**DELAYED FISSION FROM THE ANTIPROTON ANNIHILATION IN ^{209}Bi —
EVIDENCE FOR HYPERNUCLEAR DECAY**

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ABSTRACT

Delayed fission following the annihilation of stopped antiprotons in ^{209}Bi has been observed with a yield of approximately 3×10^{-4} . The lifetime for delayed fission as measured by the recoil-distance technique is $(2.5^{+2.5}_{-1.0}) \times 10^{-10}$ s. The observed delayed fission is interpreted as resulting from the decay of hypernuclei in the region of masses near 200 produced in the annihilation of antiprotons in ^{209}Bi .

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In a previous paper [1] we have reported the observation of delayed fission following the annihilation of antiprotons at rest in ^{238}U . We used the recoil-distance technique, where the lifetime is inferred from a distribution of fission fragment impacts in a detector placed in such a geometry that one can distinguish events with different decay points with respect to the target plane. (See ref. [1] for details of the experimental technique.)

The value of the lifetime reported in ref. [1], $\tau = (1.0 \pm 0.9) \times 10^{-10}$ s, was determined from comparing the experimentally measured position distribution of events with a calculated one using the Monte Carlo method. The yield of delayed-fission events was found to be close to 10^{-3} per stopped antiproton. The interpretation given in ref. [1] is that the delayed fission results from the decay of hypernuclei produced in the annihilation of antiprotons in the ^{238}U nuclei.

In the present work we report results obtained with a ^{209}Bi target in an experiment carried out at the Low Energy Antiproton Ring (LEAR) at CERN, with the same set-up that we used in our previous experiment [1]. The antiproton beam momentum was 100 MeV/c. With a Bi target, 0.1 mg/cm² thick and 2 mm wide, deposited on a 2.5 mm wide backing, 155 delayed-fission events have been collected.

Figure 1 shows the position distribution of fission fragments registered in the detector area shadowed by the target (negative values of coordinates), as well as the position distribution of coincident complementary fragments (positive values of coordinates). According to the principle of the recoil-distance technique, all these fragments correspond to delayed-fission events. Figure 2 shows the distribution of the angles between the delayed-fission fragment trajectories (opening angles). It was determined from the positions of fragment impacts in the fission chambers.

In the analysis of our present data the main purpose was the determination of the lifetime for delayed fission, and we followed the same procedure as in ref. [1]. Remaining within the framework of a phenomenological approach and using, as in ref. [1], a purely exponential momentum distribution of recoil nuclei knocked out from the target $N(p) = \exp(-p/p_0)$, we obtained a lifetime of

$$\tau = (2.5 \pm 1.0) \times 10^{-10} \text{ s},$$

where the errors correspond to the 95% confidence level in χ^2 . It turned out that all three measured distributions were characterized by a rather flat dependence of χ^2 on p_0 .

Using a different momentum distribution, of the form $N(p) = p \times \exp(-p/p_0)$, we obtained the same value of the lifetime (and its uncertainty) but a more pronounced dependence of χ^2 on p_0 . The distributions calculated with this modified expression for the momentum distribution are shown in figs. 1 and 2; they correspond to the overall best fit to the experimental results.

As an additional check of the consistency of our procedure, the previously published data for uranium [1] were re-analysed with the modified momentum distribution $N(p) = p \times \exp(-p/p_0)$. The following values of the parameters were found:

$$\tau = (1.0 \pm 0.4) \times 10^{-10} \text{ s}, \quad p_0 = 300 \text{ MeV/c}.$$

The value of the lifetime reproduces the estimate given in ref. [1]. On the other hand, the value of p_0 for uranium is somewhat different from the value of p_0 for bismuth, given in figs. 1 and 2.

Slightly different momentum distributions of hypernuclei undergoing delayed fission can be expected for uranium and bismuth for the following reasons:

- i) the probability of survival of an excited heavy hypernucleus is determined by the branching ratio for the fission channel which is a function of the excitation energy, and this dependence is different for nuclei in the regions of bismuth and uranium;
- ii) as indicated by calculations [2] some correlation may exist between the excitation energy and the momentum of residual nuclei.

The yield of delayed-fission events for ^{209}Bi is about 3×10^{-4} per stopped antiproton, which is lower by a factor of 3 than observed with ^{238}U [1]. Whereas a difference in yields could be explained by different fissility of nuclei in the regions of bismuth and uranium, the lifetimes measured for uranium and bismuth are still equal within the limits of quoted errors.

As in ref. [1] we cannot suggest any other interpretation of our present results than that we observe delayed fission arising from the decay of hypernuclei, produced in the annihilation of $\bar{p}$ in bismuth. Note that in ref. [1] we rejected the decay of fission isomers as an extremely unlikely explanation. Our present result completely excludes this hypothesis since no fission isomers are known to exist in the region of bismuth.

The present measurement does not show direct evidence for strangeness production in the investigated process. However, Condo et al. [3] observed Λ production in $\bar{p}$ annihilation on complex nuclei, with a yield of about 2%. Assuming the probability of attachment of the Λ hyperon to a heavy nucleus to be of the same order of magnitude whether it is produced in $\bar{p}$ annihilation or with stopping K^- [4], the yield of delayed fission observed in our experiment is quite reasonable.

In a recent experiment performed at the Kharkov linear electron accelerator [5], delayed fission was observed following the interaction of 1.2 GeV electrons with a ^{209}Bi target. It was likewise interpreted as resulting from hypernuclear decay. The reported lifetime is (2.7 ± 0.5) ns. The yield of delayed fission per nuclear reaction is 100 times higher in our experiment than in the experiment with electrons. For that reason we cannot exclude the possible production of long-lived hypernuclei at a level two orders of magnitude below our experimental result. On the other hand, with the set-up used in Kharkov, a 0.5 mm systematic error is quoted for the recoil ranges which could prevent the observation of any short lifetime. Consequently, it seems worth while to investigate both components in the same experiment.

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Figure captions

- Fig. 1** Measured and calculated distributions of the positions of delayed-fission fragments along the beam direction. The values of the reduced χ^2 for upstream and downstream ranges are 1.53 and 0.89 respectively.
- Fig. 2** Measured and calculated distributions of the opening angles of the delayed-fission fragments. In the Monte Carlo calculation, events with an angle smaller than 158° have been eliminated. The corresponding reduced χ^2 has a value of 0.71.

Fig. 1

Fig. 2