BINDING ENERGY AND π^+ DECAY OF LIGHT HYPERFRAGMENTS

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Abstract

Binding energy values of hyperfragments from a sample of 541 uniquely identified mesic decays with mass numbers A = 3 to 14 are presented. There does not seem to be any detectable difference in the binding energy value of Λ in ${}_\Lambda H^4$ obtained from its two-body and three-body decay modes. Within statistical error, the binding energy values of Λ in ${}_\Lambda H^4$ and ${}_\Lambda He^4$ are also the same. From a sample of $2\pi^+$ decay events of hyperfragments the branching ratio of ${}_\Lambda He^4$ decaying by π^+ to π^- mode is found to be $(1 \cdot 5 \pm 1 \cdot 0)\%$.

1. Introduction

Studies of binding energies of Λ-hyperons in light hyperfragments (HFs) have been made in the past by various groups.[1–4] These investigations, however, had two shortcomings: (i) The results obtained from individual experiments were based on poor statistics and (ii) the procedures adopted for the unique identification of HFs by different groups, namely in calibration of stacks, measurements, and selection criteria were not the same thereby casting doubt on the reliability in the procedure of combining binding energy values obtained by different groups. Recently Mayeur *et al.*[5] have obtained binding energies of light HFs from a large sample of events with stringent criteria for unique identification. However, their results indicate differences between the binding energy values for the two-body (π^-, He^4) and three-body (π^-, H^1, H^3) decay modes of ${}_\Lambda H^4$. In another paper, Mayeur

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et al.[6] have reported an experimental value for the ratio of π^+ to π^- mesic decay for ${}_{\Lambda}He^4$ which is rather high compared to other experimental values, and different from theoretical calculations.

Because of the importance of these results, there has been a need for further work in this field. The present investigation has been mainly motivated with a view to obtain results of good statistical significance and at the same time eliminate or reduce to the minimum, systematic biases. We present in this paper (i) binding energies of HFs based on 541 uniquely identified mesic HFs and (ii) the branching ratio of ${}_{\Lambda}He^4$ decaying by π^+ and π^- modes based on $2\pi^+$ decays.

2. EXPERIMENTAL DETAILS

2.1. *Details of the Stack and Selection of Events*

A stack consisting of 150, K–5 emulsion pellicles, each of size 10 cm. × 15 cm. and nominal thickness 600 μm., was exposed to the 350 MeV/c separated K^- beam of the proton synchrotron at CERN. The thickness of each pellicle was measured to an accuracy of 1 μm. at six different places before processing.

The central regions of the emulsion pellicles, where most of the K^- particles were brought to rest, were area-scanned under a magnification of 375 × for HFs of range $\geqslant 1$ μm. from stars with $N_h \geqslant 1$. All secondary particle tracks from decays of HFs were followed till they were brought to rest, interacted or left the stack. In this manner, we identified in all 1,312 examples of π^- mesic decays and 3 examples of π^+ decays of HFs where the pion was brought to rest in the stack.

2.2. *Methods of Measurements*

In principle, binding energies accurate to a few tenths of an MeV can be obtained by adopting (i) an accurate method for determining the residual ranges of particles with minimum associated systematic errors, (ii) an accurate range-energy relation and (iii) a reliable calibration of the stack. In the present experiment all possible effort and care has been taken to attain the above conditions; these will now be described.

2.2.1. *Range measurements*

We first tried to investigate whether the residual range of a particle, as obtained by us from range measurements in a number of pellicles through which the particle traverses, contains any detectable systematic errors. This was carried out in the following way: We selected events in which a Σ^+ decays at rest into a proton and π^0. Of these events we selected (*a*) 118 events in which the entire proton range was contained in a single emulsion pellicle and (*b*) 116 events in which the proton traversed two or more pellicles. The mean range of protons of group (*a*) is $1688 \cdot 3 \pm 3 \cdot 0\,\mu$m. whereas the mean range of protons of group (*b*) obtained from range measurements of tracks visible under microscope was only $1671 \cdot 5 \pm 3 \cdot 3\,\mu$m. This reduction in the mean range seems to be quite significant and the most likely reason for this according to us seems to be the scrubbing of emulsion surfaces when cleaning them of surface marks developed during processing. We therefore remeasured with care the residual ranges of protons from group (*b*) in the following way: a reference track was always chosen in each plate such that it is steep and/or its projected angle with respect to the track under measurement was $\approx 90°$. The effect due to scrubbing was then obtained by noting down the positions of the reference track with respect to the track under measurement in two consecutive plates. The mean range of protons of group (*b*) thus obtained is $1686 \cdot 2 \pm 3 \cdot 1\,\mu$m. The good agreement of this value with that obtained for protons of group (*a*) gives us confidence for our method in determining the true residual ranges of particles when they traverse more than one pellicle. All range measurements of tracks were therefore carried out in this manner in the present work. This type of range measurements, taking into account the systematic loss in range due to scrubbing, is quite important especially in the case of long-range pions. The magnitude of this effect can be demonstrated from the following: If the loss in pion range due to scrubbing is not taken into account, then the B_Λ will be overestimated by 0·45 MeV in the case of ${}_{\Lambda}H^4 \rightarrow \pi^- + He^4$ whereas in the case of ${}_{\Lambda}H^4 \rightarrow \pi^- + H^1 + H^3$, it is only about 0·20 MeV.

