who have used a spin-orbit force increased by 20% compared to other calculations. They note, however, that this state is strongly mixed with the $[862]\frac{5}{2}^+$ orbit. Since the latter is an orbit with low Ω and large j, it is particularly sensitive to Coriolis mixing and may explain the observed distortion of the band. The measured limit on $|g_K - g_R|$, however, allows only an admixture of up to 40% of any component of the wave function with spin and orbital angular momentum vectors parallel.

Since the feeding transition to the $\frac{9}{2}^+$ rotational member is most likely of $E1$ character, the spin of the excited state must be $\frac{7}{2}^-$ or $\frac{9}{2}^-$. The observed reduced branching ratios are in disagreement with intensities calculated for three K-allowed $E1$ transitions.[10] The decay of the spin isomer is thus either intrinsically forbidden or its spin and parity is $\frac{9}{2}^-$. A likely candidate would then be the $[734]\frac{9}{2}^-$ orbit.[9] This makes the main decay from the isomer a once K-forbidden $E1$ transition with a hindrance factor of 10^5 and the decay to the ground state would then be an $M2$ transition of single-particle strength.

Applying improved detection techniques, the rotational band built upon the fission isomeric state in an odd-even nucleus has been observed for the first time. The spin of the 8-μs fission isomer in ^{239}Pu is found to be $\frac{5}{2}$. Comparison with theory suggests the assignment of the $[633]\frac{5}{2}^+$ orbit which is found close to the Fermi surface only in one of numerous calculations, indicating that the spin-orbit force may have to be increased with deformation. Measurements of this kind thus provide really sensitive tests of the single-particle potentials underlying Strutinsky-type calculations of fission barriers.

We gratefully acknowledge fruitful discussions with I. Hamamoto, B. Mottelson, G. Leander, and S. G. Nilsson. One of us (J.P.) would like to thank the Max-Planck-Institut für Kernphysik for its hospitality. This work was partly supported by the Bundesministerium für Forschung und Technology.

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Second Irregularity in the Yrast Line of ^{160}Yb

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(Received 22 December 1978)

Yrast states of ^{160}Yb with spins up to $30\hbar$ were identified in the reaction ^{148}Sm(^{16}O,$4n\gamma$). In addition to an initial backbend at $I = 12\hbar$, a second backbend occurs at $I = 28\hbar$. This result is discussed in terms of recently proposed explanations of the backbending effect.

A large amount of new information allowing one to follow the rotational bands of many deformed nuclei up to levels with spin reaching $I \approx 20\hbar$ has been provided during the last few years. Recently,[1] it was even possible to observe higher-lying discrete yrast transitions in the ^{158}Er nucleus and to see, in addition to the first backbending previously established, a second discontinuity at $I = 28\hbar$.

Several mechanisms have been proposed to ex-

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plain the observed anomalies. Among them, most often discussed are rotational alignment,[2] Coriolis antipairing,[3] and gapless superconductivity.[4] It has been suggested[5-8] that the first backbending in the rare-earth region is due to the breaking of an $i_{13/2}$ neutron pair and its alignment along the rotational axis. One could expect that the second discontinuity in the yrast level sequence is due to the breaking of one of the next $i_{13/2}$ neutron pair or an $h_{11/2}$ proton pair. This hypothesis is supported by the theoretical calculations of Faessler and Ploszajczak.[9] These authors show that in the framework of the cranked Hartree-Fock-Bogoliubov method, the second anomaly around $I = 28\hbar$ is connected with an alignment of an $h_{11/2}$ proton pair.

Recent studies of Bengtsson and co-workers[10-12] have shown that the existence of the backbending anomaly in different parts of the rare-earth region can be related to the Z oscillatory behavior of the interaction between the ground-state and two-quasiparticle bands. The proton number $Z = 68$ corresponds to one of the interaction minima and should lead to a second sharp backbending while neighboring $Z = 70$ and $Z = 66$ isotones should show a smooth upbending. The ^{156}Dy nucleus has been recently studied by Ward *et al.*[13] and no evidence has been found for a second anomaly of the yrast level sequence below spin $I = 30\hbar$. In this Letter we report on the study of the ^{160}Yb nucleus, which is an isotone of ^{156}Dy and ^{158}Er. Two irregularities in the yrast line are definitively established: A first backbend occurs at $I = 12\hbar$ and a second one at $I = 28\hbar$.

