STUDY OF HYPERFRAGMENTS

Part III. Multinucleon Interactions of Λ^0 in Hyperfragments

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Received May 3, 1966

(Communicated by Prof. R. R. Daniel, F.A.Sc.)

Abstract

1101 examples of non-mesic decay of hyperfragments, produced by high energy particles in nuclear emulsion stacks, have been used to obtain information on multinucleon interaction of Λ^0 hyperon in the decay of hyperfragments. From a study of events with two fast charged particles in decays of hyperfragments, the following two conclusions are drawn: (i) multinucleon interactions of Λ^0 in decay of hyperfragments is not significant; it occurs at the most in a few per cent of the cases, and (ii) there is strong evidence for the existence of final state interactions in decay of hyperfragments.

1. Introduction

Of the non-mesic decays of hyperfragments (HFs), a large fraction is due to the stimulated decay of Λ^0 by a nucleon in the HF according to the reaction:

$$\Lambda + N \rightarrow N + N + Q \tag{1}$$

where N refers to a proton or a neutron and $Q \leq 176$ MeV. If Λ^0 is stimulated to decay by two nucleons, one might expect the emission of fast deuterons or two fast nucleons according to the reaction:

$$\Lambda + N + N \rightarrow N + N + N \tag{2}$$

Even in events due to the decay of HFs according to (1), some "fast deuteron events" and "two fast proton events" could still be accounted for by final state interactions between the nucleons and collisions within the HF itself. Secondary collision processes have relatively larger cross-sections in heavy

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HFs than in the lighter ones. Thus the study of events with two fast charged particles as a function of the HF mass could be expected to yield information concerning the stimulated decay of Λ° by two nucleons in HFs. With this in view we have analysed 1101 examples of non-mesic HFs (NMHFs), produced in nuclear emulsion by negative pions of momentum 3·5 GeV/c and 17·2 GeV/c and protons of momentum 23 GeV/c.

2. Experimental Results

2.1. *Selection of Events*

The experimental details including the measurements on HFs used in this investigation are given in Parts II and IV of this series of papers (Burte *et al.*, 1965 and 1966). From a sample of 1101 NMHFs, we have selected all events that have two fast charged particles having residual ranges $\geqslant$ 2 mm. associated with the decay vertex. Further assuming that both fast charged particles are protons, the events were grouped in the following two ways: (*a*) those with both fast particles having energy $\geqslant$ 20 MeV, and (*b*) those with both particles having energy $\geqslant$ 30 MeV. These criteria were adopted to eliminate, to a great extent, protons that are emitted in the evaporation process. The frequency of emission of two fast protons (*a* and *b* types) as a function of the range group of HFs is tabulated in Table I. In Table II†

TABLE I

Frequency of occurrence of two fast proton type of HFs

Range group of HFs (μm)	No. of HFs	Percentage of two fast proton HFs* *a*	*b*
$R_{HF} \leqslant 5$	274	7·0	2·6
$5 < R_{HF} \leqslant 10$	209	5·8	1·4
$10 < R_{HF} \leqslant 20$	154	5·2	1·3
$R_{HF} \leqslant 20$	464	3·9	1·1
Total	1101	5·2	1·5

* (*a*) both protons have energies $\geqslant$ 20 MeV.
(*b*) both protons have energies $\geqslant$ 30 MeV.

† An important objective in giving our raw data in Table II is to facilitate other workers in this field to add this to their own data from future investigations. This would be of vital importance to draw meaningful conclusions based on good statistics.

is summarised the data on all the individual events. The last column of this table gives the space angle, ψ_{12}, between the two fast particles and it is seen from this that they are preferentially emitted in opposite directions.

