Eur. Phys. J. A **20**, 375–379 (2004)
DOI 10.1140/epja/i2004-10018-8

THE EUROPEAN PHYSICAL JOURNAL A

Letter

Signature inversion in the semidecoupled $\pi h_{9/2} \otimes \nu i_{13/2}$ band of the odd-odd nucleus ^{172}Lu

Ts. Venkova[1,2], R.M. Lieder[1,a], W. Gast[1], D. Bazzacco[3], G. de Angelis[4], E.O. Lieder[1], H.M. Jäger[1], L. Mihailescu[1], R. Menegazzo[3], S. Lunardi[3], C. Rossi Alvarez[3], C. Ur[3], T. Martinez[3], M. Axiotis[4], D. Napoli[4], W. Urban[5], and T. Rząca-Urban[5]

[1] Institut für Kernphysik, Forschungszentrum Jülich, D-52425 Jülich,Germany
[2] Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, BG-1784 Sofia, Bulgaria
[3] Dipartimento di Fisica dell'Università and Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy
[4] Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, I-35020 Legnaro (Padova), Italy
[5] Institute of Experimental Physics, University of Warsaw, PL-00-681 Warszawa, Poland

Received: 7 January 2004 / Revised version: 25 March 2004 /
Published online: 26 May 2004 –
Communicated by D. Schwalm

Abstract. High-spin states in the odd-odd nucleus ^{172}Lu have been populated in a ^{170}Er(^{7}Li,5n) reaction at 51 MeV and the emitted γ-radiation was detected with the GASP array. A new semidecoupled band with the proposed $\pi 1/2^-[541] \otimes \nu 7/2^+[633]$ configuration has been established exhibiting a signature inversion. A systematic study of the signature inversion in odd-odd nuclei of the rare-earth region is presented. The variation of the inversion spin remains nearly constant for nuclei with the same $N - Z$, increases with N for an isotopic chain and decreases with Z for an isotonic chain. On the basis of the systematics a change of the spins by $1\hbar$ is proposed for the semidecoupled bands in ^{180}Re, ^{182,184}Ir and ^{184,186}Au.

PACS. 21.10.-k Properties of nuclei; nuclear energy levels – 21.10.Re Collective levels – 23.20.Lv γ transitions and level energies – 27.70.+q $150 \leq A \leq 189$

1 Introduction

The so-called low-spin signature inversion [1] has recently received special attention. It has been systematically observed in the rotational bands of odd-odd nuclei throughout the chart of nuclides for configurations involving high-j orbitals, *e.g.*, for the $\pi h_{9/2} \otimes \nu i_{13/2}$, $\pi i_{13/2} \otimes \nu i_{13/2}$, $\pi h_{11/2} \otimes \nu i_{13/2}$, $\pi h_{11/2} \otimes \nu h_{11/2}$, $\pi g_{9/2} \otimes \nu g_{9/2}$ and $\pi g_{9/2} \otimes \nu h_{11/2}$ configurations. For the two-quasiparticle bands in an odd-odd nucleus, the levels with the signature α_f defined by the proton and neutron angular momenta j_p and j_n as $\alpha_f = 1/2[(-1)^{j_p-1/2} + (-1)^{j_n-1/2}]$ are expected to lie lower in energy than the levels with the unfavoured signature $\alpha_u = (\alpha_f + 1)\mathrm{mod}2$. However, this expectation is violated for the bands showing signature inversion —the levels with the unfavoured signature lie at low spins lower in energy than those with the favoured one. The level energies follow the expectation only from a certain spin value (inversion spin). As explanations for the signature inversion have been proposed triaxiality [1,2], proton-neutron interactions [3–5], band mixing [6], band crossing [7] and quadrupole pairing [8]. However, the origin of the signature inversion is still an open question. For a deeper understanding of the signature inversion phenomenon it is important to observe new bands with different configurations in various mass regions showing this effect.

