Evidence of a New Decay Mode of ${}^{9}_{\Lambda}B$

P. Mandal, D. K. Bhattacharya, M. Saha and P. K. Sen

Department of Physics, Calcutta University, Calcutta, India

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In a sample of about 200 hyperfragments produced in the interactions of 1.8 GeV/C K^--mesons in nuclear emulsions, one example of the hitherto unobserved decay ${}^{9}_{\Lambda}B \rightarrow \pi^- + {}^{1}H + {}^{1}H + {}^{7}Be$ has been established. The value of the Λ-hyperon binding energy (B_Λ) obtained is 7.37 ± 0.42 MeV.

I. Introduction

The existence of the hypernucleus ${}^{9}_{\Lambda}B$ was predicted as early as 1963 by Dalitz and Levi Setti [1] on the basis of the ${}^{8}B$ particle stability by 0.13 MeV relative to $p + {}^{7}Be$. But the number of ${}^{9}_{\Lambda}B$ observed till recently is very small. This hypernucleus is of considerable interest as the Λ-binding energy of ${}^{9}_{\Lambda}B$ is expected to be the same as that of the mirror hypernucleus ${}^{9}_{\Lambda}Li$ because of charge symmetry. However, according to the hypernuclear B.E. formula of Bhaduri et al. [2], the predicted B_Λ of ${}^{9}_{\Lambda}B$ is around 7.2 MeV, which is one MeV smaller than the observed ${}^{9}_{\Lambda}Li$ binding energy (8.25 ± 0.13 MeV). Their prediction, if confirmed, would indicate a large charge asymmetry.

The first evidence of the existence of ${}^{9}_{\Lambda}B$ was reported by Juric [3] et al. The observed decays were

$$ {}^{9}_{\Lambda}B \rightarrow \pi^- + {}^{1}H + {}^{8}B \quad \text{(2 events)}, $$
$$ {}^{9}_{\Lambda}B \rightarrow \pi^- + {}^{1}H + {}^{1}H + {}^{1}H + {}^{6}Li \quad \text{(2 events)}, $$

giving a B_Λ value of 8.39 MeV from the first mode and 7.51 MeV from the second.

In this report we present the analysis of an event (in a sample of 200 hyperfragments) which has been unambiguously identified as a ${}^{9}_{\Lambda}B \rightarrow \pi^- + {}^{1}H + {}^{1}H + {}^{7}Be$ decay. No other evidence of this mode has been reported. The B_Λ value (7.37 ± 0.42 MeV) determined from this event agrees with the result of Juric et al. [3] for the latter of the two decay modes mentioned above and also confirms the prediction of Bhaduri et al. [2].

Reprint request to Miss P. Mandal, K. M. Mullick Scholar, Dept. of Physics, Univ. College of Science, Calcutta-9, India.

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II. Experimental Procedure

The experiment was performed using a stack consisting of 40 K-5 nuclear emulsion plates, each of size $20 \times 12 \times 0.06$ cm^3, exposed to the K^- beam of momentum 1.8 GeV/C at Brookhavon National Laboratory. Details of scanning and the nature of the beam and K-5 emulsion stack have been described in an earlier paper (Mandal et al. [4]).

The K^- interactions were found by area scanning. All stars were examined under a mgnification of 1250 X to detect the presence of double-centred stars. The decay tracks from the secondary vertex were followed upto the end. The presence of any short recoil, blobs or electron track was noted carefully.

For each hyperfragment the ranges and angle of emission of the decay prongs were measured. To detect the mesic decays, all grey and shower tracks were followed and ionisation measurements were carried out to ascertain the π^--meson tracks and to estimate their ranges. The tracks from the primary stars were classified as black, grey and shower to see whether the hyperfragments are produced due to K^--interactions with heavy (Ag, Br) or light (C, N, O) emulsion nuclei.

It has been found that the event, which is being reported here, was produced in an interaction with a heavy emulsion nucleus, as $N_h > 6$.

III. Description and Establishment of the Hypernuclear Decay

The hyperfragment emitted from the primary interaction comes to rest in the emulsion after traversing a distance of 4.91 µm where it decays with emission of a short recoil and three other charged particles. One of them, having a range of 4765.93 µm, was identified as π^--meson from ionisation measurement corresponding to an energy of 15.49 MeV. For the identification of the remaining two tracks, the mean track-widths $W(\theta)$ were measured and the charges were determined from $W(\theta)$ vs. θ calibration curves for $Z = 1$ to 5. (The calibration curves being drawn from measurements on tracks of known charges, identified kinematically from mesic and non-mesic hyperfragments, elastic scattering events etc.) These two tracks were unambiguously identified as particles of charge one ($Z = 1$). So they could be ${}^{1}H$, ${}^{2}H$ or ${}^{3}H$. The identification of the short recoil is not possible from

Table 1. Data on the decay products emitted from a hyperfragment.

