Search for Two-Phonon Superdeformed States in ^{240}Pu

M. Csatlós [a], Y. Eisermann, T. Faestermann, D. Gassmann, G. Graw, M. Groß, J. Gulyás [a], D. Habs, R. Hertenberger, M. Hunyadi [a], A. Krasznahorkay [a], H. J. Maier, A. Metz, Z. Máté [a], J. Ott, D. Rudolph, P. G. Thirolf, and B. D. Valnion

[a] Inst. of Nucl. Res. of the Hung. Acad. of Sci., Debrecen, Hungary

Recently the study of multiphonon states became a central research field again. In this 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 in a first experiment. The levels in the first well were populated by the ^{239}Pu(d,p) reaction and we expected an enhanced fission probability (transmission resonances) for those excitation energies in the first well which coincide with vibrational states in the second well (see fig.1).

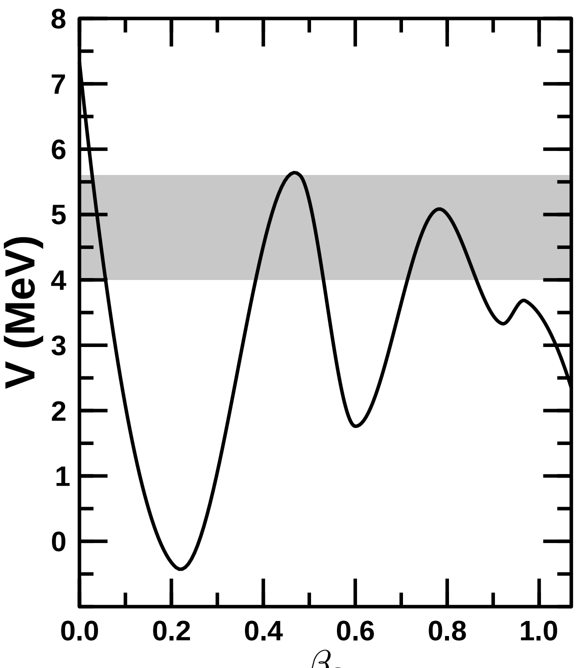

Fig. 1: Potential energy curve for ^{240}Pu as a function of the quadrupole deformation parameter β_2 [1]. The shadowed excitation energy region was presently investigated.

We expect J$^\pi$ of 0^+, 2^+ and 4^+ for these two-phonon states, whose strength might spread over many superdeformed excited states.

The experiment has been carried out at the Munich Tandem Accelerator at E$_d$ = 13 MeV. Enriched (>99%) ^{239}Pu target material was used, being the first target produced in the recently finished radioactive target laboratory. Although the activity of the target was only 0.3 μCi special care has been taken to protect the very thin and fragile target ($30\mu g/cm^2$ ^{239}Pu).

The energy of the protons was analyzed by the Q3D magnetic spectrometer ($\Theta_{\rm lab} = 130^o$) equipped with a 1.8 m long light-ion focal-plane detector in coincidence with the fission fragments. These were detected by two position-sensitive avalanche detectors (PSAD) using two wire planes (with delay-line readout) corresponding to horizontal and vertical directions. The resulting proton energy spectrum is shown in fig. 2 as a function of excitation energy.

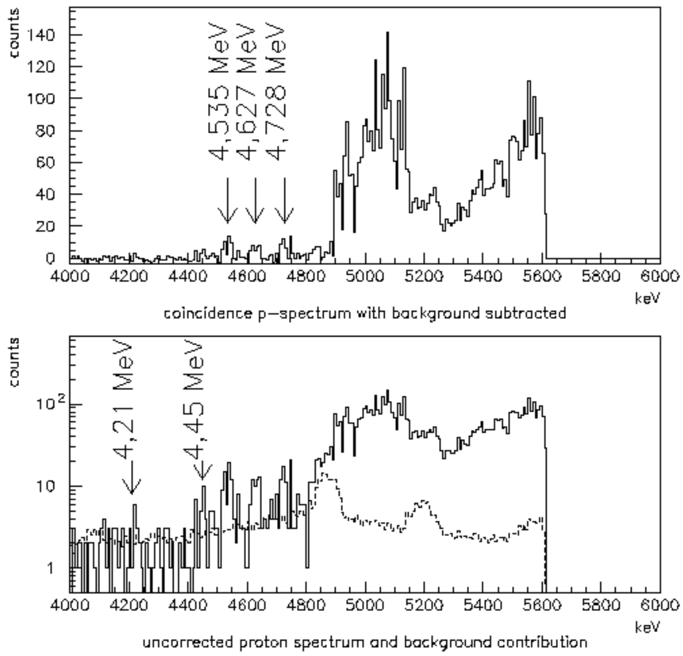

Fig. 2: Proton energy spectrum in coincidence with the fission fragments as a function of the excitation energy. Upper panel: Proton spectrum corrected for random coincidences and background from ^{239}Pu(d,p). Lower panel: uncorrected (d,pf)-proton spectrum and (d,p)-background contribution (dashed line).