2.2.2. *Range-energy relation and particle data*

In order to convert the ranges obtained (from 2.2.1) into energies for various particles, a range-energy relation is needed. For emulsions of standard density (3·815 gm./cm.^{3}), Barkas[7] has given range-energy relations for singly and multiply charged particles, in terms of two quantities λ and τ which refer to the range and energy of a particle of proton mass and charge. Later Heckman *et al.*[8] have modified the range-energy relation for singly and multiply charged fragments to be valid up to low energies by taking into account the extension in range caused by neutralisation of the charge at low velocities. With the help of a table of λ *vs.* τ given by Barkas[7] and the modified range-energy relation introduced by Heckman *et al.*,[8] range-energy relations for charged fragments up to oxygen were obtained with a sixth order least square polynomial for range and energy; the coefficients of the polynomial fit are given by Rao.[9]

The masses for various nuclei are taken from Konig *et al.*[10] and the value of Q_Λ is taken to be 37·60 MeV.[11]

2.2.3. *Calibration of the emulsion stack*

The range-energy relation described above can be used only for an emulsion of standard density 3·815 gm./cm.[3] Hence before using it, one has to calibrate the stack for density. This was done by measuring the residual ranges of 118 protons from the decay at rest of Σ^+ hyperons (class (*a*) type discussed in sec. 2.2.1). The mean value of the proton residual range was found to be $(1688 \pm 3)\,\mu$m. The expected range of the proton from Σ^+ decay in an emulsion of standard density is $(1677 \pm 2)\,\mu$m.[12] In view of this, all pion and proton ranges were corrected by a factor

$$C(\beta) = 1 - r(\beta) \times 0{\cdot}0088$$

where the values of $r(\beta)$ based on "additivity of the volume" are taken from Barkas *et al.*[13]; the factor 0·0088 represents the fractional decrease of density of our stack with respect to emulsions of standard density.

3. ANALYSIS AND RESULTS OF HFs

3.1. *Identification of Decay Schemes by Computer Programming*

All events were analysed on a CDC–3600 computer. Each hyperfragment and its decay tracks were assigned maximum and minimum charges; all other relevant data including true ranges of each of the tracks and their corresponding dip and projected angles were also fed to the computer. The computer then calculated the resultant unbalanced momentum at the decay vertex of the HF for each possible combination of identities of the tracks and assigned it either to a neutron or to an invisible recoil. If the unbalanced momentum was less than 100 MeV/c., the computer also tried decay schemes without any invisible recoil or a neutron.

A decay scheme was taken to be unique, only if it satisfied one of the following conditions: (i) the inferred range of the shortest track obtained from the resultant momentum of the remaining tracks agreed, within two standard deviations, with its measured range, or (ii) the momentum unbalance of all the charged decay particles was zero within two standard deviations.

Besides the above condition, it was also required that in case of HFs decaying by (π^-–H^1 recoil), mode of ${}_\Lambda H^{3,4}$ and ${}_\Lambda He^{4,5}$, the recoil range should be greater than 4 and 6 microns respectively for unique identification.

3·2. *Binding Energy Calculation*

The binding energy of a HF was calculated in two ways: (i) It was directly obtained from the data fed to the computer, namely from ranges, dip-angles and projected angles of various tracks and (ii) the true range of the shortest track was first obtained from the inferred dip of the resultant momentum of the remaining tracks and its measured projected range; binding energy was then calculated by using this true range for the shortest track. It is assumed here that the inferred dip angle is more reliable than the measured one.

The binding energy obtained by method (ii) was used only where the following two conditions were satisfied: (*a*) the projected range of the shortest track was less than 30 μm., and (*b*) three times the projected range of the shortest track was less than the projected range of the next longer track in the event. These criteria were set up in order to avoid large errors in the dip angle measurement of the shortest track.

