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Triaxial superdeformation in ^{163}Lu

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Abstract

High-spin states in ^{163}Lu have been investigated using the Euroball spectrometer array. The previously known superdeformed band has been extended at low and high energies, and its connection to the normal-deformed states has been established. From its decay the mixing amplitude and interaction strength between superdeformed and normal states are derived. In addition, a new band with a similar dynamic moment of inertia has been found. The experimental results are compared to cranking calculations which suggest that the superdeformed bands in this mass region correspond to shapes with a pronounced triaxiality ($\gamma \approx \pm 20°$). © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

A rotational band with very large deformation was discovered in ^{163}Lu [1] some time ago. Large transition quadrupole moments, corresponding to $\beta_2 \approx 0.4$, were derived for this band from lifetime measurements [2]. Bands with similar moments of inertia were

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subsequently reported in ^{165}Lu [3] and ^{167}Lu [4]. It has been suggested that the bands are built on the strongly prolate deformation-driving $[660]\frac{1}{2}^+$ proton orbital of $i_{13/2}$ origin.

Potential energy surface (PES) calculations using different approaches [2–6] show that the nuclei around $Z = 72$ and $N = 94$ constitute a region of exotic shapes coexisting with normal prolate deformation. Large-deformation minima exist for a γ deformation of approximately $\pm 20°$. In addition, a prolate hyperdeformed minimum is predicted. Calculations using the Ultimate Cranker (UC) code show that the large-deformation minima are expected for all symmetry groups (π, α) in ^{163}Lu and ^{165}Lu [3]. That means the large deformation is not only due to the prolate-driving effect of the $\pi i_{13/2}$ intruder orbital, but also the result of a rearrangement of the core. In particular, for the neutron number 94 a large energy gap appears at $\gamma \approx 20°$ which stabilizes the triaxial shapes. Therefore, the triaxial superdeformed (SD) states are expected as a general phenomenon in this mass region.

In this paper we report on an investigation of the high-spin states in ^{163}Lu using the Euroball spectrometer array [7]. This work is part of an investigation of both ^{163}Lu and ^{164}Lu. The results on ^{164}Lu, where eight new SD bands were found, are published elsewhere [8,9]. The main aim of the present work was to establish the decay of the previously known SD band [1,2] to the normal–deformed (ND) states and to determine its excitation energy, spin and parity. In addition, the band has been extended to higher and lower spins and a new SD band decaying into the previously known band has been found. Furthermore, the decay of the ND bands to the ground state of ^{163}Lu has been established in the present work.

2. Experimental procedure and results

High-spin states in ^{163}Lu and ^{164}Lu were populated in the ^{139}La(^{29}Si,xn) reaction with thin self-supporting targets at a bombarding energy of 145 MeV. The beam was provided by the Legnaro XTU tandem accelerator. At this energy ^{164}Lu is the main reaction product and the results obtained for this nucleus are published separately [8,9]. Gamma-ray coincidences were measured with the Euroball spectrometer array [7] which, at the time of the experiment, consisted of 13 Cluster Ge detectors, 25 Clover Ge detectors and 28 single-element tapered Ge detectors. About 3.8×10^9 events requiring six or more coincident Ge signals before Compton suppression were collected.

Since this experiment was one of the first measurements using Euroball, various problems with the Ge detector stability and the data acquisition were encountered. The stability and energy resolution have been checked in the off-line analysis by dividing the data into small segments. Most of the energy shifts could be recovered, but some of the detector elements had to be discarded, leaving 25 tapered detectors, 75 Cluster elements and 96 Clover elements for further analysis. This presorting resulted in 2.3×10^9 three- and higher fold Compton-suppressed coincidence events.

The coincidence events were sorted into gated E_γ–E_γ matrices, a three-dimensional (cube) and a four-dimensional (hypercube) array as well as into several coincidence spectra with various gating conditions [10]. For angular correlation information a gated DCO matrix was created with the forward and backward detectors on one axis and the near-90° detectors (Clovers) on the other axis.

Gamma-ray coincidence spectra obtained with gates on several transitions of the previously known [1,2] SD band and on transitions in its decay are shown in Fig. 1. It shows the members of the band and the transitions in the decay to the ^{163}Lu ground state via a ND band structure. The SD band has been extended by two transitions at high spins and by one transition at the bottom. The two spectra in the lower part of Fig. 1 highlight the decay of SD 1 into the ^{163}Lu ground state. They show the presence of a previously unobserved transition of 191 keV in parallel to the 174 keV transition. This

