PROPERTIES OF ^{236}U AT THE THIRD-MINIMUM DEFORMATION * **

M. Csatlós, A. Krasznahorkay, M. Hunyadi, J. Gulyás,
Z. Máté, J. Molnár, J. Timár and J. Végh

Institute of Nuclear Research of the Hungarian Academy of Sciences
H-4001 Debrecen, P.O. Box 51, Hungary

(Received December 10, 1996)

The fission probability and the angular distribution of the fission fragments has been measured for the $^{235}\mathrm{U}(d,pf)\,^{236}\mathrm{U}$ reaction at an excitation energy slightly below the top of the fission barrier as a function of the excitation energy in ^{236}U. A strong resonance was observed at $E^* = 5.45$ MeV. The fine structure of the resonance was measured and interpreted as a hyperdeformed rotational band.

PACS numbers: 21.10. Re, 25.85. Ge, 24.30. –v, 27.90. +b

1. Introduction

Compilations of calculated fission barriers indicate that the existence of a third well seems to be a general property of all the actinides, and it has became a challenge to find an experimental proof of this well [1].

In our earlier experiment we have studied the fission probablity of ^{236}U as a function of the excitation energy through (d,pf) reaction in order to get information for the III minimum of the fission barrier. We have observed a definite peak in the fission probability at about $E^* =$ 5.45 MeV of excitation energy [2]. The experiment turned out to be a good way for studying the hyperdeformed states of ^{236}U.

The aim of our present experiment was: to improve the statistics of the earlier measurement and to perform angular distribution measurements for fission fragments in order to get information for the J^π of the states.

* Presented at the XXXI Zakopane School of Physics, Zakopane, Poland, September 3–11, 1996.

** Work has been partly supported by the OTKA Foundation, No:7486,and the Nederlandse Organisatie vor Wetenschappelijk Onderzoek.

2. Experimental setup

The experiment was carried out at the Debrecen 103-cm isochronous cyclotron at $E_d = 9.73$ MeV. The target was enriched (97.6%) $^{235}UF_4$ with a thickness of 330 μg/cm^2.

The energy of the outgoing protons was analyzed by a split-pole magnetic spectrograph which had a solid angle of 2 msr and was set at $\Theta_L = 140°$ with respect to the incoming beam direction. The position and energy of the outgoing protons were analyzed by Si solid state position sensitive detectors (PSD) placed at the focal plane of the spectrograph. The overall proton energy resolution of the system including the effect of the target thickness and the long term stability was estimated to be FWHM$\leq$ 20 keV.

The fission fragments were detected by a position sensitive avalanche detector (PSAD) having two wire planes including 46$\times$41 wires with a spacing of 2 mm corresponding to horizontal and vertical directions, respectively. Two-dimensional delay-line read-out was used.

3. Results

The measured proton spectrum, at the E* = 5.45 MeV resonance region, in coincidence with the fission fragments as a function of the excitation energy is shown in Fig.1a.

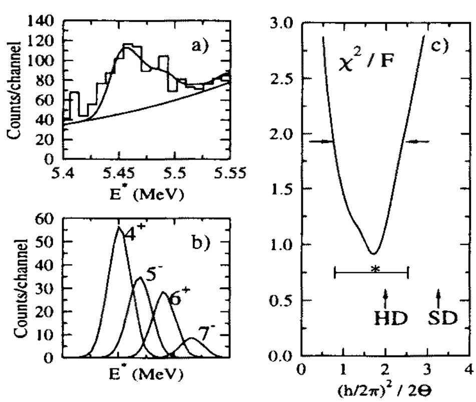

Fig. 1. Proton spectrum in coincidence with the fission fragments as a function of the excitation energy, compared with the fitted rotational band containing positive and negative contributions (a), the components of the band (b) and the results of the χ^2 analysis (c).

Assuming that the observed resonance contains a whole rotational band, we tried to fit our experimental spectrum by using simple Gaussian functions for describing the different members of the band:

$$F(x) = \text{par}(1) \sum A_i \exp(-(x - \text{par}(2)J(J+1) - \text{par}(3))^2/2\sigma^2)\,,$$

where the A_i relative excitation probabilities were taken from the work of Back *et al.* [4], par(2) $= \hbar^2/2\theta$, the par(3) is the energy of the rotational band head, and σ corresponds to the energy resolution of our experiment. Due to the reflection-asymetry in the third well both parities were included in the rotational spectrum, similarly to the fitting procedure of Blons performed for ^{231}Th [3].

