A SEARCH FOR RESONANT STATES $p - {}^5_\Lambda\mathrm{He}$ AND $\alpha - {}^5_\Lambda\mathrm{He}$

By M. Skórko van de Graaff, E. Skrzypczak and T. Tymieniecka

Institute of Expcrimetal Physics, University of Warsaw*

(Received February 28, 1970)

A sample of 164 K^- interactions with emulsion nuclei with ${}^5_\Lambda$He hypernuclei among secondaries were studied. The invariant mass distributions for ${}^5_\Lambda$He$-p$ and ${}^5_\Lambda$He$-\alpha$ systems in these stars were obtained and analysed. No maxima corresponding to particle-unstable ${}^6_\Lambda$Li or ${}^9_\Lambda$Be* systems (decaying into ${}^5_\Lambda$He and a proton or into ${}^5_\Lambda$He and an α-particle, respectively) were observed; this indicates a low, if not zero, value of cross-section for production of such systems.

Introduction

Besides numerous known hypernuclei (HF) decaying by a weak process with a life-time of $\sim 10^{-10}$ sec there may be expected systems decaying in a fast process into a hypernucleus and a non-strange nuclide. In particular, the existence of particle-unstable ${}^6_\Lambda$Li and ${}^9_\Lambda$Be* HF's was the subject of consideration by several authors [1, 2, 3]. No reliable example of a ${}^6_\Lambda$Li long-living HF was ever observed among many thousand decays of HF's registered and analysed up to now [4, 5, 6]. On the other hand, the existence of a bound ${}^6_\Lambda$He system is now well established (see for instance [4]). Since ${}^6_\Lambda$He and ${}^6_\Lambda$Li are mirror hypernuclei, therefore, from an analysis of ${}^6_\Lambda$He one can derive some indications concerning ${}^6_\Lambda$Li. The binding energy for the last neutron in ${}^6_\Lambda$He was thus estimated, leading to the value of 0.34 ± 0.19 MeV. This low value implies that the existence of ${}^6_\Lambda$Li as a particle — stable HF is rather improbable. On the other hand, it is quite possible that there exists a short-living ${}^6_\Lambda$Li-like system, decaying in a fast process into a proton and a ${}^5_\Lambda$He hypernucleus. The expected Q-value[1] for this decay is ~ 0.5 MeV [1].

Another system decaying in a fast process into a hypernucleus and a stable nuclide might be ${}^9_\Lambda$Be* in an excited state, its decay products being an α-particle and ${}^5_\Lambda$He. Among $A = 9$ hypernuclei the well known ${}^9_\Lambda$Be (ground state) with the binding energy (B_Λ) value of 6.63 ± 0.04 MeV is believed to be an isospin singlet, while ${}^9_\Lambda$Li with $B_\Lambda = 8.25 \pm 0.13$ MeV would belong to an isospin triplet together with ${}^9_\Lambda B$ and ${}^9_\Lambda$Be*; the latter is expected to be particle-unstable and to decay in a fast process into an α-particle and a ${}^5_\Lambda$He hypernucleus with a Q-value of about 12 MeV [1].

* Address: Instytut Fizyki Doświadczalnej Uniwersytetu Warszawskiego, Warszawa, Hoża 69, Polska

[1] The Q-value is, as usual, defined as the difference between the mass of the primary and the sum of masses of the secondaries.

The existence of such systems may, in principle, be established by an analysis of the invariant mass spectra of ${}^5_\Lambda$He — p for ${}^6_\Lambda$Li and ${}^5_\Lambda$He — α for ${}^9_\Lambda$Be*calculated for pairs of corresponding particles emitted in the same interactions.

Such experiments were performed by Goodhead and Evans [7] and by Frodesen *et al.* [8]. In both cases the experimental material was poor (several tens of ${}^5_\Lambda$He hypernuclei altogether). No irregularities distinguishable from the smooth background were observed in both experiments. The continuation of such studies on a statistically richer sample seemed therefore worthwhile.

