NUCLEAR STRUCTURE FEATURES IN HIGHLY DEFORMED AND FAST ROTATING NUCLEI (IDENTICAL BANDS) .

Z.Szymanski, Institute for Theoretical Physics, University of Warsaw, ul. Hoza 69, Pl-00-681 Warsaw, Poland

The intriguing discovery [1] of the twin rotational bands [2-4] (i.e. bands with identical gamma lines in pairs of neighbouring nuclei) in the superdeformed states of atomic nuclei calls for the explanation in terms of nuclear structure. Recently, it has been observed [5] that identical rotational bands (IB) i.e. bands characterised by identical dynamical moments of inertia $\mathcal{J}^{(2)}$ may also occur quite often in normally deformed nuclei, as well. This recent discovery seems to be even more intriguing as it concerns nuclei with the well established superfluid correlations. The variation of about 15% in the moment of inertia was predicted for rotational bands in odd-A nuclei as compared to their even-A neighbours. Baktash et al. [5] have found that about 30% of the 174 investigated odd-Z rotational bands have moments of inertia $\mathcal{J}^{(2)}$ almost exactly equal to the corresponding moments in their even-A neighbours. Understanding this phenomenon is a great challenge to nuclear theory. Let us first consider the IB in the superdeformed rotational bands. In this case the influence of pairing interactions between the nucleons may be neglected in the first approximation. In addition, many one-nucleon Routhians do not show any substantial dependence on rotational frequency ω. Then the appearance of the IB may result as a delicate balance between the mass dependence in the inertial moments ($\mathcal{J} \sim A^{5/3}$) and the change in nuclear deformation. It has been suggested couple of years ago [6,7] that the appearance of IB may be connected with the occupation of the deformation-aligned oblate-driving nucleonic orbits. Indeed, the increase in $\mathcal{J}^{(2)}$ due to the mass dependence may be counteracted by the decrease in $\mathcal{J}^{(2)}$ induced by the decrease in nuclear deformation in odd-A nucleus when the odd nucleon populates the oblate-driving orbit [6] (with $n_z = 0$, or 1). In the low-spin

