ON THE HYPERNUCLEI RESONANT STATES $_{\Lambda}Li^{6}$, $_{\Lambda}He^{5*}$ AND $_{\Lambda}Be^{9*}$

By N. K. Rao and M. S. Swami‡

(*Tata Institute of Fundamental Research, Bombay-5, India*)

AND

A. Gurtu and M. B. Singh

(*Physics Department, Panjab University, Chandigarh-14, India*)

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Abstract

An attempt has been made to detect narrow resonant states of $_{\Lambda}He^{5*}$ (I = 2), $_{\Lambda}Li^{6}$ and $_{\Lambda}Be^{9*}$ (I = 1) from amongst a sample of 128 uniquely identified $_{\Lambda}H^{4}$ and 195 uniquely identified $_{\Lambda}He^{5}$ hypernuclei produced by stopping K⁻-mesons in a nuclear emulsion stack. From the experimental data presented, it is concluded that the production of any of these resonant states is not appreciable; upper limits of 20% and 15% are set for the proportion of $_{\Lambda}He^{5}$ resulting from the decay of $_{\Lambda}Li^{6}$ and $_{\Lambda}Be^{9*}$ respectively.

1. Introduction

Gajewski *et al.*[1] and Bohm *et al.*[2] have established the stability of $_{\Lambda}He^{6}$ against decay into $_{\Lambda}He^{5}$ and a neutron; the binding energy of Λ in $_{\Lambda}He^{6}$ is $4\cdot09 \pm 0\cdot27$ MeV. Assuming charge symmetry, the binding energy of Λ in the mirror hypernucleus $_{\Lambda}Li^{6}$ should be nearly the same. A comparison of the energy states of He^{5} and Li^{5} suggests that $_{\Lambda}Li^{6}$ should be unstable and decay into $_{\Lambda}He^{5}$ a proton; the Q-value for the reaction is ~ 1 MeV. The question of the existence of a particle stable $_{\Lambda}Li^{6}$ hypernucleus has been investigated by Coremans *et al.*[3]; the evidence seems to be negative for a type of decay mentioned above. Thus, $_{\Lambda}Li^{6}$, if formed in any interaction, is expected[4] as a narrow *p*-wave resonance in $_{\Lambda}He^{5}$-*p* rest system.

$_{\Lambda}He^{5*}$ (I = 2) hypernucleus is also expected to be unstable, decaying into $_{\Lambda}H^{4}$ and a proton. The possibility of such a system existing as a resonance in $_{\Lambda}H^{4}$-*p* system was considered by Dalitz and Levi-Setti[4] but since

‡ Now at Physics Department, Aligarh Muslim University, Aligarh, India.

other members of this I-spin multiplet have not been discovered it is difficult to predict the Q-value of this decay; however, it is expected[4] to be about a few MeV.

The existence of ${}_{\Lambda}Be^9$ and ${}_{\Lambda}Li^9$ have been confirmed by various authors. The Λ-binding energies in these isobaric systems as obtained by Bohm *et al.*[2] are $6 \cdot 68 \pm 0 \cdot 04$ and $8 \cdot 25 \pm 0 \cdot 13$ MeV respectively. This difference in B_{Λ} is attributed to different I-spin values for these systems: ${}_{\Lambda}Be^9$ belongs to $I = 0$ and ${}_{\Lambda}Li^9$ to $I = 1$ multiplet. Along with ${}_{\Lambda}Li^9$ the other members of the triplet are ${}_{\Lambda}B^9$ and ${}_{\Lambda}Be^{9*}$. The lowest level of ${}_{\Lambda}Be^{9*}$ is unstable relative to ${}_{\Lambda}He^5$-He^4 and is expected to show up as a sharp resonance at about 12 MeV[5] in the Q-value distribution of the decay products.