We report here about the observation of signature inversion in the semidecoupled band of $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration in the odd-odd nucleus ^{172}Lu. Signature inversion for the $\pi h_{9/2} \otimes \nu i_{13/2}$ band was first found in the odd-odd nuclei ^{162,164}Tm and ^{174}Ta by Bark *et al.* [4,9], based on firm spin-parity assignments. The features of the semidecoupled band in ^{172}Lu are very similar to those of the corresponding bands in the odd-odd nuclei: $^{162-166}$Tm [4,10, 11], $^{166-170}$Lu [12–14], $^{170-176}$Ta [4,9,15–17], $^{174-178}$Re [5, 18,19], $^{176-184}$Ir [20–24] and $^{182-186}$Au [25–27].

[a] e-mail: r.lieder@fz-juelich.de

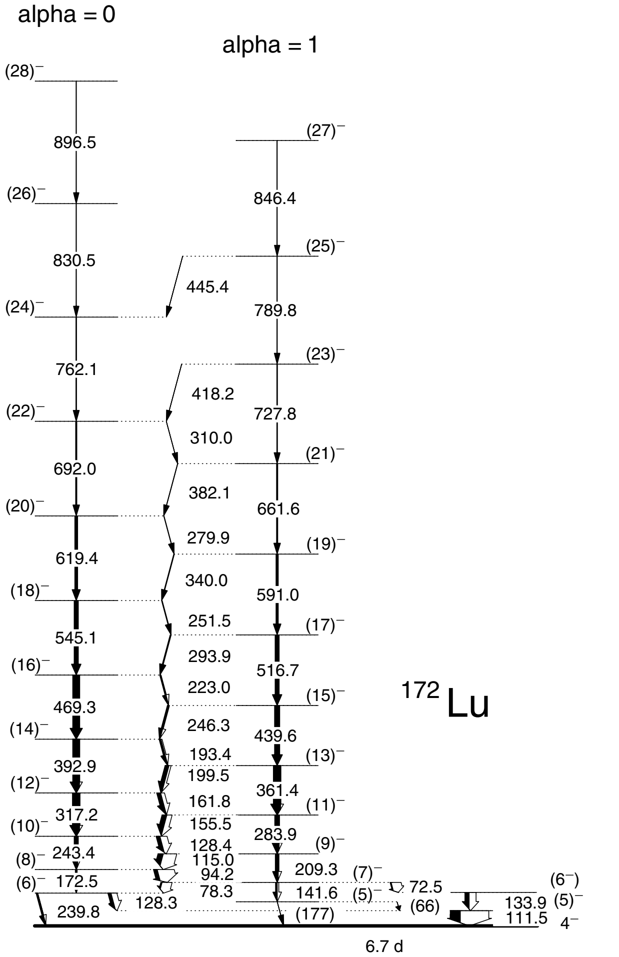

Fig. 1. Partial level scheme of ^{172}Lu. Uncertain assignments are given in brackets. The widths of the arrows are proportional to the intensities of the transitions.

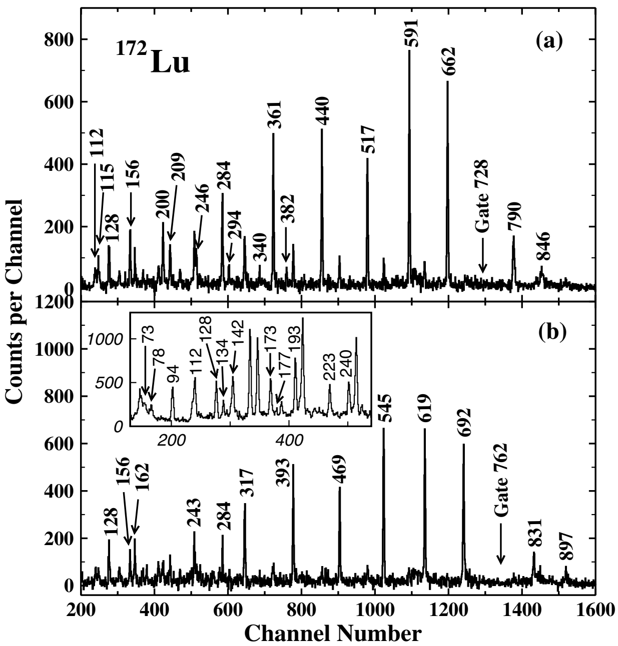

Fig. 2. Doubly gated summed concidence spectra for the semidecoupled band in ^{172}Lu. The energies are given in keV. The gating conditions are (a) $\alpha = 1$ sequence: 728 – (284 + 361 + 440 + 517) and (b) $\alpha = 0$ sequence: 762 – (243 + 317 + 393 + 469). In spectrum (a) also lines from the $\alpha = 0$ sequence are seen but for clarity they are not marked. For the inset of (b) the gating condition is 243 – (317 + 393 + 469 + 545).