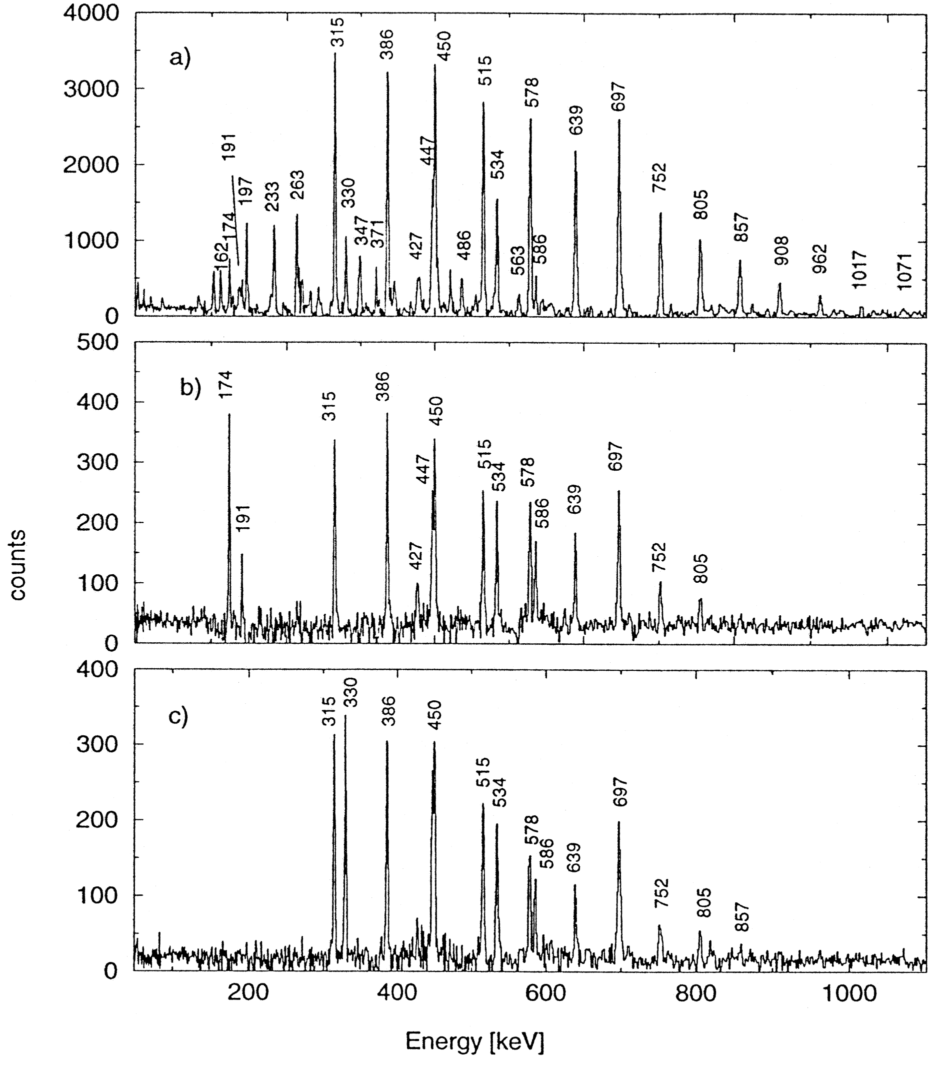

Fig. 1. (a) Gamma-ray coincidence spectrum of SD band 1 in ^{163}Lu (sum of triple gates on transitions of SD band 1). (b) Decay of SD band 1 (sum of triple gates, one from SD band 1, one from [411]1/2 band, third gate 330 keV). (c) Decay of SD band 1 through the 174 keV transition (sum of triple gates, one from SD band 1, one from [411]1/2 band, third gate 174 keV).

new transition bypasses the state which was believed to be the ground state [11] and is now placed at an excitation energy of 17 keV.

In addition, the analysis revealed a second SD band, which decays into the first band around spin 37/2. However, the connecting transitions could not be established. While