The heavy-ion reaction ^{148}Sm(^{16}O, $4n$)^{160}Yb has been used to produce high-spin states in ^{160}Yb. The experiments were performed at the Strasbourg MP tandem accelerator with 95- and 105-MeV oxygen beams. The first energy corresponds to the maximum yield of the $4n$ channel, and the second was chosen in order to favor the feeding of very high-spin states. The 1-mg/cm^2 target, enriched to 95% in ^{148}Sm, was evaporated in metallic form on a 0.1-mm lead foil. The γ-γ coincidences were measured with a three Ge(Li) array so as to increase the counting rate. The detectors were set at +90°, −90°, and 0°, with respect to the beam direction. The coincident events for each pair of detectors were recorded one by one on magnetic tapes allowing to construct all possible gated γ-γ spectra. In addition the 0° and one of the 90° detectors were put

TABLE I. Relative intensities, angular distribution coefficients, and anisotropies for γ-ray transitions of ^{160}Yb observed in the ^{148}Sm(^{16}O, $4n$)^{160}Yb reaction at $E(^{16}O) = 95$ MeV.

Transition I_i	→ I_f	E_γ (keV)	I_γ (%)	a_2/a_0	$I(0°)/I(90°)$
2	0	243.0	100(3)[a]	0.42(5)	
4	2	396.3	115(2)	0.37(2)	1.9(1)
6	4	508.7	83(2)	0.42(2)	1.7(2)
8	6	589.3	74(2)	0.41(3)	2.0(1)
10	8	637.3[b]	59(4)	0.34(2)	1.8(2)
12	10	586.6	39(1)	0.41(3)	1.9(1)
14	12	403.9	38(1)	0.39(3)	1.9(1)
16	14	484.0	30(1)	0.40(3)	1.9(1)
18	16	578.5	30(1)	0.39(3)	1.8(1)
20	18	663.9	27(1)	0.30(4)	1.9(1)
22	20	736.6	16(1)	0.30(7)	1.5(2)
24	22	795.9	10(2)	0.32(10)	1.7(2)
26	24	836.8	8(2)	0.26(9)	1.9(2)
28	26	831.1	4(1)		2.0(4)
(30)	28	965.8	2(1)		

[a]Not corrected for conversion electrons.
[b]Underlying contaminant.

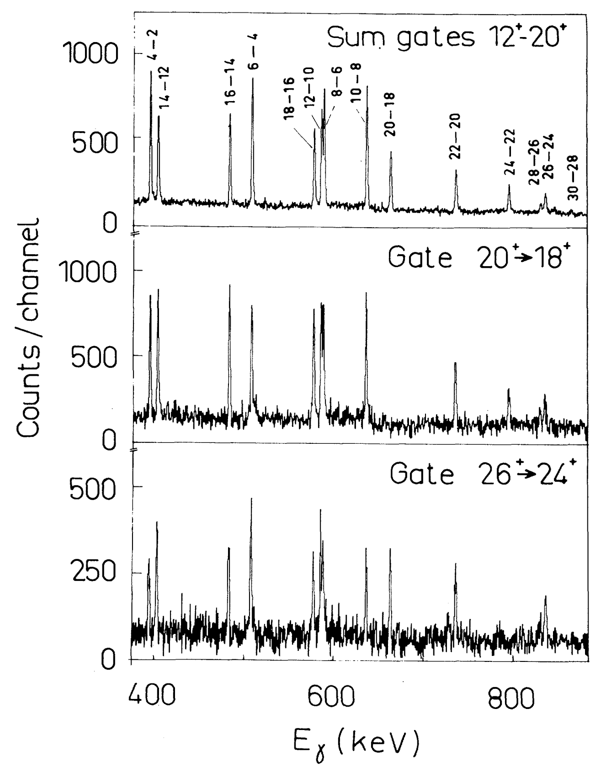

FIG. 1. Coincident γ-ray spectra from the reaction ^{148}Sm(^{16}O, $4n$)^{160}Yb summed for the two bombarding energies 95 and 105 MeV. A 847-keV γ ray, present in all coincidence spectra, is attributed to the ^{56}Fe(n,n') reaction.

in coincidence with a multiplicity filter consisting of six 15.2×12.7-cm^2 NaI crystals surrounding the target at a distance of 18 cm. In this way folded Ge(Li) spectra were simultaneously recorded. The γ-ray angular distribution measurements have been done with an Ge(Li)-NaI Compton suppression spectrometer.