2 Experimental methods and results

The high-spin states in the doubly odd nucleus ^{172}Lu were populated through the ^{170}Er(^{7}Li,5n) reaction at a bombarding energy of 51 MeV. The beam was provided by the Tandem XTU accelerator of the Legnaro National Laboratory, Italy, and γ-rays emitted by the reaction residues were detected using the GASP array [28], which consisted of 40 Compton-suppressed large-volume Ge detectors, an inner BGO ball and the charged-particle array ISIS [29]. The ^{170}Er target (enrichment 99.2%) was a self-supporting metallic foil with a thickness of 3.05 mg/cm^2. Events were recorded when ≥ 2 escape-suppressed Ge detectors and $\geq$ 3 BGO scintillators detected γ-rays in coincidence. In total $4 \cdot 10^9$ events have been collected and they were sorted into cubes and matrices using the program Ana [30].

Prior to this investigation only information on low-spin structures in ^{172}Lu known from decay, (α,t), (^{3}He,d) and (p,3nγ) studies was available [31]. In a recent publication we have reported about the observation of a pseudospin band in ^{172}Lu [32]. Details on the assignment of six new rotational bands to this nucleus is described there. The semidecoupled band being reported here has two sequences of $E2$ transitions connected up to high spins by strong $\Delta I = 1$ mixed $M1/E2$ transitions as shown in fig. 1. The placement of the γ-ray transitions in the band was established on the basis of γ-γ-γ coincidence relationships, relative γ-ray intensities, and energy sums. Three doubly gated coincidence spectra are displayed in fig. 2. In spectrum (a) the $\alpha = 1$ sequence and in spectrum (b) the $\alpha = 0$ sequence are shown. In spectrum (a) also the strong $M1$ transitions de-exciting the $\alpha = 1$ sequence into the $\alpha = 0$ sequence can be seen. In the inset of fig. 2(b) the γ-ray transitions de-exciting the band into the 4^-, (5^-) and (6^-) levels are shown. The $\alpha = 0$ sequence de-excites through the 239.8 and 128.3 keV transitions into the 4^- ground state and the known $(5)^-$ level, respectively [31]. In the inset of fig. 2(b) the existence of these lines is demonstrated since the gating transition of 243.4 keV de-excites the same level as the 128.4 keV $(10)^- \rightarrow (9)^-$ transition so that ones sees the 128.3 keV $(6)^- \rightarrow (5)^-$ transition. The 239.8 keV line appears as a singlet in this spectrum. The $\alpha = 1$ sequence de-excites through the weak 177 keV transition to the 4^- ground state as well as the 66 keV $(5)^- \rightarrow (5)^-$ and 72.5 keV $(7)^- \rightarrow (6^-)$ transitions. The 72.5 and 177 keV lines can be seen in fig. 2(b) but the 66 keV line has not been observed because of the strong conversion and the small detection efficiency at low energies. The observation of the 128.3, 239.8 and 72.5 keV lines defines the excitation energy of the band. The proposed spin-parity assignments are based on conversion coefficients deduced from coincidence intensities.