3·3. *Results and Discussion on Binding Energies*

From a total sample of 1315 complete pion events (*i.e.*, where the decay pions were brought to rest in the stack), 541 were considered to be uniquely identified; the results on the binding energy from these are presented in Table I. The distributions of binding energy values for various hyperfragments are shown in Figs. 1–3. We will now proceed to discuss the following species (${}_\Lambda H^4$, ${}_\Lambda He^4$, ${}_\Lambda He^7$, ${}_\Lambda Be^7$ and ${}_\Lambda B^{10}$) in some detail.

(i) *${}_\Lambda H^4$ and ${}_\Lambda He^4$.*—In all 128 cases of uniquely identified ${}_\Lambda H^4$ events were observed; of these 111 decayed by (π^-, He^4) mode, 16 by (π^-, H^1, H^3) mode and one by (π^-, H^2, H^2) mode. The binding energies of Λ obtained separately for the three modes agree with each other within statistical errors; the mean B_Λ being $2{\cdot}00 \pm {\cdot}08$ MeV. On the other hand Mayeur *et al.*[5] and also Gajewski *et al.*[14] obtained values of B_Λ from (π^-, He^4) mode as ($2{\cdot}29 \pm 0{\cdot}08$) and ($2{\cdot}26 \pm 0{\cdot}07$) MeV respectively, whereas from the three-body mode their values were $1{\cdot}95 \pm 0{\cdot}14$ and $1{\cdot}86 \pm 0{\cdot}10$ MeV respectively; this difference in the B_Λ values has led them to suspect that the range-energy relation might be in error by $\sim 1\%$. We, however, would like to suggest from our experimental data, that at this stage there is no need to assume an error in range-energy relation in order to explain the difference in the values of binding energy obtained by the above authors and the discrepancy may be due to statistical and/or systematic loss in the measurement of pion ranges. It is worth mentioning here that recently Fok and Barkas[15] have again looked into the errors in the range-energy relation by analysing pions obtained from the decay of τ-mesons; they have not found any noticeable deviation from the range-energy data.