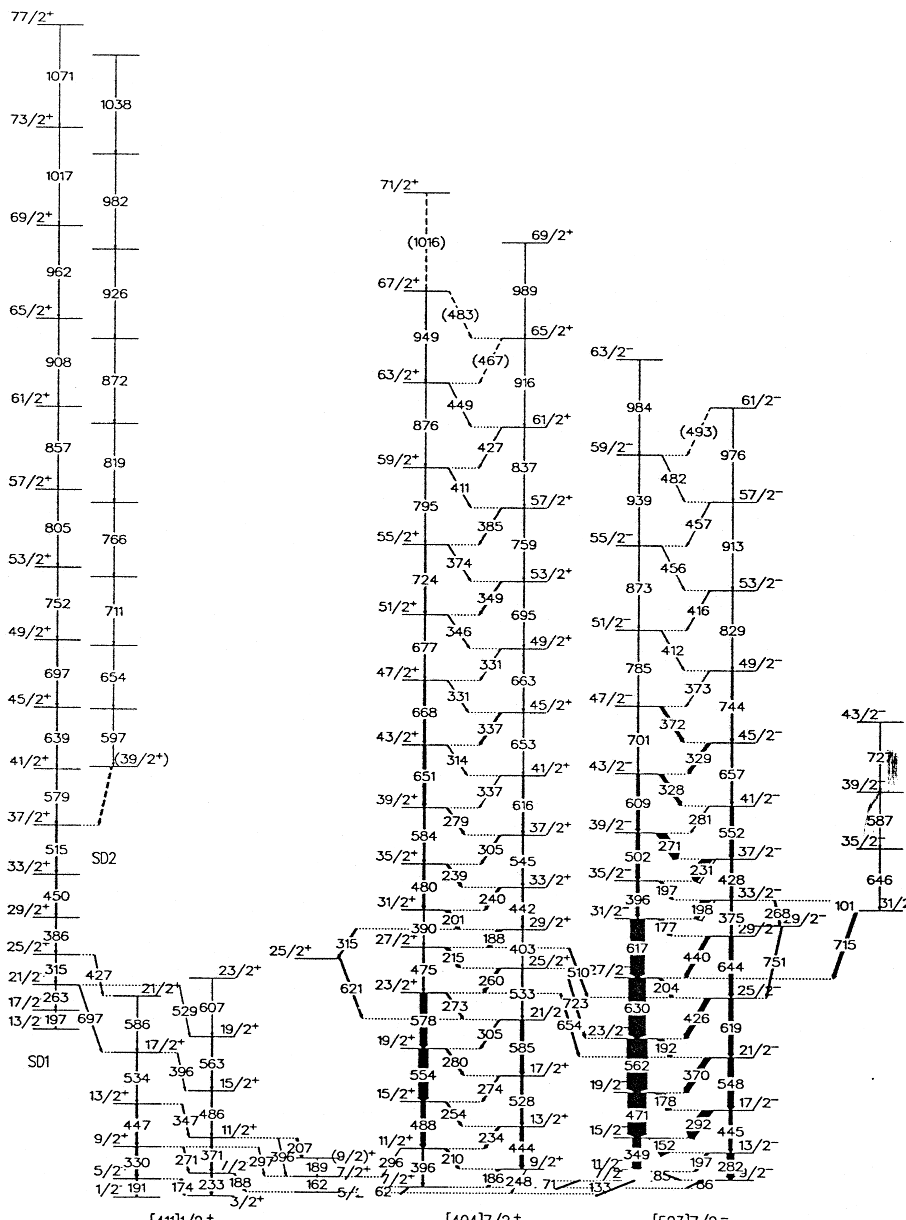

Fig. 2. Level scheme of ^{163}Lu.

Table 1
Energies, relative intensities, DCO ratios and spin assignments of γ-ray transitions in the decay of SD band 1 in ^{163}Lu

E_γ (keV)[1]	I_γ (rel.)	R_{DCO}	$I_i \rightarrow I_f$
SD transitions			
196.8	3.4(0.4)	0.82(0.42)	$17/2^+ \rightarrow 13/2^+$
263.1	18.7(1.9)	0.78(0.11)	$21/2^+ \rightarrow 17/2^+$
314.9	68.1(6.8)	0.88(0.13)	$25/2^+ \rightarrow 21/2^+$
386.2	100[2]	0.95(0.13)	$29/2^+ \rightarrow 25/2^+$
SD $\rightarrow$ ND transitions			
426.5	12.5(1.9)	0.84(0.12)	$25/2^+ \rightarrow 21/2^+$
529.4	5.4(0.8)	0.97(0.14)	$21/2^+ \rightarrow 19/2^+$
697.1[3]	23.3(4.7)	–	$21/2^+ \rightarrow 19/2^+$
ND transitions			
161.6	8.1(1.4)	–	$7/2^+ \rightarrow 5/2^+$
174.0	8.4(1.3)	0.38(0.08)	$5/2^+ \rightarrow 3/2^+$
188.2	6.9(1.0)	0.60(0.09)	$7/2^+ \rightarrow 5/2^+$
189.2	5.1(1.4)	–	$9/2^+ \rightarrow 7/2^+$
191.0	3.4(0.4)	–	$5/2^+ \rightarrow 1/2^+$
207.1	4.2(0.8)	–	$11/2^+ \rightarrow 9/2^+$
233.1	18.0(1.8)	0.75(0.11)	$7/2^+ \rightarrow 3/2^+$
270.6	9.3(1.1)	0.59(0.08)	$9/2^+ \rightarrow 7/2^+$
296.5	3.6(0.7)	–	$9/2^+ \rightarrow 7/2^+$
330.1	16.3(1.6)	0.79(0.17)	$9/2^+ \rightarrow 5/2^+$
347.0	7.1(1.1)	0.76(0.16)	$13/2^+ \rightarrow 11/2^+$
370.7	9.4(1.4)	0.83(0.12)	$11/2^+ \rightarrow 7/2^+$
394.6	4.1(0.6)		$17/2^+ \rightarrow 15/2^+$
396.3	6.1(0.9)		$11/2^+ \rightarrow 9/2^+$
446.5	36.4(3.6)	0.82(0.18)	$13/2^+ \rightarrow 9/2^+$
486.2	8.9(1.3)	0.78(0.11)	$15/2^+ \rightarrow 11/2^+$
533.8	37.4(3.7)	0.85(0.12)	$17/2^+ \rightarrow 13/2^+$
562.5	6.5(1.6)	–	$19/2^+ \rightarrow 15/2^+$
585.7	18.2(2.7)	1.05(0.15)	$21/2^+ \rightarrow 17/2^+$
606.6	2.8(0.8)	–	$23/2^+ \rightarrow 19/2^+$

