PRODUCTION OF HYPERNUCLEI BY 8.8-BeV PROTONS

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The production of hypernuclei by ~9-BeV protons was investigated. Altogether 132 decay events of hypernuclei were detected. B_{Λ}^{10} and B_{Λ}^{11} hypernuclei were observed for the first time. The results are in agreement with the conclusions of the first part of the experiment.[1]

THE present article is a continuation of the study of hypernucleus production in an emulsion stack irradiated by an internal proton beam of 8.8 BeV. The experimental method has been described in the first article.[1]

1. RESULTS

The measured sample consisted of 160 bound stars, out of which 132 were found to contain hypernuclei. A reasonable value of binding energy B_{Λ} was obtained in 27 cases; 56 cases, in which the bound track did not show clear evidence of stopping before decay, were considered as doubtful hypernuclei; 40 events, in which the criteria for a stopping hypernucleus were satisfied, but a reasonable value of the binding energy was not obtained in the kinematical analysis, were assumed to involve the emission of two and more neutrons; in 9 cases, because of a bad position of secondary tracks, it was not possible to carry out the kinematical analysis. Five mesic decays of hypernuclei were observed, in which reasonable values of B_{Λ} were obtained in two cases. The limiting errors in the determination of B_{Λ} were calculated only for mesic hypernuclei. In the case of nonmesic decays, the errors were not calculated, since, according to [1], they are then of the order of magnitude of B_{Λ}.

The decay schemes for the events in which the values of the binding energy were obtained are given in Table I for 19 heavy ($Z \geq 4$) and eight light hypernuclei. The small number of light hypernuclei can be explained by scanning bias. The values of B_{Λ}, obtained under the assumption that the decay products He^6, Li^6, and Li^7 may be in an excited state, are given in the last column.

Clear cases of decay of the Be_{Λ}^{11} and B_{Λ}^{10} hypernuclei were observed:

$$Be_{\Lambda}^{11} \to t + Li^7 + n,$$
$$B_{\Lambda}^{10} \to He^3 + Li^6 + n.$$

Other cases of decay of B_{Λ}^{10} hypernuclei are possible (events 21, 22, and 23). Event 22 is also interesting because it may be interpreted as a decay of the rare hypernuclei C_{Λ}^{14} and C_{Λ}^{15}, which was first described in the first part of this article. Event 26 is another clear example of the decay of the heavy hypernucleus C_{Λ}^{14}.

The decays of the Be_{Λ}^{11} hypernucleus (events 18 and 19) and of N_{Λ}^{15} (event 27) observed before are not certain, although the values of B_{Λ} are reasonable. A single-particle decay was observed in these three cases. Kinematical analysis was carried out under the assumption that the He^4 nuclei (events 18 and 19) and B_{Λ}^{10} (event 27) are invisible (range less than $0.4\,\mu$) and the total residual momentum of the two particles was ascribed to the neutron.

It is interesting to note that in many cases the decay schemes of hypernuclei with the same mass number repeat themselves, and out of six decay cases of the Be_{Λ}^{9} hypernucleus in four cases the decay follows the scheme:

$$Be_{\Lambda}^{9} \to p + Li^7 + n.$$

2. DISCUSSION

In the course of the experiment for the first time clear cases were observed of the decay of Be_{Λ}^{11} and B_{Λ}^{10}, and for the second time of the decay of C_{Λ}^{14}. The values of B_{Λ} averaged over the first and second part of the present experiment are given in Table II. An increase in B_{Λ} with increasing mass number can be observed.

The emission energies of the hypernuclei, averaged over the different isotopes, are given in