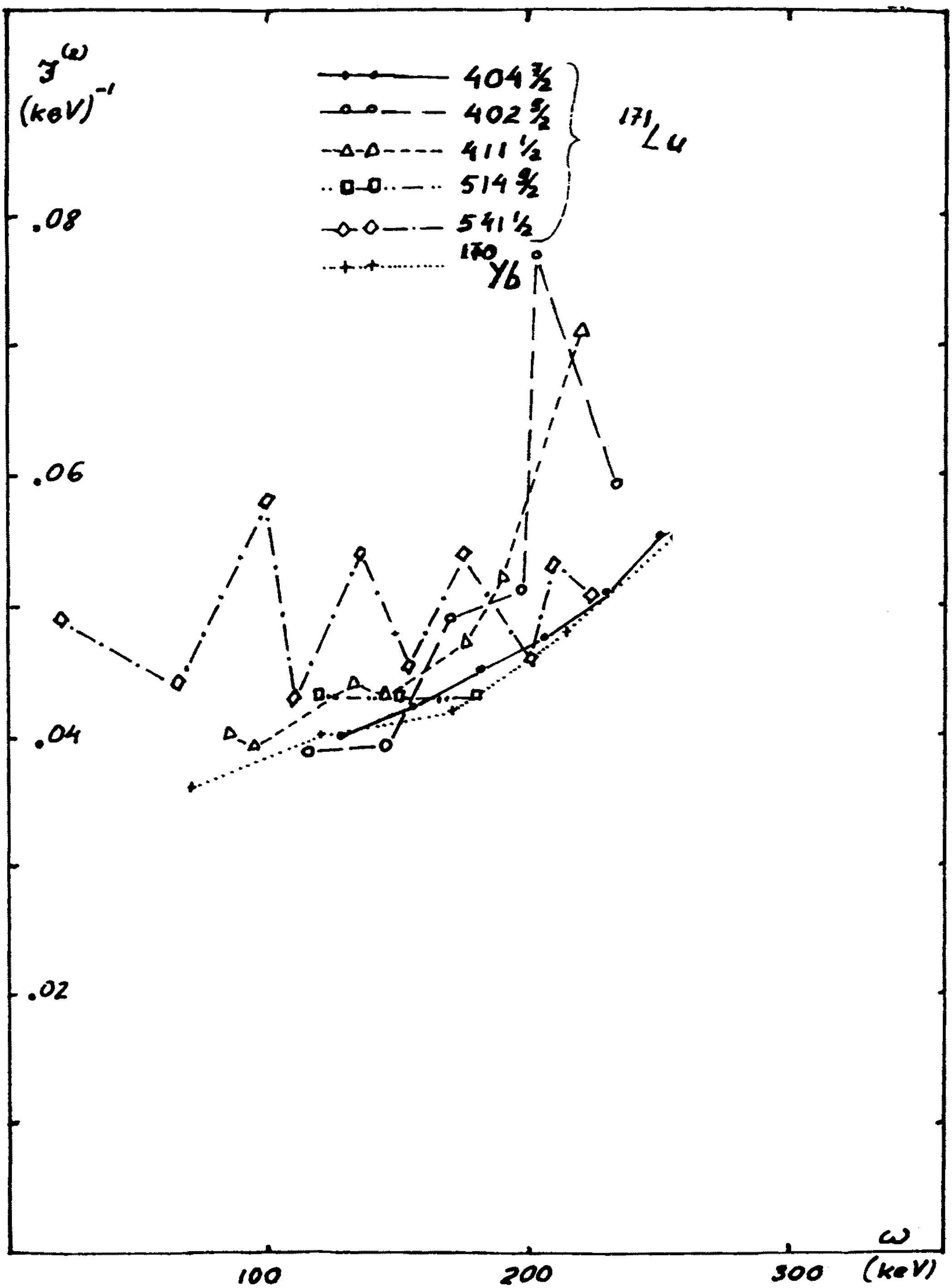

$\mathcal{J}^{(\omega)}$ $(keV)^{-1}$
404 7/2
402 5/2
411 1/2
514 9/2
541 1/2
171Lu
170Yb
.08
.06
.04
.02
100
200
300
ω (keV)

Fig. 1

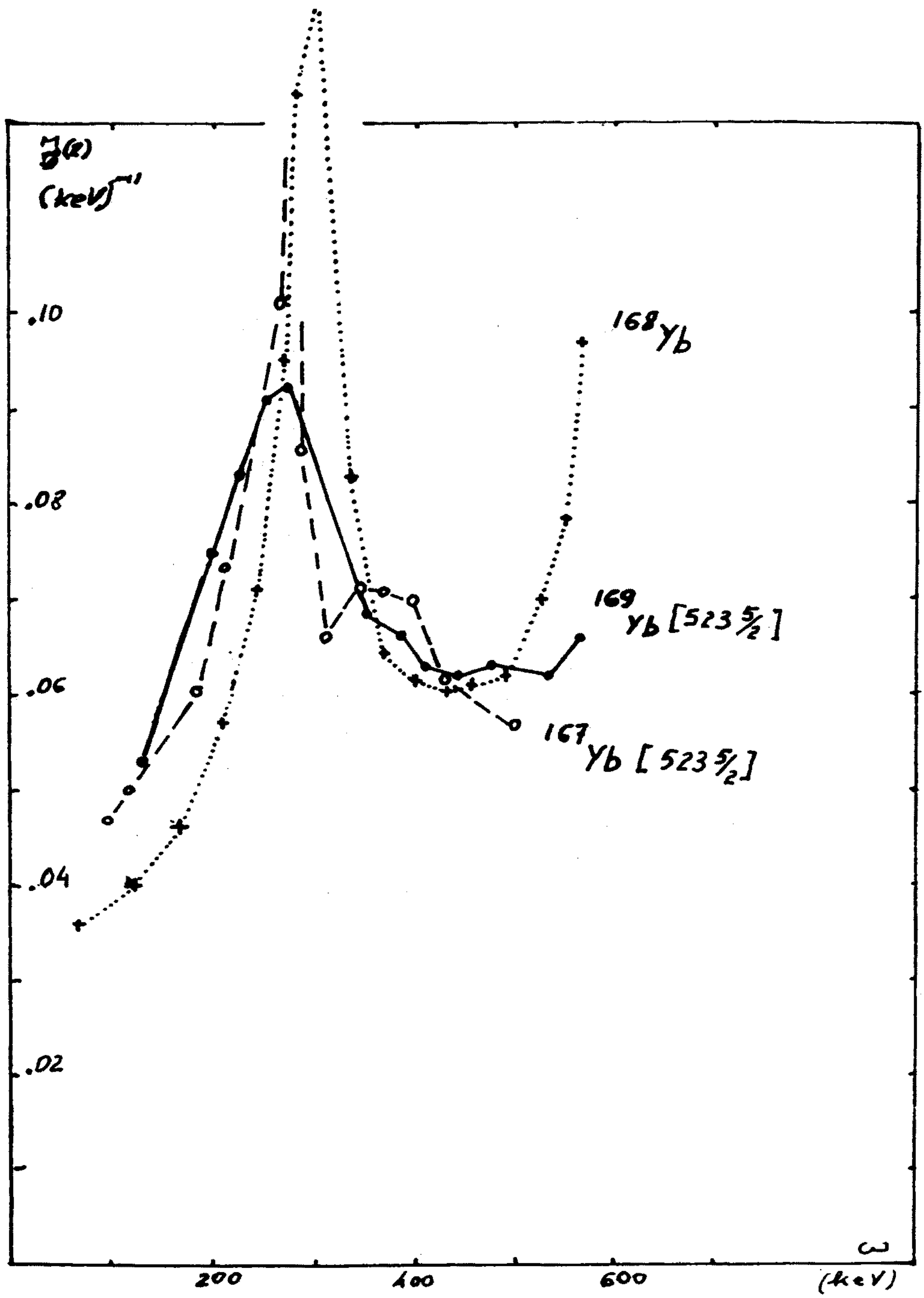
and normal-deformation region the situation is more complicated since the superfluid pairing correlations come into balance, as well. We shall discuss this effect further below in this article.