Experimental details

The search for particle-unstable systems with strangeness $S = -1$ (${}^6_\Lambda$Li and ${}^9_\Lambda$Be*) was performed on a part of the experimental material obtained by the European K^-. Collaboration during the systematic study of light hypernuclei produced in interactions of K^- mesons at

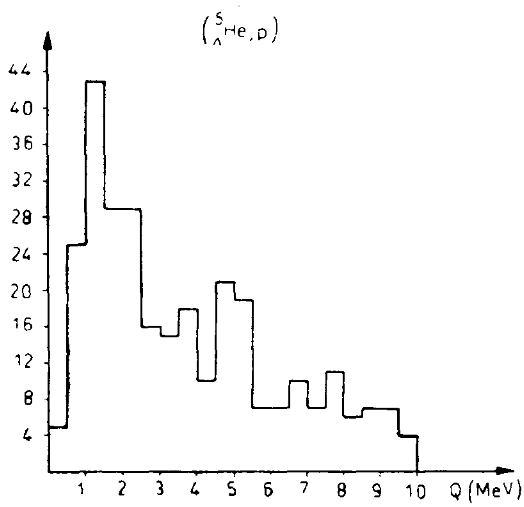


Fig. 1. Experimental histograms of Q-values for ${}^5_\Lambda$He and proton combinations

rest in the nuclear emulsion. The details concerning exposure, measurements and the identification procedure are given in [4]. For the present purpose a sample of 164 ${}^5_\Lambda$He events was used; 147 of them were events with a high confidence level of their identification corresponding to the χ^2 value for the momentum balance (three degrees of freedom) less than 6.3, while 17 events had $6.3 < \chi^2 < 11.3$; this for the case of abundantly produced ${}^5_\Lambda$He means still that a competitive identity is highly improbable.

Since direct identification of the tracks of non-strange particles emitted from K^- interactions with the emulsion nuclei is in most cases impossible, the following approach was applied. In each K^- star with an emitted ${}^5_\Lambda$He all the tracks, except those which were obviously due to pions or to $Z = 3$ particles, were considered alternatively as protons and α-particles.

A reasonable assumption that the Q-value for a ${}^5_\Lambda$He — p resonant system does not exceed 10 MeV (expected value being less than 1 MeV), and for a ${}^5_\Lambda$He — ^{4}He system does not exceed 40 MeV (expected value ~ 12 MeV) was made. This, and obvious limitations for available energy in K^- interactions at rest, allowed an *a priori* rejection of some combinations of ${}^5_\Lambda$He tracks and other tracks from the same interactions[2].

In about one third of all interactions (58 stars) the above criteria were disregarded and all the secondary tracks were measured in order to obtain some completely unbiased material for the analysis of background (see below).

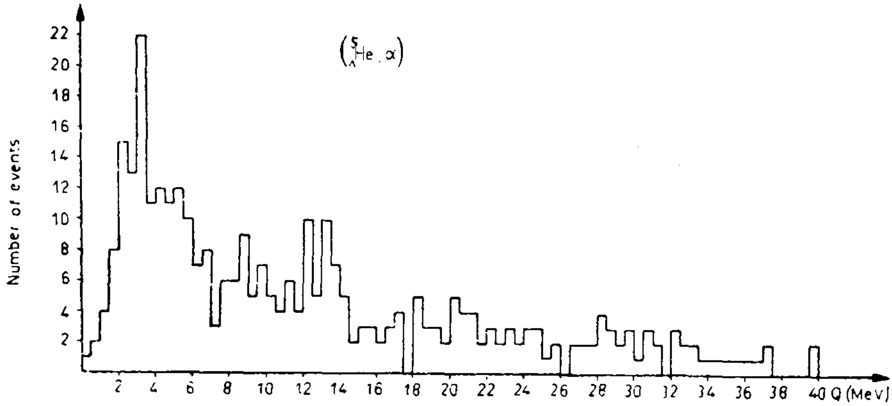


Fig. 2. Experimental histograms of Q values for ${}^5_\Lambda$He and α-particle combinations