The energy calibration was obtained from a (d,p)-measurement on a ^{208}Pb target. The data have been corrected for random coincidences. Background from the ^{239}Pu(d,p)- reaction channel was removed by a subtraction of the (d,p)- energy spectrum normalized to the low-energy part of the E$_x$-spectrum, where no contribution from the (d,pf)-channel can be expected. The upper panel of fig.2 shows the resulting corrected proton spectrum while in the bottom panel the uncorrected spectrum is shown together with the normalized (d,p)-background contribution (dashed line). This background shows no structure in the energy region of interest around 4.5 MeV, while the prominent structures around 4.88 MeV and 5.2 MeV can be attributed to (d,p)-reactions on ^{12}C and ^{16}O target contaminations.

Experimental knowledge on the resonance structures visible in fig.2 exists from two previous experiments: Two highly damped vibrational resonances with centroids of 4.5 and 5.1 MeV have been measured with a semiconductor detector setup delivering a moderate energy resolution of ≈80 keV [2]. Individual resonances with improved energy resolution but moderate statistics in the region around E$_x$ =4.5 MeV were measured by [3,7], since this experiment was optimized for the energy of the third-phonon resonances around 5.1 MeV [3,7]. In our measurement these structures around 4.5 and 5.1 MeV, respectively, have been nicely resolved into substates corresponding to SD states in the second well of the potential barrier. The width of about 30 keV observed for these states is much larger than the resolution of 5 keV. According to the energy of the SD ground state, the phonon energy, which is $\hbar\omega_2$ =5.1 - 4.5 = 0.6 MeV, the resonances around E* = 4.5 MeV should correspond to two-phonon SD states. Moreover, in the (logarithmic) display panel of fig.2 weak indications of (known) resonances at E_x = 4.21 and 4.45 MeV can be seen, whose intensities and widths are in perfect agreement with line width expectations and cross section estimates from the fission probability measured with 80 keV resolution [2]. Energetically located close to the already mentioned resonances at 4.5-4.8 MeV supports their interpretation as members of the two-phonon state group.

Comparing the present experimental results with previous measurements of the same reaction [6] shows consistency with the (d,pf)-cross section obtained there. However, a gain of about a factor of five can be expected from a lower beam energy of 12.5 MeV [3,7].

A more precise data reduction and the interpretation of the results is in progress. Information on the spins of the resonances will be obtained by comparing the measured fission fragment angular distributions with the results of PWBA calculations.

It is our goal to improve the quality of data obtained in [2] by about an order of magnitude exploiting the excellent energy resolution of the Q3D ($\approx$ 5 keV) compared to that of the semiconductor detectors [2]. By lowering the beam energy to 12.5 MeV and by optimizing the efficiency of the fission counters we should be able to increase the statistics in the energy region around E_x =4.5 MeV by about an order of magnitude compared to the present data and previous measurements [7]. Ultimately we aim at combining the spectroscopic information on the level structure of ^{240}Pu in the second well known from γ-spectroscopic studies [4,5] and transmission resonance experiments in a common level scheme. Fig.3 displays the present knowledge of (dominant) transitions in ^{240m}Pu coming from (d,pf)-reactions (left column) and γ-spectroscopic experiments (right column). While the γ-spectroscopy experiments predominantly study the low-lying transitions of the first phonon, the (d,pf)-reaction yields information on the level structure at higher excitation energies in the region of the second and the third phonon. A combination of both parts presently suffers from the large uncertainty of $\pm$200 keV in the knowledge of the excitation energy of the isomeric ground state [8].

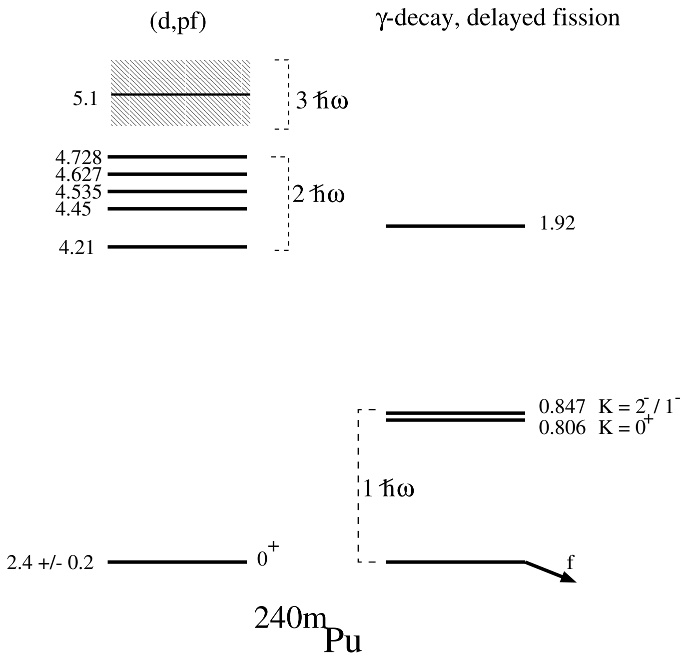

Fig. 3: Energy levels in ^{240m}Pu from (d,pf)-reaction studies (left side) and from γ-spectroscopic studies in coincidence with delayed fission.

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