A search for ${}_{\Lambda}Li^6$ and ${}_{\Lambda}Be^{9*}$ hypernuclei as resonant states in ${}_{\Lambda}He^5$-p and ${}_{\Lambda}He^5$-He^4 systems was made by Goodhead and Evans[6] and Frodeson *et al.*[7] but as the sample of events used in these investigations was small, it was not possible to draw definite conclusions as to whether or not such systems exist. No investigation on the possible existence of ${}_{\Lambda}He^{5*}$ $(I = 2)$ system has been reported so far in literature.

In view of the importance of the problems outlined above, we have investigated them using a large sample of mesic hypernuclei. For this purpose, hypernuclei produced in an emulsion stack exposed to the stopping K^--beam of the proton synchrotron at CERN was used. The details of the stack as well as the kinematic analysis of mesic decay of hypernuclei has been described by Chaudhari *et al.*[8] Out of a sample of 1,312 examples of π^--mesic hypernuclei obtained in the stack, 541 were uniquely identified. The details of hypernuclei used in this investigation are summarised in Table I.

2. Search for the Resonant States of ${}_{\Lambda}He^{5*}$ $(I = 2)$, ${}_{\Lambda}Li^6$ and ${}_{\Lambda}Be^{9*}$ $(I = 1)$ Hypernuclei

These resonant states are unstable and immediately ($\lesssim 10^{-18}$ sec.) decay according to the schemes given below:

$$ {}_{\Lambda}He^{5*} \rightarrow {}_{\Lambda}H^4 + p + Q \text{ (a few MeV)} \quad (1) $$

$$ {}_{\Lambda}Li^6 \rightarrow {}_{\Lambda}He^5 + p + Q\ (\lesssim 1 \text{ MeV}) \quad (2) $$

$$ {}_{\Lambda}Be^{9*} \rightarrow {}_{\Lambda}He^5 + He^4 + Q\ (\sim 12 \text{ MeV}) \quad (3) $$

In order to detect their presence we have to study the Q-value distributions for the respective schemes. For this purpose we have measured the residual ranges of the emitted hypernuclei and those of the tracks associated with them at the K^--absorption centers, and the space angles of these tracks with respect to the hypernuclei. The details of the procedures adopted for this purpose were similar to those described by Chaudhari *et al.*[8]

For two particles (1 and 2) the invariant mass M_{12} is given by

$$M_{12}{}^2 = (E_1 + E_2)^2 - (\vec{P}_1 + \vec{P}_2)^2$$

and the Q value of the reaction is

$$Q = M_{12} - M_1 - M_2$$

where $E_{1,2}$, $\vec{P}_{1,2}$ and $M_{1,2}$ are the total energies, momenta and rest masses of particles 1 and 2 respectively.

No attempt was made to identify the prongs associated with the HFs (hypernuclei) at the K^- centers. The tracks associated with ${}_\Lambda H^4$ and ${}_\Lambda He^5$ were assumed to be due to protons for calculating the Q-values for reactions (1) and (2). For calculating the Q values for reaction (3) the tracks associated with ${}_\Lambda He^5$ were assumed to be alpha-particles. The resulting Q-value distributions for the reactions (1), (2) and (3) are given by the solid histograms in Figs. 1 (*a*), 2 (*a*) and 3 (*a*) respectively. After taking into account the errors in measurement it is estimated that the error in Q-values of individual events is less than 1 MeV.

2.1. *Background Estimation*

To detect the significant production of these resonant states, it is essential to compare the measured Q-value distribution with the corresponding background Q-distribution. We have adopted two procedures for estimating the background Q-distribution; they are described below:

Procedure A.—In this method the momentum distributions of the hypernuclei and the associated particles, and the space angle distribution were fed into the computer as input data for a Monte-Carlo type of calculation. The program selects at random momenta of the hypernucleus and the second particle and the space angle between them from the respective distributions and calculates the Q-value. This procedure was repeated 3,000 times for each species of the hypernuclei investigated and the normalised background Q-value distributions are indicated by dashed line histograms in Figs. 1, 2 and 3.