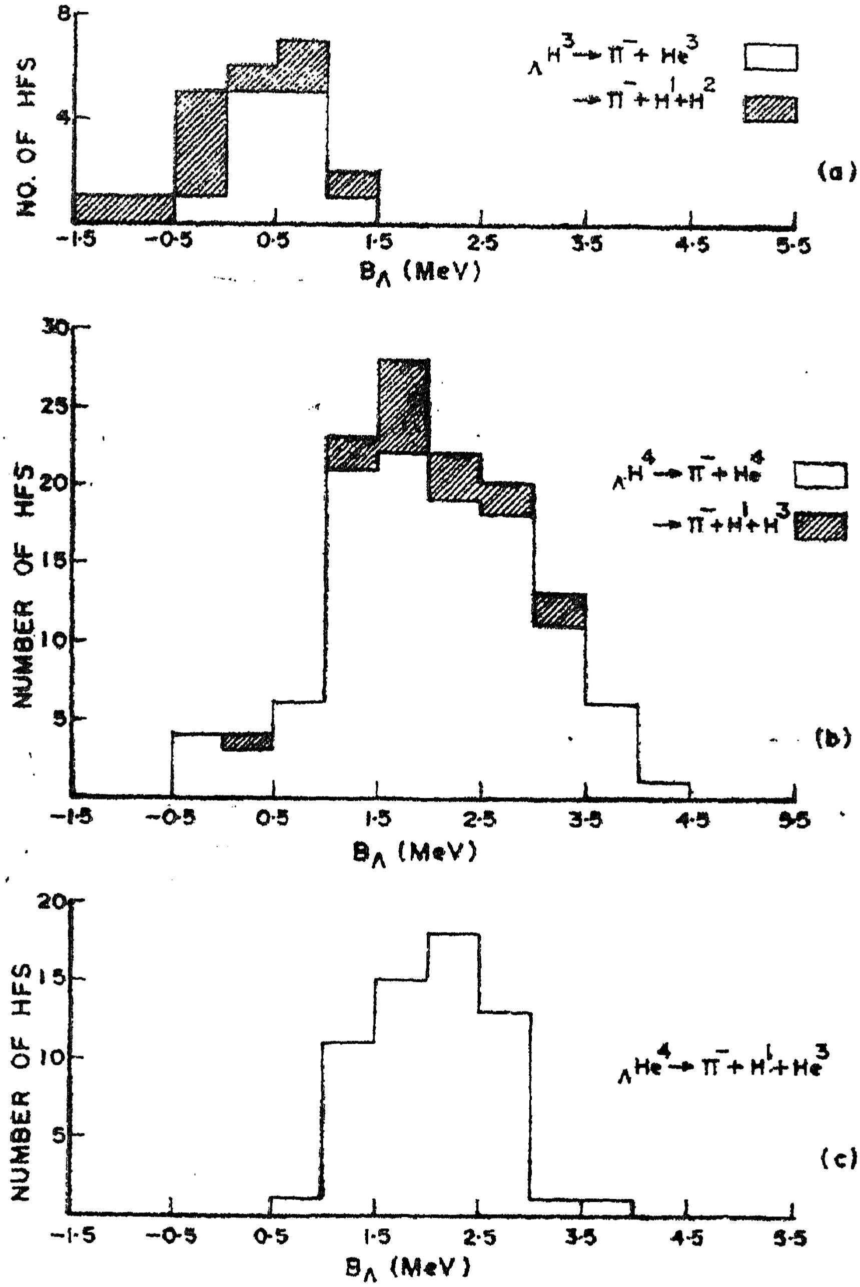

FIG. 1

Regarding $_\Lambda He^4$ it is found that the binding energy from 62 examples obtained in this investigation, is $2{\cdot}04 \pm 0{\cdot}08$ MeV (*see* Table I); on the other hand the mean value of B_Λ in $_\Lambda H^4$ is $2{\cdot}00 \pm 0{\cdot}08$ MeV. This then gives the value of ΔB_Λ as:

$$\Delta B_\Lambda = B_\Lambda(_\Lambda He^4) - B_\Lambda(_\Lambda H^4) = +0{\cdot}04 \pm 0{\cdot}11 \text{ MeV}.$$

TABLE I

Binding energy values

Hyper-fragment	Decay Mode	No. of events	$B_\Lambda \pm \Delta B_\Lambda$† (MeV)
${}_\Lambda H^3$	$\pi^- + He^3$	12	$0{\cdot}48 \pm 0{\cdot}15$
	$\pi^- + H^1 + H^2$	10	$-0{\cdot}057 \pm 0{\cdot}19$
	Total	22	$0{\cdot}24 \pm 0{\cdot}12$
${}_\Lambda H^4$	$\pi^- + He^4$	111	$2{\cdot}01 \pm 0{\cdot}09$
	$\pi^- + H^1 + H^3$	16	$1{\cdot}98 \pm 0{\cdot}19$
	$\pi^- + H^2 + H^2$	1	$1{\cdot}28 \pm 0{\cdot}54$
	Total	128	$2{\cdot}00 \pm 0{\cdot}08$
${}_\Lambda He^4$	$\pi^- + H^1 + He^3$	60	$2{\cdot}06 \pm 0{\cdot}08$
	$\pi^- + H^1 + H^1 + H^2$	2	$1{\cdot}45 \pm 0{\cdot}32$
	Total	62	$2{\cdot}04 \pm 0{\cdot}08$
${}_\Lambda He^5$	$\pi^- + H^1 + He^4$	195	$3{\cdot}00 \pm 0{\cdot}03$
${}_\Lambda He^7$	$\pi^- + Li^7$	3	$4{\cdot}66 \pm 0{\cdot}62$
	$\pi^- + H^1 + He^6$	7	$4{\cdot}55 \pm 0{\cdot}21$
	$\pi^- + H^3 + He^4$	1	$4{\cdot}63 \pm 0{\cdot}75$
	Total	11	$4{\cdot}59 \pm 0{\cdot}21$
${}_\Lambda Li^7$	$\pi^- + Be^7$	27	$5{\cdot}45 \pm 0{\cdot}13$
	$\pi^- + He^3 + He^4$	13	$5{\cdot}35 \pm 0{\cdot}22$
	$\pi^- + H^1 + Li^6$	3	$5{\cdot}23 \pm 0{\cdot}49$
	Total	43	$5{\cdot}40 \pm 0{\cdot}11$
${}_\Lambda Li^8$	$\pi^- + He^4 + He^4$	47	$6{\cdot}76 \pm 0{\cdot}14$
	$\pi^- + Be^9$	1	$7{\cdot}58 \pm 0{\cdot}88$

TABLE I (*Contd.*)

