NON-MESONIC DECAY MODES

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The decay of a Λ^0 hyperon bound to a nuclear fragment does not always proceed by the emission of a pion; it is well known that with increasing mass of the nuclear core the non-mesonic mode rapidly begins to be the dominant decay process. The non-mesonic decay of hypernuclei is considered to be the result of the stimulated decay of the Λ^0 hyperon in the presence of nucleons. As suggested by Cheston and Primakoff$^{1)}$, the decay proceeds through an intermediate step involving a virtual pion which is subsequently re-absorbed by a neighbouring nucleon.

The reactions are as follows:

$$\Lambda^0 + p \rightarrow (p + \pi^-) + p \rightarrow p + n \qquad (1)$$

$$\rightarrow (n + \pi^0) + p \rightarrow n + p \qquad (2)$$

$$\Lambda^0 + n \rightarrow (n + \pi^0) + n \rightarrow n + n \qquad (3)$$

the energy release being of the order of 180 MeV $(m_{\Lambda^0} - m_n)$.

These stimulation processes have been analysed in some detail by different authors$^{2-5)}$ and, in particular, their matrix elements have been estimated taking account of the contributions from the interactions involving either one or more exchange pions, or a K meson, and including the possibility of the existence of the Λ in a virtual Σ state when in the presence of nucleons. It is not within my competence to discuss here these studies; I will restrict myself to trying to give a summary of what has been done from the experimental point of view. You will easily see that the situation is particularly confused due to the experimental difficulties one meets in the study of the non-mesonic decays.

Two problems have been particularly investigated.

i) The variation of Q, the non-mesonic to mesonic decay ratio as a function of the HF charge

Ruderman and Karplus[2] have shown that the ratio Q is very sensitive to the angular momentum of the pion emitted in the free Λ decay. The study of the variation of Q with the HF charge has been used as a means to determine the spin of the Λ^0 hyperon. However, extensive studies of the free Λ^0 hyperon have now provided definite information concerning the spin of the Λ^0 hyperon. More recently, it was pointed out by Dalitz and Liu[5] that the determination of Q could give us with good accuracy the value of the ratio p/s of the p- and s-channel amplitudes of the decay of the free Λ^0 hyperon. Recent experiments carried out by Beall et al.[6], and Cronin et al.[7], have clearly established that the s interaction is dominant. The results of Cronin et al. indicate that $p/s = 0.36^{+0.5}_{-0.8}$. Dalitz and Rajasekharan[8] have suggested that definite predictions of the lifetimes of light hyperfragments would require a better knowledge of the interaction $\Lambda + n \rightarrow n + n$.

ii) The ratio of proton to neutron stimulation

This could provide useful information concerning the Λ^0-nucleon interaction[4].

The detailed study of both these problems involves the detection of all hyperfragment decay modes and the elaboration of an unbiased charge distribution. It is, however, well known that the experimental study of the non-mesonic decays presents great difficulties, both in the classification of the events as definite hyperfragments and in the subsequent interpretation of their identity from decay kinematics. The energy release in such a decay is ~ 175 MeV, so that in the case of light hyperfragments this will normally lead to a more or less complete break-up of the nuclear core followed by the emission of fragments and of neutrons. The absence among the decay products of an easily identified particle like the π^- meson in the mesonic decays, makes the kinematic analysis extremely difficult and leads, in general, to confusion with other phenomena such as slow pions, K^- or Σ^- captures, collision of moderately energetic particles, etc. Moreover, typical decay modes, such as those involving only one charged particle, are practically undetectable because they are overwhelmed by scatterings. These difficulties have led to the use of selection criteria which were not always perfectly adapted to the problem. In particular, any selection criteria on the decay characteristics must undoubtedly lead to biased statistics. This was clearly pointed out by Zakrzewski and St. Lorant[9)] in their review analysis of work published in 1962. In some cases the use of measurements of the track of the hyperfragments has been of great importance. However, these measurements are only useful on long-range hyperfragments which are very rare especially in K^- meson absorptions at rest, the richest source of hyperfragments actually used, and also the only one for which the contamination due to other events is rather easily eliminated by applying some selection criteria on the parent star.