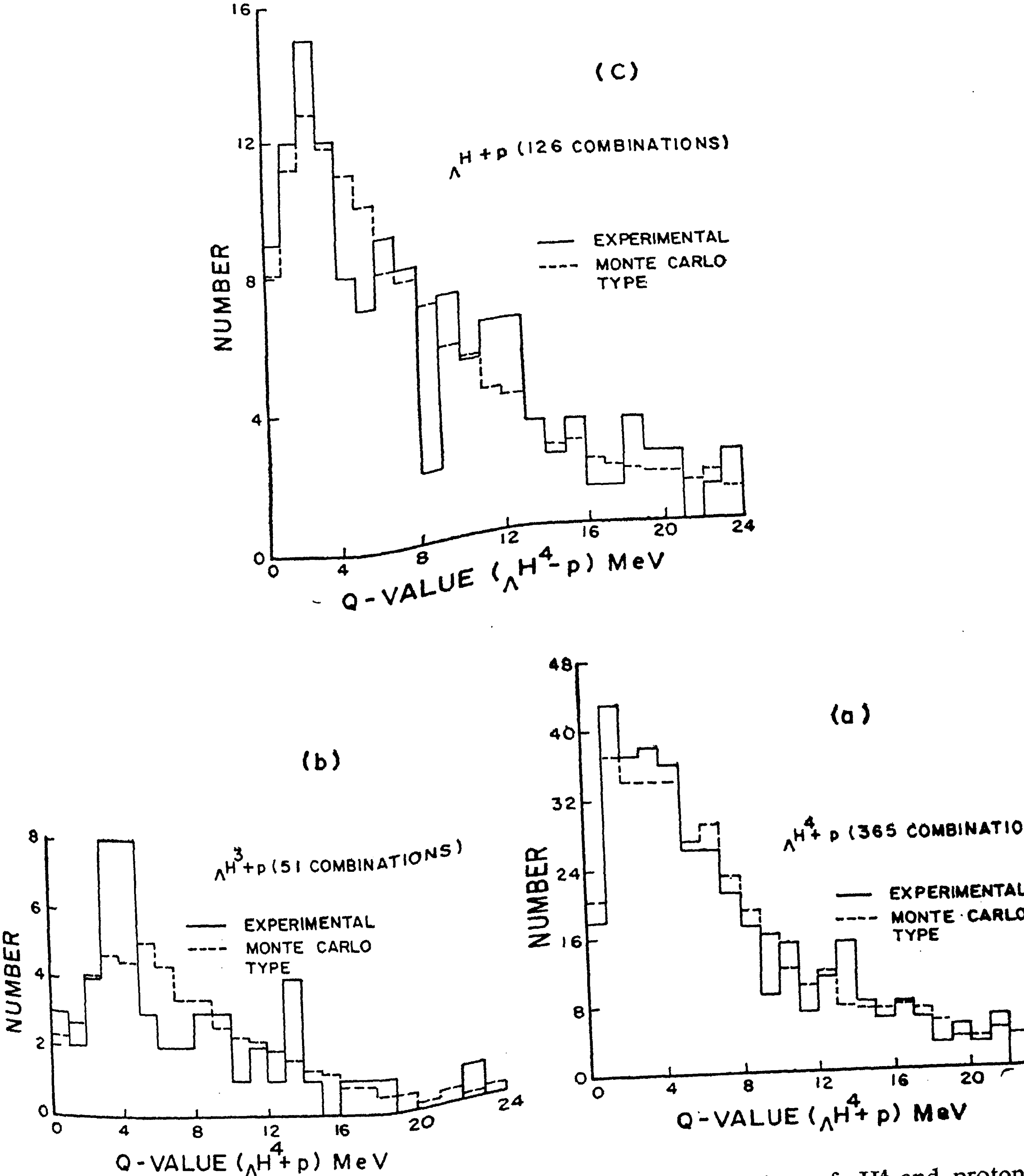

FIG. 1. The solid line represents the experimental Q-distribution of $_{\Lambda}H^{4}$ and proton their rest system. The dashed line refers to the background calculation obtained by Monte-Ca procedure. (*a*) For the sample of 128 uniquely identified $_{\Lambda}H^{4}$ events. (*b*) For the 22 uniq identified $_{\Lambda}H^{3}$ events treated as $_{\Lambda}H^{4}$ events. (*c*) For the 65 uniquely charge identified $_{\Lambda}H$ ev and treated as a sample of $_{\Lambda}H^{4}$ events.

