THE RATIO OF NON-MESIC TO π^--MESIC DECAY OF LIGHT HYPERFRAGMENTS*

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Received September 16, 1968

(Communicated by Dr. R. R. Daniel, F.A.SC.)

Abstract

A new method of obtaining the charge spectrum of light hyperfragments from their residual range distribution is described. This method has been used to determine the ratio (Q^-) of non-mesic to π^--mesic decay of light hyperfragments. The values of Q^- for hyperfragments of different charges are found to be in good agreement with theoretical calculations of Dalitz.

1. Introduction

In the past many attempts[1-7] have been made to estimate the ratio, Q^-, of non-mesic to π^--mesic decay of light hyperfragments (HFs) as a function of their charge. There have been two short comings in these investigations: (*a*) the results were usually based on poor statistics and (*b*) the methods of estimation of charges of the HFs were such that they suffered from subjective biases. In the present investigation we have based our results on a large number of events; we also report a new method for estimating the number of HFs of different charges on a statistical basis which we claim is free from subjective biases. This method is based on the fact that an analysis of the world data of uniquely identified mesic HFs, produced by stopping K^--mesons in nuclear emulsion, reveals a marked and significant variation of their range distribution with increasing charge; hence starting from the

* Preliminary version of this work was circulated in the preprint, TIFR NE 67-10.

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range distribution for the whole sample of HFs, it becomes possible to make a sufficiently clean separation of events according to their charge values.

2. Experimental Procedure and Results

In this investigation we have used a total of 2994 HFs (1721 non-mesic and 1273 mesic) of range $\geqslant 5\,\mu$m produced in interactions of stopping K^--mesons in nuclear emulsion. The cut-off range of $5\,\mu$m was employed in order to remove from the sample the contamination due to heavy HFs. The range distribution of non-mesic HFs is shown in Fig. 1 (*a*). Figure 1 (*a*) does not include non-mesic single pronged HFs. The procedures followed for scanning and selection of HFs were the same as described by Chaudhari *et al.*,[8] while the selection criteria for non-mesic HFs was the same as described by Ganguli *et al.*[9]

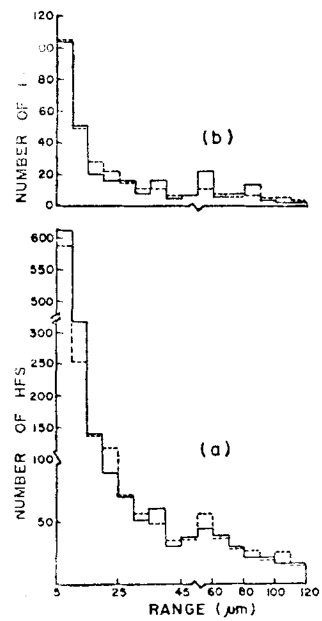

Fig. 1. (*a*) —— represents the range distribution of non-mesic HFs of range 5–120 μm. - - - represents the same obtained by statistical method.

(*b*) —— represents the range distribution of the 303 π^--mesic HFs of the non-unique or incomplete type. - - - represents the corresponding calculated range distribution.

2.1. *Method of charge splitting of HFs*

The range distributions of uniquely charge identified π^--mesic HFs of charges 1, 2, 3 and $\geqslant 4$ given in Figs. 2 (*a*) through 2 (*d*) have been constructed from the raw data of the Bombay, the Chicago[10] and the European collaboration groups.[11] The total number of HFs of charges 1, 2, 3 and $\geqslant 4$ thus obtained are 663, 1294 and 77 respectively. It is seen from Fig. 2 that the range distributions of uniquely identified mesic HFs of various charges have characteristic features which are quite different from one another. In particular it is found that among HFs with $Z \geqslant 4$, events with range $> 120\,\mu m$ are completely absent, while among those with $Z = 3$, events with range $> 120\,\mu m$ constitute only about 1–2%. The latter value of 1–2% for HFs of $Z = 3$ also agrees well with that obtained ($\approx 2\%$) for Li^8 fragments emitted from K^--capture stars. Hence we are able to conclude that HFs of range $> 120\,\mu m$ are almost exclusively of charge 1 and 2.

Based on the above experimental observations, any sample of HFs can be divided into two groups according to their range and the charge splitting of these two groups carried out in the following manner:

(*a*) *HFs of range* 5–120 *μm*.—The charge splitting of HFs in this group has been achieved using a statistical method of least square fit, the procedure for which is described in detail by Hudson.[12] The general outlines of this method are described below.