Several attempts [8-12] have been made in order to under- stand the IB often providing very exotic explanations. Nevertheless, the question why do IB occur in some bands and are not present in the others remains not answered. Nor the understanding of the phenomenon in terms of our present knowledge of nuclear structure has been offered.

In this article we would like to suggest a more detailed analysis of the moments of inertia $\mathcal{J}^{(2)}$ in various rotational bands and their relations to other features of nuclear structure such as, for example, the nature of band-heads in odd-A nuclei, the variation of nuclear pairing, deformations, alignments etc. It is believed that such analysis may provide clues to the appearence of the IB.

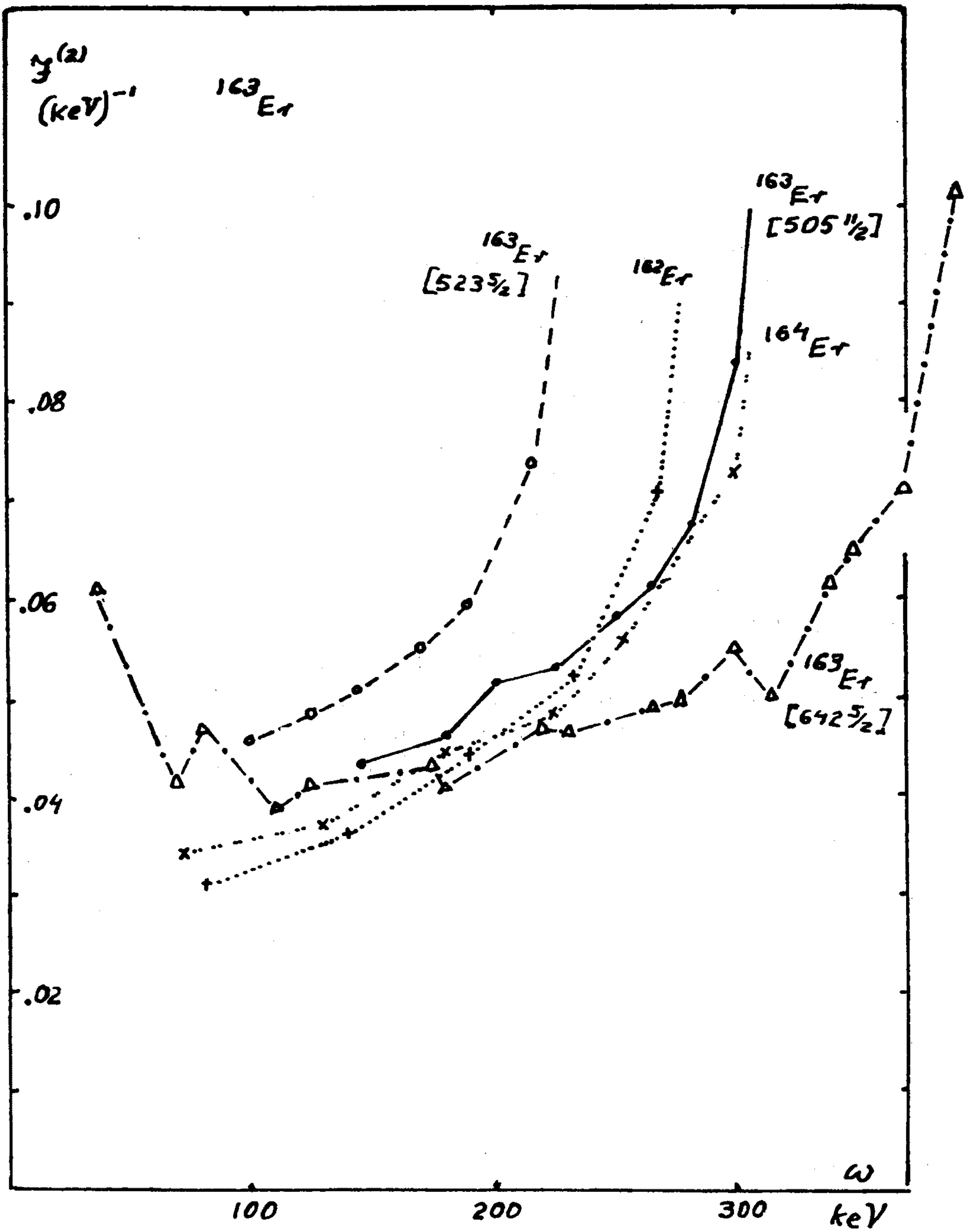
Fig.1 shows the moments of inertia $\mathcal{J}^{(2)}$ for various rotational bands in ^{171}Lu compared with the ground state band in ^{170}Yb nucleus which is considered as an even core. The nucleus ^{171}Lu has been chosen by the authors of ref.[5] as an example of good identical band as compared to the even core ^{170}Yb. The constancy in the angular momentum alignment i was employed as the criterion for the existence of IB. Here, we employ rather the moments of inertia $\mathcal{J}^{(2)}$ which are defined as the derivatives of angular momentum I with respect to rotational frequency ω. It can be seen that the $\mathcal{J}^{(2)}$ values exhibit quite a substantial increase as function of ω for most of the bandheads. The band built on a state [404 9/2] seems to lie closest to the ^{170}Yb core (the largest deviations in moments of inertia $\mathcal{J}^{(2)}$ being of the order of 4.5% in the spin range between I = 7/2 and 25/2). Band originating from the state [402 5/2] exhibits slightly higher relative deviation (say, 5% to 12% and around 20% at the upper end). Next comes the band built on [411 1/2] with deviations of the order of 9%. Band originating on[514 9/2] is poorly known. Finally, the [541 1/2] band which shows a very substantial signature splitting differs obviously in a major way from the ^{170}Yb core. If we took the ^{171}Lu nucleus as a representative example we could conclude that the oblate driving configurations with low n_z value which are deformation aligned originate best examples of IB.

Fig.2 illustrates the rotational bands in two odd-neutron nuclei ^{167}Yb and ^{169}Yb as compared to the even nucleus ^{168}Yb. One can see that identical bands can occur at most in the very narrow range of ω corresponding roughly



J(2)
(keV)⁻¹
.10
.08
.06
.04
.02
200
400
600
ω
(keV)
168Yb
169Yb [523 5/2]
167Yb [523 5/2]

Fig. 2



$\mathcal{J}^{(2)}$
$(keV)^{-1}$
^{163}Er
.10
.08
.06
.04
.02
^{163}Er [523 5/2]
^{162}Er
^{163}Er [505 11/2]
^{164}Er
^{163}Er [642 5/2]
ω
100
200
300
keV

Fig. 3

to angular momenta $I = 22$ to 30. This example seems to prove that the existence of IB may sometimes be limited to a rather narrow range of angular momenta.

