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SUMMARY

In this study of hyperfragment production by K^- meson absorptions at rest in emulsion nuclei, an attempt has been made to estimate the contribution of heavy spallation hyperfragments to the total observed number. In a sample of *24640* K^- meson captures, *1612* secondary events have been attributed to the production and subsequent decay of hyperfragments. From a study of the characteristics of both the production and decay disintegrations, it is concluded that about one half of the observed hyperfragments consists of Λ° hyperons trapped in the heavy spallation products of silver and bromine and these are almost entirely confined to the *0-3* μm range interval. The consequences of their presence are discussed.

1. INTRODUCTION.

From studies of the interactions of K^- mesons of momenta between *300 MeV/c* and *1.5 GeV/c* with emulsion nuclei, it is evident that the dominant process of hyperfragment formation is the trapping of Λ° hyperons in the residual spallation products of silver and bromine *(1 to 4)*. On the other hand, it has been shown by Abeledo et al.(5) that the mesonically hyperfragments produced in K^- meson absorptions at rest originate mainly from the disintegrations of carbon, nitrogen and oxygen nuclei. However, an emulsion study of the frequency of neutral hyperon emission indicates that about *30%* of K^- meson captures at rest subsequently lead to the trapping of Λ° hyperons in the residual nucleus without the resulting hyperfragments being observed (6). That this process is predominent in heavy nuclei has been demonstrated by Knight et al.(7) from a study of Λ° hyperons arising from the absorption of K^- mesons at rest in a bubble chamber filled with a propane-freon mixture. The recent observation (8) of two π^- mesonic decays of heavy spallation hyperfragments produced by K^- absorptions at rest has established that these hyperfragments occasionally receive sufficient momentum to travel observable distances in emulsion(*).

In this study of hyperfragment production by K^- meson absorptions at rest in emulsion nuclei, an attempt has been made to estimate the contribution of heavy spallation hyperfragments to the total observed number. The consequences of their presence in this sample are discussed.

2. EXPERIMENTAL METHOD

The experiment was carried out using two stacks made up of unbacked pellicles of Ilford *K5* emulsion, each *600 μm* thick. Both stacks were exposed at the CERN PS to slow K^- mesons suitably degraded from a momentum of *800 MeV/c* (10). The K^- meson interactions at rest in the emulsion were found by a line-scanning procedure to ensure that the sample

(*) A heavy spallation hyperfragment of mass number $A=90$ requires a momentum of about *500 MeV/c* to travel *0,5 μm* in emulsion (9).

used should not be biased against the inclusion of small stars. In order to obviate the necessity of distinguishing between proton endings and K^- meson zero prong stars $(K^-\rho)$, these events were excluded from the sample. The true number of K^- meson interactions was obtained by making a correction for the omitted $K^-\rho$ events using the results of Amerighi et al.(11).

All tracks from each K^- meson star were followed within the pellicle containing the primary disintegration using a magnification of $\sim X\ 1000$, and secondary interactions and decays were noted. The vertex of each capture star was then viewed under high magnification $(\sim X\ 2000)$ to detect the presence of two closely spaced centres. In addition, an eyepiece hair-line was aligned along each track of the star in turn and careful extrapolations of depth were also made in order to detect events in which the centres were the more closely spaced $(< 2\ \mu m)$. This procedure was repeated by at least one other observer for events in which there was even the slightest doubt. Events in which the two centres could not be satisfactorily resolved or where there was considerable doubt as to which disintegration was that of the hyperfragment were termed "double-centred" (DC). The hyperfragment were classified as mesonic *(MHF)* or non-mesonic *(NMHF)*(*) according to whether or not their disintegration involved the emission of a π^- meson. The contamination in the sample of non-mesonic hyperfragments was reduced by eliminating all obvious examples of Σ^- hyperon and π^- meson capture events. It has been shown previously that where the connecting track is short $(< 100\ \mu m)$ and this rejection is not possible, the contamination in the hyperfragment sample of negative particle capture events is negligible (12).