Table I

Event number	Length of connecting track, μ	Decay scheme	B_Λ, MeV (fragment in ground state)	B_Λ, MeV (fragment in excited state)
1	58	$H^3_\Lambda \to \pi^- + p + p + n$	−0.36±1.43	—
2	157	$He^5_\Lambda \to p + t + n$	+2.55	—
3	36	$He^5_\Lambda \to p + t + n$	4.36	—
4	265	$Li^7_\Lambda \to \pi^- + d + p + He^4$	3.86±2.19	—
5	106	$Li^7_\Lambda \to Li^6 + n$	7.76	4.19
6	210	$Li^7_\Lambda \to p + d + t + n$	5.84	—
		$Li^8_\Lambda \to p + t + t + n$	7.95	—
7	112	$Li^7_\Lambda \to p + d + t + n$	7.47	—
8	97	$Li^8_\Lambda \to Li^7 + n$	3.45	—
9	124	$Be^8_\Lambda \to p + t + He^3 + n$	4.00	—
		$B^{10}_\Lambda \to p + He^4 + He^4 + n$	5.13	—
10	103	$Be^8_\Lambda \to d + d + He^3 + n$	3.44	—
11	229	$Be^8_\Lambda \to d + d + He^3 + n$	7.44	—
12	170	$Be^9_\Lambda \to He^4 + He^4 + n$	12.26	—
13	48	$Be^9_\Lambda \to p + Li^7 + n$	8.1	7.62
14	237	$Be^9_\Lambda \to p + Li^7 + n$	10.74	10.26
15	59	$Be^9_\Lambda \to p + Li^7 + n$	8.86	8.38
16	108	$Be^9_\Lambda \to p + Li^7 + n$	7.88	7.40
17	56	$Be^9_\Lambda \to d + Li^6 + n$	10.61	7.04
18	120	$Be^{11}_\Lambda \to He^4 + He^6 + n$	11.26	7.76
19	106	$Be^{11}_\Lambda \to He^4 + He^6 + n$	4.81	—
20	45	$Be^{11}_\Lambda \to t + Li^7 + n$	6.59	—
21	367	$B^{10}_\Lambda \to He^3 + Li^6 + n$	15.42	11.85
22	55	$B^{10}_\Lambda \to p + d + d + He^4 + n$	7.31	—
		$C^{14}_\Lambda \to d + d + He^3 + He^6 + n$	11.16	—
		$C^{15}_\Lambda \to d + d + He^4 + He^6 + n$	11.78	—
23	116	$B^{10}_\Lambda \to p + d + d + He^4 + n$	6.05	—
		$C^{11}_\Lambda \to p + p + d + Li^6 + n$	8.9	—
24	66	$B^{11}_\Lambda \to He^3 + Li^7 + n$	6.64	—
		$B^{12}_\Lambda \to He^4 + Li^7 + n$	8.94	—
25	33	$B^{12}_\Lambda \to He^4 + Li^7 + n$	11.90	11.42
26	145	$C^{14}_\Lambda \to He^4 + Be^9 + n$	6.73	—
27	71	$N^{15}_\Lambda \to He^4 + B^{10} + n$	10	—

Table II

Hypernucleus	$\bar{B}_\Lambda$, MeV	Number of events	Mean energy of the emitted hypernucleus	Hypernucleus	$\bar{B}_\Lambda$, MeV	Number of events	Mean energy of the emitted hypernucleus
He^5_Λ	3.45	2		Be^9_Λ	9.13	7	48.1
Li^7_Λ	6.80	5	32.1		8.34*		
Li^8_Λ	6.00	3		Be^{11}_Λ	7.58	3	
Be^8_Λ	5.75	3		C^{14}_Λ	9.5	2	108.0

*$\bar{B}_\Lambda$ is calculated assuming that the fragments are in an excited state.

the last column of Table II. The observed increase in the emission energy of the hypernucleus with increasing charge (which contradicts the results of [2]) indicates that in the emission from the primary nucleus, the independently produced Λ^0 hyperon and one of the fragments combine together most efficiently when the velocities are approximately equal.

