Shell structure effects on the high-spin rotational states in ytterbium nuclei (populated in $^{160}Gd(^{14}C, 4n)^{107}Yb$ reaction)

1973 J. Phys. A: Math. Nucl. Gen. 6 L60

(http://iopscience.iop.org/0301-0015/6/5/003)

J. Phys. A: Math., Nucl. Gen., Vol. 6, May 1973. Printed in Great Britain. © 1973

LETTER TO THE EDITOR

Shell structure effects on the high-spin rotational states in ytterbium nuclei

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MS received 12 March 1973

Abstract. The ground state rotational band members up to spin 18^+ have been identified in $^{170}Yb(N = 100)$ by studying the γ rays from the $^{160}Gd(^{14}C, 4n)\ ^{170}Yb$ reaction. The nuclear moment of inertia of the band shows an abrupt increase at high-spin values similar to that observed in nuclei with $N = 90$–96, but in contrast with the smooth increase in the $N = 98$ nucleus ^{168}Yb. This dependence on neutron number is difficult to explain in terms of the decoupling of neutrons in the $i_{13/2}$ orbital alone, but is consistent with the Coriolis antipairing description of a phase transition from a superfluid to a normal state if account is taken of the reduction in pairing correlations caused by the shell structure peculiar to ^{168}Yb.

An anomalous increase in the moment of inertia of the ground state band at high-spin values has recently been observed for nuclei having $N = 90$–96 in the rare earth region (Johnson *et al* 1971, Lieder *et al* 1972, Thieberger *et al* 1972). In the $N = 98$ nucleus ^{168}Yb levels are known up to $J^\pi = 20^+$ (Mo *et al* 1972) and this nucleus exhibits a smooth increase in moment of inertia with increasing rotational angular momentum. We have studied the ground state band of the $N = 100$ nucleus ^{170}Yb to determine whether the smooth increase in moment of inertia is peculiar to the $N = 98$ isotones. Previously this band in ^{170}Yb was known up to the $J^\pi = 14^+$ level (Mo *et al* 1972).

A ^{14}C beam from the Manchester Hilac was used to bombard a thin ($2{\cdot}5$ mg cm^{-2}), self-supporting target of ^{160}Gd. The γ rays from the $^{160}Gd(^{14}C, 4n)\ ^{170}Yb$ reaction were studied with Ge(Li) detectors. The reaction was observed to populate the ground state band in ^{170}Yb up to the $J^\pi = 18^+$ level. The assignment of transitions to the band was made using the methods reported previously (Mo *et al* 1972). These consist of measurements of γ ray excitation functions, angular distributions, and a three-parameter γ–γ coincidence experiment.

The reaction cross section was found to peak at a ^{14}C beam energy of 62 MeV. Figure 1 shows a singles γ ray spectrum obtained with a Ge(Li) detector at this energy. Figure 2 shows the background-subtracted coincidence spectrum obtained with a window on the $597{\cdot}3$ keV γ ray (the $14^+ \to 12^+$ transition). In table 1 the measured energies, relative intensities and angular distribution coefficients of the intraband γ rays are listed.

In figure 3 the nuclear moment of inertia is plotted as a function of the square of the angular frequency ($\mathscr{I} = \mathscr{I}(\omega^2)$) following Johnson *et al* (1971). This shows an anomalous increase in the moment of inertia at $J^\pi = 16^+$ for ^{170}Yb. The effect is comparable to that in ^{164}Yb and ^{166}Yb (Lieder *et al* 1972, Beuscher *et al* 1972), but is in sharp contrast to the smooth increase in ^{168}Yb. Tentative assignments of the