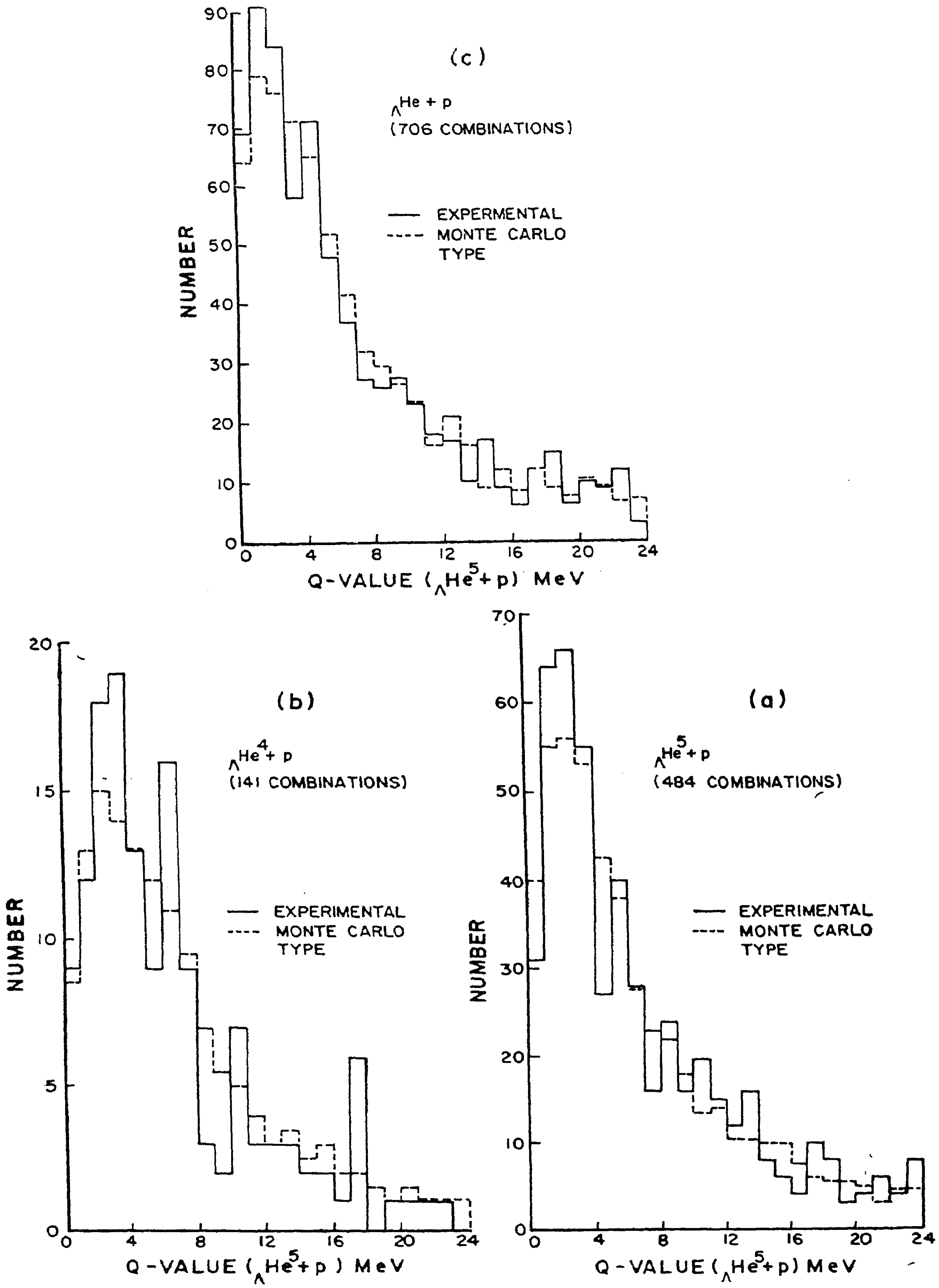

FIG. 2. The solid line represents the experimental Q-distribution of $_{\Lambda}He^5$ and proton in their rest system. The dashed line refers to the background calculation obtained from Monte-Carlo procedure. (*a*) For the sample of 195 uniquely identified $_{\Lambda}He^5$. (*b*) For the sample of 62 uniquely identified $_{\Lambda}He^4$ treated as $_{\Lambda}He^5$. (*c*) For the sample of 306 uniquely charge identified $_{\Lambda}He$ treated as $_{\Lambda}He^5$.