When a hyperfragment had been found and classified, its range was measured and the numbers of tracks from both the primary and secondary stars were noted and roughly graded according to ionization, black, grey or light. In addition the presence of "blobs" and of tracks of

(*) Events resembling scatterings were defined as hyperframents if range before "scatter" was less than $5\mu m$, range after "scatter" was greater than $20\mu m$ and the angle of "scatter" was greater than 15°(19).

electrons, recoils $(R \leqslant 3\ \mu m)$ and so-called under-barrier particles $(3\ \mu m < R \leqslant 30\ \mu m)$ was recorded for both the primary and hyperfragment decay stars. Finally, a careful search was made at each primary star for the presence of the tracks of lightly ionizing π mesons.

3. EXPERIMENTAL RESULTS AND ANALYSIS.

A sample of *22190* K^- meson absorption stars which contain at least one prong has been used in this experiment and corresponds, when corrected for the omission of K^-p events, to *24640* K^- meson captures at rest. *1612* secondary events have been attributed to the production and subsequent decay of hyperfragments, thus the rate of production of observable hyperfragments by K^- meson captures in emulsion is $6.5 \pm 0.2\%$. Of these decays *281* were π^- mesonic, *802* were non-mesonic and *529* could not be satisfactorily resolved.

The range distribution of the hyperfragments is given in Fig. 1 and shows a large accumulation of events in the range interval $0\text{-}2\ \mu m$. This is as has been observed for the hyperfragments produced in emulsion by the interactions in flight of low momentum K^- mesons (*50* to *500* MeV/c) (*1-2*), but differs markedly from the distribution obtained for K^- meson interactions at rest by the K^- Collaboration (13), where the peak was situated between *2* and $5\ \mu m$. The difference is due partly to the finer grain size of the present emulsion(*) and partly to the more careful scanning procedure adopted to detect the shortest hyperfragments. In fact, the low rate of hyperfragment production found previously, $(5.0 \pm 0.5\%)$, is very well accounted for by the considerable observational loss of hyperfragments of range less than $2\ \mu m$.

Some characteristics of both the production and decay disintegrations as a function of the hyperfragment range are set out in table I. The main feature to note is the very low value of the fraction of mesonic decays for the shortest hyperfragments $(1.8 \pm 0.2\%)$ and the rapid increase of this fraction beyond a hyperfragment range of $2\ \mu m$. This result indicates that most of these short range hyperfragments have high mass values,

(*) The grain diameter in the processed emulsions was $0.85\ \mu m$ in the *G5* stack (13) and is about $0.50\ \mu m$ in the present stack.

as in the case of the hyperfragments produced in the interactions of K^- mesons in flight *(1 to 4)*. The other results contained in table I provide additional evidence for this conclusion. It is seen that the emission of particles of range between *3* and *30* μm ("short prongs"), usually accepted as an indication of the disintegration of a light nucleus (14), is infrequent at both the production and decay vertices of the short range hyperfragments and also in the *DC* events. On the other hand, tracks of range less than *3* μm, which can be attributed to nuclear recoils, are much more common in the non-mesonic decay stars of the short range hyperfragments than in the others. Finally, the observation frequency of Auger electrons, generally considered as an indication of the absorption of a negative particle in a heavy nucleus (15), is about *50%* for the primary disintegrations involving short range hyperfragments.

In table II, some characteristics of the decay stars of the hyperfragments of range less than *2* μm are compared with those of the heavy spallation hyperfragments observed in the interactions of K^- mesons in flight *(1 to 4)* and are seen to be very similar.