2.2. *Mass Measurements by Constant Sagitta Method*

In Section 2.1 it has been assumed that all fast particles are protons; however, it would be advantageous to have information on their composition for better interpretation of the results. For this purpose mass measurements were made on all tracks having residual ranges $\geqslant 2$ mm. and which subtended dip angles $\leqslant 30°$ with respect to the plane of emulsion. Such measurements were made using the constant sagitta method (Scheme P-0·7 μm) on 38 tracks associated with HFs of range $\leqslant 20\ \mu$m and 20 tracks associated with HFs of range $> 20\ \mu$m. The distribution of second difference values, after appropriate corrections for distortion, noise and dip angle obtained for singly charged particles is shown in Figs. 1 (*a*) and 1 (*b*). The mass values

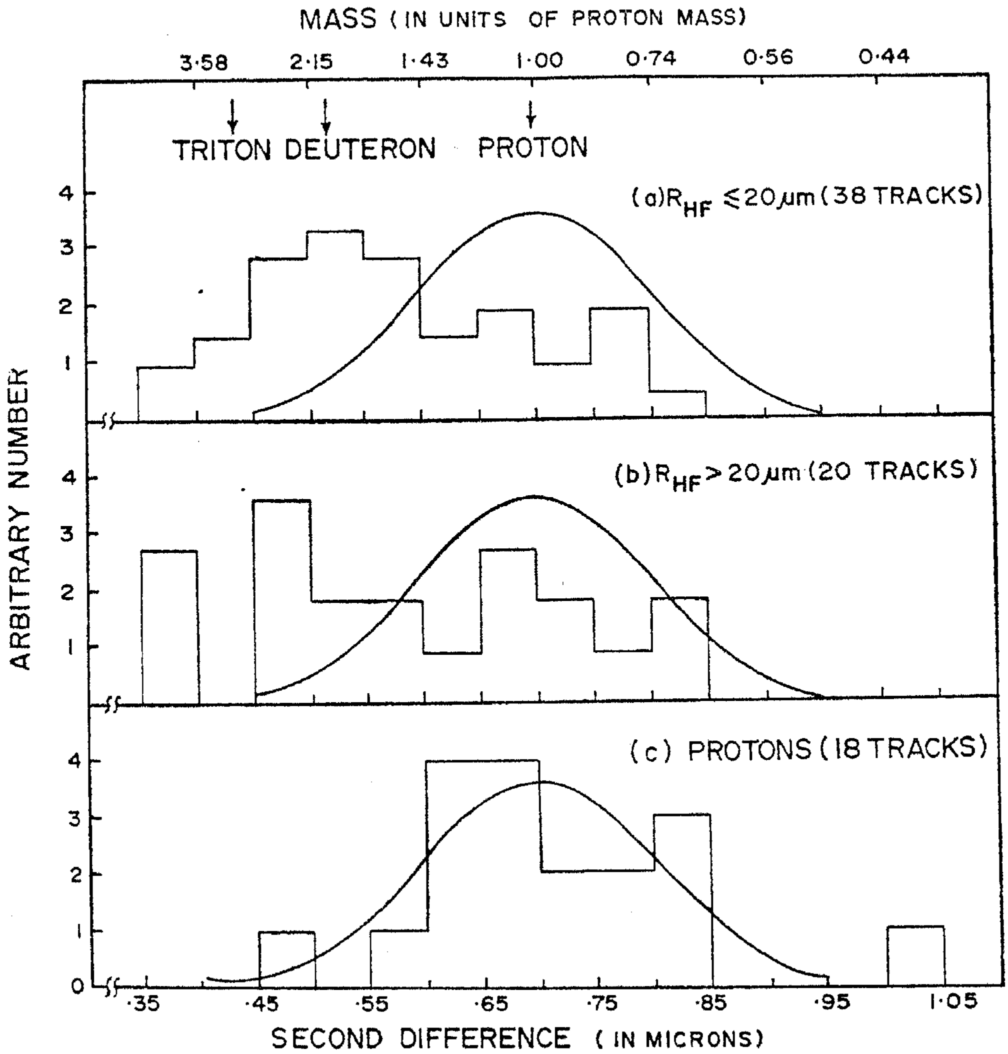

Fig. 1.

TABLE II

Details of events with two fast protons among HFs
($R_{HF} \leqslant 5\ \mu m$)