The range distribution of a sample of HFs, whose charge splitting is to be made (*e.g.*, Fig. 1), can be reproduced by summing the properly weighted frequency distributions of uniquely charge identified mesic HFs from Figs. 2 (*a*) through 2 (*d*). The weight factors can be determined by the method of least squares. For this purpose the sample of HFs with range $\leqslant 120\,\mu m$ was divided into 16 range intervals as shown in Figs. 1 and 2. Let $a_\nu s$ represent the multiplying factors for the range distributions of uniquely charge identified mesic HFs of different charges. Let $F(r_i)$ and $f_\nu(r_i)$ represent the frequencies in the given sample of HFs and uniquely charge identified mesic HFs respectively for a particular range interval r_i; here r_i represents the 16 range intervals, namely, 5–10 μm, 10–15 μm, etc., upto 110–120 μm. The residue is then defined as

$$\epsilon_i = \frac{[F(r_i) - \Sigma\, a_\nu f_\nu(r_i)]}{K_i}$$

where

$$K_i^2 = \sigma^2{}_{F(r_i)} + \Sigma\, a_\nu^2 \sigma^2{}_{f_\nu(r_i)}$$

Here $\sigma^2{}_{F(r_i)}$ and $\sigma^2{}_{f_\nu(r_i)}$ refer to the square of the statistical errors on the frequencies of the given sample of HFs and uniquely charge identified mesic

HFs respectively. The sum of the squares of the residues were then minimised with respect to the $a_\nu s$ giving rise to ν simultaneous linear equations in a_ν. Since $a_\nu s$ are involved in K_i also, the values of $K_i s$ were first obtained by taking all $a_\nu s = 1$; then by the least square method $a_\nu s$ were obtained. Using these values of $a_\nu s$ in the expression for K_i, the whole calcula ion was repeated to obtain more accurate values of a_ν. It was found that the third step iteration process gives the same values of $a_\nu s$ as obtained by the two step process.

In this way, values of $a_\nu s$ were obtained which then immediately yielded the total number of HFs of different charges in the given sample.

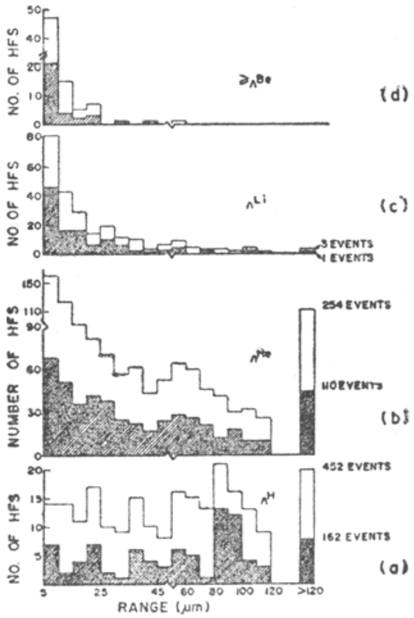

FIG. 2. (*a–d*) ——— represent the distributions of uniquely charge identified mesic HFs of range $\geqslant 5\mu m$ and of charges 1, 2, 3 and $\geqslant 4$ respectively taken from available world raw data. The hatched histogram refers to the raw data of the present work.

(*b*) *HFs of range* $> 120\,\mu m$.—As discussed in Sec. 2.1 this group of HFs does not contain HFs of charge $Z \geqslant 4$. Hence charge splitting of this group into $_\Lambda H$, $_\Lambda He$ and $_\Lambda Li$ was made by knowing (i) the number of $_\Lambda H$, $_\Lambda He$ and $_\Lambda Li$ in the given sample with ranges between 5 and $120\,\mu m$ as obtained from method (*a*), and (ii) the relative proportion of the uniquely charge identified mesic HFs of range $> 120\,\mu m$ compared to those of 5–$120\,\mu m$ interval (Fig. 2) for $_\Lambda H$, $_\Lambda He$ and $_\Lambda Li$.

2.2. *Validity for the present method of charge splitting of HFs*:

The validity for the method of charge splitting suggested above can be demonstrated by analysing a sample of π^--mesic HFs whose unique charge identification is made independently with the help of binding energy values obtained from computer analysis.

In the present investigation 674 such uniquely charge identified π^--mesic HFs (5–120 μm) are considered. Of these the singly charged HFs were first removed from the sample and the remaining 594 were charge split according to the statistical method described in 2.1 (*a*). Charge splitting of the total 674 HFs was also made as suggested for mesic HFs in Sec. 2.4, by the statistical method. The results are shown in Table I. The good agreement of values in rows 2 and 3 with those in row 4 gives confidence, and demonstrates the reliability for the method of charge splitting of HFs by the statistical method.