Hyper-fragment	Decay Mode	No. of events	$B_\Lambda \pm \Delta B_\Lambda$† (MeV)
${}_\Lambda Li^9$	$\pi^- + H^3 + Li^6$	3	8·72±0·29
	Total	4	8·43±0·30
${}_\Lambda Be^7$	$\pi^- + H^1 + H^1 + H^1 + He^4$	1	5·10±0·43
	$\pi^- + H^1 + H^1 + H^1 + (He^4)$*	2	4·92±0·38
	Total	3	4·98±0·29
${}_\Lambda Be^8$	$\pi^- + H^1 + He^3 + He^4$	1	6·66±0·53
	$\pi^- + H^1 + Be^7$	1	7·52±0·58
	Total	2	7·09±0·39
${}_\Lambda Be^9$	$\pi^- + H^1 + He^4 + He^4$	11	6·24±0·14
${}_\Lambda Be^{11}$	$\pi^- + H^1 + (Be^{10})$*	1	11·04±0·26
${}_\Lambda B^{10}$	$\pi^- + C^{10}$	2	11·95±0·37
	$\pi^- + H^1 + H^1 + Be^8$	1	8·75±0·47
${}_\Lambda B^{12}$	$\pi^- + (C^{12})$*	1	11·24±0·75
	$\pi^- + He^4 + He^4 + He^4$	4	10·86±0·35
	Total	5	10·94±0·31
${}_\Lambda C^{13}$	$\pi^- + (N^{13})$*	2	10·10±0·37
${}_\Lambda C^{14}$	$\pi^- + H^1 + (C^{13})$*	2	13·77±0·21

* The track of the bracketed particle is not seen.

† (*a*) For an individual event ΔB_Λ refers to experimental error. (*b*) For small samples ($n < 30$), ΔB_Λ is $\sum_{i=1}^{n} (\Delta B_\Lambda)_i / n \sqrt{n}$. (*c*) For large samples ($n \geqslant 30$), ΔB_Λ is $\sqrt{\frac{\bar{B}_\Lambda^2 - \bar{B}_\Lambda^2}{n-1}}$. Possible systematic errors of the order of 0·15 MeV are not included.

The value of ΔB_Λ as obtained by Mayeur *et al.*,[5] considering only three-body decays in ${}_\Lambda H^4$ and ${}_\Lambda He^4$, is $(0{\cdot}12 \pm 0{\cdot}17)$ MeV, whereas the combined values of European, EFINS and North-western groups as given by Gajewski *et al.*[14] is $(0{\cdot}36 \pm 0{\cdot}12)$ MeV.

As this $\triangle B_\Lambda$ is expected to be negative (—0·25 MeV, Private Communication from Dalitz) and all the $\triangle B_\Lambda$ values quoted above are positive there is an indication for charge symmetry breaking in $\Lambda - N$ interaction.

(ii) ${}_\Lambda He.^7$—We have 3 examples of ${}_\Lambda He^7$ decaying *via* (π^-, Li^7) mode, 7 examples *via* (π^-, H^1, He^6) mode and one *via* (π^-, H^3, He^4) mode. The average binding energy for these comes out to be (4·59 ± 0·21) MeV. The distribution of binding energy for ${}_\Lambda He^7$ after combining the present values with 10 examples of Gajewski *et al.*[14] and one example each from Prem,[16*] Sacton,[17*] Prakash *et al.*[18*] and Chaudhari *et al.*,[19] is presented in Fig. 2 (*b*).