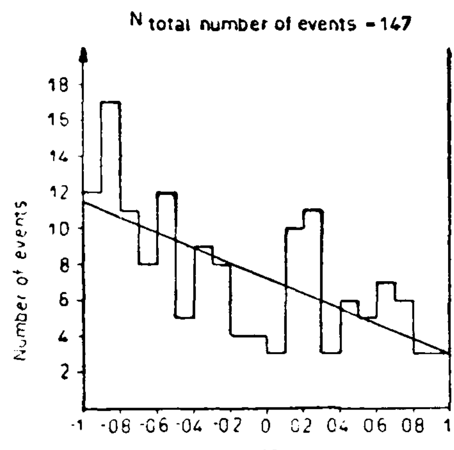
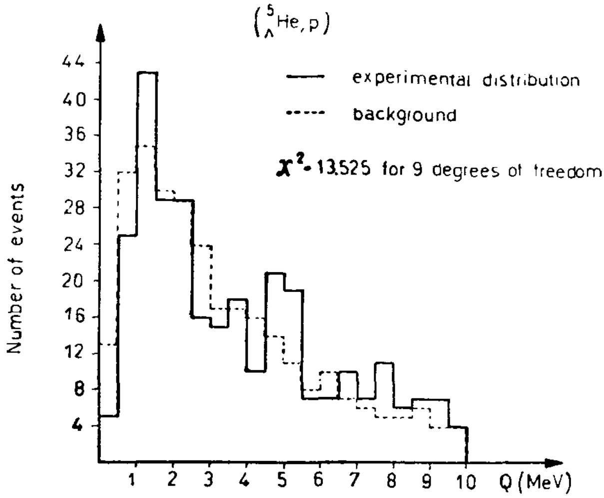


Fig. 3. Experimenta ldistribution of cosines of angles between ${}^5_\Lambda$He and non-strange $Z = 1,2$ tracks emitted in K^- interactions at rest

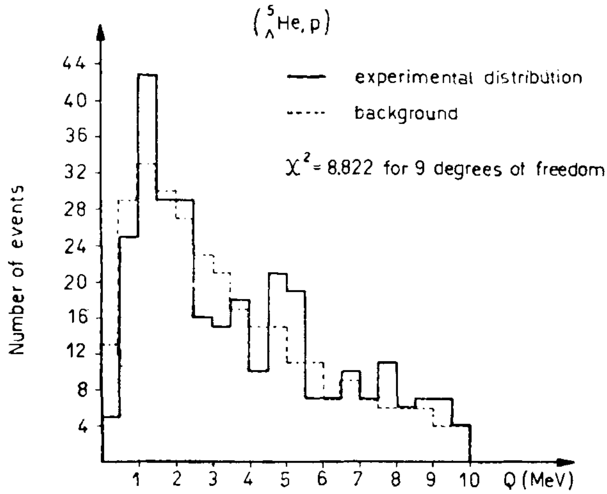
Results and discussion

For all accepted pairs of tracks the Q-values for the assumed decay into a) ${}^5_\Lambda$He and a proton, and b) ${}^5_\Lambda$He and an α-particle were calculated. The corresponding distributions are shown in Fig. 1. and Fig. 2.

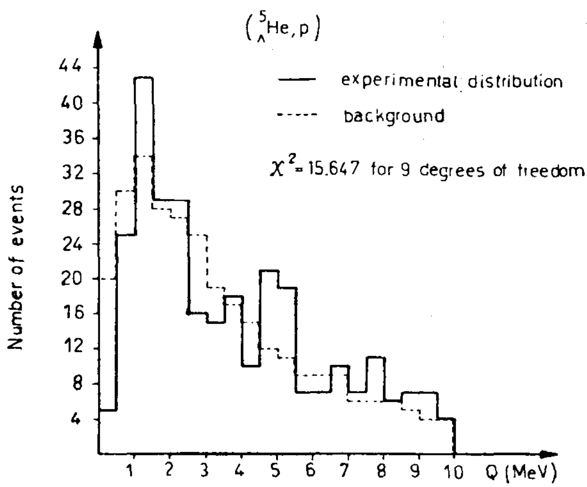
[2] Details of the criteria used for rejecting some combinations are given in [9].


(${}^{5}_{\Lambda}$He, p)
experimental distribution
background
χ^2= 13.525 for 9 degrees of freedom
Number of events
Q (MeV)
44
40
36
32
28
24
20
16
12
8
4
1 2 3 4 5 6 7 8 9 10