Stack	HF Number	R_{HF} (μm)	N_h of HF	Ranges of tracks (μm) 1	2	3	4	5	6	Space angle between tracks 1 and 2 in degrees
A	50	4·0	3	12400	2216	239·0	..	..	..	119·0
	53	4·0	2	15691·5	3040	..	..	..	..	57·0
	110	5·0	2	2652	2480	..	..	..	..	101·0
	118	4·0	3	>5230	2997	2·5	..	..	..	126·0
	135	2·0	3	10000	1941	Blob	..	..	..	131·0
B	317	4·1	3	20800	3880	310·0	..	..	..	147·5
	361	3·2	3	7822	5011	2·5	..	..	..	118·0
	449	4·4	3	4029·4	3353·6	47·0	..	..	..	157·5
	489	1·9	4	19000±1100	3750	42·0	18·0	..	..	147·4
	597	4·5	3	9990·8	3877·8	207·0	..	..	..	138·0
	648	2·7	4	3940	2300	845·0	3·6	..	..	62·3
C	44	4·9	3	11965	9800	1	..	..	..	119·5
	68	5·0	2	15710	4275	..	..	..	..	156·5
	134	3·0	3	13673	4100	123·0	..	..	..	138·5
	177	4·5	3	8805	3280	374·0	..	..	..	117·5
	250	5·0	3	2359	1873·8	216·0	..	..	..	110·1
	304	4·0	3	8530	5955	534·0	..	..	..	122·0
	339	4·5	4	3690	2332·6	296·0	55·0	..	..	75·5
	524	3·0	4	>24510	2275	222·0	210·0	..	..	158·0

				(5 μm $< R_{HF} \leqslant$ 10 μm)						
A	2	7·3	3	26000± 1000	4050	Blob	..	..	..	153·0
	66	8·8	3	8048	2139·7	Blob	..	..	..	107·6
	111	6·0	5	>4440	1865	80·0	51·0	Blob	..	84·0
B	74	5·6	2	19600± 1400	4020	..	..	..	..	133·0
	179	5·1	3	3600	1860	203·0	..	..	..	169·0
	233	5·6	2	11670	5650	..	..	..	..	82·0
	324	5·4	2	>3580	>2100	..	..	..	..	118·5
	350	6·3	4	22533	2377	48·0	8·0	..	..	107·0
C	284	9·8	3	8960	3280	20·0	..	..	..	135·5
	15	5·4	2	3122	3024	..	..	..	..	92·5
	358	5·4	3	9581	2150	63·0	..	..	..	114·5
	512	7·0	6	5930	1944·9	737·0	114·0	41·0	4·5	28·2
				(10 μm $< R_{HF} \leqslant$ 20 μm)						
A	72	10·8	4	4182·0	>2900	103·0	3·2	..	..	19·0
B	81	12·5	3	4125	2530	259·0	..	..	..	49·2
	376	11·3	4	12482.2	2178·5	5·8	1·3	..	..	133·5
	460	17·5	2	6420	2800	..	..	..	..	44·0
	617	19·0	3	2800	2320	984	..	..	..	86·5
C	109	12·4	2	17254	2328·4	..	..	..	..	144·2
	181	14	3	11785	1966	5	..	..	..	27·0
	458	10·6	3	3960	3862	556·0	..	..	..	115·5

TABLE II (*Contd.*)

($R_{HF} > 20\ \mu m$)

Stack	HF Number	R_{HF} (μm)	N_h of HF	Range of tracks (μm) 1	2	3	4	5	6	Space angle between tracks 1 and 2 in degrees
A	68	24·0	4	>5840	>1945	399·0	9·7	..	..	157·0
	139	31·4	4	10150	5575	1491·0	40·0	..	..	170·0
B	10	35·0	3	>5830	4929·1	9·5	..	—	..	145·5
	80	21·8	2	6850	2960	..	..	..	..	125·0
	166	55·7	5	6650	2650	1337·0	53·0	14·9	..	44·5
	182	42·7	3	14600± 800	>6550	104·0	..	..	..	133·0
	186	53·1	4	4930	2450	321·0	54·0	..	..	159·5
	203	114·6	4	20097·5	2950	98·0	23·0	..	..	149·5
	231	55·8	2	3139·7	2971·5	...	..	..	..	105·0
	258	34·9	5	5630	4342·7	1336·0	6·7	4·9	..	150·0
	334	21·3	5	2614·6	2395·4	1496	79·1	30·4	..	81·4
	595	180·7	2	6813	3060	..	..	..	..	142·0
C	162	41·2	4	7150	2225	1218·0	787·0	..	..	168·0
	167	106·5	2	3283·8	2533	..	..	..	..	69·9
	71	59·9	2	12430	2530	..	..	..	..	124·0
	266	474·0	2	34500± 6200	2184·6	..	..	..	..	174·2
	278	301·5	2	39269	2040·5	..	..	..	..	169·5
	488	65·8	3	11024	4030	..	..	..	..	146·7

