Eur. Phys. J. A **15**, 439–441 (2002)
DOI 10.1140/epja/i2002-10094-8

THE EUROPEAN
PHYSICAL JOURNAL A

Short Note

First triaxial superdeformed band in ^{170}Hf

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Received: 11 September 2002 /
Published online: 10 December 2002 –
Communicated by D. Schwalm

Abstract. First evidence is presented for triaxial superdeformation in ^{170}Hf. High-spin states in this nucleus have been investigated in a γ-ray coincidence measurement using the EUROBALL spectrometer array. A new band was discovered which has moments of inertia that are very similar to the ones of triaxial superdeformed bands in neighbouring Hf and Lu nuclei. The intensities with which these bands are populated are different from what may be expected from calculated potential-energy minima.

PACS. 21.10.-k Properties of nuclei; nuclear energy levels – 23.20.Lv Gamma transitions and level energies – 25.70.-z Low and intermediate energy heavy-ion reactions – 27.70.+q $150 \leq A \leq 189$

Minima in the nuclear potential-energy surface with a large quadrupole deformation ($\epsilon \approx 0.4$) and with a substantial triaxiality ($|\gamma| \approx 20°$) had been predicted theoretically for a long time in the $A = 165$ mass region [1]. In recent years, this region of triaxial superdeformation has also been established experimentally. One triaxial superdeformed (TSD) band has been found in ^{161}Lu [2], three have been discovered in ^{162}Lu [2], four in ^{163}Lu [3–5], eight in ^{164}Lu [6], three in ^{165}Lu [7,8], three in ^{167}Lu [9, 10], three in ^{168}Hf [11] and four in ^{174}Hf [12]. For the strongest TSD bands in $^{163\text{-}165}$Lu and ^{168}Hf the large deformation has been confirmed by lifetime measurements. These measurements revealed quadrupole moments between $7.4^{+0.7}_{-0.4}$ b [13,14] and 10.7 ± 0.7 b [3] for ^{163}Lu, $7.1^{+0.5}_{-0.6}$ b [13] and $7.4^{+2.5}_{-1.3}$ b [14] for ^{164}Lu, $6.0^{+1.2}_{-0.2}$ for ^{165}Lu [14] and $11.4^{+1.1}_{-1.2}$ b for ^{168}Hf [11]. Experimental proof of the triaxiality is the occurrence of the wobbling mode which was recently discovered for the first time in ^{163}Lu [5,15,16].

Calculations with the Ultimate Cranker (UC) code [17, 18] based on a modified harmonic-oscillator potential have shown that large-deformation minima are expected for all combinations of parity π and signature α in the mass region around $A = 165$ [7,18]. These calculations predict that the lighter Hf isotopes, ^{164,166}Hf, are the best candidates to show TSD shapes. However, in spite of extensive searches, until now only very weakly populated TSD bands have been found in the heavier isotopes ^{168}Hf [11] and ^{174}Hf [12], while the TSD bands in the Lu isotopes are more strongly populated. Thus, it appears that the UC calculations do not predict the magnitude of the TSD shell gaps precisely. This is probably due to an insufficient knowledge of the exact positions of the deformation driving $\pi i_{13/2}$, $\pi h_{9/2}$ and $\nu i_{13/2}$ orbitals [18].

In the present work, we report on a spectroscopic investigation of high-spin states in ^{170}Hf which reveales the first evidence for triaxial superdeformation in this nucleus. High-spin states in ^{170}Hf have been populated in the reaction ^{124}Sn(^{50}Ti, 4n) at 216 MeV at the Vivitron accelerator at IReS, Strasbourg. Gamma-ray coincidences have been measured with the EUROBALL spectrometer array [19] which, at the time of the experiment, consisted of 29 single, tapered Ge detectors, 15 Cluster and 26 Clover composite detectors, each of them surrounded by a BGO anti-Compton shield. Six of the Cluster and Clover segments were not operational during this experiment. The inner ball of 210 BGO detectors has been used as a multiplicity filter. The target consisted of a stack of two thin ^{124}Sn foils of $600\,\mu$g/cm^2 and $460\,\mu$g/cm^2, respectively. Events were written to tape with the requirement that

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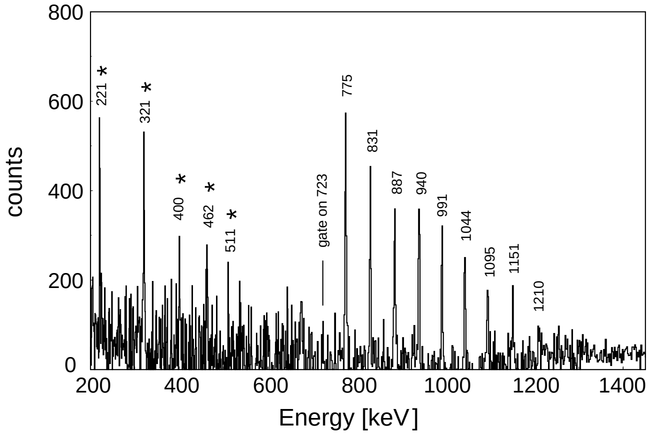

Fig. 1. Double-gated γ-ray coincidence spectrum of the new TSD band in ^{170}Hf; first gate on the 723 keV transition, second gate from a list of all other transitions in the band without the 775 keV transition. ND transitions in ^{170}Hf are marked with a star.

