# First Identification of Nilsson Orbitals in $^{237f}$Pu ◇

T. Morgan, B. Bruyneel [a], L. Csige, I. Daoutidis, D. Habs, T. Kotthaus [a], R. Lutter, H.J. Maier, P. Reiter [a], P. Ring, C. Schürmann, W. Schwerdtfeger, P.G. Thirolf, N. Warr [a], and K. Wimmer

[a] Universität zu Köln

While rotational (in $^{236f}$U and $^{240f}$Pu) and vibrational excitations ($^{240f}$Pu) had already been identified earlier in the even-even neighbouring nuclei [1], now the fission isomers in $^{237}$Pu ($t_{1/2}$ = 115ns/1.12 $\mu$s) were investigated in a $\gamma$-spectroscopy experiment at the Cologne Tandem accelerator [2,3]. Using the $^{235}$U($\alpha$,2n) reaction with a pulsed $\alpha$ beam, states in the second minimum were populated. Following the prompt decay of excited states into the ground states of the two shape isomers, the nucleus decays with its halflife, the resulting fission fragments were detected in a specially built $4\pi$ parallel plate detector. The extremely rare isomeric $\gamma$ decays were measured in coincidence with the fission fragments using the highly efficient MINIBALL spectrometer.

The background-subtracted $\gamma$-ray spectrum was disentangled into contributions from the two shape isomers and 9 excited rotational bands were identified built on the ground states of the two isomers. The ground state spins of the two shape isomers were determined to be I = 5/2 (115 ns isomer) and I = 9/2 (1120 ns isomer). From the 149 identified $\gamma$ transitions, independent level schemes were constructed for the two fission isomers in $^{237}$Pu [2,3]. The consistency of these level schemes was supported by the connecting $\gamma$ transitions between rotational bands. Furthermore, both level schemes could be combined to a common level scheme, in which the ground state of the long-lived 9/2 isomer was placed 54.0(3) keV above the ground state of the short-lived 5/2 isomer, shown on the right in Fig. 1. This resulting level scheme was compared to Hartree-Fock-Bogoliubov single-particle (HFB) calculations, Nilsson model and Woods-Saxon potential calculations.

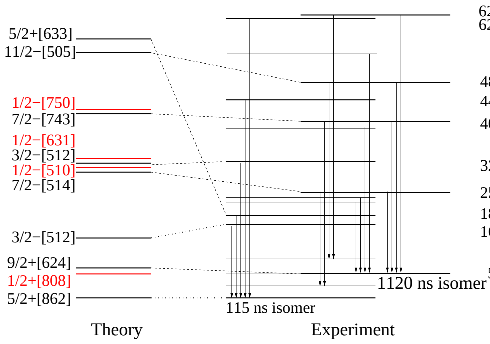


Fig. 1: Left, Single-particle neutron levels from a Nilsson type calculation of $^{237f}$Pu for $\beta_2$ = 0.61 [4]. Right, the experimentally observed level scheme of $^{237f}$Pu.

The first calculations performed were Nilsson model type calculations (see Fig. 1), in these it was found that for $\beta_2$ = 0.61 the deformed magic neutron number N = 146 could, for the first time, be reproduced. Furthermore, it was seen that not only the experimentally observed ground states of J = 5/2 for the 115 ns isomer and J = 9/2 for the 1120 ns isomer, respectively, were reproduced, but also excited rotational bands could be found. Fig. 2 shows the results of the Woods-Saxon type calculation.

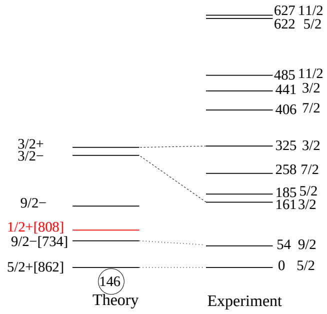


Fig. 2: Single-particle neutron levels from a Woods Saxon type calculation of $^{237f}$Pu for $\beta_2$ = 0.61 [4].

The calculation shown in Fig. 2 reproduces our experimental findings for the isomeric ground states, unfortunately besides two J = 3/2 states predicted above the ground state no further single-particle levels were found that could be attributed to experimentally observed levels. In a third series of calculations, the HFB approach was used (see Fig. 3). In these only two J = 3/2 states could be reproduced above the 5/2+[862] ground state, however the magic neutron number here was found to be at N = 142 and not as experimentally verified at N = 146.

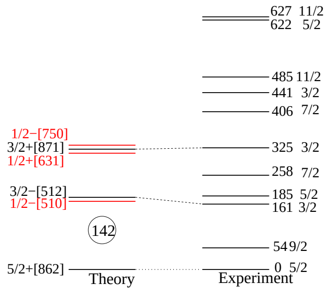


Fig. 3: Single-particle neutron levels from a HFB diagonalisation of $^{237f}$Pu for $\beta_2$ = 0.61 [4].

These comparisons allow for the first time an assignment of Nilsson quantum numbers in an odd-N fission isomer. The $5/2^+$[862] and $9/2^+$[624] Nilsson single-particle states were identified for the ground states of the two isomers in $^{237f}$Pu, for the first time based on calculations reproducing the deformed magic neutron number N = 146. The identification of Nilsson orbitals will provide an important input for the validation and improvement of theoretical nuclear models and will lead to improved predictions for fission barriers and their extrapolations to neutron-rich heavy elements in the mass region of the r-process path of the astrophysical nucleosynthesis.

## References

[1] D. Habs and P.G. Thirolf, Progr. Nucl. Part. Phys. **49** (2002) 325
[2] T. Morgan *et al.*, Annual report 2006, p. 19
[3] T. Morgan, Ph.D. thesis, LMU München, 2008
[4] P. Ring and I. Daoutidis, private communication (2007)

◇ Supported by the DFG via the cluster of excellence, The Origin and Structure of the Universe, Munich and HA1101/12-1