TABLE I

Charge splitting of 674 uniquely charge identified π^--mesic HFs to demonstrate the validity of the statistical method

Charge of HFs / Method used	${}_\Lambda$H	${}_\Lambda$He	${}_\Lambda$Li	$\geqslant{}_\Lambda$Be
Statistical method as applied for non-mesic HFs [2.1 (*a*)]	..	418$\pm$52	137$\pm$83	39$\pm$42
Statistical method as applied for mesic HFs (2.4)	89$\pm$19	430$\pm$47	103$\pm$80	52$\pm$42
From binding energy values obtained from computer analysis	80	448	114	32

2.3. *Charge spectrum of non-mesic HFs*

The number of non-mesic HFs of range $\geqslant 5\,\mu$m in this investigation is 1721, the range distribution of which is shown in Fig. 1 (*a*). Though these do not contain HFs with $N_h = 1$ or 0, such losses are taken into consideration in 2.5 while estimating the total number of non-mesic HFs in their respective charge groups. As the HFs in the present sample have $N_h \geqslant 2$ they possess charges $\geqslant 2$. Of these, the number belonging to 5–120 μm range interval is 1549 and that $> 120\,\mu$m is 172. The charge splitting of the former group (1549 HFs) was carried out according to the statistical method described in Sec. 2.1 (*a*) and that of the latter group by the method discussed in Sec. 2.1 (*b*). The final break down of non-mesic HFs according to their charges is summarised in Table II. The errors quoted are those from the method of least squares.

TABLE II

Charge spectrum of 1721 *non-mesic HFs from statistical method*

Charge / Range (μm)	$_\Lambda$He	$_\Lambda$Li	$\geqslant_\Lambda$Be
5–120 μm	497±70	475+118	577±66
>120 μm	163±13	9± 3	0
Total ($\geqslant 5\,\mu$m)	660±71	484±118	577±66

2.4. *Charge spectrum of* π^--mesic HFs

Among the total sample of 1273 π^--mesic HFs obtained by us, unique charge identification has been made on 947 (*i.e.*, 75%) by computer analysis. The remaining 326 events are of two types: (i) non-unique events which fit two decay schemes of the type $_\Lambda$H or $_\Lambda$He, $_\Lambda$He or $_\Lambda$Li, etc., and (ii) incomplete events, in which the pion interacted in flight or left the stack, or no good scheme could be found by computer. For charge splitting these 326 π^--mesic HFs the detailed methods discussed in Sec. 2.1 have been used with the following modifications.

Of these 326 mesic HFs, 303 are in the range interval 5–120 μm (Fig. 1 *b*) and the rest $> 120\,\mu$m; they have charges $Z \geqslant 1$. It can be seen that the statistical method of charge splitting gives satisfactory results only if the range spectra exhibit a systematic variation with Z with a well defined cut-off value. Since the singly charged mesic HFs in Fig. 2 (*a*) do not show such a shape, charge splitting was first made for mesic HFs with $Z=1$ and 2 together; these were subsequently divided into charges 1 and 2 according to their relative proportions ($_{\Lambda}H$: $_{\Lambda}He$) known from uniquely charge identified π^--mesic HFs; the justification for this procedure is again the good agreement between the numbers given in rows 3 and 4 of Table I. The final break down of charges of all the mesic HFs is shown in Table III.

TABLE III

Charge spectrum of 1273 π^-*-mesic HFs*

Range (μm) \ Charge		$_{\Lambda}H$	$_{\Lambda}He$	$_{\Lambda}Li$	$\geqslant {_{\Lambda}Be}$
From computer analysis for 947 events	($\geqslant 5\,\mu$m)	242±16	556±24	117±11	32±5
From statistical analysis for 326 non-unique and incomplete events	(5–120 μm)	18±13	88±21	112±45	85±27
	(>120 μm)	13	9	1	0
Total $\geqslant 5\,\mu$m		273±21	653±33	230±46	117±28

2.5. *Systematic errors*

Q^-, is the ratio of the number of HFs which decay by non-mesic, to those that decay by π^--mesic mode. The important systematic errors involved in the estimation of Q^- are the following. Firstly, HFs which decay by π°-mode are quite often misclassified as non-mesic HFs. Secondly, as the non-mesic HFs in this investigation have $N_h \geqslant 2$ an estimate of the loss of HFs with $N_h = 1$ and 0 has to be made. An evaluation of these factors is essential before determining the value of Q^-; these are described below for different charge groups.

