Micro-Structure of Vibrational Resonances in Superdeformed ^{240}Pu* ◇

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Whenever intrisic excitations in the second minimum couple with nearby β-vibrations with some fission width, transmission resonances appear in the fission probability peaking at the vibrational energies. In the case of ^{240m}Pu, the overall structure of fission resonances has already been studied [2,3], however, the micro-structure of the vibrational resonances has never been sufficiently analyzed.
Therefore the aim of the present work was to resolve the fission resonance structures of ^{240}Pu and thus identify high-lying superdeformed rotational bands for the first time. The ^{239}Pu(d,pf)-reaction at E_d =12.5 MeV (target: 30μg/cm^2 ^{239}Pu$_2$O$_3$, 99.9% enriched) was used to populate the second minimum in ^{240}Pu. Protons were measured using the Q3D magnet spectrograph ($\Theta_{\rm lab}$ =130° relative to the incoming beam) and a light ion focal-plane detector of 1.6 m active length in coincidence with fission fragments detected in two position sensitive parallel plate detectors (PSAD). The spectrum of the outgoing protons in coincidence with the fission fragments after subtraction of random coincidence events is shown in Fig. 1a). Two enhanced structures of highly damped vibrational resonances at E* =4.5 and 5.1 MeV have been resolved into substates due to the underlying compound states coupled to to the β-vibrations. The observation of both groups is consistent with the results of earlier experiments [3,4,5,6].
According to the well-known rotational spacings on the lowest-lying vibrational states in the SD minimum of ^{240}Pu, the distances of the observed peaks were compared to the well-known J(J+1) rotational formula. In this way rotational bands can confidently be identified with a moment of inertia within reasonable limits of about 150 MeV^{-1} [7,8,9], which corresponds to a rotational parameter of R= $\hbar^2/2\Theta$ =3.3 keV. As a result, three pairs of peaks between E* =4.4 and 4.62 MeV seem to form three bands with an equal spacing of 18 keV, which mainly supports the presence of $K^\pi = 0^+$-bands. The upper part of this resonance group in the region of E* =4.62 - 4.8 MeV exhibits a denser, but still not overlapping structure. In the excitation energy region of E* =4.8-5.2 MeV a highly overlapping structure of peaks has been observed with five times higher intensity than in the E* =4.5 MeV vibrational resonance. Our data suggest, in good agreement with photofission experiments [4,6], the presence of $K^\pi = 0^+$ superdeformed compound states in the whole resonance region centered around the two β-vibrational states at E* =4.5 and 5.1 MeV. This assignment is supported by the angular correlation data measured with the PSAD's. The measured data have been fitted with even Legendre-polynomials up to fourth order. The extracted a_2 and a_4 angular correlation coefficients for each peak have been compared to theoretical values, checking the agreement with the suspected spin assignments (see Fig.1 b) and c). The overall presence of K=0 resonances could be stated. According to these assignments the resonance regions have been fitted with rotational bands, using a common value for the intensity ratio of the band members and for the rotational parameter (3.16±0.28 keV as an average value of the identified $K^\pi = 0^+$ bands). This fit for both resonance regions is included as a solid line in Fig. 1a). Due to the selectivity for $K^\pi = 0^+$-states a complete spectroscopy can be performed in the excitation energy region just below the fission barrier top. Therefore the probability distribution of the observed $K^\pi = 0^+$-states was compared to the predictions of the back-shifted Fermi-gas formula, which contained the shifted ground state energy as the only free parameter. The distribution was successfully described by the theoretical Wigner-type distribution with a back-shift term of 2.25±0.2 MeV, in good agreement with the fission isomer energy obtained from the method of extrapolated excitation functions [10]. Recently conversion electron spectroscopy in ^{240m}Pu showed a K= 0^+-band with strong J→J transitions resulting in an energy of the first β-vibrational phonon of 758 keV [11]. Using this phonon energy and the energy difference between the ground state of the second minimum of 2.25 MeV and the resonance at 4.5 MeV shows that this resonance corresponds to the third β-phonon. The somewhat reduced energy difference between the third and the fourth vibrational excitation of 600 keV is expected, because the potential well opens up at the top of the barrier.

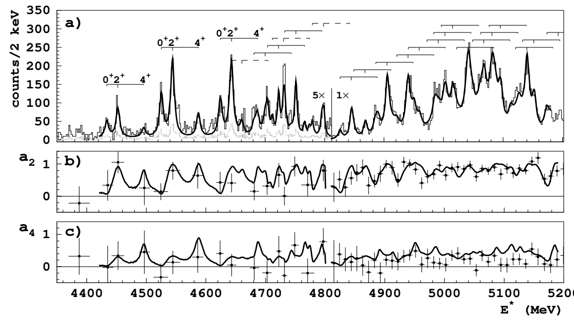

Fig. 1: a) Result of the fit to the observed resonance structures with $K^\pi = 0^+$ rotational bands. Dashed markers indicate the ambiguous presence of some additional bands. b) and c) Experimental and calculated a_2 and a_4 coefficients of the fission anisotropy as a function of the excitation energy. The calculated values resulted from combining theoretical coefficients by the obtained fit of the spectrum.

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