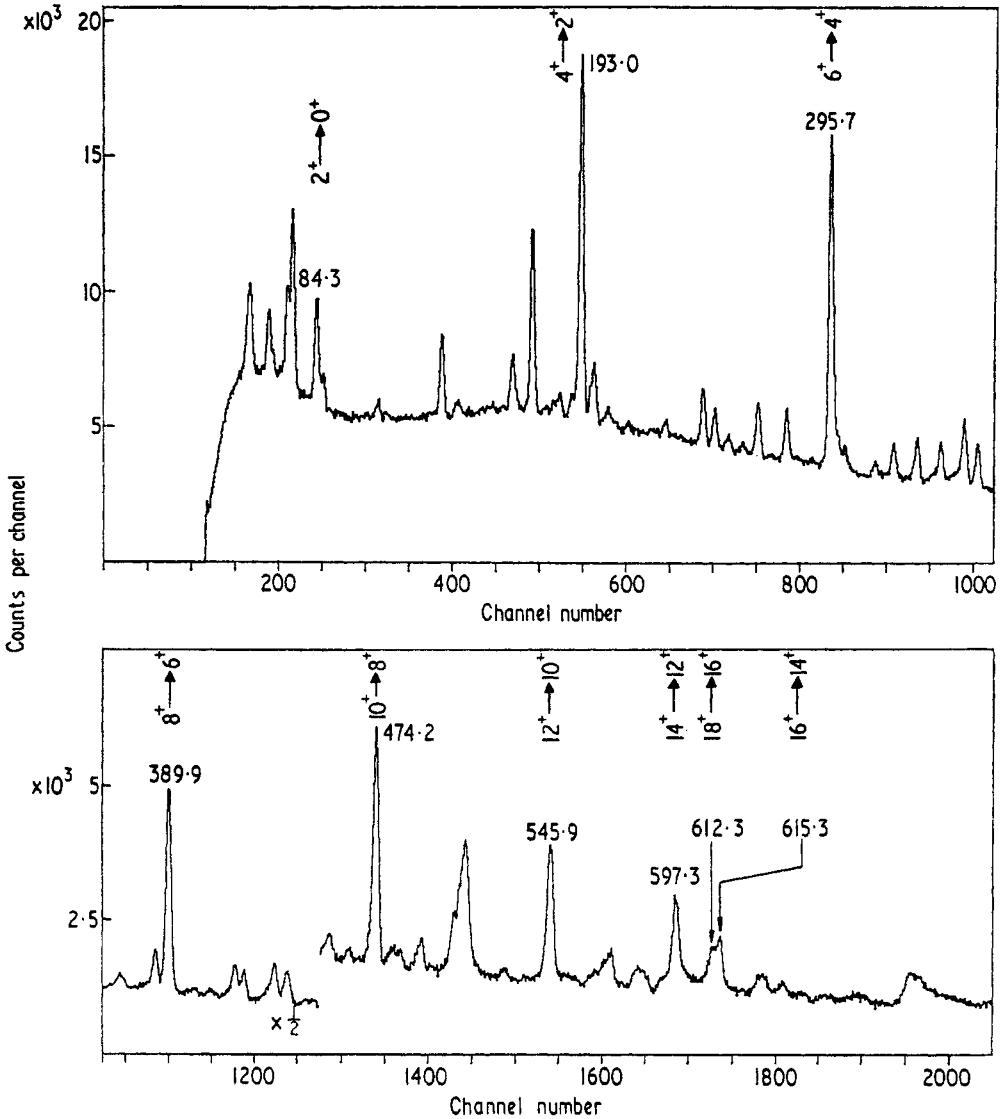

Figure 1. Singles γ ray spectrum from the $^{160}Gd(^{14}C, 4n)^{170}Yb$ reaction, measured at a bombarding energy of 62 MeV with a Ge(Li) detector at 125° to the beam direction.

high-spin states in ^{170}Hf and ^{172}Hf (Stephens *et al* 1965) which have been confirmed (Sunyar *et al* 1972, Saethre *et al* 1972) during the course of this work, together with data for ^{168}Hf (Lieder *et al* 1972) indicate that the dependence of the form of the $\mathscr{I}(\omega^2)$ curve on neutron number is paralleled in these corresponding hafnium isotopes, although the increase in moment of inertia in ^{172}Hf is much less dramatic than