[1] Uncertainties typically 0.2 keV, for weak transitions 0.5 keV.
[2] Normalization.
[3] Unresolved from SD transition of similar energy.

the first band collects about 10% of the intensity of the reaction channel, the new SD band is much weaker with an intensity of about 2%. The extended level scheme, based on these data and on previous work [11], is shown in Fig. 2. Gamma-ray energies, relative intensities and DCO ratios connected to the decay of the SD band are listed in Table 1. Table 2 shows the energies, intensities and spin assignments of the new transitions in the decay of the ND bands.

3. Discussion

An important result of the present work is that the previously known [1,2] SD band 1 and the strongly–coupled ND bands [10], which were not properly connected to the

Table 2
Energies, relative intensities and spin assignments of γ-ray transitions in the decay of the $[404]7/2^+$ and $[523]7/2^-$ bands in ^{163}Lu

E_γ (keV)[4]	I_γ (rel.)	$I_i \to I_f$
61.5	20.0(0.5)	$7/2^+ \to 5/2^+$
70.7	15.8(0.3)	$7/2^- \to 7/2^+$
85.5	20.8(0.3)	$9/2^- \to 7/2^+$
247.6	1.6(0.6)	$9/2^+ \to 5/2^+$
296.1	2.1(0.7)	$11/2^+ \to 7/2^+$
349.2[5]	100	$15/2^- \to 11/2^-$
487.7[6]	100	$15/2^+ \to 11/2^+$

[4] Uncertainties typically 0.5 keV.
[5] Normalization for decay from $[523]7/2^-$ band.
[6] Normalization for decay from $[404]7/2^+$ band.

ground state, are now tied together in the level scheme of ^{163}Lu presented in Fig. 2; only the excitation energy of SD band 2 remains unknown.

3.1. ND bands

The structure into which SD band 1 decays via the 427, 529 and 697 keV γ-ray transitions was only partly known before our work [1,10]. The properties of this structure are very similar to the proton $[411]\frac{1}{2}^+$ bands found in other odd-Z nuclei of this mass region. In addition, the systematics of the energies of these bands in neighbouring nuclei suggest that the $[411]\frac{1}{2}^+$ orbital might be the ground state in ^{163}Lu. Therefore, we adopt this Nilsson configuration assignment for the ground band.

One might speculate that the three states of the intermediate structure with the transition energies of 162 and 189 keV could be the low-spin part of the $[402]\frac{5}{2}^+$ band which is also expected at low excitation energy in this nucleus. However, it is not understood why this band is not populated to higher-spin states.

3.2. SD bands

With the multipolarity assignments of the transitions listed in Table 1, the band-head spin and parity of SD band 1 are $13/2^+$ as expected for a proton $i_{13/2}$ band. The new SD band 2 could not be connected to the remaining level scheme. It decays predominantly into SD band 1 around spin $37/2$. Its excitation energy and spin can therefore only approximately be given as 4.4 MeV and $39/2$, respectively. Under this assumption it has been included in the plot of the excitation energies as a function of spin for the bands in ^{163}Lu shown in Fig. 3.

As can be seen, SD band 1 lies rather close to the yrast states which explains its large intensity. It approaches the $[411]\frac{1}{2}^+$ and $[404]\frac{7}{2}^+$ bands with energy differences of only 111 and 24 keV at $I = 21/2^+$ and $45/2^+$, respectively.

