EVIDENCE FOR HYPERDEFORMED NUCLEAR SHAPE IN ^{236}U*

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The fission probability as a function of the excitation energy in ^{236}U has been measured for the ^{235}U(d,pf)^{236}U reaction at an excitation energy slightly below the top of the fission barrier, with the aim of disclosing new resonant class III hyperdeformed states in the third minimum of the fission barrier. A strong resonance at $E^* = 5.476$ MeV was observed and interpreted as the hyperdeformed ground-state (band). Some weaker resonances around $E^* \approx 5.3$ MeV have also been observed as a consequence of the high energy, dumped superdeformed states.

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1. Introduction

One of the most exciting aspects of nuclear structure physics in recent years is the study of superdeformed (SD) and hyperdeformed (HD) nuclear states [1, 2] with a ratio of 2:1 and 3:1 for the long to short axis in deformed nuclei, respectively. Such states are extensively studied in fast rotating nuclei, where they result from an interplay of centrifugal forces due to rotation, the surface tension and shell effects. In this work we studied these highly deformed states in the actininides, particularly in ^{236}U, where the strong stable deformation is predicted to be the result of the Coulomb forces, surface tension and shell effects. Very little is known about these systems,

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especially for the HD states, although their properties would give basic information on the behavior of the shell model at very large deformations.

The aim of the present work was the study of super- and hyperdeformed states in the second and third minimum of the potential energy surface of ^{236}U by measuring the transmission resonances of the fission probability in the ^{235}U(d,pf) reaction with the method of Blons [3, 4].

2. Experimental procedure

The experiment was carried out at the Debrecen 103-cm isochronous cyclotron at $E_d = 9.73$ MeV. Enriched (97.6 %) $^{235}UF_4$ target with a thickness of 250 $\mu g/cm^2$ was evaporated onto 37 $\mu g/cm^2$ polyimide foil, and coated with 50 $\mu g/cm^2$ of gold [6]. Energy of the emitted protons was measured at $\Theta_L = 130°$ with respect to the beam direction in coincidence with the fission fragments (see Fig. 1).

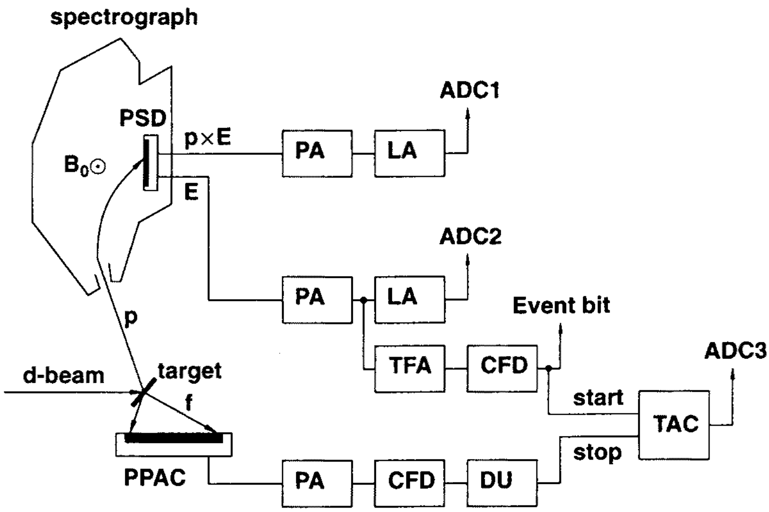

Fig. 1. Schematic layout of the experimental set-up used for the p–f coincidence measurements, showing the split-pole magnetic spectrograph, the parallel plate avalanche counter (PPAC) and the associated electronic modules.

The energy of the outgoing protons was analyzed by a split-pole magnetic spectrograph [6], which had a solid angle of 2 msr. The position and energy of the protons were analyzed by Si solid state position sensitive detectors (PSD) placed at the focal plane of the spectrograph. The overall proton energy resolution including the long term stability of the system was estimated to be FWHM$\leq$ 20 keV. The fission fragments were detected by a 25 cm^2 parallel plate avalanche counter [7] placed at $\Theta = 90°$ with respect to the beam direction. The solid angle of this detector was 2.10 sr. Beam currents were typically limited to 100–200 nA in order to get an acceptable (2:1) real to random coincidence ratio between protons and fission fragments.

3. Results

The fission probability spectrum shown in Fig. 2.a. was calculated from the measured singles and coincidence proton spectra and normalized at $E^* = 5.4$ MeV to the one determined by Back and Britt [9]. The energy range was chosen to cover the theoretically predicted third well HD resonance [8]. A strong and well separated resonance has been obtained at $E^* = 5.476$ MeV very close to the predicted value of 5.51 MeV [8].