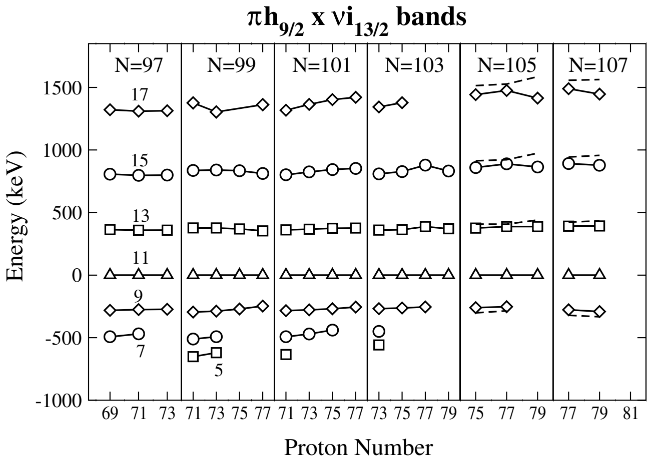

Fig. 3. Level systematics of the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands in the odd-odd nuclei $^{162-166}$Tm, $^{166-170}$Lu, $^{170-176}$Ta, $^{174-180}$Re, $^{176-184}$Ir and $^{182-186}$Au. The energies of the $\alpha = 1$ levels are plotted as functions of proton and neutron numbers. The energies of the $I = 11$ states have been used as reference. The dashed lines for $N = 105$ and 107 result from the published spin assignments. The full curves were obtained after a re-assignment of the spins (see text).

From coincidence intensities the conversion coefficients of the 111.5 $(5)^- \to 4^-$ and 128.3 keV $(6)^- \to (5)^-$ transitions were determined to be $\alpha_{\text{tot}} = 3.6 \pm 0.5$ and 3.0 ± 0.6, respectively. The theoretical conversion coefficients are for the 111.5 keV transition $\alpha_{\text{tot}}(E1) = 0.27$ and $\alpha_{\text{tot}}(M1) = 4.00$ and for the 128.3 keV transition $\alpha_{\text{tot}}(E1) = 0.19$ and $\alpha_{\text{tot}}(M1) = 2.99$, showing that both transitions are of $M1$ character. This allows to assign negative parities to the 111.5 keV level and to the semidecoupled band. The spin of the lowest-lying observed member of this band of 239.8 keV could range from 4 to 6. If the 128.3 and 239.8 keV transitions were both of $M1$ character then an intensity ratio $I_\gamma(128)/I_\gamma(240) = 0.15$ would be expected but a value of 2.1 ± 0.8 has been found experimentally. Hence, the 239.8 keV transition is considered to have an $E2$ character and $I = 6$ is the most plausible spin assignment for the 239.8 keV level. The spin assignments shown in fig. 1 are furthermore supported by the level systematics (cf. fig. 3), discussed in detail in the subsequent section and by the knowledge of band structures in the neighbouring odd-odd nuclei.

Bands of $\pi 1/2^-[541]$ configuration with the signature $\alpha = +1/2$ are strongly populated in the neighbouring odd-proton isotopes ^{171,173}Lu [33,34] and $\nu 7/2^+[633]$ bands with both signatures in the odd-neutron nuclei ^{171,173}Yb [35,36]. The $\pi 1/2^-[541]$ sequence with $\alpha = -1/2$ is only weakly populated in ^{171,173}Lu [33,34]. A strong population of sequences of $\pi 1/2^-[541] \otimes \nu 7/2^+[633]$ configuration with $\alpha(\pi) = +1/2$ and $\alpha(\nu) = +1/2$ and $-1/2$ can, therefore, be expected in ^{172}Lu. A calculation of the quasiparticle energy e' as a function of rotational frequency $\hbar\omega$ (Routhian) for the semidecoupled band in ^{172}Lu, obtained by summing those of the $\pi 1/2^-[541]$ and $\nu 7/2^+[633]$ bands, (additivity rule [37]) reproduces rather well the experimental quasiparticle energy if $I = 6$ is assumed for the lowest member of the $\alpha = 0$ sequence. If the spin of the semidecoupled band in ^{172}Lu is reduced by $1\hbar$, the Routhian moves to considerably higher energies (at $\hbar\omega = 0.4$ MeV by $\Delta e' \approx 0.5$ MeV) away from the calculated Routhian. No band crossing is observed in the semidecoupled band of ^{172}Lu. The $\alpha = 1$ sequence of this band, which should be the favoured cascade, lies however higher in excitation energy than the $\alpha = 0$ sequence, which should be the unfavoured cascade. Hence, the semidecoupled band in ^{172}Lu shows a signature inversion like the bands of $\pi 1/2^-[541] \otimes \nu 7/2^+[633]$ configuration in neighbouring odd-odd nuclei.