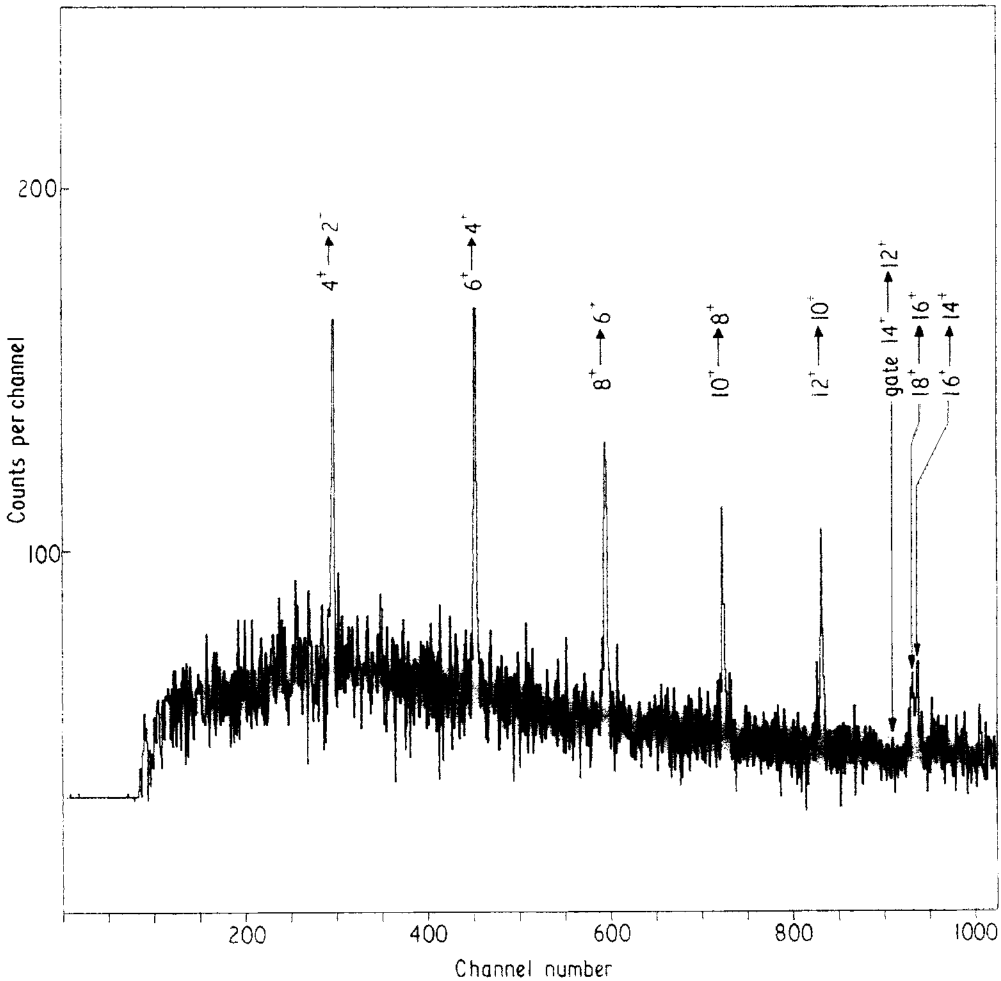

Figure 2. Background-subtracted coincidence γ ray spectrum from the ^{160}Gd(^{14}C, 4n) ^{170}Yb reaction with a window set on the 597·3 keV γ ray (the $14^+ \rightarrow 12^+$ transition).

that found in ^{170}Yb. These results indicate that the $N = 98$ isotones exhibit a substantially different variation of moment of inertia with angular frequency from that of their neighbours.

Most of the models proposed to explain the anomalous increase in moment of inertia attribute the effect to the reduction in pairing correlations by the Coriolis force (the Coriolis antipairing effect) as originally suggested by Mottelson and Valatin (1960). Krumlinde and Szymanski (1971) and Sorensen (1971) have calculated the effect of Coriolis antipairing in simplified two-level models which are capable of reproducing

Table 1. Transition energies, relative intensities and angular distribution coefficients in ^{170}Yb

