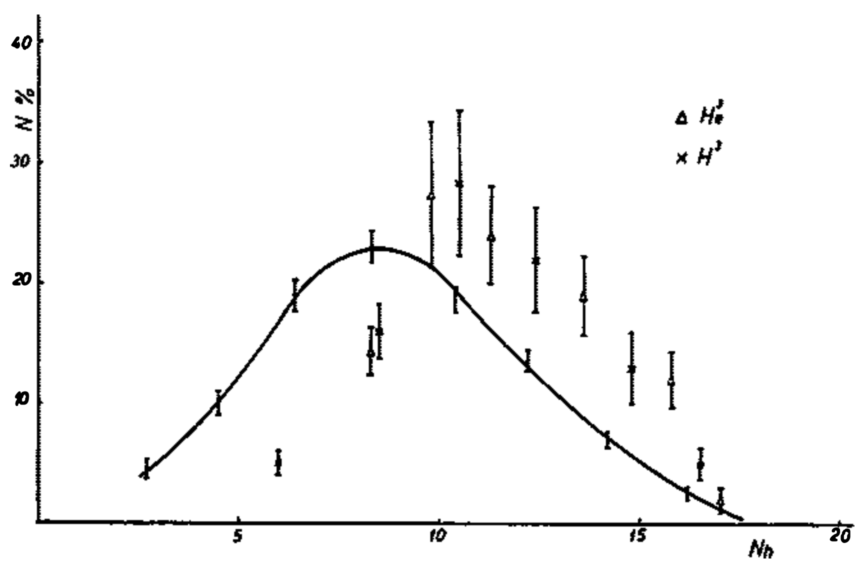

Fig. 4. Distribution of stars with and without fast ^{3}He nuclei and tritons over N_h.

In events with a hyperfragment the largest number of π mesons are emitted with energy lower than 150 MeV. The energy spectrum of π mesons extends up to 250 MeV. The π^-/π^+ ratio of mesons emitted in events with a hyperfragment is 2.16.

The energy spectrum of the identified protons extends up to 500 MeV. Assuming the ratio of emitted neutrons to protons to be the same as the n/p ratio in the nucleus, we determined the number of cascade nucleons per one event. The results obtained show that the number of emitted nucleons with energy in the interval 100—200 MeV per one event is 0.9. The number of cascade nucleons emitted with energy higher than 250 MeV per one interaction act is considerably lower and amounts to 0.2.

3. *Discussion*

It is most likely that near the surface of heavy nuclei clusters of an even number of nucleons are formed[12]. Some estimations show that even-nucleon clusters in the outer regions of heavy nuclei are mostly produced in the form of ^4He[13].

Table 1

	$70 < E_K \leqslant 100$ MeV	$100 < E_K \leqslant 200$ MeV	$E_K > 200$ MeV
N_t	0.31 ± 0.17	0.09 ± 0.07	0.40 ± 0.37
N_g	3.23 ± 0.81	3.23 ± 0.92	1.50 ± 1.20
N_b	8.12 ± 1.85	7.72 ± 1.91	10.12 ± 4.13

The production of fast ^3He nuclei and tritons together with a hyperfragment can be expected from:

a) interaction of cascade nucleons,

b) absorption of the secondary π mesons produced in the primary interaction of K^- mesons, and

c) Absorption of the primary K^- meson in nucleon clusters present in the outer regions of heavy nuclei.

Since the production of fast nuclei of $A = 3$ is associated with the nuclear surface, it can be assumed that the energy spectra of the cascade nucleons and secondary π mesons taking part in the production are similar to those of the emitted cascade nucleons and π mesons.