3 Discussion

A support for the spin assignment of the semidecoupled $\pi 1/2^-[541] \otimes \nu 7/2^+[633]$ band in ^{172}Lu comes from the systematics of level energies of the corresponding bands of $\pi h_{9/2} \otimes \nu i_{13/2}$ configurations in the odd-odd nuclei $^{162-166}$Tm [4,10,11], $^{166-170}$Lu [12–14], $^{170-176}$Ta [4, 9,15–17], $^{174-180}$Re [5,18,19,38], $^{176-184}$Ir [20–24] and $^{182-186}$Au [25–27]. The excitation energies of the $\alpha = 1$ sequences, relative to those of the 11^- levels, are shown for these nuclei in fig. 3. The level energies of the semidecoupled band in ^{172}Lu fit well with the systematics for the proposed I^π values. The systematics shows that the relative excitation energies remain rather constant as functions of proton and neutron numbers up to the 17^- levels for $Z = 69$–79 and $N = 97$–103. For the nuclei ^{180}Re, ^{182,184}Ir and ^{184,186}Au deviations occur from this systematics of level energies, shown as dashed lines in fig. 3, if one uses the published spin assignments. These spin assignments are, however, not unambiguous and the deexcitation of the semidecoupled bands for ^{180}Re [38] and ^{184}Au [26] has not and for ^{186}Au [27,39] not definitely been established. The spin-assignments were partly based on the systematics of these band structures, established before the signature inversion was discovered by Bark *et al.* [4,9]. The level energies of the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands in these nuclei fit however well with our systematics, shown as open symbols connected by solid lines in fig. 3, if the proposed spin values are increased by $1\hbar$ with respect to the previous assignments [23,24,26,27,38]. The present systematics confirms furthermore the previous re-assignment of the spins for this band in ^{178}Re [5,9] based on the additivity of alignments and in ^{168}Lu on the basis of systematics [12]. Hence, we propose a re-assignment of the spins for the nuclei ^{180}Re, ^{182}Ir, ^{184}Ir, ^{184}Au and ^{186}Au.

In fig. 4 the signature splitting $S(I) = E(I) - [E(I+1) + E(I-1]/2$ is plotted as a function of the spin I for the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands in ^{170,172}Lu [14]. In this sensitive representation a strong staggering effect is visible. Furthermore the signature inversion can be seen since the points for $\alpha = 0$ (open circles) lie lower than the points for $\alpha = 1$ (full circles). In ^{170}Lu the staggering amplitude becomes smaller at high spins and at a spin of $25.5\hbar$ the signature splitting reverts to the normal order. This is called the inversion point. In the neighbouring

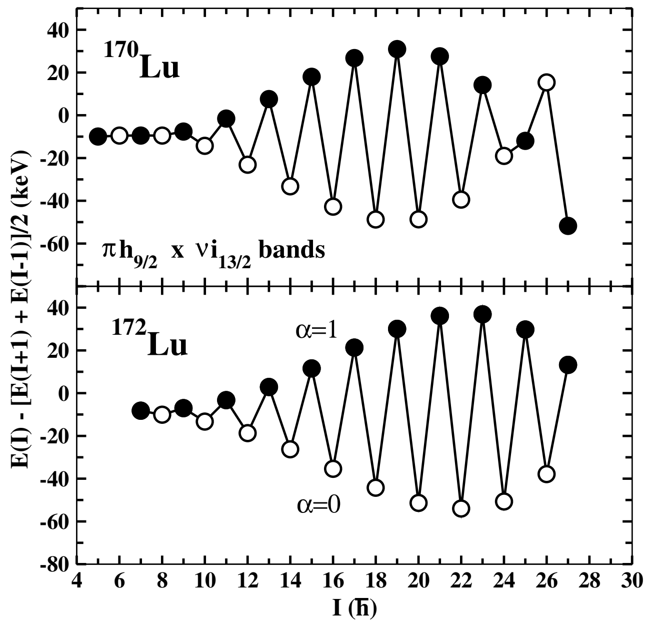

Fig. 4. Signature splitting *vs.* spin for the $\pi h_{9/2}\otimes\nu i_{13/2}$ bands in ^{170,172}Lu.