The moments of inertia of the two SD bands displayed in Fig. 4 are very similar. Therefore, both bands probably have similar deformation. The deformation for band 1

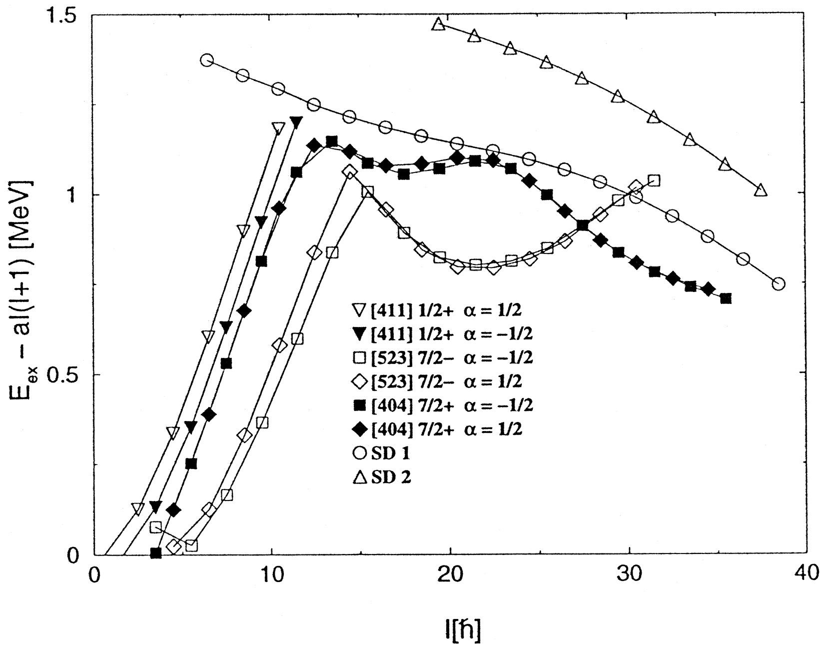

Fig. 3. Experimental excitation energy as a function of spin for the band structures in ^{163}Lu. A common rigid rotor reference with $a = 7.5\,\mathrm{keV}/\hbar^2$ has been subtracted. Excitation energy and spin of SD band 2 are tentative.

was previously derived from lifetime measurements [2] as $\beta_2 \approx 0.4$. The kinematic moment of inertia $J^{(1)}$ of band 2 is included in the figure under the assumption of $I = 39/2$ for its lowest state (see above).

In the low-spin region the $J^{(2)}$ moment of inertia of band 1 shows large fluctuations which are due to mixing of the $21/2^+$ SD state with the state of the same spin and parity in the $[411]\frac{1}{2}^+$ band. The strong decay branches from the SD band 1 to the $[411]\frac{1}{2}^+$ band of 427 and 697 keV which comprise about 40% of the SD band intensity can be explained by that mixing. The situation is very similar to the decay of the SD bands in Nd nuclei [12,13] which has also been explained by mixing of SD and ND states lying close in energy.

We perform a two-band mixing calculation to derive the mixing of the wave functions and the interaction energy assuming that only the $21/2^+$ states at 2087 and 2198 keV are mixed. For the linking transition of 426.5 keV the out-of-band to in-band branching ratio is

$$\frac{B(\mathrm{E2},426.5)}{B(\mathrm{E2},314.9)} = \frac{\alpha^2}{1-\alpha^2} = \frac{I_\gamma(426.5)}{I_\gamma(314.9)} \cdot \left(\frac{314.9}{426.5}\right)^5, \tag{1}$$

where α is the amplitude of the admixture of the ND to the SD state. Using the relative γ-ray intensities listed in Table 1, we obtain $\alpha^2 = 0.04(1)$ and an interaction energy of 22(3) keV.