These features combine to suggest that the bulk of the short range hyperfragments produced in K^- meson captures at rest are the heavy spallation products of silver and bromine[*]. On the basis of the mean number of charged particles emitted in the primary disintegration (16), it is estimated that the mass numbers of these hyperfragments differ on the average from those of the parent nuclei by about *12* nucleon masses. The great majority of the heavy spallation hyperfragments observed in this work are thus of mass number greater than *60*. It is to be noted here that until now the decay characteristics of the heavy spallation hyperfragments have been studied in K^- meson interactions of high momenta *(8-17-18-19)* where they are known to be produced with mass numbers down to *40*.

[*] In a few cases *(~10%)*, the sum of the heavy prong numbers of both the parent and the decay stars is seen to exceed *7* ; these events at least, must involve a K^- meson interaction with a heavy nucleus. In computing this sum, the tracks of the hyperfragment themselves were not included.

Four examples of π^- mesonic decays of heavy spallation hyperfragments have been found in this experiment. Details of these events and of two similar ones previously reported are presented in table III. It is seen that the lowest value for the upper limit of the binding energy of the Λ° hyperon in a heavy nucleus is *26 MeV*. This value is slightly higher than the best estimate of B_{Λ} obtained by E.R. Fletcher et al.(19) by combining all available data from high energy K^- meson interactions, *i.e.* 22.7 ± 1.5 *MeV*.

It is clear from the results portrayed in table I that hyperfragments in the range interval, $5 \mu m < R_{HF} \leqslant 20 \mu m$, are almost exclusively light and arise predominantly from the break-up of the light nuclei(*). However for the longest-range hyperfragments, $R_{HF} > 50 \mu m$, it is to be noted that the rate of observation of Auger electrons increases markedly, indicating that the production of the lightest hyperfragments is significant from heavy nuclei, a fact already pointed out by Abeledo et al.(5).

Having established that heavy spallation hyperfragments are observed in the captures of K^- mesons at rest, an attempt is now made to estimate their relative contribution to the number of hyperfragments. Table IV gives an expanded view of table I for the range interval, $0 \mu m < R_{HF} \leqslant 10 \mu m$. The fact that there is a mixture of both heavy and light hyperfragments in this range interval is shown by the observation of light mesonically-decaying hyperfragments of ranges down to *1 μm* and less. In order to estimate the number of light hyperfragments in the *0-5 μm* range interval it has been assumed that for these light hyperfragments of short range the chance of a particle other than the hyperfragment itself, from either the production or decay interaction, having a range between *3 μm* and *30 μm* is *54%*, as it is in the case of hyperfragments of range between *5* and *20 μm*. The estimate for the relative numbers of light and heavy hyperfragments in the *0-5 μm* range interval obtained by this procedure is given in table V. The fact that the value of $\bar{Q}^-$, the non-mesonic to mesonic decay ratio, for the light hyperfragments remains of the order of *5* throughout the range interval *0* to *5 μm* can be considered as a check of the method (20).

(*) see also Abeledo et al.(5).

It is seen from table V that below $2\ \mu m$ range about 90% of the hyperfragments are heavy and that the range distribution of the heavy hyperfragments extends up to $5\ \mu m$. The total number of heavy spallation hyperfragments is estimated to be about 800, *i.e.* some 50% of the hyperfragments observed from K^- meson captures at rest in nuclear emulsions. The observation of 4 π^- mesonic decays leads to a value of the order of 200 for Q^- for the heavy spallation hyperfragments.

4. DISCUSSION.

One consequence of the above results is that it becomes necessary to reconsider some of the previously published values of Q^- for light hyperfragments. In particular, Abeledo et al.(5), in order to estimate the overall value of Q^- for hyperfragments in the mass range $A = 7$ to $A = 16$, assumed that the heavy spallation hyperfragments formed by K^- meson captures at rest on silver and bromine would never travel observable distances and consequently that all observed hyperfragments were light. Since this is not so, it is obvious that the Q^- value they quote for this class of hyperfragments, 8 ± 2, is too high. Recently Holland (20), again from a study of hyperfragments produced by K^- meson interactions at rest, found a Q^- value of 3.2 ± 0.7 for the hyperfragments with mass number $7 \leqslant A \leqslant 16$. However, he applied a range cut-off below $3.3\ \mu m$ to his sample in order to reduce any detection biases and also to allow reliable measurements to be made of the direction of the hyperfragment. In this way, it is evident that he has also eliminated the great majority of the heavy spallation hyperfragments (see table V) and therefore this value of Q^- for hyperfragments of mass number A between 7 and 16, namely 3.2 ± 0.7, is the more reliable(*).

