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A SEARCH FOR HEAVY HYPERNUCLEI AT LEAR (PS177)

Amsterdam (NIKHEF-K)-CERN-Grenoble (CEN)-
Saclay (CEN)-Swierk-Uppsala Collaboration

Presented by T. Johansson at the
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With Low-Energy Cooled Antiprotons
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ABSTRACT

The aim of the experiment is to produce heavy hypernuclei by $\bar{p}$ annihilations and to measure their lifetimes. Kaons emitted in $\bar{p}$ annihilation on nuclei could possibly interact with the residual nucleus and undergo a strangeness exchange reaction: $K + N \rightarrow \Lambda + \pi$. The Λ -hyperon could then be attached to the nucleus, forming a hypernucleus. One signature of its decay would be delayed fission. For the detection of delayed fission events, the "recoil distance method" will be used.

INTRODUCTION

Although more and more information is becoming available on hypernuclei¹⁾ there is still one observable that is poorly known, namely the lifetime of a hypernucleus. In fact data are non-existent for hypernuclei with $A > 16$, and even for lighter ones the data are sparse (Fig. 1).

The free mesic Λ -decay

$$\Lambda \rightarrow N + \pi \quad (1)$$

($\tau = 2.6 \times 10^{-10}$ s) is strongly suppressed in the nuclear matter. This comes from the fact that most of the decay energy goes into the decay particle rest masses (Q-value 35 MeV), and therefore their momentum is only 100 MeV/c. In particular for heavier nuclei, most of the possible states for the nucleon in process (1) are already

Fig. 1 The experimental situation on mean lifetimes of hypernuclei (Ref. 2). The theoretical estimate for large A is from Ref. 3.

occupied, according to the Pauli principle. Therefore inside the nucleus the most likely decay of the Λ particle is the non-mesic weak interaction process

In fact this process is the only strangeness-changing weak interaction involving four strongly interacting fermions. Furthermore, this interaction takes place inside the nucleus, and it might be speculated whether the nuclear media will somehow modulate this interaction. For example, it has been suggested by Salam and Strathdee⁴), that a heavy nucleus could provide the necessary electric or magnetic field strengths to decrease the Cabibbo angle. Evidence of this would be an increase of the Λ lifetime.

The energy release of 176 MeV in the non-mesic decay means that, especially for lighter nuclei, these events are accompanied by emission of high-energy nucleons. However, for heavy nuclei the formation of highly excited compound states is probable and, for suitable targets, decay into the fission channel is open. Thus the observation of delayed fission in connection with the formation of heavy hypernuclei could be used to obtain information about their lifetime inside a heavy nucleus.

PRODUCTION OF HYPERNUCLEI IN ANTIPROTON ANNIHILATION AT REST

The "normal" way of producing a hypernucleus is by using an secondary K^- beam. In the strangeness exchange (SEX) reaction

$$K^- + n \rightarrow \Lambda + \pi^- , \quad (3)$$

under certain kinematical conditions the Λ will be produced at rest in the laboratory system (Fig. 2a), the so-called recoilless production. This means that a hypernucleus can be formed where the Λ particle replaces a neutron.

However, there are other sources of kaons. One of them is antiproton annihilation at rest, where it is known that about 7% ⁵⁾ of all events are accompanied by strange-particle emission, namely $K\bar{K}$ pairs. If one looks at the kinematics of this process, one finds that the momenta of the emitted kaons fall into the region of recoilless production (Fig. 2b). Especially good is the overlap for channels where the kaons are accompanied by the emission of one or two pions. The important difference here, compared to a K^- beam where the nuclear cross-section and target thickness are of importance, is that once the $\bar{p}$ is stopped the kaons are created on the surface of the nucleus which is going to be converted into a hypernucleus. Hence it is the very large solid angle of the residual nucleus at the position of annihilation that enters into the production probability. The high quality of the LEAR beam allows us here to use very thin targets which, as will be shown later, are of importance for the experiment.

