MULTI-PHONON SUPERDEFORMED STATES IN ^{240}Pu*

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The fission probability has been measured in the ^{239}Pu$(d,pf)^{240}$Pu reaction as a function of the excitation energy. A new resonance group was found in the excitation energy region of 4.4-4.8 MeV and was interpreted as superdeformed rotational bands with an observed rotational parameters of $\hbar^2/2\Theta = 3.2$ keV corresponding to the superdeformed nuclear shape.

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The study of multiphonon states became an interesting research field again. In this work multi-phonon superdeformed states have been investigated in ^{240}Pu. After the first observation of the fission isomers in the actinide nuclei [1] a whole region of fission isomers was established. Measurements of the moments of inertia and quadrupole moments showed that fission isomers are shape isomers with an axis ratio of 2 : 1 for the long to short axis, respectively. They did represent the first superdeformed (SD) states [2]. The high spin superdeformed states were discovered later on in the A = 150 mass region [3,4].

The γ and conversion electron spectroscopy investigations of the SD excited states in the actinide region turned out to be very difficult. These

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states (especially highly excited states) can more efficiently be studied by measuring the transmission resonances across the fission barrier like we applied it in our earlier work [5].

In the present work the states predominantly of β vibrational type (*i.e.* the stretching mode, which leads to fission) have been studied by measuring the fission probability as a function of the excitation energy. The levels in the first well were populated by the ^{239}Pu(d,p) reaction and we expected enhanced fission probability (transmission resonances) for the excitation energies in the first well, which coincide with vibrational states in the second well.

The experiment was carried out at the Munich Tandem accelerator using a $E_d = 12.5$ MeV deuteron beam. Enriched (99.9 %) targets of ^{239}Pu were used. The energy of the outgoing protons was analyzed by a Q3D magnetic spectrograph set at $\Theta_{Lab} = 130^o$ relative to the incoming beam. The position in the focal plane was measured by a light-ion focal-plane detector [7]. Fission fragments were detected by two position-sensitive avalanche detectors (PSAD) which were developed in Debrecen [8]. They contain two wire planes (with delay-line read-out) corresponding to horizontal and vertical directions. Protons were measured in coincidence with fission fragments. The measured coincidence proton spectrum is shown in Fig. 1. for the excitation energy region of 4.4-5.2 MeV. The two highly damped vibrational resonances with centroids of 4.5 and 5.1 MeV, which were previously known [9], have nicely been resolved into substates.

The evaluated angular correlation data of the fission fragments are also shown in Fig. 1. The values of the angular correlation coefficients as well as the energy differences of the peaks for the well separated resonances suggested that maybe the whole spectrum can be described as a superposition of rotational bands. It seems that the damping widths caused by underlying β-vibrational state(s) remain well below the experimental resolution of 7 keV. This fact allows the 0^+, 2^+ and 4^+ states to be observable as transmission resonances, and their intensity ratios depend on the $\sigma_{d,p}(J^\pi, j, K)$ population cross sections. The states with higher J^π angular momentum cannot be observed this way because they can hardly be populated in a (d,p) process.

In order to prove the above idea, the spectrum was fitted by rotational bands consisting of three Gaussians for the 0^+, 2^+ and 4^+ members with fixed intensity ratios of 0.60, 1.00 and 0.26, respectively. Earlier considerations suggested [9] to involve exclusively K=0 bands into the fitting procedure. The widths of the Gaussians were determined by the experimental energy resolution. (The fission widths of the individual peaks were neglected comparing to our experimental resolution of $\approx$7 keV.) Assuming the rotational parameter of $\hbar^2/2\Theta = 3.2$ keV corresponding to a SD nuclear shape

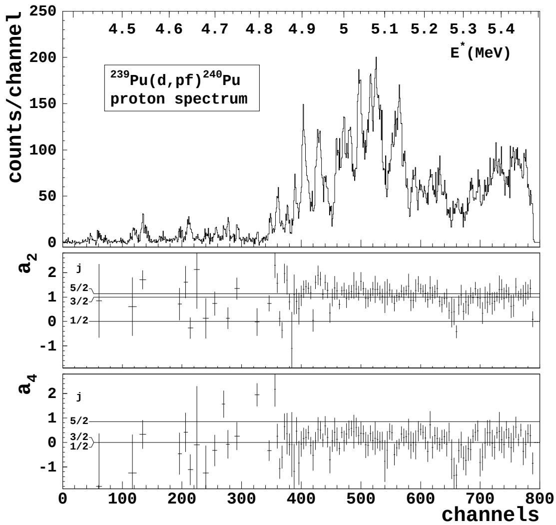

Fig. 1. Proton energy spectrum measured in coincidence with the fission fragments and the corresponding a_2 and a_4 Legendre-polynomial coefficients of the experimentally determined fission fragment angular distributions. Theoretical values of the transfer angular momentum j are also shown [9].

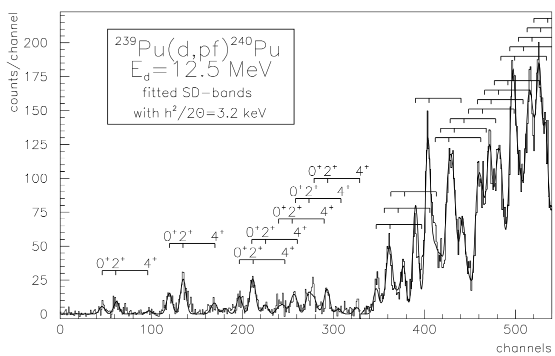

Fig. 2. Low excitation energy part of the measured proton energy spectrum fitted with rotational bands with a common rotational parameter of $\hbar^2/2\Theta = 3.2$ keV

with $\beta_2 = 0.6$ [2] the distances of the rotational members were kept fixed. The fitting variables were the following: (1) the position of the 0^+ band head, (2) the absolute intensity of the band. As can be seen in Fig. 2 the structure of the spectrum could nicely be reproduced with the superposition of K=0 SD rotational bands.

In the high excitation energy part of the spectrum around $E^* = 5.1$ MeV another resonance group appears, which was already seen in the work of

Glässel et al. [9]. According to our angular correlation data we have found this group having mostly $J^{\pi}=2^{+}$ character like Glässel stated. However, this group could have been also nicely decomposed by assuming the above SD rotational bands. According to the γ-ray spectroscopy work in the second minimum [10, 11] the energy of the quadrupole phonon in ^{240}Pu should be higher than 0.8 MeV, because the first excited 0^{+} state at 0.806 MeV has only 0.1 W.U.. As the energy of the SD ground state is $E_{g.s.}$(SD) = 2.4±0.2 MeV these states around E^{*} = 5.1 MeV might correspond to three-phonon SD vibrational states.

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