A further feature of the results is the marked dependence on the nature of the target nucleus of the emission frequency of charged π mesons from K^- meson absorptions from which hyperfragments are seen to come. Table VI gives the variation of this frequency as a function of the range of the accompanying hyperfragment. It is seen that the chance of emission

(*) A detailed study of the variation of Q^- with mass number A for the light hyperfragments is in progress; results will be published in a forthcomming paper.

of a charged π meson is about *25%* in the stars with a hyperfragment of range shorter than $3\ \mu m$ (which are predominantly produced in the heavy nuclei of the emulsion), and about *50%* in the stars containing a hyperfragment of range between *3* and $20\ \mu m$ (which result mainly from absorptions in the light nuclei). A decrease of the charged π meson emission frequency is also observed in the K^- meson stars containing a long range hyperfragment $(R_{HF} > 20\ \mu m)$. The hyperfragments have been assigned as originating from light or heavy emulsion nuclei on the basis of observations of 'short prongs' and 'Auger electrons'. As a result of such a classification it is seen that the chance of emission of a charged π meson from K^- meson stars containing a hyperfragment is $(55 \pm 3)\%$ when the struck nucleus is light and $(22 \pm 2)\%$ when it is heavy.

This result, in particular the low frequency of emission of π mesons from heavy nuclei, is in apparent contradiction with the surmise that the K^- meson absorption takes place on the periphery of the nucleus (21) and that the absorption probability of charged π mesons is small (22). It can, however, be explained in the following ways :

a) K^- meson captures in heavy nuclei might not be confined to the periphery and hyperfragments are most likely to be produced when the absorption takes place within the nucleus;

b) To be observed the heavy spallation hyperfragments require a large momentum $(\geqslant 500\ MeV/c)$ and this may be most often provided either by a direct K^- multinucleon interaction or by the subsequent absorption of a created π meson. In neither case will a π meson be among the final products of the reaction. It should be remarked here that only about *10%* of all the heavy spallation hyperfragments produced by stopping K^- mesons (6) have momenta high enough to be directly observed in the emulsion.

Furthermore, if one assumes that the absorption probability of π mesons created in light emulsion nuclei is *10%* and estimates by charge independence the number of created π° mesons, one finds that $92 \pm 5\%$ of hyperfragments in light emulsion nuclei are created together with π mesons. This means that the initial K^--multinucleon capture mechanism is not responsible for the production of a large number of hyperfragments in light nuclei.

It is also possible to estimate the trapping probabilities of $\Lambda^{\bullet}$ hyperons following K^- meson captures on heavy and light emulsion nuclei. It has been shown by Csejthey-Barth and Sacton (15) that the capture of K^- mesons at rest in emulsion occurs in the proportion *2* to *3* in the light and heavy nuclei. If it is assumed that all cryptofragments (*i.e.* unobserved hyperfragments) (6) involve heavy nuclei, a likely assumption since about *90%* of the hyperfragments seen with ranges less than $2\ \mu m$ have been shown to be heavy, one finds that $8 \pm 2\%$ of captures in carbon, nitrogen and oxygen and $58 \pm 15\%$ of captures in silver and bromine lead to the trapping of the $\Lambda^{\bullet}$ hyperon. By adopting similar procedures Knight et al.(7) find the $\Lambda^{\bullet}$ hyperon trapping rate to be $51 \pm 14\%$ in bromine and $18.5 \pm 3.5\%$ in carbon and fluorine.