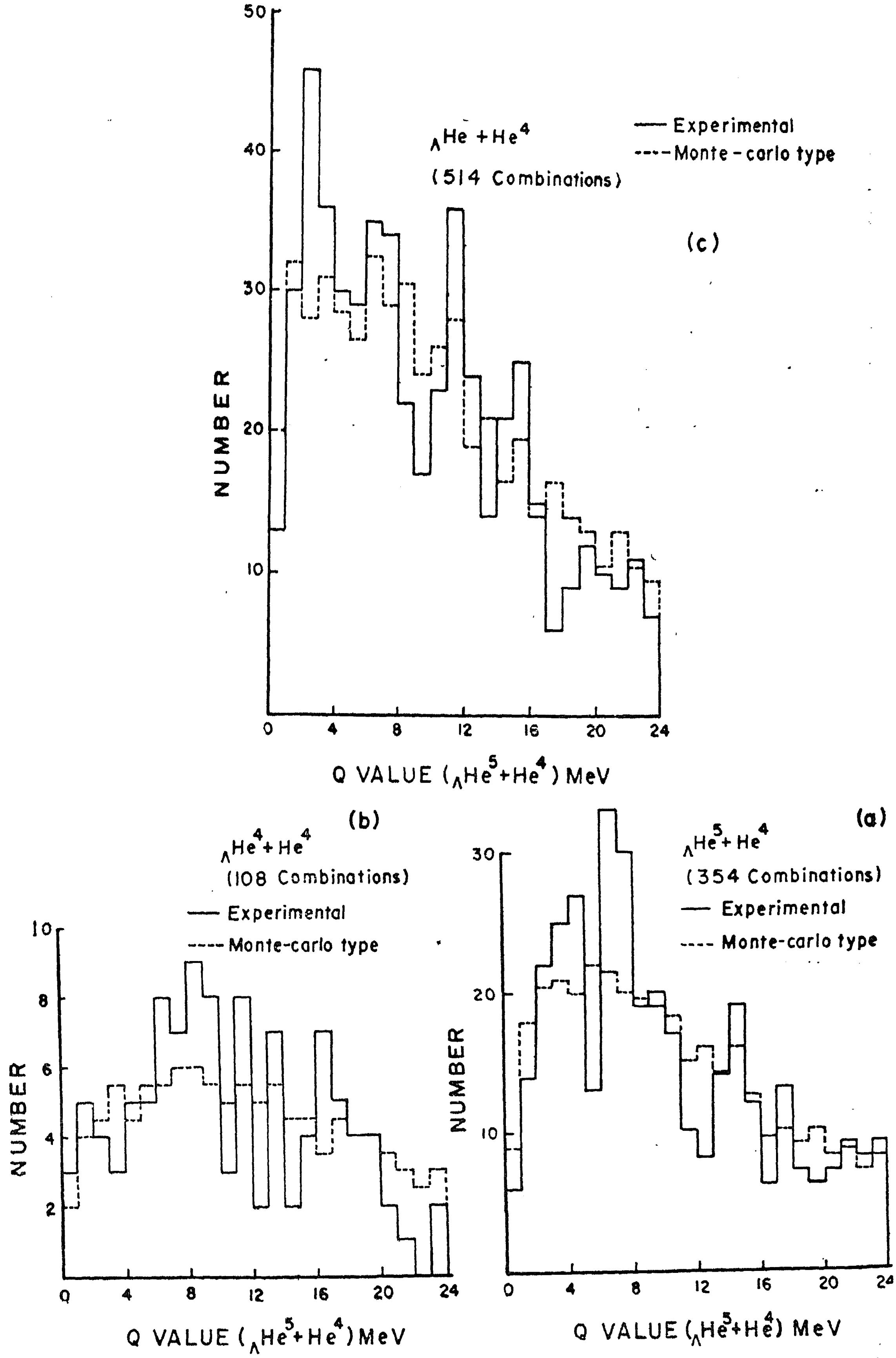

FIG. 3. The solid line represents the experimental Q-distribution of $_\Lambda He^5$ and $_\Lambda He^4$ in their rest system. The dashed line refers to the background calculation obtained by Monte-Carlo procedure. (*a*) For the sample of 195 uniquely identified $_\Lambda He^5$. (*b*) For the sample of 62 uniquely identified $_\Lambda He^4$ treated as $_\Lambda He^5$, (*c*) For the sample of 306 uniquely charge identified $_\Lambda He$ treated as $_\Lambda He^5$.

Procedure B.—This procedure makes use of the fact that the range distributions of various HFs of a given charge are almost the same. Thus, for example, if the uniquely identified ${}_{\Lambda}He^4$ are assumed to be ${}_{\Lambda}He^5$ their momentum distribution will be identical to that obtained for unique ${}_{\Lambda}He^5$ HFs. If we now calculate the Q-values using such a sample of ${}_{\Lambda}He^4$ hypernuclei (assuming them to be ${}_{\Lambda}He^5$) and their associated tracks at the production center, the resulting distribution will essentially constitute a background as it does not contain any resonant state information pertaining to ${}_{\Lambda}He^5$. In a similar way, the background for reaction (1) was calculated assuming uniquely identified ${}_{\Lambda}H^3$ to be ${}_{\Lambda}H^4$ hypernuclei.