The kinematic analysis of non-mesonic decays proceeds generally as follows. The computer runs each possible combination of the decay products under each of the assumptions:

a) no neutral particles
b) a π meson
c) a neutron
d) two neutrons (not in all cases).

The machine is instructed to derive B_Λ. The B_Λ values are compared with those obtained for mesonic hyperfragments, taking into account the large errors.

That this type of analysis is insufficient was clearly demonstrated by Silverstein[10]) who compared, for "uniquely" identified events, the energy distributions of both the neutrons and the protons resulting from the decays and found them completely different, the neutrons being shifted systematically to higher energy. Such a shift is due to a systematic underestimate of the number of neutrons involved in the decays leading to an overestimate of the energy imparted to each of them.

Another proof of the weakness of this type of analysis is obtained from the comparison of the range distribution of both the non-mesonic and mesonic hyperfragments of a given charge identified in the same experiment. In most cases it was found that the range distribution of the non-mesonic hyperfragments was more concentrated in the region of shorter ranges (background of heavy hyperfragments).

Keeping all these restrictions in mind we will now try to look at the experimental results.

1. NM/M as a function of Z

Most of the information comes from Silverstein[10]), Sacton[11]), Gorge et al.[12]), and more recently from Bhowmik[13]) and Block[14]). The hyperfragments are produced in K^- absorptions at rest except in Silverstein's experiment where the hyperfragments are produced in high-energy π^- interactions.

The problem here is to get a true idea of the charge distribution of the hyperfragments, both mesonic and non-mesonic. The charge distribution of M hyperfragments produced in K^- absorption at rest has been determined with large statistics by Abeledo et al.[15]) and is as follows: $Z = 1$, 26%; $Z = 2$, 45%; $Z = 3$, 22%, and $Z > 3$, 7%.

Concerning the non-mesonic decays, the statistics are not only poorer but also less homogeneous: 131 events have been collected in three different laboratories using different selection criteria (Brussels, 55; Delhi, 54; Bern, 22). The charge distribution of these hyperfragments is established as follows.

i) Uniquely identified events

These are events for which only one interpretation leads to an acceptable value for the Λ^0 hyperon binding energy.

Table 1

Z =	2	3	4	≥ 5
Brussels	6	4	6	10
Bern	5	7	7	12
Bombay	17	-	3	-
Total	28	11	16	22

Large discrepancies are observed between these results. (In the Bombay experiment the emission of two neutrons was not considered.)

ii) Non-uniquely identified events

For the remaining events for which the charge is not uniquely determined, a rather similar analysis was used by all the authors to get a true idea of the charge distribution; for such events, all the possible interpretations were assumed to be equally probable and normalized in each case to unity. Combining all these events, one obtains the following distribution:

Table 2

Z =	2	3	4	≥ 5
Brussels	8	7	8	22
Bern	5.5	8.6	7.4	13.5
Bombay	21	5.7	4.7	0.6
Total 112	34.5	21.3	20.1	36.1

Note: I have excluded the DC events which are probably very heavy hyperfragments.

Using the results of Abeledo et al.[15]) for the M hyperfragments, one obtains for the non-mesonic to mesonic decay ratio the values given in Table 3. These values must be taken with great care.

Table 3

Z	2	3	≥ 3
Q	1.4	~3	~50

Indeed, I would remind you that almost all the decays into a single charged particle have not been recorded so that the values quoted here are surely underestimated.

In the case of hyperhelium, another approach has been made by Schlein[16]) in 4.5 GeV/c π^- meson interactions, and led to the value $Q = 1.5 \pm 0.4$. The theoretical values to which these results are to be compared are as follows:

Table 4

Z	1	2	> 2
$\ell = 0$	0.55 0.3 (H^3) 0.8 (H^4)	0.9 0.85 (He^4) 1.0 (He^5)	40
$\ell = 1$	9.0 4.5 (H^3) 13.6 (H^4)	16 14 (He^4) 17 (He^5)	680

It is concluded that the ratio p/s is definitely smaller than 1 in agreement with the information obtained by Cronin and Overseth[7]) for free Λ hyperons. It is, however, too early to get any information of the type asked of the experimentalists by Dalitz and Rajasekharan[8]).