5. CONCLUSIONS.

This study of hyperfragments produced by K^- meson absorptions at rest in emulsion nuclei has yielded the following results:

1) the frequency of observation of hyperfragments is $6.5 \pm 0.2\%$, that of mesonically decaying hyperfragments is $1.14 \pm 0.07\%$.

2) A large proportion of the observed hyperfragments, about one half, consists of $\Lambda^{\bullet}$ hyperons trapped in the heavy spallation products of silver and bromine and these are almost entirely confined to the $0\text{-}3\ \mu m$ range interval.

3) The mass number of the heavy spallation hyperfragments observed in stopping K^- meson interactions are estimated to differ on the average from those of the parent nuclei by only about *12* nucleon masses.

4) Four further examples of the π^- mesonic decays of heavy spallation hyperfragments have been observed, leading to a value of Q^- for such hypernuclei of about *200*.

5) As the hyperfragments are not all light, as had been supposed by Abeledo et al.(5), the value for Q^- for hyperfragments of mass number $7 \leqslant A \leqslant 16, 8 \pm 2$, given by these authors should be reconsidered. The value $Q^- = 3.2 \pm 0.7$ quoted by Holland (20) would seem to be a more reliable estimate.

6) The low frequency of observation of charged π mesons accompanying the heavy spallation hyperfragments suggest that eitheir K^- meson captures in heavy nuclei are not confined to the periphery or that multinucleon or π meson reabsorption processes are often required to impart a sufficient momentum to a heavy spallation product to render it observable.

7) From the frequency of emission of π mesons it is concluded that the K^--multinucleon reaction mechanism does not contribute significantly to the number of hyperfragments produced in light nuclei.

8) It is estimated that the probability of trapping a $\Lambda^{\bullet}$ hyperon following a K^- meson absorption at rest on carbon, nitrogen or oxygen is $8 \pm 2\%$ and on silver and bromine it is $58 \pm 15\%$.

*

* *

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REFERENCES.

(I) J.P. Lagnaux, J. Lemonne, J. Sacton, L. Bishara, D.H. Davis and M.A. Hussain : Phys. Lett. 4 - 341 - 1963.

(2) J. Lemonne, P. Renard, J. Sacton, J.E. Allen, L. Bishara, D.H. Davis and D.A. Garbutt : Bulletin de l'Institut de Physique de l'Université de Bruxelles n° 10 - 1963.

(3) see for example : B.D. Jones, B. Sanjeevaiah, J. Zakrzewski, M. Csejthey-Barth, J.P. Lagnaux, J. Sacton, M.J. Beniston, E.H.S. Burhop and D.H. Davis : Phys. Rev. *127* - 236 - 1962.

(4) see for example : E.R. Fletcher, J. Lemonne, P. Renard, J. Sacton, D. O'Sullivan, T.P. Shah, A. Thompson, P. Allen, Sr. M. Heeran, A. Montwill, J.E. Allen, M.J. Beniston, D.A. Garbutt, R.C. Kumar, P.V. March, T. Pniewski and J. Zakrzewski : Phys. Lett. *3* - 280 - 1963.

(5) D. Abeledo, L. Choy, R.G. Ammar, N. Crayton, R. Levi-Setti, M. Raymund and O. Skjeggestad : Nuovo Cimento *22* - 1171 - 1961.

(6) D.H. Davis, M. Csejthey-Barth, J. Sacton, B.D. Jones, B. Sanjeevaiah, and J. Zakrzewski : Nuovo Cimento *22* - 275 - 1961.

(7) W. Knight, F.R. Stannard, F. Oppenheimer, B. Rickey and R. Wilson : Contribution to the International Conference on Hyperfragments - St Cergue - 1963 - to be published.