The experimental results obtained at $E(^{16}O) = 95$ MeV are summarized in Table I. The yrast level scheme up to $I = 28\hbar$ and tentatively up to $I = 30\hbar$ is established. No extension to higher yrast levels was possible from the data collected at $E(^{16}O) = 105$ MeV. Some of the γ-γ coincidence spectra are shown in Fig. 1. Small Doppler broadening effects appear on the γ lines above the $I = 22^+$ state. This can explain the systematical lowering of the a_2 value observed for these transitions. The relative intensities for the transitions from states with $I \leq 22\hbar$ are those extracted from the angular distribution data, whereas the summed coincidence spectra with gates set on transitions between levels of spin $20\hbar$ to $12\hbar$ were used to obtain the intensities of the other transitions. Directional correlation with oriented nuclei (DCO) ratios $R(90°, 0°)$ were also derived up to transition $28 \rightarrow 26$, mainly from summed coincidence spectra with gates set on appropriately chosen transitions. The measured values were found to be close to 1.0 which implies the same multipolarity character for all transitions. The averaged intensity ratios $I(0°)/(90°)$ between the yields of the γ rays measured at 0° and 90° in coincidence with three and four NaI detectors are also given in Table I. These ratios, as well as the a_2 values from the angular distributions and the DCO ratios, are consistent with stretched $E2$ decays.

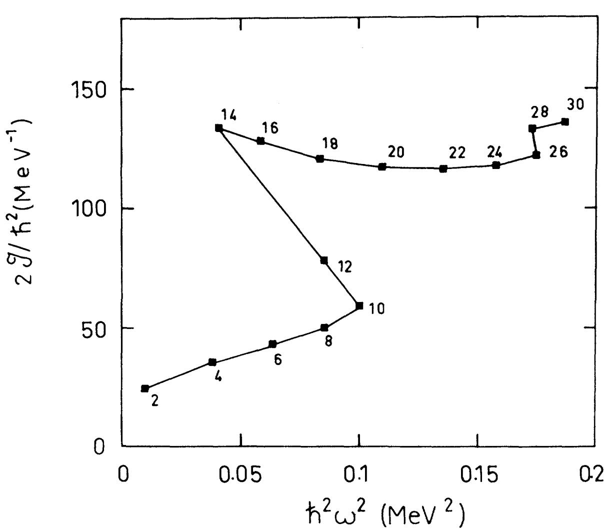

FIG. 2. Plot of the moment of inertia vs the square of the angular velocity for ^{160}Yb.

A first discontinuity in the yrast-level sequence is evident from the sharp energy decrease of the transitions after the $10 \rightarrow 8$ one. A second discontinuity is revealed by the close spacing of the 836.8- and 831.1-keV transitions. Figure 2 shows a plot of the moment of inertia versus the square of the rotational frequency. The two discontinuities lead to rapid increase of the moment of inertia of the states with $I \geq 12\hbar$ and $I \geq 28\hbar$.

The first sharp backbending of ^{160}Yb starts at spin $12\hbar$, at approximately the same rotation frequency as seen for the first anomaly in ^{158}Er. The second discontinuity appears also at the same spin value for both nuclei, but is more pronounced in ^{160}Yb. It should be stressed that within the experimental errors the γ-ray intensities attributed to the $24^+ \rightarrow 22^+$ and $26^+ \rightarrow 24^+$ transitions (see Table I) are only slightly in favor of the 837-keV transition to precede the 796-keV transition. A reversing of this sequence would result in an even stronger backbending effect.

It has been emphasized in Ref. 9 that the second irregularity in the yrast spectrum of ^{158}Er should be a proton effect. The interpretation of the upbending in ^{158}Er by the rapid alignment of two $h_{11/2}$ protons is equivalent to the description of the phenomenon as resulting from the crossing of two weakly interacting rotational bands.[12] One of these bands is the ground-state band and the other one the rotational band with two aligned $h_{11/2}$ protons. For $Z = 68$ these bands should interact particularly weakly at their crossing region. In neighboring nuclei with charge numbers 66 and 70 the interaction is expected to be significantly stronger and the anomaly smoother. The ^{160}Yb nucleus is one of the neighboring isotones of ^{158}Er. The first backbending in these nuclei look similar, reflecting the same structure of their neutron components. For the second anomaly one expects that, as a result of the oscillatory dependence of the interaction between the two crossing bands, a stronger bending of the moment of inertia will be seen for ^{158}Er than for ^{160}Yb and ^{156}Dy. Experimentally, however, the strongest bending is observed in ^{160}Yb. It may be possible that the interaction minimum predicted at $Z = 68$, occurs at a slightly higher Z value. This would agree with the observation of the second backbending effect in ^{160}Yb and ^{158}Er, while no such effect has been observed for ^{156}Dy.

The authors are greatly indebted to Dr. Polszajczak for fruitfull discussions.

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