Energy (keV)†	Relative intensity‡	Angular distribution coefficients A_2/A_0	A_4/A_0	Assignment
84·3§	—	—	—	$2^+ \rightarrow 0^+$
193·0	100	$0{\cdot}19 \pm 0{\cdot}01$	$-0{\cdot}10 \pm 0{\cdot}02$	$4^+ \rightarrow 2^+$
295·7	81	$0{\cdot}25 \pm 0{\cdot}02$	$-0{\cdot}11 \pm 0{\cdot}03$	$6^+ \rightarrow 4^+$
389·9	64	$0{\cdot}28 \pm 0{\cdot}02$	$-0{\cdot}09 \pm 0{\cdot}04$	$8^+ \rightarrow 6^+$
474·2	44	$0{\cdot}30 \pm 0{\cdot}04$	$-0{\cdot}09 \pm 0{\cdot}06$	$10^+ \rightarrow 8^+$
545·9	33	$0{\cdot}31 \pm 0{\cdot}04$	$-0{\cdot}05 \pm 0{\cdot}05$	$12^+ \rightarrow 10^+$
597·3	28	$0{\cdot}31 \pm 0{\cdot}05$	$-0{\cdot}10 \pm 0{\cdot}10$	$14^+ \rightarrow 12^+$
615·3	16	$0{\cdot}36 \pm 0{\cdot}08$	$-0{\cdot}04 \pm 0{\cdot}10$	$16^+ \rightarrow 14^+$
612·3	9	$0{\cdot}34 \pm 0{\cdot}09$	$-0{\cdot}06 \pm 0{\cdot}12$	$18^+ \rightarrow 16^+$

† The transition energies are accurate to $\pm 0{\cdot}3$ keV.
‡ The relative intensities are accurate to $\pm 10\%$.
§ $2^+ \rightarrow 0^+$ transition attenuated by graded absorbers.

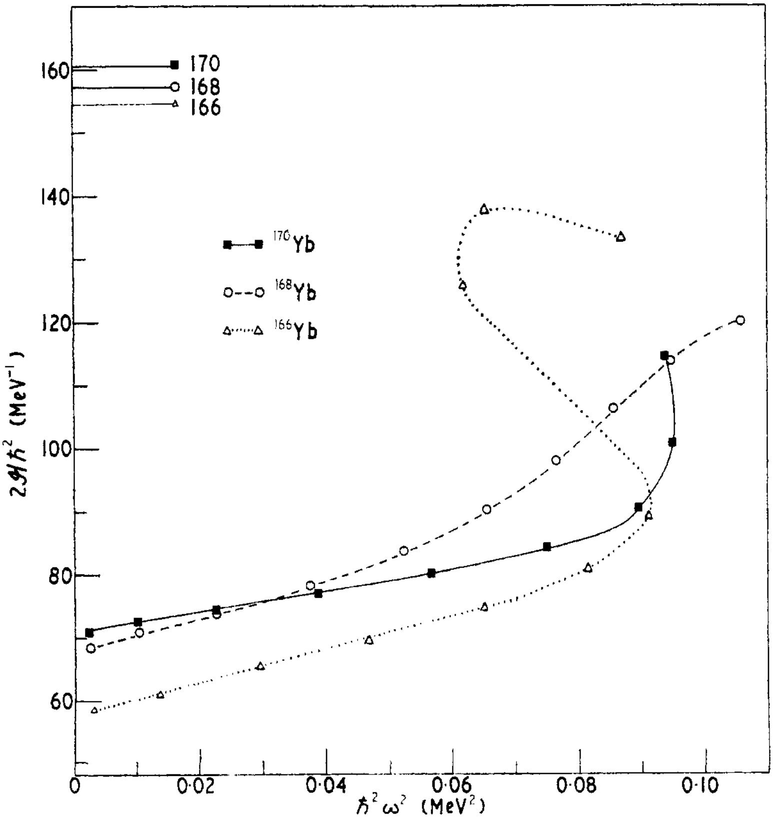

Figure 3. The nuclear moments of inertia as a function of the square of the angular frequency in ^{166}Yb, ^{168}Yb and ^{170}Yb.

the general form of the observed $\mathscr{I}$ against ω^2 curves. In particular, the form of the curve is sensitive to the single-particle energy-level separation near the Fermi surface and for approximate level degeneracy the calculations reproduce the anomalous effect. An increase in this separation causes a reduction in the pairing correlations which, in turn, results in a smoother increase in the moment of inertia with increasing angular frequency.

Stephens and Simon (1971) have proposed a model in which the anomalous increases in the moments of inertia are attributed to the Coriolis force decoupling two $i_{13/2}$ neutrons from a rotating deformed core. This model can also reproduce qualitatively the general form of the $\mathscr{I}$ against ω^2 curve and it predicts (Stephens and Simon 1973) that the anomaly should become less marked for increasing neutron number in the $i_{13/2}$ orbital.