(8) D.H. Davis, R. Levi-Setti, M. Raymund, O. Skjeggestad, G. Tomasini, J. Lemonne, P. Renard and J. Sacton : Phys. Rev. Lett. *9* - 464 - 1962.

(9) M. Danysz and J. Zakrzewski : private communication 1963.

(10) B. Aubert, N. Courant, H. Filthuth, A. Segar and W. Willis : Proceedings of the 1962 Conference on Instrumentation for High Energy Physics held at Cern-Nuclear Instruments and Methods *20* - 51 - 1963.

(11) M.C. Amerighi, F. Baldassare, M.J. Beniston, A. Bonetti, D.H. Davis, M. Di Corato, C. Dilworth, D. Ferreira, E. Frotta-Pessoa, W.B. Lasich, N. Raina, M. René, J. Sacton and A.E. Sichirollo : Nuovo Cimento *12* - 91 - 1959.

(12) J. Sacton : Thesis - Université Libre de Bruxelles - 1961.

(13) K^- Collaboration - Part I : Nuovo Cimento *13* - 690 - 1959.

(14) see for example : M. Demeur, A. Huleux and G. Vanderhaeghe : Nuovo Cimento *4* - 509 - 1956.

(15) see for example : M. Csejthey-Barth and J. Sacton : Bulletin de l'Institut de Physique de l'Université de Bruxelles n° 4 - 1962.

(16) I. Dostrowsky, P. Rabinowitz and R. Bivins : Phys. Rev. *III* - 1659 - 1958.

(17) A.Z.M. Ismail, I.R. Kenyon, A.W. Key, S. Lokanathan and Y. Prakash : Nuovo Cimento *29* - 1019 - 1963.

(18) J. Cuevas, J. Diaz, D. Harmsen, W. Just, H. Kramer, H. Spitzer and M.W. Teucher : Contribution to the International Conference on Hyperfragments - St Cergue 1963 - to be published.

(19) E.R. Fletcher et al, to be published.

(20) M.W. Holland : preprint 1963.

(21) P.B. Jones : Phil. Mag. *3* - 33 - 1958.

(22) K^- Collaboration - Part II : Nuovo Cimento *14* - 315 - 1959.

Figure Caption :

Figure I - Range distribution of the hyperfragments :

a) mesonic hyperfragments,

b) non-mesonic hyperfragments. Hatching indicates double-centred events.