In all 25 cases of non-mesic decay for which the values of B were obtained, two nucleons (p, n) with a high energy ($E_N > 30$ MeV) were expected according to theoretical predictions based on a single-nucleon mechanism of the Λ^0 hyperon interaction.[3] This was satisfied only in six events. In 17 cases, only one high-energy neutron was present. In one case two high-energy fragments were observed, while in another a proton and deuteron (or two high-energy protons) were observed. Consequently, 19 cases out of 25 cannot be explained by the single-nucleon mechanism of Λ^0 hyperon interaction. Only 24% of the cases where a reasonable value of B_Λ was obtained can be explained by such a mechanism. In the first part of the experiment this fraction amounted to 30%. We also estimated the upper limit (60%) of the fraction of events which can be explained by such a mechanism of Λ^0 hyperon interaction, including in the statistics 30 events in which B_Λ was determined. 17 cases with a determined B_Λ, in which only one high-energy neutron was observed, could be explained assuming the absorption of a virtual π meson in the decay of the Λ^0 hyperon in the hypernucleus.[4] A neutron would then carry away almost the total kinetic energy ($\approx$127 MeV), which is approximately equal to the total average kinetic energy of the proton and the neutron ($\approx$149 MeV); the results are averaged over the first and second parts of the experiment. In the case when the large kinetic energy of the neutron is not due to the absorption of a virtual π meson by a nucleon in the nucleus we would expect a more uniform energy distribution over all the particles, which is not observed.

In four events (two of which were described in the first part of the experiment) the main energy fraction was carried away by charged particles other than nucleons. An explanation could be found by assuming that the Λ^0 hyperon interacts with a particle complex. It is, however, impossible to check this assumption because of poor statistics.

The momentum spectrum of fast nucleons from non-mesic decays of hypernuclei shown in Fig. 1 confirms the previous result that the neutron momentum shifts toward high values.

The relation between the total nucleon energy and the energy of the remaining particles in decays for which the values of B_Λ were determined is shown in Fig. 2. It can be seen from the figure that the points corresponding to the energy of a single high-energy neutron and to the total energy of a proton and a neutron concentrate in the same region.

In non-mesic decays the fraction of decays due to the interaction of the Λ^0 hyperons with a neutron and a proton $R = W_1(\Lambda^0 n \to nn)/W_2(\Lambda^0 p \to np)$ was found to lie within the range $2.73 \leq R \leq 5$, which confirms the result obtained in the first part of the experiment, and indicates that the interaction of the Λ^0 hyperon with a nucleon goes through a virtual Σ state.

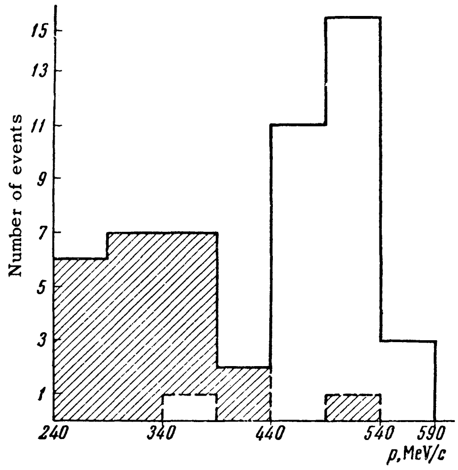

FIG. 1. Momentum spectrum of fast nucleons emitted in non-mesic hypernucleus decays (from the first[1] and second part of the experiment). The shaded rectangles correspond to protons and the unshaded to fast neutrons.

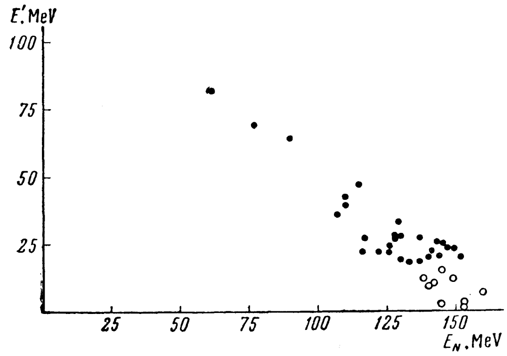

FIG. 2. Relation between the total energy of fast nucleons E_N and the energy of the remaining particles E' for decays in which B_Λ was measured (from the first[1] and second parts of the experiment); ● – energy of the neutrons (fast protons absent); ○ – total energy of the proton and the neutron.

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[1] Tumanyan, Sarinyan, Galstyan, Kanetsyan, Arustamova, and Sarkisyan, JETP 41, 1007 (1961), Soviet Phys. JETP 14, 716 (1961).

[2] U. G. Gulyamov, Dissertation, Tashkent, 1961.

[3] F. Ferrari and L. Fonda, Nuovo cimento 7, 320 (1958).

[4] H. Primakoff and W. B. Cheston, Phys. Rev. 92, 1537 (1953).

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145