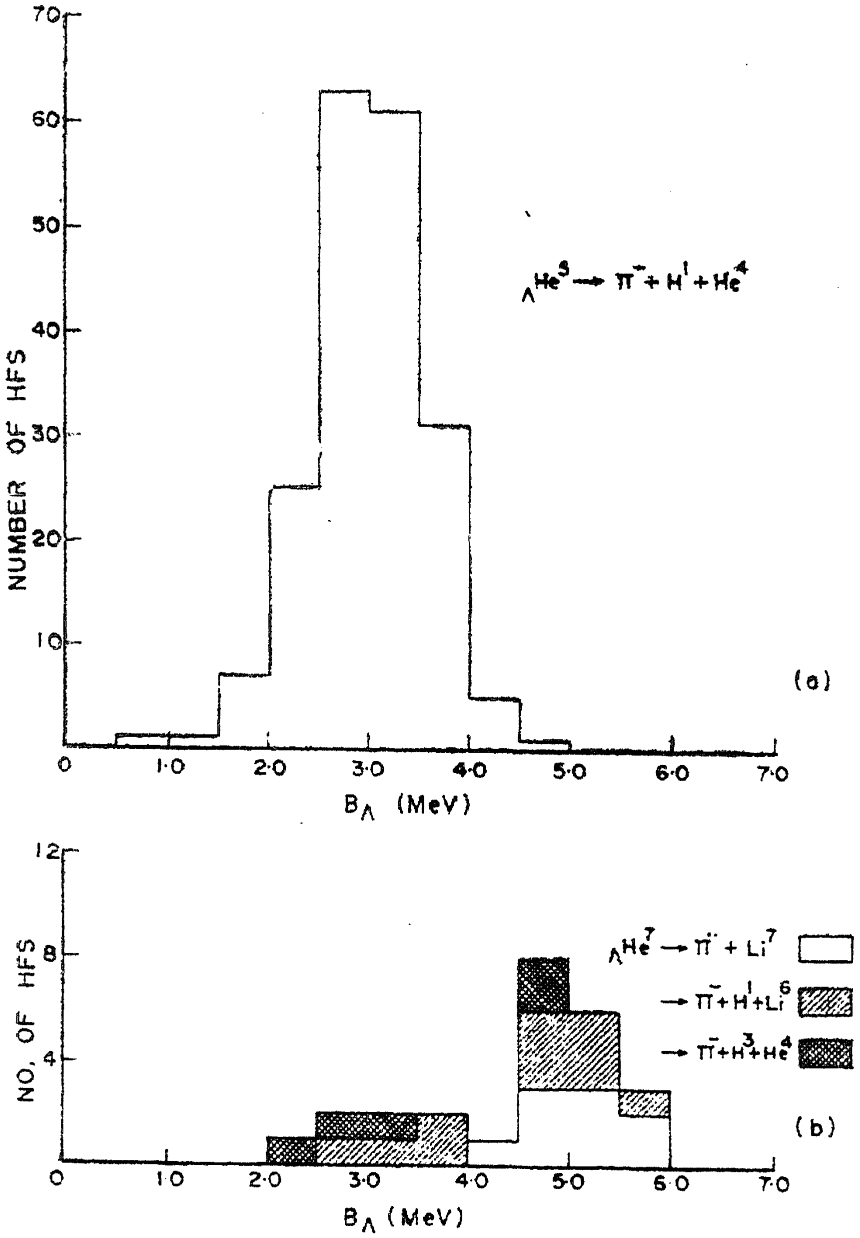

FIG. 2

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* These three events have been reanalysed by our programme and the value of B_Λ thus tained, are used in B_Λ distribution.

The broad distribution in B_Λ values seems unlikely, due to experimental errors; it has been previously attributed by Danysz and Pniewski[20] as due to the decay of $_{\Lambda}\mathrm{He}^7$ from ground state and from the long-lived isomeric state.