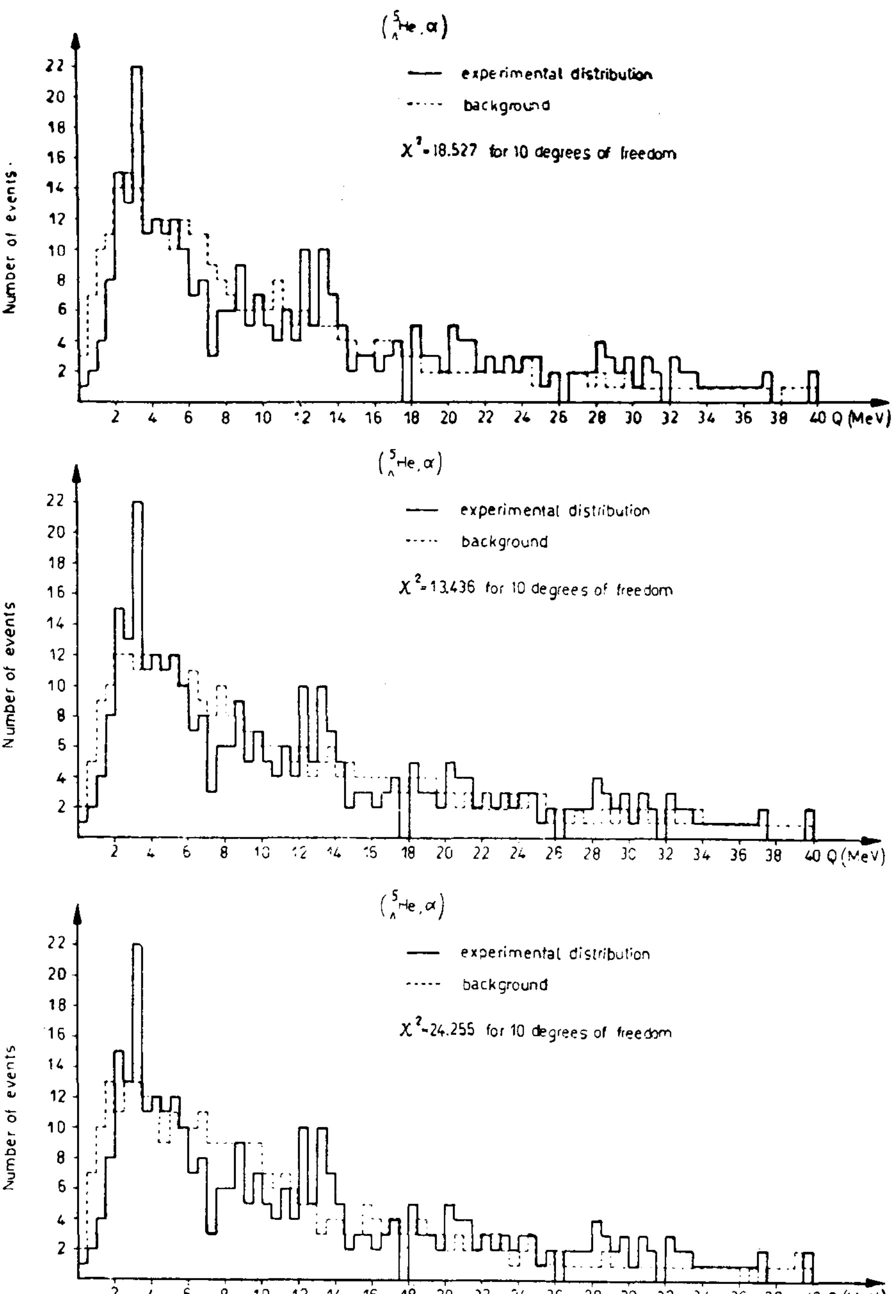
a


(${}^{5}_{\Lambda}$He, p)
experimental distribution
background
χ^2= 8.822 for 9 degrees of freedom
Number of events
Q (MeV)
44
40
36
32
28
24
20
16
12
8
4
1 2 3 4 5 6 7 8 9 10

b


(${}^{5}_{\Lambda}$He, p)
experimental distribution
background
χ^2= 15.647 for 9 degrees of freedom
Number of events
Q (MeV)
44
40
36
32
28
24
20
16
12
8
4
1 2 3 4 5 6 7 8 9 10

c



a b c

Fig. 5. *a*, *b*, *c*. The same as Fig. 4 for ${}^{5}_{\Lambda}$He — particle combinations

←

Fig. 4. *a*, *b*, *c*. The comparison of background distributions of Q-values for random combinations of ${}^{5}_{\Lambda}$He and proton tracks and the experimental distribution (thick line) of Fig. 1, after normalization. Figures *a*, *b*, and *c* present the results for three different approaches applied in the background combinations (see text)

Some irregularities in the distributions can be seen but their statistical significance had to be checked by a comparison with the shapes of corresponding distributions for the background, that is for an uncorrelated emission of HF's and protons (or α-particles).