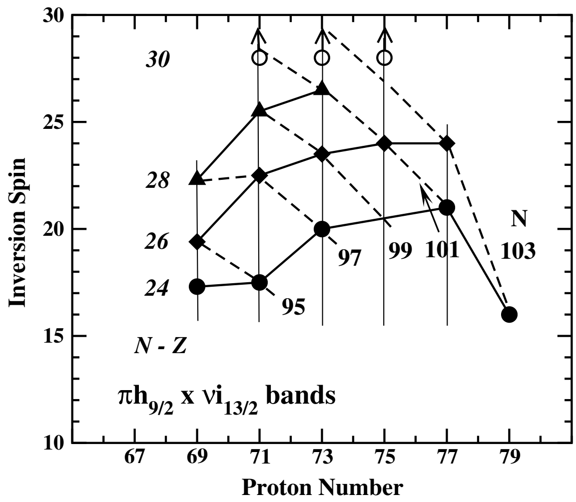

Fig. 5. Systematics of the signature inversion spin *vs.* proton number for the $\pi h_{9/2}\otimes\nu i_{13/2}$ bands of odd-odd rare-earth nuclei. The points with the same $N-Z$ are connected by full lines and those of the same N by dashed lines.

isotopes ^{166,168}Lu [12,13] a similar signature inversion exists, but the inversion points lie lower in spin, *viz* at 17.5 and $\approx 23\hbar$, respectively. It can be seen in fig. 4 that for ^{172}Lu the staggering amplitude becomes smaller at high spins indicating that the inversion point is approached. The $\pi 1/2^-[541]\otimes\nu 7/2^+[633]$ band has not been observed to high enough spins to establish the inversion point. It can, however, be estimated that the inversion point lies at a spin of $\gtrsim 28\hbar$ in ^{172}Lu.

A systematics of the signature splitting $S(I)$ for the $\pi h_{9/2}\otimes\nu i_{13/2}$ bands of odd-odd nuclei in the rare-earth region has been reported in refs. [5,12]. In many cases the spin of the inversion point has been extracted. In an investigation of the dependence of the inversion spin on the proton (Z) and neutron (N) numbers for the $\pi h_{11/2}\otimes\nu i_{13/2}$ bands in rare-earth nuclei with $63\le Z\le 75$ and $89\le N\le 103$ it was noted that the inversion point remains fairly constant for nuclei with the same $N-Z$ value and decreases when $N-Z$ decreases [5]. We present in fig. 5 a systematics of inversion spins for the $\pi h_{9/2}\otimes\nu i_{13/2}$ bands of odd-odd nuclei with $69\le Z\le 79$ and $93\le N\le 105$. In fig. 5 the inversion spin is plotted as a function of the proton number Z. The points with the same $N-Z$ are connected by full lines and the points of equal N with dashed lines. The following observations can be made:

i) The inversion spin is fairly constant for nuclei with the same $N-Z$ (cf. fig. 5) in the region $69\le Z\le 77$. The $N-Z$ values are equal to the sum of the valence neutron particles $N_{\rm n}=N-82$ and the valence proton holes $N_{\rm p}=82-Z$, introduced by Casten *et al.* [40].

ii) For a given isotopic chain the inversion spin increases with increasing neutron number N (cf. fig. 5). as in the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands [41], while it decreases for the $\pi h_{11/2}\otimes\nu i_{13/2}$ bands [5].

iii) For a given isotonic chain, the inversion point decreases with increasing proton number Z (cf. fig. 5), while it increases for the $\pi h_{11/2}\otimes\nu i_{13/2}$ bands [5].

The systematics of the inversion spin allows to make predictions for nuclei in which the inversion point has not yet been observed. For the case of ^{172}Lu, $N-Z=30$, an inversion spin of $28.3\hbar$ can be predicted from fig. 5 in agreement with the observation that it should be $\gtrsim 28\hbar$.