Ad a). The production of ^3He nuclei and tritons can be expected from the following interactions of fast cascade nucleons with a two-nucleon cluster

$$p + d \rightarrow t + \pi^+, \qquad \text{or} \qquad ^3He + \pi^0, \tag{1}$$

$$n + d \rightarrow t + \pi^0, \qquad \text{or} \qquad ^3He + \pi^-. \tag{2}$$

The threshold energy of nucleons for these reactions is 200 MeV. The production of $A = 3$ nuclei of energy greater than 70 MeV can be expected from the interaction of nucleons of energy higher than 250 MeV. However, the number of cascade nucleons of energy higher than 250 MeV per one event is small, hence the production of ^3He nuclei and tritons of energy greater than 70 MeV from the above mentioned interactions is negligible. Our experimental results show that the ratio of emitted tritons to protons of energy greater

Table 2

	Stars without fast ^3He nuclei and tritons	Stars with fast ^3He nuclei and tritons
% of stars with protons of $E_p > 100$ MeV	29 ± 2	27 ± 5
% of stars with a meson	31 ± 2	15 ± 3

than 70 MeV is 0.12. This ratio is higher by a factor of 10^4 than that estimated by Yasin[1] on the assumption that the production of tritons is due to interaction (1). The facts quoted show that the production of fast nuclei of $A = 3$ from the interaction of fast cascade nucleons with a two-nucleon cluster can be neglected.

The production of nuclei of $A = 3$ can be expected from the following interactions of cascade nucleons with ^4He-cluster

$$p + {}^4He \rightarrow t + 2p, \qquad \text{or} \qquad ^3He + d, \tag{3}$$

$$n + {}^4He \rightarrow t + d, \qquad \text{or} \qquad ^3He + 2n. \tag{4}$$

In previous works[14,15] it has been shown that these interactions proceed through quasielastic scattering of fast incident nucleons with one nucleon in ^4He. In such a process of interaction, the ^3He nucleus and triton are the residues of the ^4He nucleus and cannot have an energy greater than the evaporation energy.

The percentage of protons of energy higher than 100 MeV is, within the limits of experimental error, the same in events with and without fast nuclei of $A = 3$ (Table 2).

The facts mentioned show that the production of $A = 3$ nuclei of energy greater than 70 MeV from the interaction of fast cascade nucleon with nucleon clusters present in the outer regions of heavy nuclei can be neglected.

Ad b). In previous works[6, 7] it has been shown that the ratio of emitted protons, deuterons and tritons from the absorption of π mesons in light elements is the same as from the absorption of π mesons in ^{4}He. This shows that the capture of π mesons by ^{4}He-clusters plays the dominant part in light elements.

Amongst particles of energy greater than 60 MeV produced by the absorption of π mesons in Ag and Br nuclei, 15% of tritons have been found[7]. The production of fast nuclei of $A = 3$ by K$^-$ mesons can be explained by the absorption of secondary π mesons in ^{4}He-clusters present in the outer regions of heavy nuclei.

Fast nuclei of $A = 3$ can be emitted from the following absorptions of a π meson in ^{4}He-cluster

$$\pi^{\overset{-}{0}} + {}^4\mathrm{He} \to t + n, \qquad \text{or} \qquad p, \tag{5}$$

$$\pi^{\overset{+}{0}} + {}^4\mathrm{He} \to {}^3\mathrm{He} + p, \qquad \text{or} \qquad n. \tag{6}$$

We see that π^- mesons take part only in the production of tritons, and π^+ mesons in the production of ^{3}He. In events with a hyperfragment, twice as many π^- mesons as π^+ mesons are emitted. Hence it is to be expected that the number of events in which a fast triton is emitted will be higher than that of events giving rise to a fast ^{3}He nucleus. We found the ratio of emitted tritons to ^{3}He nuclei to be about 2.

Amongst events in which we detected fast nuclei of $A = 3$ we found a low percentage of those in which also a π meson is emitted. This percentage is lower by a factor of 2 than in events in which we did not detect any fast nuclei of $A = 3$ (Table 2). The facts quoted show that secondary π mesons play dominat part in the production of fast ^{3}He nuclei and tritons.