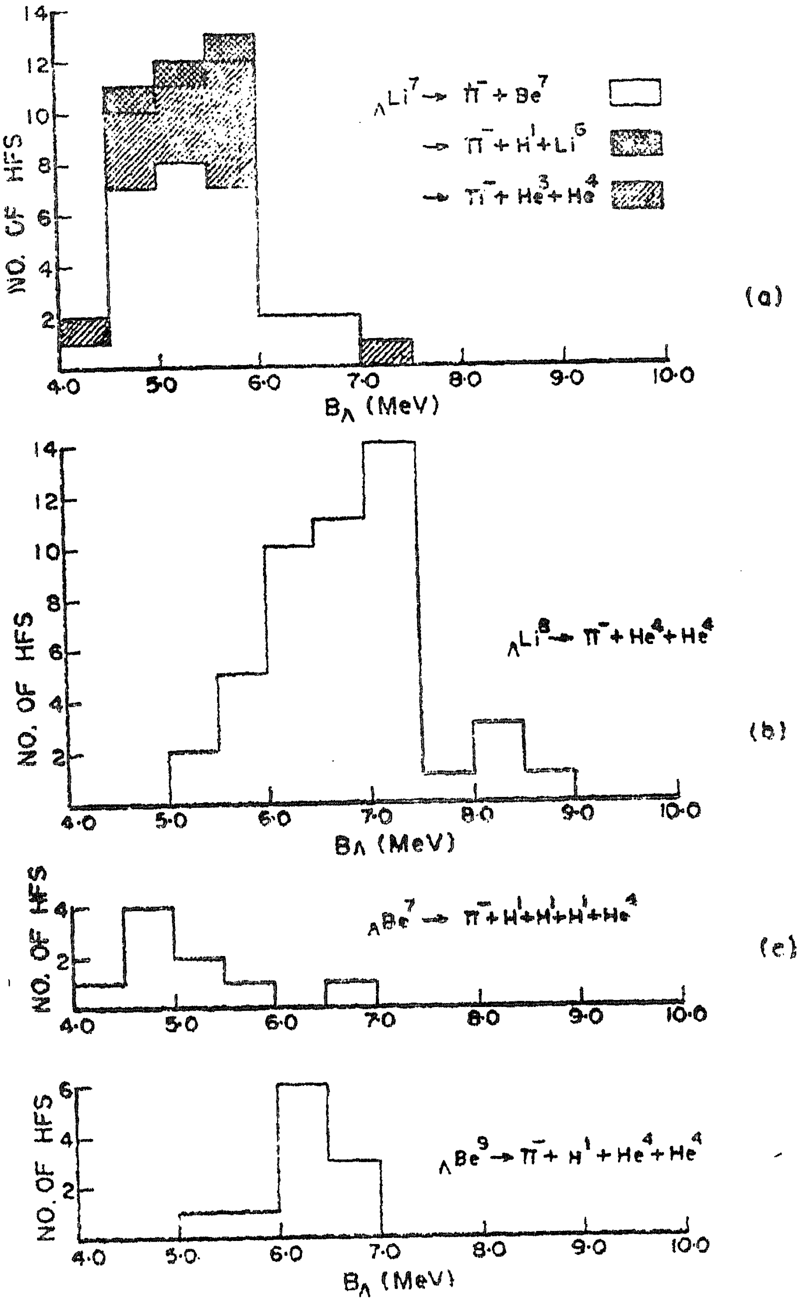

FIG. 3

(iii) $_{\Lambda}$*Be.*^{7}—There are 3 examples of $_{\Lambda}\mathrm{Be}^7$ decaying by the mode $\pi^-\mathrm{H}^1\mathrm{H}^1\mathrm{H}^1\mathrm{He}^4$ of which the recoil of He^4 was not seen in two cases. The mean binding energy obtained from these is (4·98 ± 0·29) MeV, which when combined with our previous example,[21] 3 examples of Mayeur *et al.*[5] and one example each of St. Lorant and Lokanathan[22]† and Ammar *et al.*[23]†

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† These two events have been reanalysed by our programme and the values of B_Λ are found o be (5·74 ± 0·60) and (4·2 ± 0·70) MeV respectively.

(all calculated with the same Q_Λ and mass of Be^6 core used in this work) gives a value of $(5{\cdot}29 \pm 0{\cdot}19)$ MeV.

(iv) *$_\Lambda Be$.*[11]—We have one example which is uniquely identified to be $_\Lambda Be^{11}$ decaying by $\pi^- H^1$ (Be^{10}) mode with a B_Λ of $11{\cdot}04 \pm 0{\cdot}26$ MeV. The only other possible interpretation for this event is $_\Lambda He^8$ where the recoil (He^6) should have a range of $9{\cdot}6\,\mu$m. associated with the decay vertex of the HF. Such a track with the expected geometry was not seen. Therefore we consider this event as an unique example of $_\Lambda Be^{11}$ decaying by $(\pi^- H^1 Be^{10})$ mode in which the momentum of Be^{10} was such that it would not give rise to a visible recoil.

(v) *$_\Lambda B^{10}$*.—We have two examples of $_\Lambda B^{10}$ which decayed by $(\pi^- C^{10})$ mode and one example by $(\pi^- H^1 H^1 Be^8)$ mode; the B_Λ values differ by 3·2 MeV for these two modes. For the event decaying by the latter mode the measured range of the shortest track (Be^8) is $1{\cdot}2\,\mu$m. and the expected range of α-particles from such a (Be^8) is $2\,\mu$m. Though we have looked at this event carefully, it was not possible to identify with confidence the recoil as one track or superposition of two tracks. The B_Λ of this event agrees with that $(_\Lambda B^{10} \rightarrow \pi^- H^1 H^1 He^4 He^4)$ obtained by Mayeur *et al.*[5] The only other possible interpretation for this event is $_\Lambda B^9 \rightarrow \pi^- H^1 H^1 Be^7$ with a B_Λ of $8{\cdot}38 \pm 0{\cdot}47$ MeV but so far there is no evidence for this in the literature. In view of this we interpret our event as due to $_\Lambda B^{10}$.

The difference in B_Λ values of 3·2 MeV obtained in the present experiment for two-body and many-body decay modes of $_\Lambda B^{10}$ could be understood if we assume, C^{10} was formed in its first excited state at 3·36 MeV ± 17 KeV above its ground state $(J^\pi = 0^+)$. Ammar *et al.*[3] had also observed 6 events which were attributed to two-body decay modes of $_\Lambda B^{10} \rightarrow \pi^- C^{10}$ with an average B_Λ of $10{\cdot}0 \pm 0{\cdot}4$ MeV and the standard deviation was $1{\cdot}0 \pm 0{\cdot}3$ MeV. These results are also suggestive that in a few cases, C^{10} in the decay of $_\Lambda B^{10}$ was formed in its first excited state.

(vi) *$_\Lambda C^{13,\,14}$*.—We have two examples each of $_\Lambda C^{13}$ and $_\Lambda C^{14}$, recoils in both of which were not seen. The average value of binding energy for $_\Lambda C^{13}$ is found to be $(10{\cdot}10 \pm 0{\cdot}37)$ MeV and that for $_\Lambda C^{14}$ is $(13{\cdot}77 \pm 0{\cdot}21)$ MeV.