3. Experimental Results and Discussion

${}_{\Lambda}He^{5*}$ (I = 2) *hypernucleus.*—This hypernucleus may appear as a resonance in the ${}_{\Lambda}H^4 + p$ rest system. The uniquely identified ${}_{\Lambda}H^4$ events, which were 128 in all, listed in Table I were used and the resulting Q-distribution is given in Fig. 1 (*a*). The Q-distribution by procedure B was

TABLE I

Classification of singly and doubly charged hypernuclei

Species of HFs	Decay Mode	Number of events	Remarks
${}_{\Lambda}H^3$	$\pi^- + He^3$	12	Uniquely identified
	$\pi^- + H^1 + H^2$	10	Uniquely identified
	$\pi^- + He^4$	111	Uniquely identified
${}_{\Lambda}H^4$	$\pi^- + H^1 + H^3$	16	Uniquely identified
	$\pi^- + H^2 + H^2$	1	Uniquely identified
${}_{\Lambda}H^{3,4}$	..	65	Uniquely charge identified
${}_{\Lambda}He^4$	$\pi^- + H^1 + He^3$	60	Uniquely identified
	$\pi^- + H^1 + H^1 + H^2$	2	Uniquely identified
${}_{\Lambda}He^5$	$\pi^- + H^1 + He^4$	195	Uniquely identified
${}_{\Lambda}He^{4,5}$	..	306	Uniquely charge identified

obtained by using 22 uniquely identified $_{\Lambda}H^{3}$ and the resulting histogram is shown in Fig. 1 (*b*). Figure 1 (*c*) gives the Q-value histogram obtained by using 65 uniquely charge identified $_{\Lambda}H$ hypernuclei. The dashed line histograms of Fig. 1 were obtained by procedure A.