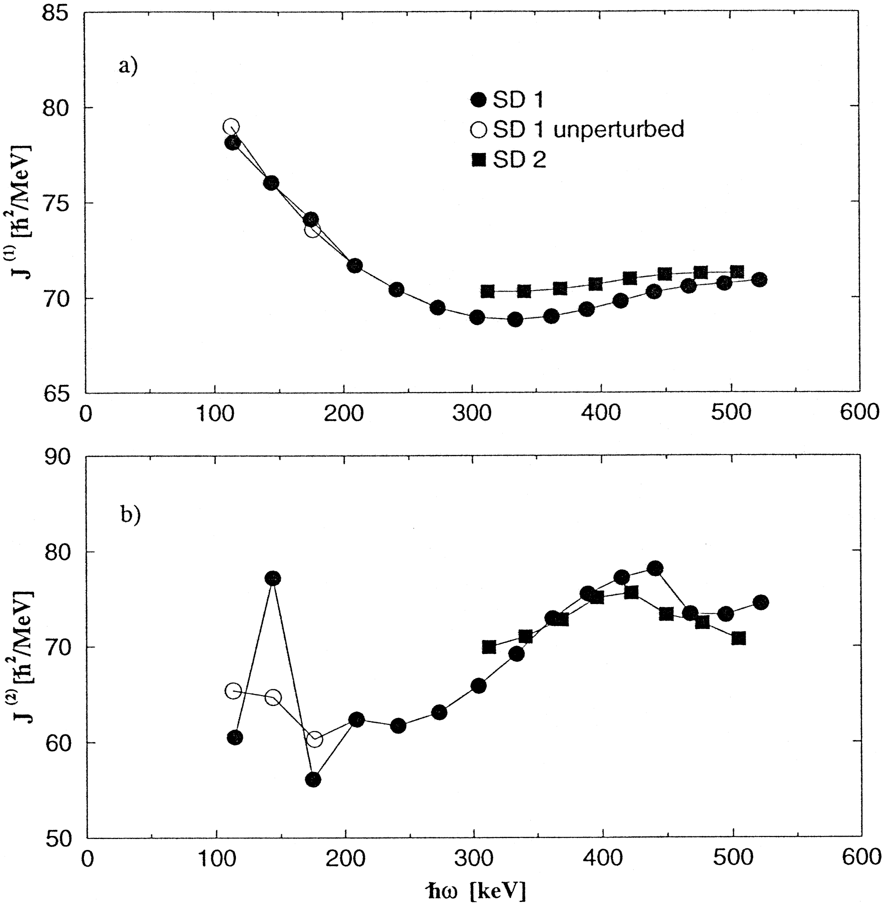

Fig. 4. (a) Experimental kinematic ($J^{(1)}$) and (b) dynamic ($J^{(2)}$) moments of inertia as a function of rotational frequency for SD band structures in ^{163}Lu.

The other strong branching of out-of-band to in-band transitions of 697 and 263 keV, respectively, may serve as a consistency check. This ratio involves the ratio of the ND and SD quadrupole moments

$$\frac{B(\mathrm{E2},697.1)}{B(\mathrm{E2},263.1)} = \frac{\alpha^2}{1-\alpha^2} \cdot \frac{Q_{\mathrm{ND}}^2}{Q_{\mathrm{SD}}^2} = \frac{I_\gamma(697.1)}{I_\gamma(263.1)} \cdot \left(\frac{263.1}{697.1}\right)^5. \tag{2}$$

With the value of the mixing amplitude α^2 derived above and using the γ-ray intensities of Table 1 we obtain $Q_{\mathrm{ND}}/Q_{\mathrm{SD}} = 0.48(7)$. This ratio is consistent with the values of the quadrupole moments $Q_{\mathrm{ND}} = 6.0(5)$ b and $Q_{\mathrm{SD}} = 10.7(7)$ b determined from lifetimes [2]. The interaction results in a repulsion of the two $21/2^+$ levels of about 5 keV. The observed energy of the $21/2^+$ SD state (2198 keV) has to be corrected by this amount to obtain the energy of the unperturbed SD state. If the corrected energy is used to determine the dynamic and kinematic moments of inertia of SD band 1 we obtain the values plotted as open circles in Fig. 4. As expected for an unperturbed band, the dependence of the moments of inertia on rotational frequency is rather smooth.

The interaction strength of about 22 keV is similar to the one found from the band-mixing decay of SD bands in Nd isotopes [12,13]. Similarities might be expected because the main deformation-driving effect stems from an excited $i_{13/2}$ nucleon in both mass regions: an $i_{13/2}$ proton in Lu an $i_{13/2}$ neutron in Nd. The large interaction strength and mixing amplitudes are indicative of small or vanishing barriers between the SD and ND minima, as is indeed shown by our PES calculations (see Fig. 5, left panel). According to the calculations, the barrier vanishes around spin 25/2.

At higher spins, around $I = 45/2^+$, several levels of SD band 1 lie close to states of the same spin of the $[404]\frac{7}{2}^+$ ND band (see Fig. 3). However, the moments of inertia show only a small distortion in the corresponding frequency region of $\hbar\omega = 0.33$ MeV (see Fig. 4) consistent with a shift of ~ 1 keV in the excitation energy of the $45/2^+$ states. Such a small shift may be produced by an interaction strength of ~ 4.5 keV and a corresponding mixing amplitude of $\alpha^2 = 0.009$. This interaction is consistent with an upper limit of about 1% for the branching ratio of the 697 keV $49/2^+ \rightarrow 45/2^+$ SD transition to an unobserved 721 keV transition from the $49/2^+$ level of the SD band to the $45/2^+$ state of the $[404]\frac{7}{2}^+$ band. The small mixing around spin 45/2 is probably due to a high barrier between the SD and the ND potential–energy minima. In our PES calculations this barrier turns out to be about 500 keV (see Fig. 5, right panel) which seems to be sufficient to prevent the mixing of the rather close-lying ND and triaxial SD states around spin $45/2^+$.