Fig. I

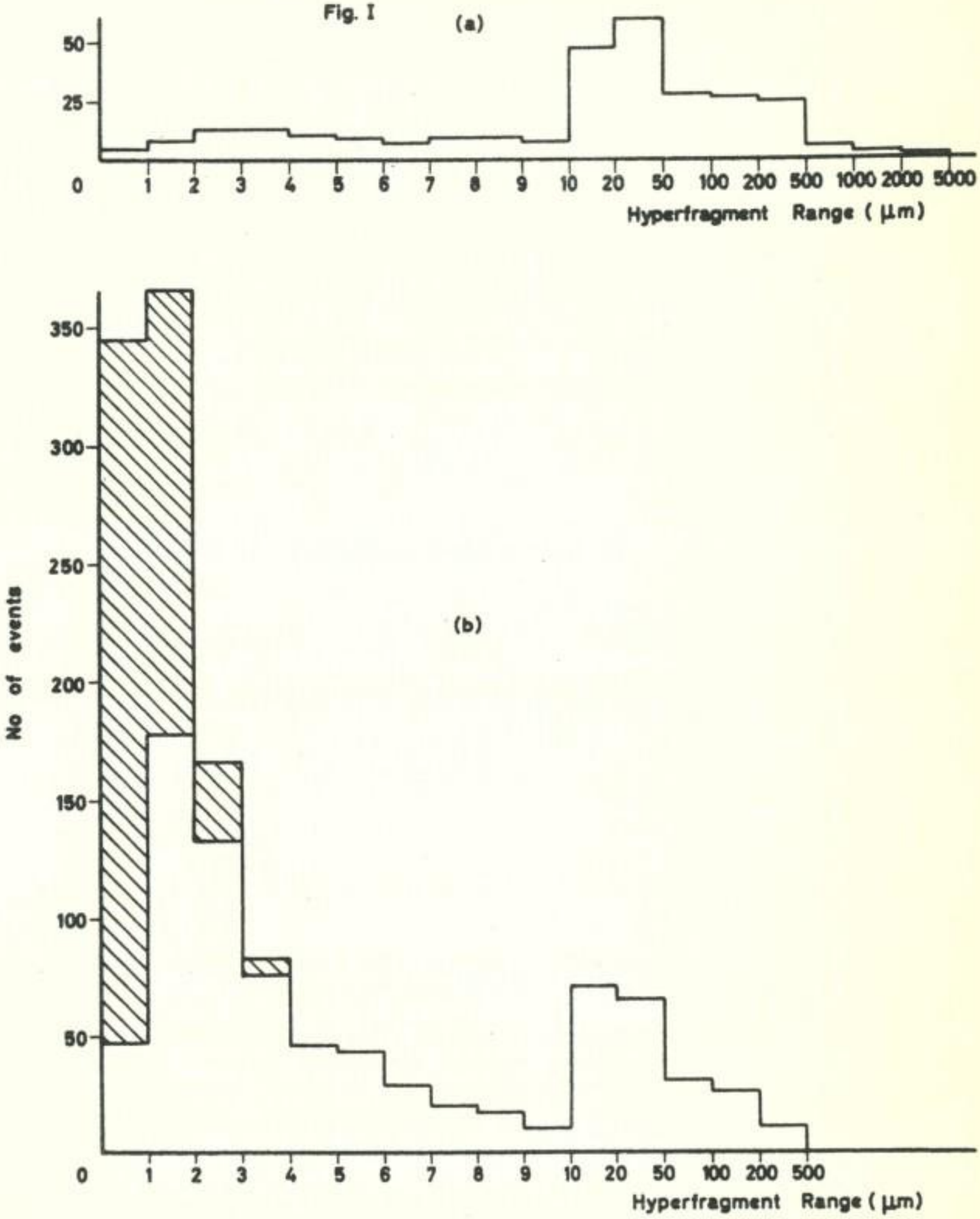
(a)
50
25
0
1
2
3
4
5
6
7
8
9
10
20
50
100
200
500
1000
2000
5000
Hyperfragment Range (µm)
(b)
No of events
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
20
50
100
200
500
Hyperfragment Range (µm)

Table I

Hyperfragment ranges (μm)	0 - 2	2 - 5	5 - 10	10 - 20	20 - 50	> 50
No of hyperfragments	724	331	160	118	125	154
No of mesonic hyperfragments	13	36	41	47	59	85
No of non-mesonic hyperfragments	225	254	117	71	66	69
No of double centred events	486	41	2	-	-	-
Percentage of mesonic decays (%)	1.8±0.5	10.9±1.8	25.6±4.0	39.8±5.8	47.2±6.1	55.2±6.0
Non mesonic over mesonic decay ratio (Q^-)	55	8.2	2.9	1.5	1.1	0.8
Percentage of K^- stars with a short prong(*) (%)	5.0±1.5	15.5±2.3	34.2±4.6	41.5±5.9	46.4±6.1	30.5±4.5
Percentage of mesonic decay stars with a short prong (%)	4.9±1.5	25.6±3.2	34.2±5.5	32.4±6.8	25.6±6.2	13.0±4.3
Percentage of *DC* events with a short prong (%)	2.9±0.8	7.3±4.2	-	-	-	-
Percentage of non-mesonic decay stars with a recoil(**)	36.4±4.0	26.4±3.2	17.9±3.9	11.3±4.0	9.1±3.7	2.9±2.0
Percentage of *DC* events with a recoil (%)	28.2±2.4	31.7±8.8	-	-	-	-
Percentage of K^- stars with an Auger electron (%)	52.3±2.7	26.0±2.8	8.1±2.3	5.1±2.1	8.8±2.7	21.4±3.7