In the context of these models it is important to establish the position of the Fermi level relative to the Nilsson orbitals for ^{168}Yb and ^{170}Yb. Burke *et al* (1966) have used (d, p) and (d, t) reactions to assign the ground states of ^{167}Yb and ^{169}Yb to the [523] $\Omega^\pi = \frac{5}{2}^-$ and [633] $\Omega^\pi = \frac{7}{2}^+$ Nilsson orbitals respectively. Further, quadrupole moment measurements for these ytterbium isotopes indicate that the deformation parameter $\epsilon \simeq 0{\cdot}26$ (Nathan and Nilsson 1966). For this value of ϵ there is a large energy gap between the [523] $\Omega^\pi = \frac{5}{2}^-$ and [633] $\Omega^\pi = \frac{7}{2}^+$ Nilsson orbitals. Taken together these results suggest that the Fermi level for ^{168}Yb lies in the large gap between these two orbitals whilst that for ^{170}Yb lies above the [633] $\Omega^\pi = \frac{7}{2}^+$ orbital and the gap.

There is evidence from the values of the $\mathscr{I}_0$ parameter in the VMI model (Mariscotti *et al* 1968) that this energy gap results in a reduction in pairing correlations for the $N = 98$ isotones. Therefore, the models of Krumlinde and Szymanski (1971) and Sorensen (1971) imply an anomalous increase in the moment of inertia for ^{170}Yb and a smooth increase for ^{168}Yb which is consistent with our results.

The model of Stephens and Simon (1971, 1973), however, implies that the anomalous effect should be less pronounced in ^{170}Yb than in ^{168}Yb and this is contrary to the observed behaviour in these nuclei. Thus it is difficult to account for the present results in ^{170}Yb solely in terms of the decoupling of two $i_{13/2}$ neutrons.

It can be concluded from our results that the form of the $\mathscr{I}(\omega^2)$ curve is sensitive to the position of the Fermi level, and that the Coriolis effects for the few particles near the Fermi level have the most significant effect on the form of the increase of the moment of inertia at high-spin values in these nuclei.

We should like to thank the staff of the Manchester Hilac for their assistance. A J Hartley and S Flanagan would like to acknowledge the support of the Science Research Council during the course of this work.

References

Beuscher H, Davidson W F, Lieder R M and Mayer-Böricke C 1972 *Phys. Lett.* **40B** 449–52

Burke D G, Zeidman B, Elbek B, Herskind B and Olesen M 1966 *K. danske Vidensk. Selsk., Math-fys. Meddr* **35** No. 2

Johnson A, Ryde H and Sztarkier J 1971 *Phys. Lett.* **34B** 605–8

Krumlinde J and Szymanski Z 1971 *Phys. Lett.* **36B** 157–60

Lieder R M *et al* 1972 *Phys. Lett.* **39B** 196–8

Mariscotti M A J, Scharff-Goldhaber G and Buck B 1968 *Phys. Rev.* **178** 1864–87

Mo J N, Chapman R, Dracoulis G D, Gelletly W and Hartley A J 1972 *Particles and Nuclei* **4** 126–42
Mottleson B R and Valatin J G 1960 *Phys. Rev. Lett.* **5** 511–2
Nathan O and Nilsson S G 1966 *Alpha, Beta and Gamma Ray Spectroscopy* ed K Siegbahn (Amsterdam: North-Holland) pp 601–700
Saethre O, Hjorth S A, Johnson A, Jägare S, Ryde H and Szymanski Z 1972 to be published
Sorensen R A 1971 *Proc. Colloq. on intermediate Nuclei, Orsay July* 1971
Stephens F S, Lark N L and Diamond R M 1965 *Nucl. Phys.* **63** 82–96
Stephens F S and Simon R S 1971 *Nucl. Phys.* A **183** 257–84
——1973 to be published
Sunyar A W, Cochavi S, Kistner O C, der Mateosian E, Thieberger P and Lumpkin A 1972 *Symp. on High Spin Nuclear States and Related Phenomena, Stockholm May* 1972
Thieberger P *et al* 1972 *Phys. Rev. Lett.* **28** 972–4