The PES have been calculated using the UC computer code [3], which provides the tools for a diabatic treatment of crossings between quasiparticle energy levels with a weak or moderate interaction strength. The quasiparticle levels occupied in a given configuration are ordered energetically within each symmetry group of parity and signature (π, α). As can be seen in the examples of the calculations shown in Fig. 5 (right panel), several minima are visible. There is a minimum at $(\epsilon, \gamma) = (0.20, 0°)$ which corresponds to the ND states. Then, there are two minima at (0.41,20.6°) and

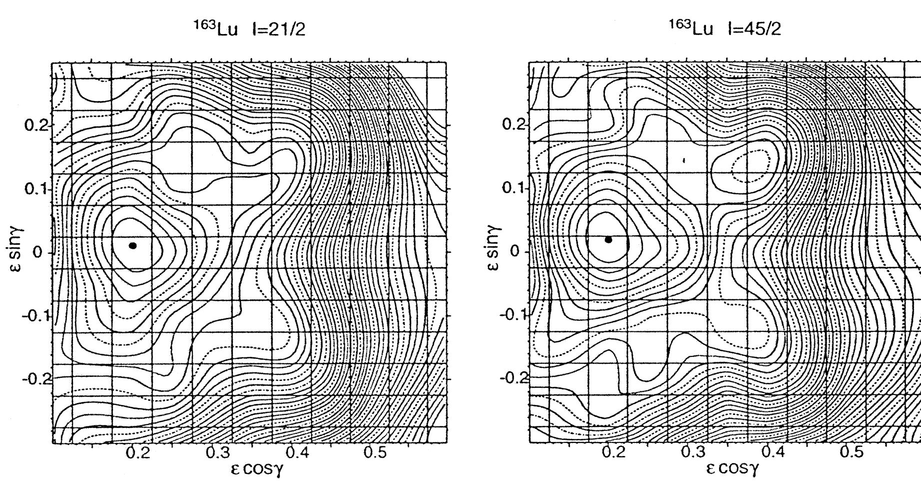

Fig. 5. Configuration separated potential energy surfaces at $I = 21/2$ and $I = 45/2$ corresponding to the lowest $(\pi, \alpha) = (+, +1/2)$ configuration in ^{163}Lu. The energy difference between the contour lines is 0.1 MeV.

(0.39, − 15.0°); these are the minima of the triaxial SD bands. Similar minima occur for all symmetry groups (π,α) since the neutron energy levels develop a large gap for $\gamma \approx 20°$ around $N = 94$ [3]. At even larger deformation, $\epsilon \approx 0.7$, a further minimum is present which becomes more pronounced at very high spins. This minimum corresponds to the experimentally not yet observed hyperdeformation.

Calculated excitation energies for the lowest lying energy for each symmetry group (π,α) are given in Fig. 6. They may be compared to the experimental energies shown in Fig. 3. According to the calculations, the bands with $\gamma \approx +20°$ are expected at lower energy than the ones with negative γ. The comparison shows that SD band 1 should have quantum numbers $(+,1/2)$. SD band 2 is then expected to have $(\pi,\alpha) = (-,1/2)$ and, according to the calculation, lies about 400 keV above the $(+,1/2)$ band at spin 20. This would be consistent with a decay of this band into SD band 1 by E1 transitions. However, it is interesting to note that the calculation overestimates the energy of SD band 1 relative to the ND bands. The experimental energies lie much closer together than the calculated values.

The average experimental quadrupole moment of SD band 1 of $Q = 10.7(7)$ b [2] does not distinguish between the configurations with positive and negative γ deformation. The calculated quadrupole moment for positive γ deformation is $Q = 9.9$ b, compared to $Q = 11.0$ b for negative γ. Systematic quadrupole moment measurements of many triaxial SD bands would be needed to decide this question.

There may be an alternative explanation for SD band 2. For large-γ deformation theory predicts the so-called wobbling mode [14,15] which gives rise to bands with identical moments of inertia at higher excitation energies. The wobbling bands may then decay into the yrast SD band by M1 and E2 transitions. It would be of great interest to find the transitions connecting SD bands 1 and 2 and to determine their multipolarities.

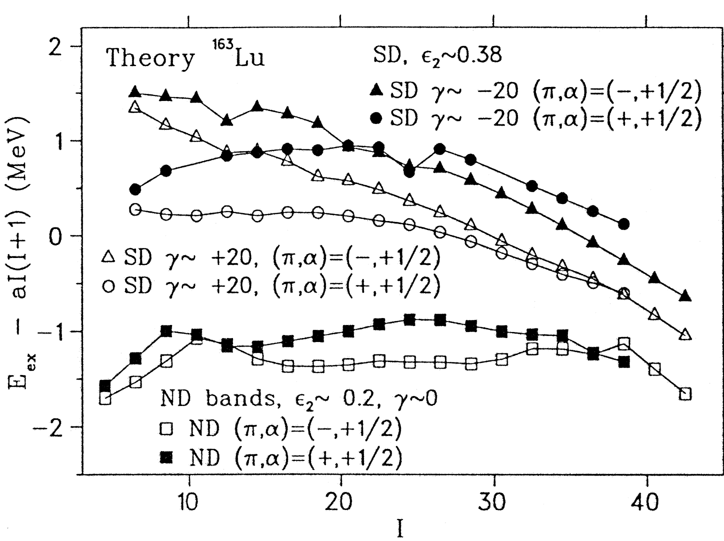

Fig. 6. Excitation energy as a function of spin calculated for the lowest-lying configuration of each symmetry group (π,α). A rigid rotor reference has been subtracted.