Stack A → 3·5 GeV/c π^-. Stack B → 23 GeV/c P Stack C → 17·2 GeV/c π^-.

in terms of proton mass are also shown there. Figure 1 (*c*) represents the same distribution obtained from measurements on well-identified protons (identified by ionisation measurements); the residual range used here for scattering measurements was ≈ 4 mm. The continuous curve in Fig. 1 represents the Gaussian distribution fitted to the histogram; its mean and standard deviation values are 0·7 and 0·1 μm respectively. All histograms in Fig. 1 are normalised to the same area for comparison purposes. From Figs. (1 *a*) and (1 *b*) it is estimated that in about 60% of the two fast track type of events one of the fast track is due to a deuteron or triton; in about 15% of the events both the fast tracks are due to deuterons or tritons. Within statistical uncertainties these values do not seem to change for different range groups of HFs.

3. Discussion of the Results

It has been shown in Part II of this series that in the same sample of 1101 HFs analysed in the present investigation, $\approx 30\%$ and $\approx 70\%$ of the HFs in the range groups $R \leqslant 5\,\mu$m and $5 < R \leqslant 10\,\mu$m respectively, have masses $A \lesssim 50$; all HFs of range $> 20\,\mu$m have $A \leqslant 15$ (light HFs). In what follows, we first assume that the two fast charged particles are due to protons and discuss our results accordingly for light and heavy HFs. However, the contribution of deuterons and tritons will be taken into account in the final interpretation of the results.

(*a*) *Light HFs.*—In order to be able to interpret events with two fast charged particles emitted from light HFs, we will first show from an analysis of π^--capture in light nuclei that secondary collisions suffered by fast nucleons in the capturing nucleus is negligibly small.

Negative pion absorptions in nuclei take place according to the reactions:

$$\pi^- + (\mathrm{PN}) \rightarrow \mathrm{N} + \mathrm{N} + 140\ \mathrm{MeV} \tag{3 a}$$

$$\pi^- + (\mathrm{PP}) \rightarrow \mathrm{P} + \mathrm{N} + 140\ \mathrm{MeV} \tag{3 b}$$

Each of the two nucleons produced in reactions (3 *a*) and (3 *b*) will have an energy ~ 70 MeV. Since in both reactions (1) and (3) two nucleons are produced with about the same Q-value, there is good reason to justify a comparison between the decay of NMHFs and π^--absorption in nuclei; relevant data on π^-—capture is summarised in Table III. In the Diffusion Chamber experiment (Ammiraju and Lederman, 1956) as well as the emulsion experiment (Menon *et al.*, 1950) no two fast proton event ($E_1 \geqslant 20$ MeV and $E_2 \geqslant 20$ MeV) was observed. Ozaki *et al.* (1960) have determined lower limits on the ratio, $R_\pi = (\pi^- pn)/(\pi^- pp)$, of reaction (3 *a*) to that of (3 *b*) for π^--absorptions in carbon and aluminium targets; the values of R_π were 5·0 and 3·9 respectively. They have also obtained the values of R_π, with poor statistics, for Li, S and Cu targets; these results were consistent with those from carbon and aluminium targets. These observations indicate a value of 20% for *pp*-pairs being found in carbon nuclei as compared to *pn*-pairs. Investigations of Bortolani *et al.* (1962) also indicate that π^--absorption in helium takes place mostly by a *pn*-pair and only about 6% of them occur, *via* absorption by a *pp*-pair.

TABLE III

Percentage of one fast proton events ($\geqslant$ 30 MeV) *produced by the absorption at rest of negative pions in light and heavy nuclei*

Reference	Technique used	No. of events observed	Targets used for absorption	Percentage of events with one fast proton
Ammiraju and Lederman (1956)	Diffusion Chamber	944	C	8±1
		430	N	2±1
Menon *et al.* (1950)	Emulsion	990	C, N, O	4·2±1·3*

* In estimating these percentages, zero pronged capture stars have also been added to the number of stars with $N_h \geqslant 1$ observed by the authors.