(*) $(3\ \mu m < R \leqslant 30\ \mu m)$

(**) $(R \leqslant 3\ \mu m)$

Table II

K^- meson momentum (MeV/c)	At rest (this work)	50 to 500 (1-2)	800 (3)	1300 (4)	1500 (4)
Percentage of mesonic HF	1.8 ± 0.5	~ 0	$0.3^{+0.4}_{-0.3}$	0.9 ± 0.4	0.8 ± 0.5
Percentage of non-mesonic decay stars with a short prong $(3 < R \leqslant 30\ \mu m)$ (%)	4.9 ± 1.5	~ 5	5 ± 3	9 ± 2	8 ± 2
Percentage of non-mesonic decay stars with a recoil $(R \leqslant 3\ \mu m)$ (%)	36.4 ± 4.0	~ 45	53 ± 7	43 ± 3	43 ± 4

Table III

Event No	HF range (μm)	No of heavy prongs at K^- star	HF decay products		Assumed decay mode	Upper limit of B_Λ (MeV)
			Identity	Energy (MeV)		
61T/23	0.8	0	π^-	7.8	$\pi - R$	37.8
38T/85	1.8	4	π^-	15.9	$\pi - R$	29.7
44T/21	2.6	5	π^-	15.9	$\pi - R$	29.7
48T/20	0.9	6	π^-	14.3	$\pi - R$	31.3
EFINS 1(8)	~ 1	0	π^-	7.1	$\pi - R$	38.5
EFINS 2(8)	~ 1	1	π^-	6.4	$\pi - p - R$	26.0
			(p)	5.2		

Table IV

HP ranges (μm)	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10
No of *HP*	350	374	179	96	56	52	36	29	26	17
No of *M HP*	5	8	13	13	10	9	7	9	9	7
No of *NM HP*	47	178	133	76	45	42	29	20	16	10
No of *DC* events	298	188	33	7	1	1	-	-	1	-
Q^-	69	46	13	6.4	4.6	4.8	4.1	2.2	1.8	1.4
Fraction of K^- stars with a short prong	3/52	9/186	12/146	20/89	13/55	12/51	22/36	6/29	11/25	3/17
Fraction of *NM* decay stars with a short prong	1/47	10/178	22/133	30/76	13/45	17/42	9/29	6/20	5/16	3/10
Fraction of *DC* with a short prong	6/298	8/188	1/33	2/7	-/1	1/1	-	-	1/1	-
Fraction of *NM* decay stars with a recoil	19/47	63/178	37/133	24/76	6/45	7/42	9/29	3/20	2/16	-/10
Fraction of *DC* with a recoil	79/298	58/188	7/33	5/7	1/1	1/1	-	-	-/1	-
Fraction of K^- stars with an Auger electron	193/350	186/374	62/179	18/96	6/56	5/52	3/36	2/29	2/26	1/17

Table V

HF ranges (μm)	0-1	1-2	2-3	3-4	4-5
No of light HF	18	43	63	80	47
No of heavy HF	332	331	116	16	9
Total No of HF	350	374	179	96	56

Table VI

HF ranges (μm)	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-50	> 50
No of K^- stars with a charged π meson	91/350	88/374	51/179	53/96	31/56	82/160	62/118	54/125	53/154
Percentage of K^- stars with a charged π meson (%)	26.0 $\pm$2.7	23.5 $\pm$2.5	28.5 $\pm$4.0	55.2 $\pm$7.6	55.3 $\pm$9.9	51.3 $\pm$5.7	52.5 $\pm$6.7	43.2 $\pm$5.9	34.4 $\pm$4.7