The identification of the wobbling mode would be an experimental signal for a large stable γ deformation.

4. Summary

In summary, we have extended the previously known SD band in ^{163}Lu and found an additional band with a similar moment of inertia. SD band 1 is now firmly connected to the ND states and its spin, parity and excitation energy are determined. A large fraction of the decay of SD band 1 can be explained by level mixing. The rather large mixing amplitude and interaction strength suggest a vanishing barrier between the SD and ND minima at low rotational frequency. PES calculations show a large triaxiality $(\gamma \pm 20°)$ for the minima at large deformation $(\epsilon \approx 0.4)$ relevant for the SD bands discussed here. Triaxial SD minima are predicted for all symmetry groups (π, α). It is suggested that SD band 1 corresponds to the lowest-energy $(+, +1/2)$ configuration. Band 2 is not connected to known levels and its nature remains speculative at present.

Acknowledgements

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References

[1] W. Schmitz, C.X. Yang, H. Hübel, A.P. Byrne, R. Müßeler, N. Singh, K.H. Maier, A. Kuhnert, R. Wyss, Nucl. Phys. A 539 (1992) 112.
[2] W. Schmitz, H. Hübel, C.X. Yang, G. Baldsiefen, U. Birkenthal, G. Fröhlingsdorf, D. Mehta, R. Müßeler, M. Neffgen, P. Willsau, J. Gascon, G.B. Hagemann, A. Maj, D. Müller, J. Nyberg, M. Piiparinen, A. Virtanen, R. Wyss, Phys. Lett. B 303 (1993) 230.
[3] H. Schnack-Petersen, R. Bengtsson, R.A. Bark, P. Bosetti, A. Brockstedt, H. Carlsson, L.P. Ekström, G.B. Hagemann, B. Herskind, F. Ingelbretsen, H.J. Jensen, S. Leoni, A. Nordlund, H. Ryde, P.O. Tjøm, C.X. Yang, Nucl. Phys. A 594 (1995) 175.
[4] C.X. Yang, X.G. Wu, H. Zheng, X.A. Liu, Y.S. Chen, G.W. Shen, Y.J. Ma, J.B. Lu, S. Wen, G.S. Li, G.J. Yuan, P.K. Weng, Y.Z. Liu, Eur. Phys. J. A 1 (1998) 237.
[5] S. Åberg, Nucl. Phys. A 520 (1990) 35c, and references therein.
[6] I. Ragnarsson, Phys. Rev. Lett. 62 (1989) 2084.
[7] J. Simpson, Z. Phys. A 358 (1997) 139.
[8] S. Törmänen, G.B. Hagemann, A. Harsmann, M. Bergström, R.A. Bark, B. Herskind, G. Sletten, S.W. Ødegård, P.O. Tjøm, A. Görgen, H. Hübel, B. Aengenvoort, U.J. van Severen, H. Ryde, C. Fahlander, D. Napoli, S. Lenzi, C. Petrache, C. Ur, H.J. Jensen, A. Bracco, S. Frattini, R. Chapman, D.M. Cullen, S.L. King, Nuovo Cim. A 111 (1998) 685.
[9] S. Törmänen, S.W. Ødegård, G.B. Hagemann, A. Harsmann, M. Bergström, R.A. Bark, B. Herskind, G. Sletten, P.O. Tjøm, A. Görgen, H. Hübel, B. Aengenvoort, U.J. van Severen, H. Ryde, C. Fahlander, D. Napoli, S. Lenzi, C. Petrache, C. Ur, H.J. Jensen, A. Bracco, S. Frattini, R. Chapman, D.M. Cullen, S.L. King, Phys. Lett. B 454 (1999) 0000.

[10] B. Aengenvoort, PhD thesis, Univ. Bonn, 1998, unpublished.
[11] R.B. Firestone, V.S. Shirley, C.M. Baglin, S.Y.F. Chu, J. Zapkin, eds., Table of Isotopes (Wiley, New York, 1996).
[12] D. Bazzacco, F. Brandolini, R. Burch, S. Lunardi, E. Maglione, N.H. Medina, P. Pavan, C. Rossi-Alvarez, G. de Angelis, D. De Acuna, M. De Poli, J. Rico, D. Bucurescu, C. Ur, Phys. Rev. C 49 (1994) R2281.
[13] C.M. Petrache, Contribution to the Conf. on Nuclear Structure '98, Gatlinburg.
[14] A. Bohr, B.R. Mottelson, Nuclear Structure, Vol. II (Benjamin, New York, 1975) p. 190.
[15] Y.R. Shimizu, M. Matsuzaki, Nucl. Phys. A 588 (1995) 559.