Ad c). Fig. 1 shows that there are several events in which nuclei of $A = 3$ are emitted with energy higher than 200 MeV. The production of these nuclei cannot be explained by the absorption of secondary π mesons in ^{4}He-clusters, because the percentage of π mesons in events with a hyperfragment with energy higher than 150 MeV is low. In events giving rise to $A = 3$ nuclei of energy higher than 200 MeV the number of emitted cascade-particles is lower than that in events in which these nuclei are emitted in the energy interval 70—200 MeV (Table 1). This fact indicates that the interaction of the K$^-$ meson in events in which $A = 3$ nuclei are emitted with energy higher than 200 MeV took place most likely at the surface of the nucleus. Nuclei of $A = 3$ can be emitted in the following interactions of a K$^-$ meson with ^{4}He-cluster at the surface of heavy nuclei:

$$K^- + {}^4He \rightarrow {}^3He + \Lambda + \pi^-, \quad (7)$$

$$\rightarrow \quad t + \Lambda + \pi^\circ. \quad (8)$$

In events in which a fast ^{3}He nucleus was detected, a fast π meson was also found. The total kinetic energy in these events, determined from the kinetic energies of the ^{3}He nucleus and of π meson and the excitation energy of the nucleus, is in agreement, within the limits of experimental error, with the total kinetic energy from the absorption of 1.5 GeV/c K^- mesons in ^{4}He (reaction 7). From this it can be concluded that $A = 3$ nuclei with energy higher than 200 MeV are most likely emitted from the absorption of primary K^- mesons in ^{4}He-clusters present in the outer regions of heavy nuclei.

4. Conclusion

It is stated that the production mechanism of fast ^{3}He nuclei and tritons in events with a hyperfragment is the same. The production of $A = 3$ nuclei of an energy in the interval 70—200 MeV is most likely due to the absorption of secondary π mesons in ^{4}He-clusters. Nuclei of $A = 3$ with energy higher than 200 MeV are emitted most likely from the absorption of primary K^- mesons in ^{4}He-clusters present in the outer regions of heavy nuclei.

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References

1) M. Yasin, Nuovo Cimento 34 (1964) 1145;
2) S. O. C. Sørensen, Phil. Mag. 42 (1951) 188;
3) V. I. Ostroumov and R. A. Filov, Ž. E. T. F. 37 (1959) 643;
4) Ž. S. Tabibaev et al., Yadernaya Fizika 3 (1966) 849;
5) V. N. Kuzmin, R. M. Yakovlev, Yadernaya Fizika 6 (1967) 1158;
6) P. J. Castleberry et al., Physics Letters 34B (1971) 57;
7) A. O. B. Vaisenberg et al., Ž. E. T. F. 47 (1964) 1262;
8) Z. S. Takibaev et al., Izv. A. N. Kaz. URSS 2 (1965) 51;
9) O. Adamović, to be published.
10) D. A. Tidman et al., Proc. Phys. Soc. A66 (1953) 1019;
11) Ž. Todorović, M. Jurić, Physics Letters 30*B* (1969) 568;
12) M. Rottenberg, L. Wilets, Phys. Rev. 110 (1958) 1126;
13) D. H. Wilkinson, Proc. of Rutherford Jubilee International Conference, Manchester (1961), p. 339.
14) Y. Sakamoto, Nuovo Cimento 25 (1962) 595;
15) N. S. Kozodaev et al., Ž. E. T. F. 38 (1960) 708.

PRODUKCIJA ENERGETSKIH JEZGARA A = 3 ZAJEDNO SA HIPERJEZGROM IZAZVANA K^- MEZONIMA OD 1,5 GeV/c

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S a d r ž a j

U ovom radu je analizirana produkcija helijevih jezgara i tritona energije veće od 70 MeV u događajima sa hiperfragmentom, koja je izazvana K^- mezonima od 1,5 GeV/c.

Rezultati merenja mase helijevih jezgara pokazuju, da su ove jezgre uglavnom ^3He. Iz karakteristika produkcije jezgara ^3He i tritona sledi da su njihovi mehanizmi produkcije isti.

Pokazano je da ove jezgre najverovatnije nastaju iz apsorpcije sekundarnih π mezona i primarnog K^- mezona sa ^4He klasterima, koji su prisutni u površini teških jezgara.