Following the suggestion of Semmes and Ragnarsson [3] a large number of calculations of the signature inversion in odd-odd nuclei have been made using a particle-rotor model including residual proton-neutron (p-n) interactions for various mass regions and configurations [4,5, 9,20,42]. These calculations are successful in reproducing the inversion spin. Systematic calculations of the inversion spin have been carried out for the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in the mass $A\approx 130$ region showing that the inversion spin increases with neutron number for an isotopic chain in agreement with experimental results [41,42]. The opposite dependences of the inversion spin on the neutron and proton numbers for the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in the mass $A\approx 130$ region and the $\pi h_{11/2}\otimes\nu i_{13/2}$ bands in the mass $A\approx 160$ region have been explained by the population of Nilsson states by protons and neutrons, respectively [41]. For the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands the $\Omega\approx 1/2$ levels of the $\pi h_{11/2}$ orbital and the $\Omega\approx 9/2$ levels of the $\nu h_{11/2}$ orbital are occupied. Opposite, for the $\pi h_{11/2}\otimes\nu i_{13/2}$ bands the $\Omega\approx 7/2$ levels of the $\pi h_{11/2}$ orbital and the $\Omega\approx 1/2$ levels of the $\nu i_{13/2}$ orbital are occupied. For the $\pi h_{9/2}\otimes\nu i_{13/2}$ bands, again the $\Omega\approx 1/2$ levels of the $\pi h_{9/2}$ orbital and the $\Omega\approx 7/2$ levels of the $\nu i_{13/2}$ orbital are filled. Hence, a similar behaviour of the $\pi h_{11/2}\otimes\nu h_{11/2}$ and $\pi h_{9/2}\otimes\nu i_{13/2}$ bands can be expected opposite to that of the $\pi h_{11/2}\otimes\nu i_{13/2}$ bands. The effect of the p-n interaction is clearly influenced by the particle and hole character of the participating quasiparticles. Systematic calculations of inversion spins with the particle-rotor model including residual proton-neutron (p-n) interactions are desirable to elucidate this point.

The increase of the inversion spin of the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands with neutron number maybe related to the observation that the crossing frequency for the alignment of the first $\nu i_{13/2}$ quasineutron pair in the $\pi h_{9/2} 1/2^-[541]$ bands in the neighbouring odd-proton nuclei generally also increases with neutron number [34]. Both effects should be explained on the same footing.

4 Summary

A semidecoupled $\pi h_{9/2} \otimes \nu i_{13/2}$ band consisting of two $E2$ sequences connected by strong mixed $M1/E2$ transitions has been newly established in ^{172}Lu. The nucleus has been populated in a ^{170}Er(^{7}Li,5n) reaction at 51 MeV and the emitted γ-radiation was detected with the GASP array. The band shows a signature splitting and a signature inversion (the states with the signature $\alpha = 0$ lie lower in energy than the $\alpha = 1$ levels) up to the highest observed spin.

From a systematics of the inversion spin, at which the signature splitting reverts to the normal order, for the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands of odd-odd nuclei with $69 \leq Z \leq 79$ and $93 \leq N \leq 105$ it was found that the inversion spin is fairly constant for nuclei with the same $N - Z$, that for an isotopic chain the inversion spin increases with increasing neutron number N and that for an isotonic chain, the inversion point decreases with increasing proton number Z. For ^{172}Lu an inversion spin of $28.3\hbar$ has been predicted. From a systematics of the level energies of these semidecoupled bands a change of the spins by $1\hbar$ for these bands in ^{180}Re, ^{182,184}Ir and ^{184,186}Au has been proposed.

The GASP experiment was performed at Legnaro and was financially supported under the EU contracts ERB-FMGEST-980110 and HPRI-CT-1999-00083. Financial support from the Deutsche Forschungsgemeinschaft (DFG) by the grants 436 BUL 17/7/02 and 17/6/03 for stays of Ts.V. in Jülich is gratefully acknowledged.