4. π^+ DECAY OF HYPERFRAGMENTS

Three examples of π^+ decay of hyperfragments have been observed in the present sample. The details of these events are summarised in Table II.

Two of these events (No. 1022 and 1023) are uniquely identified as ${}_\Lambda He^4 \rightarrow \pi^+ + n + H^3$ with values of binding energy as (3·31 ± 1·04) MeV and (2·48 ± 0·51) MeV respectively. Since event No. 1021 could not be identified uniquely, an estimate of its charge was attempted by measurement of track width.[24] From this, the charge of the HF seems to be probably three. (If, however, the charge is two, one can easily rule out the possibility of its being ${}_\Lambda He^5$ or ${}_\Lambda He^7$ simply from consideration of visible energy.)

TABLE II

Details of π^+ events

Event No.	Track	Range* (μm.)	Dip angle (degrees)	Projected angles (degrees)	Identity	Energy (MeV)	Binding energy (MeV)
1021..	HF	12·9	8·2	..	..	..	..
..	1	4318·0	40·1	..	π^+	14·2	..
1022..	HF	17·1	12·1	..	He^4	..	..
..	1	7196·0	36·2	0·0	π^+	19·15	3·31±1·04
	2	13·4	53·9	307·0	H^3	1·29	..
1023..	HF	195·9	37·8	..	${}_\Lambda He^4$	..	..
	1	12123·0	− 3·4	0·0	π^+	25·96	2·48±0·51
	2	70·2	17·3	164·5	H^3	4·16	..

* Ranges are corrected for density.

4.1. *Estimation of the Ratio R of π^+ to π^- Decay Rates of ${}_\Lambda He^4$*

In the present sample we have 62 examples of unique decays of ${}_\Lambda He^4$ and 195 of ${}_\Lambda He^5$. There are further 308 events of the type ${}_\Lambda He^{4,5}$, *i.e.*, where ${}_\Lambda He^4$ cannot be distinguished from ${}_\Lambda He^5$. In order to estimate the ratio R of decay rates going to π^+ to π^- of ${}_\Lambda He^4$, it is essential to estimate the number of ${}_\Lambda He^4$ from the sample of ${}_\Lambda He^{4,5}$. While various procedures to achieve this have been adopted in the past,[6, 25] we feel that a reliable procedure will be to assume the fraction of ${}_\Lambda He^4$ among the non-uniquely identified ${}_\Lambda$He–HFs to be the same as in the unique ones. From the uniquely identified events this fraction is (0·24 ± 0·03) which would mean that there are 74 ± 10 $_\Lambda He^4$ events among the 347 events. Adding this to the uniquely identified $_\Lambda He^4$ events, the total number of $_\Lambda He^4$ that decayed by π^- mesic mode is (136 ± 13) events.

We have two uniquely identified $_\Lambda He^4$ events, in the present sample that decayed by π^+ mode (*see* Section 4). From this it is found that

$$R = \frac{_\Lambda He^4 \rightarrow \pi^+}{_\Lambda He^4 \rightarrow \pi^-} = (1\cdot5 \pm 1\cdot0)\,\%.$$

If the third π^+ decay is also included as due to $_\Lambda He^4$, R becomes (2·1 ± 1·2) %.

4·2. *Discussion of the Branching Ratio R*

The estimate of the ratio R in the present experiment is (1·5 ± 1·0) %. The value of R as quoted by Beniston *et al.*[25] and Block *et al.*[26] are $\leqslant (2\cdot9 \pm 1\cdot1)\,\%$ and ~4% respectively, whereas that obtained by Mayeur *et al.*[6] is (9 ± 3) %.

The mechanisms for π^+ decay have also been theoretically studied by various authors;[27–32] these lead to values of $R \lesssim 1\cdot0\%$ for $_\Lambda He^4$. At this stage it is only possible to state that the experimental (except probably that of Mayeur *et al.*[6]) and theoretical values are not inconsistent with one another.

5. SUMMARY

From an analysis of 541 uniquely identified π^- mesic decays and $2\pi^+$ decays of HFs, the following results are obtained: (i) There is no detectable difference in the binding energy of Λ in $_\Lambda H^4$ as obtained from its three-body and two-body decay modes. (ii) There seems to be no measurable difference in binding energy between $_\Lambda H^4$ and $_\Lambda He^4$ within existing experimental errors. (iii) The branching ratio R for the decay of $_\Lambda He^4$ by π^+ mode to π^- mode is (1·5 ± 1·0) %.

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