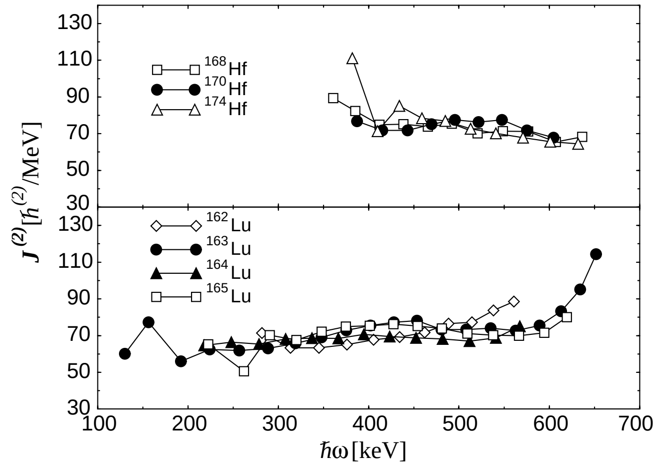

Fig. 2. Comparison of dynamic moments of inertia $J^{(2)}$ for the new TSD band in ^{170}Hf and for TSD bands 1 in ^{168,174}Hf and in neighbouring Lu isotopes [2,5,6,8,11,12].

at least eight BGO and four unsuppressed Ge detectors are in prompt coincidence. This resulted in a total of 2.3×10^9 events with a γ-ray coincidence fold of $f \geq 3$ after Compton suppression and add-back for the composite detectors. The γ-ray coincidences were sorted into a three-dimensional coincidence array (cube) that has been analysed with the RADWARE software package [20]. Extensive searches revealed the spectrum of a band shown in fig. 1 which is clearly seen in coincidence with transitions of ^{170}Hf.

The new band, consisting of 10 transitions with energies between 722.9 keV and 1210.3 keV with an average spacing of about 54 keV, shows similar characteristics as the TSD bands in neighbouring ^{168}Hf. Indeed, it has even very similar transition energies as band 1 in that nucleus. The DCO ratios of the in-band transitions are compatible with stretched $E2$ multipolarity. The band has an intensity of about $(0.9\pm0.4)\%$ of the intensity of the yrast band, *i.e.* it is about a factor of three stronger than the strongest TSD band in ^{168}Hf [11]. Nevertheless, no linking transitions between the new band and the normal-deformed (ND) states could be found. Therefore, spin, parity and excitation energy could not be determined for the band. From the observed decay pattern of the band, its intensity relative to the ND bands and from a comparison of the aligned angular momentum with those in neighbouring nuclei, we estimate that the spin of the lowest observed level and its excitation energy above the yrast band lie in the range of 22–24 $\hbar$ and 400 keV, respectively. The dynamic moment of inertia $J^{(2)}$ is independent of spin and excitation energy and can be compared directly to the values in Hf and Lu isotopes. This comparison is shown in fig. 2. The dynamic moment of inertia of the new band is almost identical to those of TSD bands 1 in ^{168}Hf and ^{174}Hf and similar to those of TSD bands 1 in the Lu isotopes. It is about 30% larger than those of the normal-deformed bands in ^{170}Hf. This behaviour suggests that the new band can also be associated with the potential-energy minimum with large deformation ($\epsilon \approx 0.4$) and large triaxiality ($|\gamma| \approx 20°$) found in the UC calculations [18]. As mentioned above, a large quadrupole moment ($Q_t = 11.4^{+1.1}_{-1.2}$ b) was deduced from a lifetime measurement for the band with similar energy spacings in ^{168}Hf [11].

Triaxial superdeformation is now experimentally established in three Hf and in six Lu isotopes. In spite of various searches in the lighter Hf isotopes, no TSD band structures could be found in those nuclei. The TSD bands in the Lu isotopes are generally populated with higher intensity than the ones in the Hf isotopes. This is in contrast to the predictions of the UC calculations which show more pronounced minima in the potential-energy surfaces in the Hf than in the Lu isotopes, in particular for the lighter ones, ^{164}Hf and ^{166}Hf [18]. This discrepancy indicates that the potential parameters used in the UC calculations do not place the deformation-driving orbitals, $\pi i_{13/2}$, $\pi h_{9/2}$ and $\nu i_{13/2}$, at the correct positions. The experimental results, including the present observation of a TSD band in ^{170}Hf, may help to optimize the mean-field parameters.

This work was supported by BMBF, Germany (contract no. 06BN907), DFG (contract no. Hu 325/10), the Danish Science Foundation and the EU (contracts nos. HPRICT 1999-00078 and ERBFMGECT980145). One of us, AKS, acknowledges a fellowship from the A. von Humboldt foundation.

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