We have used par(1), par(2) and par(3) as free parameters and fitted to the measured spectrum with the least χ^2 method. The non-resonant part of the fission probability was taken into account as a "background" and fitted with an exponential curve. Using $K = 0$ the best fit appeared at $\hbar^2/2\theta = 1.4$ keV, which is much less than the values of $\hbar^2/2\theta$, predicted for the hyperdeformed and superdeformed minima, 2.0 keV and 3.3 keV, respectively.

According to the latest calculations of Ćwiok *et al.* [6] in the heavier U nuclei the HD minimum splits into two distinct minima. The minimum with $\beta_3 \approx 0.6$ is very deep ($E_{\text{HD}} = 2.5$ MeV [5]). In the above deep minimum many vibrational states can be excited and different two-neutron excitations can be built on them. These kind of two-neutron states can be excited very effectively by (d,p) reactions. The K value of these bands can be as big as $K = 4$.

Supposing that we saw a rotational band built on an excited state rather than on the ground state in the HD potential well, we tried to vary the K value of the band head during the fitting procedure. We obtained $\hbar^2/2\theta =$ 1.4, 1.5, 1.6 and 1.7 keV for $K = 1$, 2, 3 and 4, respectively. The continuous curve in Fig. 1a represents the "best fit" and the components are shown in Fig. 1b. The calculated χ^2/F values as a function of $\hbar^2/2\theta$ are plotted in Fig. 1c. HD shows the predicted value of the $\hbar^2/2\theta$ for hyperdeformed state and SD for the superdeformed one. From our best fit we have got $\hbar^2/2\theta = 1.7 \pm 0.9$ keV in good agreement with the value predicted [3] for the hyperdeformed state.

Fission fragment angular distributions were generated for the 5.45 MeV line as well as for the continuous non-resonant part of the fission probability. As a representative example, the angular distribution for the 5.45 MeV line is shown in Fig. 2. All distributions were fitted with even Legendre polynomials up to forth order. The resultant angular distribution coefficients are

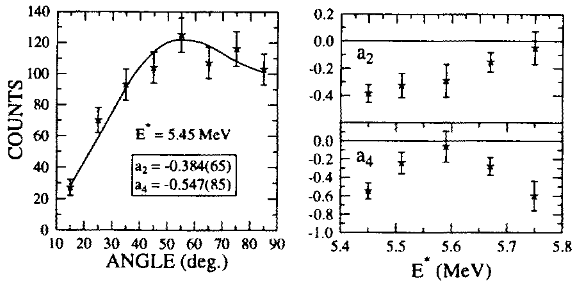

Fig. 2. Fission fragment angular distribution for the 5.45 MeV resonance and the determined angular distribution coefficients as a function of the excitation energy.

also shown in Fig. 2 as a function of the excitation energy. The angular distribution of the fission fragments produced in the ^{235}U(d,pf) ^{236}U reaction has already been studied earlier [6], but the energy resolution was much worse than in our experiment. The Legendre coefficients of the present angular distribution for the background region are in good agreement with the published data.

4. Discussion and conclusions

The fission probability of ^{236}U was studied as a function of the excitation energy through (d,pf) reaction. In fact our results support the presence of a deep HD minimum as predicted by Ćwiok *et al.* [5]. In this potential well our transmission resonances observed in the fission probability of ^{236}U correspond to some two-neutron states built on the basic vibrational states. The measured angular distribution of the fission fragments supports also the above assignment. The experimentally observed shape of the 5.45 MeV resonance was interpreted as a rotational band structure with a $\hbar^2/2\theta = 1.7 \pm 0.9$ keV which is characteristic for the hyperdeformed states.

REFERENCES

[1] P.A. Butler, W. Nazarewicz, *Rev. Mod. Phys.* **68** , 349 (1996).
[2] A. Krasznahorkay *et al.*, *Acta. Phys. Pol.* **B27**, 139 (1996).
[3] J. Blons *et al.*, *Nucl. Phys.* **A414**, 1 (1984).
[4] B.B. Back *et al.*, *Nucl. Phys.* **A165**, 449 (1971).
[5] S. Ćwiok *et al.*, *Phys. Lett.* **B322**, 304 (1994).
[6] H.J. Specht *et al.*, *Phys. Rev. Lett.* **B322**, 1187(1967).