References

1. R. Bengtsson *et al.*, Nucl. Phys. A **415**, 189 (1984).
2. I. Hamamoto, B. Mottelson, Phys. Lett. B **127**, 281 (1983).
3. P.B. Semmes, I. Ragnarsson, *Proceedings of the International Conference on Future Directions in Nuclear Physics with* 4π *Gamma Detection Systems of the New Generation, Strasbourg (1991)*, edited by J. Dudek, B. Haas, AIP Conf. Proc. **259**, 556 (1992).
4. R.A. Bark *et al.*, Phys. Lett. B **406**, 193 (1997).
5. M.A. Cardona *et al.*, Phys. Rev. C **59**, 1298 (1999).
6. A.K. Jain, A. Goel, Phys. Lett. B **277**, 233 (1992).
7. K. Hara, Y. Sun, Nucl. Phys. A **531**, 221 (1991).
8. F.R. Xu *et al.*, Nucl. Phys. A **669**, 119 (2000).
9. R.A. Bark *et al.*, Nucl. Phys. A **630**, 603 (1998).
10. W. Reviol *et al.*, Phys. Rev. C **59**, 1351 (1999).
11. M.A. Cardona *et al.*, Phys. Rev. C **66**, 044308 (2002).
12. G. Zhao *et al.*, Eur. Phys. J. A **9**, 299 (2000).
13. S.K. Katoch *et al.*, Eur. Phys. J. A **4**, 307 (1999).
14. G. Levinton *et al.*, Phys. Rev. C **60**, 044309 (1999).
15. Y.H. Zhang *et al.*, Phys. Rev. C **60**, 044311 (1999).
16. D. Hojman *et al.*, Phys. Rev. C **61**, 064322 (2000).
17. F.G. Kondev *et al.*, Nucl. Phys. A **632**, 473 (1998).
18. Y.H. Zhang *et al.*, Eur. Phys. J. A **7**, 19 (2000).
19. A.J. Kreiner *et al.*, Phys. Rev. C **40**, R487 (1989).
20. R.A. Bark *et al.*, Phys. Rev. C **67**, 014320 (2003).
21. D. Hojman *et al.*, Phys. Rev. C **67**, 024308 (2003).
22. Y.H. Zhang *et al.*, Phys. Rev. C **65**, 014302 (2002).
23. A.J. Kreiner *et al.*, Phys. Rev. C **42**, 878 (1990).
24. A.J. Kreiner *et al.*, Nucl. Phys. A **489**, 525 (1988).
25. Y.A. Zhang *et al.*, Eur. Phys. J. A **14**, 271 (2002).
26. F. Ibrahim *et al.*, Phys. Rev. C **53**, 1547 (1996).
27. V.P. Janzen *et al.*, Phys. Rev. C **45**, 613 (1992).
28. D. Bazzacco, *Proceedings of the International Conference on Nuclear Structure at High Angular Momentum, Ottawa, 1992,* Vol. **2** (AECL-10613, Chalk River, 1992) p. 376.
29. E. Farnea *et al.*, Nucl. Instrum. Methods A **400**, 87 (1998).
30. W. Urban *et al.*, Manchester University, Nuclear Physics Report (1991-1992) p. 95
31. B. Singh, Nucl. Data Sheets **75**, 199 (1995).
32. Ts. Venkova *et al.*, Eur. Phys. J. A **18**, 1 (2003).
33. R.A. Bark *et al.*, Nucl. Phys. A **644**, 29 (1998).
34. Ts. Venkova *et al.*, Eur. Phys. J. A **18**, 577 (2003).
35. D. Archer *et al.*, Phys. Rev. C **57**, 2924 (1998).
36. Ts. Venkova *et al.*, *High-spin states in the neutron-rich* $^{172,173}Yb$ *isotopes*, to be published in Eur. Phys. J. A (2004).
37. R. Bengtsson, S. Frauendorf, Nucl. Phys. A **327**, 139 (1979).
38. Ts. Venkova *et al.*, Nucl. Phys. A **514**, 87 (1990).
39. M.-G. Porquet, private communication (2003).
40. R.F. Casten *et al.*, Phys. Rev. Lett. **58**, 658 (1987).
41. Y. Liu *et al.*, Phys. Rev. C **54**, 719 (1996).
42. N. Tajima, Nucl. Phys. A **572**, 365 (1994).