ii) n/p ratio in stimulated decay

The other point I should like to discuss is the question of the stimulated decay of the Λ^0 hyperon. My task in this case is considerably reduced due to the fact that a careful and critical re-examination of the published work was made recently by Zakrzewski and St. Lorant$^{9)}$. Several attempts have been made to study this problem. All of them are based on the examination of the energy spectrum of fast protons emitted from non-mesonically decaying hyperfragments. Most of the remarks and criticisms which I have put forward previously must be kept in mind in the analysis of the experimental results.

The method of analysis first proposed by Baldo-Ceolin et al.$^{17)}$ is based on the following assumptions:

i) the one-nucleon stimulated decays are dominant;

ii) the nucleons emitted as a result of these processes and, in particular, the proton resulting from reaction (1) have a momentum above a certain cut-off which has to be determined;

iii) the nucleons do not lose so much energy by collisions that all memory of their origins disappears.

The bottle-neck in this type of analysis is the estimate of the cut-off energy at which the two processes merge. This is made from consideration of the energy distribution of all charged particles emitted in the non-mesonic decay stars. A typical such distribution appears to consist of two energy groupings: one contains the protons of energy less than 30 MeV; the other constitutes the tail of the distribution extending to ~ 140 MeV. The low-energy part is interpreted as being due to the break-up of the residual nucleus following the emission of the two fast nucleons from the stimulation process. The fast protons are attributed to the initial stimulation process by protons. The total energy release in a stimulated decay (180 MeV) is shared equally between the two nucleons resulting from the reaction (in the Λ-n rest frame). Outside the nucleus, the energy is slightly reduced due to binding energy of Λ and nucleon. Assuming that the effect of the Fermi momentum of the stimulating nucleons is to introduce a symmetrical spread around a mean value, the cut-off can be obtained experimentally from the energy distribution of all charged particles. In this way, Baldo-Ceolin et al.[17)] and Silverstein[10)] have obtained 30 and 40 MeV (240 MeV/c and 275 MeV/c), respectively. All the events containing a proton of energy greater than this limit are attributed to a proton-stimulated process.

It is very difficult, for the reasons given before, to study the n/p ratio for a particular species of hyperfragment, so that in the beginning no attempts were made to separate the hyperfragments according to their charges. The results of different experiments lead to n/p ranging from 1 to 2. Selection criteria and scanning losses seem, however, to play an important role in these results.

Moreover, Zakrzewski and St. Lorant[9)] have suggested that in some cases the sample of events could be artificially enriched in very heavy hyperfragments for which it is to be expected that the criteria used to study the stimulation processes could be less reliable. This is especially true for the hyperfragments produced in high-energy interactions and for very short-range hyperfragments ($< 2\mu$) produced in K^- absorption at rest.

The stimulation processes have recently been studied by Bhowmik et al.[13)]. The hyperfragments were produced by stopping K^- and Σ^-. The results of this work are:

$$\text{for He} \quad : \frac{p}{n} = 15/4 = 3.8$$

$$\text{for } Z \geq 3 \quad : \frac{p}{n} = 10/4 = 2.5 \,.$$

The result is to be compared to that of Block et al.[14)] for helium hyperfragments:

$$\sim 5 = \frac{p}{n} \quad ({}_{\Lambda}He^4 \; 2p \; 1n) \,.$$

It seems that for helium, p/n is clearly > 1, which following Ferrari and Fonda implies that the stimulated decay takes place when the hyperon is in the Λ state.

It is to be noted that the p/n ratio could be drastically dependent on nucleon structure or on diffferent distributions of p and n inside the nucleus.

As a conclusion, I should say that practically everything remains yet to be studied. Even if many competing processes are likely to contribute to the production of HF, it seems that valuable experimental information could be obtained with rather clean statistics selected on the basis of the production rather than on the decay processes. At the present time, it seems that K^- absorptions at rest are best suited for such a study, even if most of the hyperfragments with $Z \geq 3$ are of such short range that no measurements are possible on the tracks themselves.

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