Fig. 2 a) Recoil of the Λ particle in the reaction $K^- + n \rightarrow \Lambda + \pi^-$ as a function of the kaon momentum for different $K\pi$ laboratory angles (Ref. 6).

b) Momentum distribution of the kaons emitted in the $\bar{p}p$ annihilation (assuming isotropy). The curves are weighted by the known branching ratios (Ref. 5) and the Fermi momentum is schematically taken into account. The solid line indicates approximately the total momentum distribution of the kaons.

Measurements by Bertini et al.⁷⁾ showed that at 0° pion emission, as compared to the free process (3), the number of effective neutrons in the reaction

was about five, with a beam momentum of 640 MeV/c. This number includes the probability that the Λ is attached to the nucleus. Since our aim is just to produce hypernuclei (no pion spectroscopy), we can profit from all possible SEX reactions, e.g.

It could therefore be assumed that in addition we can estimate the number of effective protons to be three.

The total cross-section for the reactions 5a and 5b is 5 mb and 2.5 mb respectively at 700 MeV/c and is fairly constant in the region of interest.

With all this in mind we arrive at a production probability of a hypernucleus in a $\bar{p}$ annihilation at rest on a Bi nucleus of $\sim 10^{-4}$ as an order-of-magnitude estimate.

By using a Bi target of thickness 30 $\mu\text{g}/\text{cm}^2$, one gets a stop efficiency of 1% with a beam momentum of 100 MeV/c at LEAR, assuming that the antiproton slowing down has the same straggling as a proton. Thus with a beam intensity of 10^6 $\bar{p}$ per second, the production rate of hypernuclei is of the order of one per second. Again it should be stressed that this is just an order of magnitude estimate, but the principle of hypernuclear production in $\bar{p}$ annihilation applies to all nuclei.

DETECTION OF HEAVY HYPERNUCLEI DECAY

The 175 MeV released in the non-mesic hyperon decay (2) will be dissipated in the residual nucleus. For heavy nuclei, an excited compound nucleus will be formed which will decay mainly via neutron emission or fission. The purpose of this experiment is to detect the delayed fission decay of the hypernucleus; therefore the following conditions should be fulfilled.

- a) the loss of events due to prompt fission in the $\bar{p}$ annihilation should be small;
- b) the fission probability for the hypernucleus decay should be large;

Fig. 4 Simulated hit-distributions in the shadow region for different lifetimes ($P_f = 250$ MeV/c). The geometry used gives an amplification (ℓ/x) of the recoil distance of ~ 200 .

The fission fragment detector will consist of the following parts. Four position-sensitive, large-surface avalanche counters operating under low pressure will be placed in a square surrounding the target at a distance of 25 cm. To accept an event in the backward region a corresponding hit in the opposite detector will be required. Furthermore, the angular correlation between the two fragments will give information on the recoil velocity. In order to cover completely the solid angle of the shadow region, these detectors will be complemented with foil track detectors which will be scanned off line. With a detection efficiency of 1%, one would arrive at ~ 1000 recorded events per day.

CONCLUSIONS

In order to study the target question further, prompt-fission probabilities should be measured for a set of targets ranging from Pb to U. Simultaneously, information can be obtained about the recoils involved in the annihilation process by measuring the angular correlations between the two fragments.

This as well as preliminary data taking can easily be done with a beam of 300 MeV/c at LEAR. However, not knowing in detail the production yield of heavy hypernuclei in $\bar{p}$ annihilation nor their decay ratio into the fission channel, the experiment would certainly profit from having the lowest possible momentum from LEAR, although results could already emerge at 300 MeV/c.

As shown, the experiment is feasible, but if one wants to bring about an essential increase in the $\bar{p}$ stop rate and hence in the sensitivity, one would need to further decrease the energy of the $\bar{p}$ beam at LEAR with good energy resolution. This could be achieved within the framework of ELENA, Medicyc, or an RF energy correction system after normal degradation. It should be noted that we are not sensitive to the divergence or to the time structure of the beam.

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