Finally, fig.3 illustrates various bands in the nucleus ^{163}Er which have been observed in experiment [13]. One can see that the band [505 11/2] lies closest to the ^{162}Er core (considering moments of inertia) while the band built on the state [523 5/2] deviates considerably from the ^{162}Er core. It is interesting to note [13] that the crossing frequencies ω_{cr} in those two bands (corresponding to the rotational alignment in some configurations) behave differently when compared to the ω_{cr} in the even core. In fact the quantity

$$\delta\omega_{cr} = \omega_{cr}(\text{even}) - \omega_{cr}(\text{odd})$$

is usually of the order of 40 keV. This estimate corresponds well to the typical decrease in pairing Δ in ^{163}Er as compared to ^{162}Er. On the other hand, bands built on the state [514 9/2] (not shown in fig.3) and [505 11/2] exhibit a substantial decrease in $\delta\omega_{cr}$ (0 and -40 keV, respectively, see ref.[13]). One could then conclude that occupying the state [514 9/2] (and also [505 11/2]) does not decrease the pairing correlations contrary to the case of [523 5/2]. It is interesting to note that in these two configurations also the moment of inertia $\mathcal{J}^{(2)}$ remains almost unchanged. This may lead to the conclusion that blocking certain nucleonic orbits implies that both the crossing frequency ω and moment $\mathcal{J}^{(2)}$ of inertia are left almost not affected for similar reasons. These reasons may be connected with the intrinsic structure of the orbits blocked. In fact the orbits [514 9/2] and [505 11/2] are deformations aligned and carry negative (oblate) quadrupole moments.Perhaps such orbits when populated are able to modify the pairing correlations in the minor way only.

Finally, it is believed that the changes in nuclear deformation induced by the collective rotation may be also important for the explanation of the identical bands.

References

1. T.Byrski, F.A.Beck, D.Curien, C.Schuck, P.Fallon, A.Alderson, I.Ali, M.A.Bentley, A.M.Bruce, P.D.Forsyth, D.Howe, J.W.Roberts, J.F.Sharpey-Schaffer, G.Smith and P.J.Twin, Phys.Rev.Letters **64** (1990) 1650.

2. F.S.Stephens, M.A.Deleplanque,J.E.Draper, R.M.Diamond, C.W.Beausang, W.Korten, W.H.Kelly, F.Azaiez, J.A.Becker, E.A.Henry, S.W.Yates, M.J.Brinkman, A.Kuchnert and J.A.Cizewski, Phys.Rev.Lett. **64** (1990) 2623.

3. F.S.Stephens, M.A.Deleplanque, J.E.Draper, R.M.Diamond, A.O.Macchiavelli, C.W.Beausang, W.Korten, W.H.Kelly, F.Azaiez, J.A.Becker, E.A.Henry, S.W.Yates, M.J.Brinkman, A.Kuhnert and J.A.Cizewski, Phys.Rev.Lett. **65** (1990) 301.

4. B.Haas et al., Phys.Rev. **C42** (1990) R1817.

5. C.Baktash, J.D.Garrett, D.F.Winchell and A.Smith, Phys. Rev.Lett., to be published.

6. J.Dudek, Z.Szymanski and T.Werner, to be published; see also Z.Szymanski, Proc. Conf. Nuclear Structure in The Nineties, ed. by N.R.Johnson, North-Holland 1990, page 1c.

7. I.Ragnarsson, ibid., page 67c; see also Phys.Lett. **264B**, (1991) 5.

8. C.Baktash, W.Nazarewicz and R.Wyss, to be published (see also the referenes quoted therein).

9. R.F.Casten, N.V.Zamfir, P.von Brentano and W.T.Chou, Phys.Rev. **C45** (1992) R1413.

10. W.Nazarewicz, P.J.Twin, P.Fallon and J.D.Garrett, Phys.Rev.Lett. **64** (1990) 1654.

11. A.Gelberg, P.von Brentano and R.F.Casten, J.Phys. **G16** (1990) L143.

12. D.Bonatsos, E.N.Argyres, S.B.Drenska P.P.Raychev, R.P.Roussev and Yu.F.Smirnov, Phys.Lett. **B251** (1990) 477.

13. J.C.Bacelar, M.Diebel, O.Andersen, J.D.Garrett, G.B.Hagemann, B.Herskind, J.Kownacki, C.X.Yang, L.Carlen, J.Lyttkens, H.Ryde, W.Walus and P.O.Tjom, Phys. Lett. **152B** (1985) 157.