Event No.	Prong No.	Range μm	Emission angle in degrees		Identified	Energy MeV
			dip	Projected		
	1	4765.93 ± 58.00	$+17.686 \pm 2.00$	0.0	π^-	15.491
1	2	126.98 ± 5.00	$+45.53 \pm 1.80$	5.80 ± 2.00	^1H	4.187
	3	3.20 ± 0.70	0.0 ± 12.00	135.45 ± 2.00	^7Be	2.381
	4	403.45 ± 11.00	-33.5 ± 1.50	270.72 ± 2.00	^1H	8.196

track-width or ionisation measurements. So it was taken to be ^4He, ^6Li, ^7Be, ^8Be, ^9Be, ^9B, ^{12}C etc. in turn and it was tried to fit the momentum balance. Of these the decay mode $^9_\Lambda B \rightarrow \pi^- {}^1H\,{}^1H\,{}^7Be$ was the most probable interpretation of the event since it gave the smallest momentum imbalance (29.5 MeV/c). As the hyperfragment decays at rest with the emission of a π^- it has been assumed that no neutron emission took place.

The event also fitted to some extent with the modes, (a) $^8_\Lambda Be \rightarrow \pi^- {}^1H\,{}^1H\,{}^6Li$ and (b) $^{10}_\Lambda B \rightarrow \pi^- {}^1H\,{}^1H\,{}^8Be$. But the following reasoning indicate that these possibilities can be excluded. Interpretation (a) is untenable as B_Λ was found to be only 2.65 MeV which is very small compared to the previously determined value. In case the event is a $^{10}_\Lambda B$ decay (interpretation (b)), one of the decay products, namely ^8Be, is unstable and should have decayed into two α-particles. If the ^8Be decays in flight from its ground state then it may give rise to two α-particles with small opening angle between them in the laboratory frame and thereby entailing a possibility of superposition of two α-tracks. However, careful considerations led us to exclude that possibility. The range of the smallest track in this event was 3.2 μm, and if it is attributed to α's from ^8Be then the α-emission is along the direction of ^8Be (the fit was good assuming the direction of ^8Be along the direction of the smallest track). In that case the range of the forward α should be 5.69 μm (decaying from a 186.25 MeV/c ^8Be) which is larger than the observed length of 3.2 μm. The maximum opening angle between the two α's decaying from a 186.25 MeV/c ^8Be in laboratory is 23.5° and the corresponding range of α's is 4.06 μm. If the ^8Be decay after traversing some distance from the primary vertex, the opening angle increases and it becomes more and more unlikely to be missed in careful scanning. So the interpretation of the event as due to a ^{10}B was discarded. Also, the calculated B.E. for this mode (7.75 MeV) does not agree well with that determined by other authors [3, 5, 6]. In view of the above arguments the event has been interpreted as being a decay of $^9_\Lambda B \rightarrow \pi^- + {}^1H + {}^1H + {}^7Be$. This interpretation is well supported by the good agreement of the measured B_Λ (7.37 ± 0.42 MeV) with the value predicted by Bhaduri [2] et al.

Table 2. Comparison of B_Λ for different decays of $_\Lambda B^9$.

HF	Decay mode	No. of Events	$B_\Lambda \pm \Delta B_\Lambda$	Reference
	$\pi^- {}^1H\,{}^8Be$	2	8.39 ± 0.23	[3]
$^9_\Lambda B$	$\pi^- {}^1H\,{}^1H\,{}^1H\,{}^6Li$	2	7.51 ± 0.20	[3]
	$\pi^- {}^1H\,{}^1H\,{}^7Be$	1	7.37 ± 0.42	Present work

IV. Conclusion

A new decay mode of $^9_\Lambda B \rightarrow \pi^- + {}^1H + {}^1H + {}^7Be$ has been established with little ambiguity. Bohm et al. [6] had difficulty in distinguishing $^9_\Lambda B$'s from $^{10}_\Lambda B$'s as their sample consisted of 5 body decays with two heavy prongs either of which could be identified as ^3He or ^4He. In our case, we had only one heavy prong and the length of the prong was large enough to distinguish it from a ^8Be (more specifically 2 superposed α's from ^8Be). It should be mentioned that Dalitz and Levi Setti [1] suggested two decay modes of $^9_\Lambda B$ ($^9_\Lambda B \rightarrow \pi^- + {}^1H + {}^1H + {}^7Be$ and $^9_\Lambda B \rightarrow \pi^- + {}^1H + {}^1H + {}^3He + {}^4He$) which could unambiguously identify a $^9_\Lambda B$. One mode (as stated earlier) was observed by Juric et al. [3], the other one in the present work.

The measured B_Λ value of $^9_\Lambda B$ agrees well with one of the findings of Juric et al. [3], and also with the theoretical value (7.09, 7.26 MeV) predicted by Bhaduri et al. [2] using the Garvey and Kelson's mass formula, which was found to hold remarkably well for the Λ-separation energy of light hypernuclei. The stability against $^9_\Lambda B \rightarrow {}^8_\Lambda Be + {}^1H$ requires that $B_\Lambda(^9_\Lambda B) > 6.67 \pm 0.07$ MeV. Our estimate of $B_\Lambda({}^9_\Lambda B)$ shows that ${}^9_\Lambda B$ is likely to be stable against the decay ${}^9_\Lambda B \rightarrow {}^8_\Lambda Be + {}^1H$ and thereby making an identification of ${}^9_\Lambda B$ rather straight forward. The observed value of B_Λ turned out to be 1 MeV smaller than the known B_Λ value of ${}^9_\Lambda Li$, which is a member of the isospin triplet to which ${}^9_\Lambda B$ belongs, indicating a large charge asymmetry.

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