It is clear from Fig. 1 that $_{\Lambda}He^{5*}$ (I = 2) hypernucleus does not show up as a detectable resonance in the $_{\Lambda}H^{4}$-p rest system for Q-values ranging from 0 to 24 MeV. The departure of the Q-distributions from their corresponding backgrounds is negligible and can be attributed to satistical fluctuations.

$_{\Lambda}$*Li*^{6}*-hypernucleus.*—This unstable hypernucleus may appear[4] as a resonance in the Q-value distribution of $_{\Lambda}He^{5} + p$ rest system. The 195 uniquely identified $_{\Lambda}He^{5}$ events have been used to obtain the Q-distribution which is given in Fig. 2 (*a*). The Q-distribution as per procedure B was obtained by using 62 uniquely identified $_{\Lambda}He^{4}$ events and is given in Fig. 2 (*b*). Figure 2 (*c*) represents the Q-distribution for 306 uniquely charge identified $_{\Lambda}He$ events. The dashed line histograms of Fig. 2 represent background Q-distributions obtained by procedure A.

From the results presented in Fig. 2, it is evident that the Q-value histograms do not show prominence at small Q-values ($\lesssim$ 1 MeV) as compared with background distributions. Within the experimental limitations the data is consistent with no evidence for the production of $_{\Lambda}Li^{6}$ as a resonant state in the $_{\Lambda}He^{5} + p$ rest system; by considering the Q-distribution between 0–2 MeV an upper limit of 20% may be placed for the number of observed $_{\Lambda}He^{5}$ hypernuclei which are produced from a resonant state of $_{\Lambda}He^{5} + p$.

$_{\Lambda}$*Be*^{9*} *(I = 1) hypernucleus.*—We have made an attempt to look for this hypernucleus as a resonance at Q $\sim$ 12 MeV in the $_{\Lambda}He^{5} + He^{4}$ rest system. The Q-value histograms using uniquely identified $_{\Lambda}He^{5}$, $_{\Lambda}He^{4}$ and those $_{\Lambda}He$ events where only charge could be inferred well are shown in Figs. 3 (*a*), (*b*) and (*c*) respectively; the dashed line histograms represent Q-distributions according to procedure A.

From these histograms it can be said that there is no statistically significant peak in the Q-values (Fig. 3) at $\sim$12 MeV. The data presented in Fig. 3 is consistent with no production of $_{\Lambda}Be^{9*}$ (I = 1), as a resonant state in the $_{\Lambda}He^{5}$–He^{4} rest system, within experimental limitations; the distribution of Q-values between 11–13 MeV sets an upper limit of 15% on the number of observed $_{\Lambda}He^{5}$ hypernuclei resulting from a resonant state of $_{\Lambda}He^{5} + He^{4}$.

4. CONCLUSIONS

The analysis of the data presented in this paper is consistent with the absence of $_{\Lambda}He^{5*}$ (I = 2), $_{\Lambda}Li^{6}$ and $_{\Lambda}Be^{9*}$ (I = 1) hypernuclei, as resonant states, in interactions of stopping negative K-mesons with emulsion nuclei and sets an upper limit of 20% and 15% for the proportion of $_{\Lambda}He^{5}$ hypernuclei resulting from $_{\Lambda}Li^{6}$ and $_{\Lambda}Be^{9*}$ respectively.

5. ACKNOWLEDGEMENT

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