$_{\Lambda}$*He*.—This charge group of HFs consists of $_{\Lambda}He^4$ and $_{\Lambda}He^5$ in the ratio 1:4. The π°/π^--decay ratios of $_{\Lambda}He^4$ and $_{\Lambda}He^5$ have been calculated to be 2 and $\frac{1}{2}$ respectively by Dalitz and Liu.[13] In $_{\Lambda}He^4$, the number of π° mesic mode of HFs contributing to HFs with $_{\Lambda}N_h = 2$ is estimated from the percentage of $\pi^- pH^3$, $\pi^- H^2H^2$, etc., decay modes of $_{\Lambda}He^4$. This number is found to be $\approx 11\%$. The dominant π°-decay mode of $_{\Lambda}He^5$ is due to π°, *n*, He^4. This decay mode will mostly result in short single prong type of HFs. Hence this π°-mode will not contribute to non-mesic HFs with $N_h = 2$.

The loss of HFs with $N_h = 1$ and 0 is expected to be almost equal to the number of stars with $N_h = 1$ and 0 in the π^- capture in He-bubble chamber ($\approx$ 10%). Since, however, it is found that the effects of π°-contamination and loss of HFs with $N_h = 1$ and 0 are of the same magnitude but opposite in sign, no correction has been made for these effects for ${}_\Lambda He$-HFs.

${}_\Lambda$*Li*.—This group mostly consists of ${}_\Lambda Li^7$, ${}_\Lambda Li^8$ and ${}_\Lambda Li^9$ in which the π°/π^- ratio is expected to be $\frac{1}{2}$. From the data reported in the paper by Chaudhari *et al.*[8] it is estimated that the total number of π° decay type of events included as non-mesic ${}_\Lambda Li$ HFs with $N_h \geqslant 2$ is ≈ 40. On the other hand we have been able to estimate the loss of ${}_\Lambda Li$ non-mesic HFs with $N_h = 1$ and 0 from the work of Ammiraju and Leederman,[14] who studied π^- captures in carbon as $\approx$ 30%. The corresponding number of HFs with $N_h = 1$ and 0 is then found to be ≈ 144. These loss factors have been taken into account and the final number of non-mesic ${}_\Lambda Li$ HFs is given in Table IV.

TABLE IV

Q^-, ratio of non-mesic HFs to π^--mesic HFs

Type of HFs	${}_\Lambda H$	${}_\Lambda He$	${}_\Lambda Li$	$\geqslant Be$
π^--mesic events	273±21	653±33	230±46	117±28
Non-mesic events	..	660±71	588±118	769±66
Q^-	..	1·01±·12	2·55±·66	6·6± 1·4

$\geqslant {}_\Lambda$*Be*.—As the charge of HFs increases, the π^-mode is suppressed because of Pauli exclusion principle and hence π°-mode will also be suppressed. In analogy to π^--mesic mode, the π°-mode will be mostly π°-recoil type resulting in HFs with $N_h = 0$, resulting in a negligible contribution to HFs with $N_h \geqslant 2$. The loss of HFs with $N_h = 1$ and 0 is therefore taken to be $\approx$ 30% as discussed for ${}_\Lambda Li$ HFs. The total number of non-mesic HFs, after these corrections are made, is presented in Table IV.

3. RESULTS ON Q^-

The corrected numbers of π^--mesic and non-mesic events for $_{\Lambda}He$, $_{\Lambda}Li$ and $\geqslant$ $_{\Lambda}Be$ events is summarised in Table IV; the Q^- value for $_{\Lambda}He$, $_{\Lambda}Li$ and $\geqslant$ $_{\Lambda}Be$ are also given in this table. Dalitz[15] has calculated the expected values of Q^- for $_{\Lambda}Li^7$, $_{\Lambda}Be^9$ and $_{\Lambda}C^{13}$ relative to $_{\Lambda}He$ to be 2·7, 6·2 and 11·3 respectively; in these calculations the value of Q^- for $_{\Lambda}He$ was taken to be 1·5. Our experimental Q^- values given in Table IV are in good agreement with those calculated by Dalitz.[15]

In conclusion we feel that we have demonstrated the potentialities of this new statistical method for charge splitting of HFs. However, the results will have greater significance if one has a larger statistics for uniquely charge-identified mesic HFs particularly for $Z \geqslant 4$.

4. ACKNOWLEDGEMENTS

We are extremely grateful to Professor R. R. Daniel for comments on the manuscript and helpful discussions. Mr. M. B. Singh and Mr. A. Gurtu are grateful to the DAE and CSIR respectively for financial assistance.

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