The distributions for the background were obtained by the use of Monte Carlo calculations, based on the construction of random combinations of ${}^{5}_{\Lambda}$He tracks and tracks of presumed protons or α-particles. In the construction of Monte Carlo events the anisotropy of distribution of relative angles between secondaries from K^- interactions at rest (shown in Fig. 3) was taken into account.

The information on HF ranges, on ranges of other particles (assumed protons or α-particles) and on angles between HF tracks and other tracks in K^- stars were the basis for Monte Carlo calculations.

TABLE I

	${}^{5}_{\Lambda}$He$-p$			${}^{5}_{\Lambda}$He$-\alpha$		
	I	II	III	I	II	III
Number of events for M. C. calculation	4488	4453	4464	4859	4958	4954
Number of the degrees of freedon	9	9	9	10	10	10
χ^2 value	13.5	8.8	15.6	18.5	13.4	24.3
Confidence level	20%	50%	7.5%	5%	20%	1%

Three, slightly different approaches were applied:

I. HF ranges, proton (or α-particle) ranges and cosines of the angle between them were chosen at random and independently of each other.

This procedure was done for 58 stars in which all tracks were measured completely with no tracks rejected.

II. HF ranges and proton (or α-particle) ranges were chosen at random from the corresponding distributions based on all K^- stars in which ${}^{5}_{\Lambda}$He were emitted; cosines of the angle between a HF track and a proton (or an α-particle) track were chosen at random from the sample of 58 completely measured stars.

III. HF ranges were chosen at random from the corresponding distribution of all the stars (as in II), while ranges of protons (or α-particles) together with corresponding angles with respect to HF directions in the corresponding primary K^- stars were chosen at random from the data based on the whole sample.

For all the combinations of ${}^{5}_{\Lambda}$He and p (or α) obtained in the three above described approaches the corresponding Q-values were calculated; their distributions, normalized to the number of events analysed in the experiment, are shown in Figs 4 and 5 together with the experimental histograms from Figs 1 and 2. The cut-off at $Q = 10$ MeV and $Q = 40$ MeV, respectively, was applied.

The comparison of experimental and background distributions was done by means of the χ^2 test for consistency. The results of this analysis are shown in the Table I.

It can be seen that the three methods applied for background calculation do not lead to essentially different results. For both combinations ($^{5}_{\Lambda}He$ — p and $^{5}_{\Lambda}He$ — α) the Q-value distributions are consistent with those for the background corresponding to the uncorrelated emission. No significant maxima in the distributions in expected regions of energy ($\sim$ 0.5 MeV and $\sim$ 12 MeV for the $^{5}_{\Lambda}He$ — p and $^{5}_{\Lambda}He$ — α systems respectively) were observed.

The existence of particle unstable $^{6}_{\Lambda}Li$ and $^{9}_{\Lambda}Be^{*}$ hypernuclei remains still an open question. It seems it would be impracticable to perform further experiments along the same lines as described aboves. The search for resonant states p — $^{5}_{\Lambda}He$ and α — $^{5}_{\Lambda}He$ should be probably undertaken by means of other experimental techniques.

REFERENCES

[1] R. H. Dalitz, R. Levi Setti, *Nuovo Cimento*, **30**, 489 (1963).
[2] R. H. Dalitz, *Proc. Rutherford Jubilee Conf., Heywood* (1962).
[3] L. Lovitch, S. Rosati, R. H. Dalitz, *Nuovo Cimento*, **53**, 301 (1968).
[4] G. Bohm *et al.*, *Nuclear Phys.*, **B4**, 511 (1968).
[5] D. M. Harmsen, *Phys. Rev. Letters*, **19**, 1186, 1409 (1967).
[6] G. Coremans *et al.*, *Nuclear Phys.*, **B4**, 580 (1968).
[7] D. T. Goodhead, D. A. Evans, *Nuclear Phys.*, **B2**, 121 (1967).
[8] A. G. Frodesen *et al.*, *Phys. Norvegica*, **1**, 277 (1965).
[9] M. Skórko van de Graaff, Thesis, Warsaw 1968.