From the π^- data presented above, the following conclusions may be made:

(i) The results of Ozaki *et al.* (1960) and Bortolani *et al.* (1962) show that the ratio of captures by *pp* to *pn* pairs is $\lessapprox$ 10–20% in light nuclei; this ratio can explain the frequency of " one fast proton " events observed in light nuclei; and

(ii) The contribution of secondary charge exchange type of collisions resulting in fast protons ($\geqslant$ 20 MeV) in light nuclei is very small and can be assumed to be negligible. Further from the results of Ammiraju and Lederman (1956), it is estimated that the probability for the emission of two fast charged particles is less than 1/100.

Conclusion (ii) strongly suggests that the " two fast proton " events, which constitute about 4% among light HFs (*see* Table I), cannot be due to secondary collisions of the nucleons produced in the stimulation process in the parent nucleus. Further, it is estimated from the total sample of identified helium hyperfragments, obtained from the present investigation, that the contribution of two fast proton type of events is about 5%. Therefore these " two fast proton " type of events could be attributed to the stimulated decay of Λ° by a *pp*-pair in the nucleus; if this is the case then it can be seen that according to reaction (2), Λ° can be stimulated to decay by a *pn* as well as a *nn* pair. Therefore in order to estimate the total fraction of events stimulated by two nucleons, the value of 4·2% attributed to stimulation by a *pp*-pair has to be suitably corrected to take into account stimulation by *pn* and *nn* pairs. On the other hand, the appreciable number of deuterons and tritons present among events with two fast charged particles (*see* Section 2.2) strongly suggests the existence and importance of final state interactions in the decay of light hyperfragments. But since the contribution due to final state interactions is also not known, it is not possible to estimate in a reliable manner the fraction of events due to Λ°-multinucleon interaction in decay of HFs. Thus on the basis of the present investigation it is only possible to say that the Λ°-multinucleon interaction is not a dominant process and its frequency is probably a few per cent only.

(*b*) *Heavy HFs.*—It has already been mentioned that secondary collision processes have larger cross-sections in heavy HFs than in the lighter ones. An estimate for this cross-section has been made by Ganguli and Swami (1965) from a calculation using kinematical considerations, where they assume that the only process responsible for the decay of heavy non-mesic HFs is the Λ°-single nucleon stimulation process, and that the emission of two fast protons results from secondary collisions inside the nucleus. It is found from this calculation that in order to explain the shape of the energy spectrum of fast protons and their frequency of occurrence, the *n*/*p* stimulation ratio should be ≈ 5 for HFs with $A = 50$. Using this ratio, it has been deduced that the emission frequency of two fast protons (both of $E \geqslant 20$ MeV) is $\approx 3\%$. The experimentally observed emission frequency of two fast charged particles from HFs of range $\leqslant 10\,\mu$m is 6·4%; this value has to be corrected for the scanning losses of HFs with $N_h = 0$ and 1. Though this correction factor is not known accurately, a reasonable estimate can be made from π^- interactions in heavy (Ag, Br) and light (C, N, O) nuclei (Menon *et al.*, 1950). From such a comparison it is estimated that $\sim 50\%$ of the short-range HFs will decay with $N_h \leqslant 1$. Applying this correction factor, one obtains for the true frequency of events with two fast charged particles among short-range NMHFs, a value of $\sim 3{\cdot}2\%$, which is not much different from the calculated frequency of $\approx 3\%$ for secondary collisions mentioned above.

It has been shown in Section 2·2 that the emission frequency of fast deuterons and tritons among events with two fast charged particles is quite large and therefore this would again suggest the existence of final state interactions in the decay of heavy HFs. Since as in the case of light HFs, the contribution of final state interactions is not known, it is only possible to say that in case of heavy HFs also, if Λ-multinucleon interaction exists, it contributes only about a few per cent of the events. Further calculations on final state interactions and pick-up and stripping processes in the parent nucleus might help us to draw more meaningful conclusions from these experiments.

4. CONCLUSIONS

(i) There is strong evidence for the existence of final state interactions in the decay of HFs, as is seen in the frequent emission of fast deuterons and tritons from their decays.

(ii) In stimulated decay of NMHFs, the frequency of Λ-multinucleon interactions, if they exist, can only be a few per cent.

5. ACKNOWLEDGEMENT

We are extremely grateful to Prof. R. R. Daniel for helpful and stimulating discussions.

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