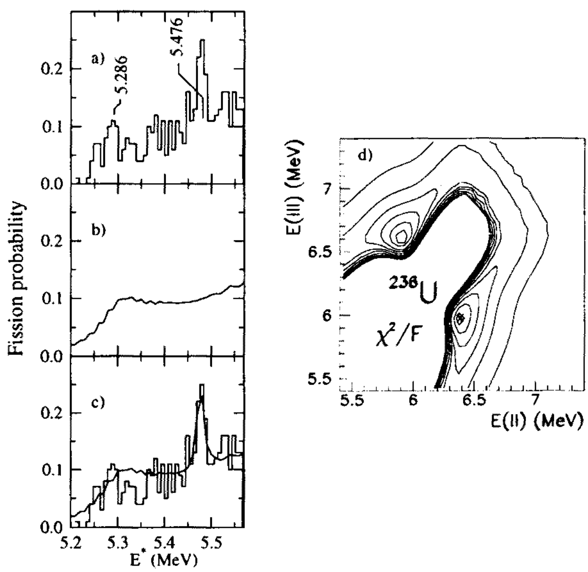

Fig. 2. Fission probabilities of ^{236}U as a function of the excitation energy E^*. (a) experimental values, (b) values calculated by the program FISALL, (c) comparison of the measured fission probabilities (histogram) with the calculated ones using the result of FISALL and the result obtained for a triple-humped potential barrier (see in the text). (d) comparison of the measured and calculated fission probabilities using the χ^2 method. The χ^2 values were calculated as a function of the heights of the second and third potential barriers.

By supposing a double-humped structure of the fission potential with the parameters given by Bhandary [10] and using the resonant version of the program FISALL of Back and Britt [11], the gross structure of the fission probability was calculated and is shown in Fig. 2.b. For the description of the underlying model see ref. [11]. This model has successfully been used to describe fission probabilities obtained from direct reactions in the actinide region. The population amplitudes $\alpha(E^*, J^\pi)$ for the calculations were obtained from the measured values of [12]. Although the gross structure of the fission probability with the effect of the dumped superdeformed states at ≈5.3 MeV could be reproduced, the sharp resonance at $E^* = 5.476$ MeV could not be described.

In order to understand the nature of the above strong resonance, a triple-humped potential barrier of Howard and Möller [8] was taken into account. The transmission probability through the triple-humped barrier was calculated by using the analytical expressions of Bhandary and Al-Kharam [13]. The place of the resonance could be reproduced exactly by slightly changing the depth of the third well. The strength and widths of the resonance were obtained from a least square fitting procedure by varying the height of the second and third barrier (see Fig.2.c full curve). The result of the analysis with a few confidence levels is shown in Fig.2.d. We found two equally good minima.

4. Discussion and conclusions

The fission probability of ^{236}U was studied as a function of the excitation energy through (d,pf) reaction in order to confirm the presence of a third minimum of the fission barrier. In fact, the present experiment is a beautiful confirmation of the appearance of the hyperdeformed shape. Without considering the triple-humped potential barrier, the observed 5.475 MeV resonance could not be described. According to Fig. 3 the experimentally determined barrier heights are somewhat higher than the calculated ones. This may be due to the fact that we mostly excited the $J>0$ members of the ground-state band in the third well, for which the potential barrier is higher.

We are going to improve the energy resolution of the system and also to perform angular distribution measurements for the fission fragments in order to resolve and identify the members of the hyperdeformed ground-state rotational band.

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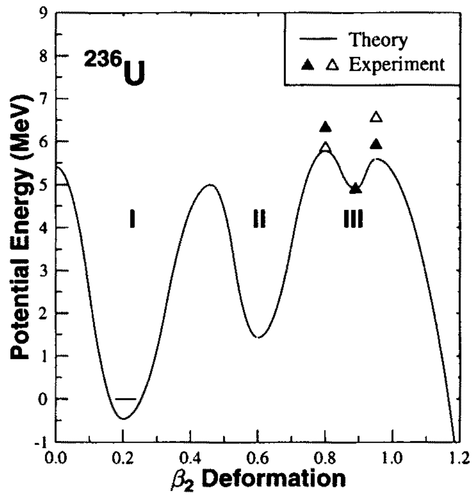

Fig. 3. Fission barrier relative to the ground-state of ^{236}U as calculated by Howard and Möller [8] compared with the experimentally determined barrier heights corresponding to both χ^2 minima (full and open triangles).

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