^{159}Yb may be more typical for the statistical decay process. The absence of hindrance may be explained by a closer similarity of these states to the highly excited high-spin states. Unfortunately, our values for $t_{1/2}^{\text{feed}}$ in ^{159}Yb are only upper limits, also the intensity of $E2$ transitions has to be measured yet for this nucleus. We therefore cannot decide whether the $E2$ component of the continuum radiation has s.p. strength or whether it is collectively enhanced as both possibilities are compatible with our present data.

Summarizing, we conclude that the multiplicity of the statistical pre-yrast cascades increases characteristically with increasing effective deexcitation energy and that $E2$ character dominates the continuous γ radiation up to at least about 5 MeV. Still open questions are whether the $E2$ part in the statistical decay process is collectively enhanced and whether the slow feeding of the gsb states in ^{158}Yb is a particular property of this nucleus or whether it indicates a more generally occurring K hindrance in the decay of the highly excited high-spin states.

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High-Spin States in ^{165}Tm

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We have studied the properties of the four rotational bands developed in ^{165}Tm for high spin values. The $\frac{1}{2}^-$ [541] is the only one which does not show the backbending effect. These results are in agreement with other recent experiments showing the role of the $h_{9/2}$ protons in the backbending effect. A strong $\Delta K = 3$ coupling between $\frac{1}{2}^+$ [411] and $\frac{7}{2}^+$[404] bands has been found.

Studies of backbending in the odd-A nuclei have been used as a test of validity of the different proposed backbending models.[1] In good agreement with the rotation-alignment model,[2] experiments on Dy,[3] Er,[1] and Yb[4] have shown the importance of $i_{13/2}$ neutrons in the backbending behavior. Recent results on odd-proton nuclei, Lu[5] and Re,[6] have proved that the $h_{9/2}$ proton subshells participate actively in backbending.

In order to obtain more information on the contribution of the proton subshells to backbending we have carried out a study of the high-spin levels of the ^{165}Tm. This nucleus was selected for the following reasons: (1) The two even-even nuclei ^{164}Er and ^{166}Yb which differ from the ^{165}Tm by one proton show the "backbending effect."[7,8]

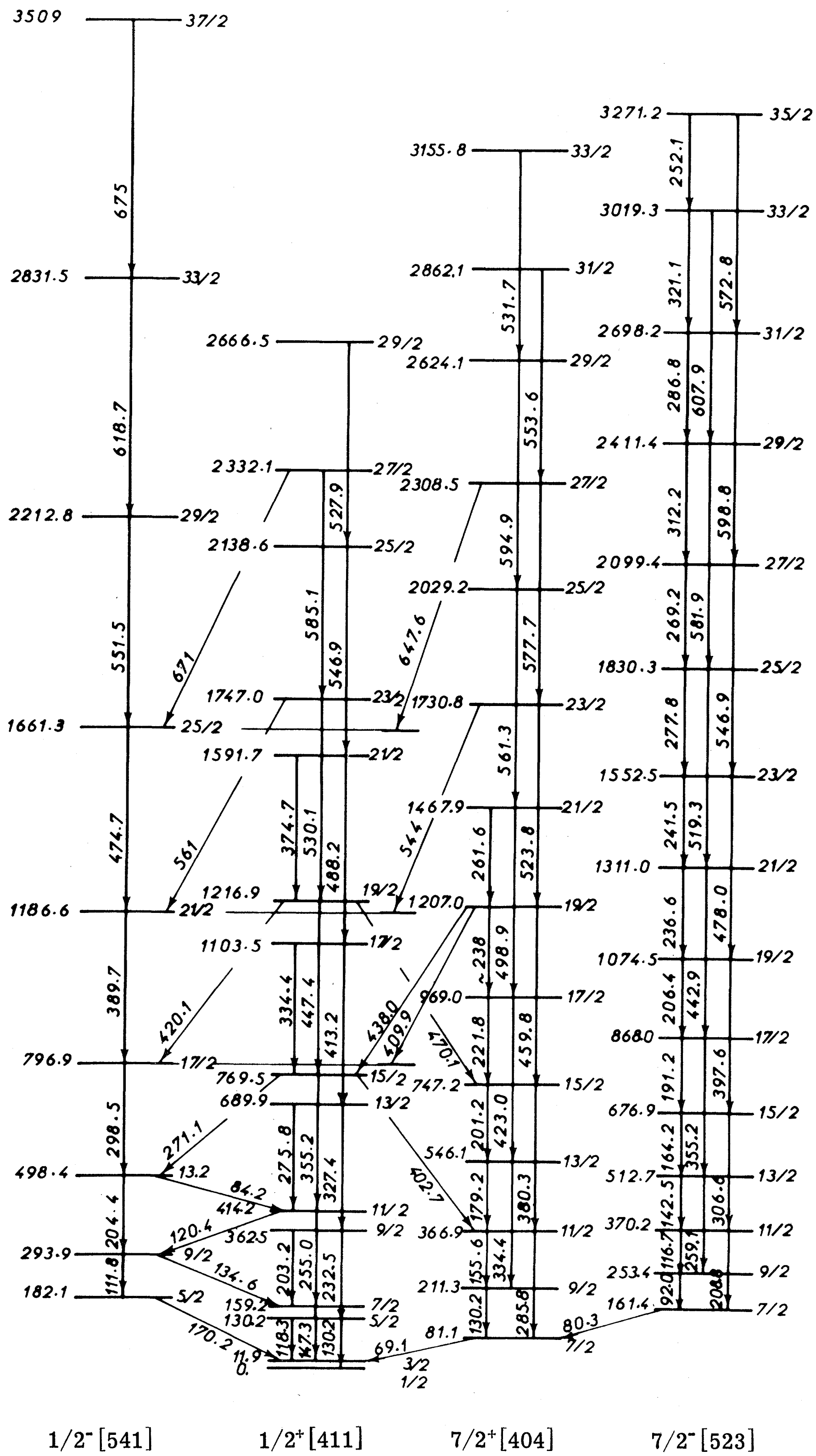

FIG. 1. Level scheme of ^{165}Tm.

(2) The rotational bands built on $\frac{1}{2}^-[541]$, $\frac{7}{2}^-[523]$, $\frac{1}{2}^+[411]$, and $\frac{7}{2}^+[404]$ intrinsic states, originating from the $h_{9/2}$, $h_{11/2}$, $d_{3/2}$, and $g_{7/2}$ spherical subshells respectively, are simultaneously developed as studies of $(\alpha, xn\gamma)$[9] and $(^{11}\mathrm{B}, xn\gamma)$[10] reactions have shown, and consequently should indicate the role played in the backbending process by the different subshells. However the spin values reached in these experiments[9,10] were not high enough to observe the backbending on the $J = f(\omega^2)$ curve.

In order to feed higher spin levels, the α beam energy chosen was 53 MeV (3 MeV above the energy used in Ref. 9). A long-counting γ-γ coincidence experiment (4×10^7 events stored) and angular-distribution measurements with good statistics were performed using the experimental arrangement for in-beam γ-ray spectroscopy at the Grenoble cyclotron.[11]

The analysis of the results allowed us to build the level scheme shown in Fig. 1. Each rotational band is developed to spin values at least two units higher than in previous works.[9,10] The $E2$ cascades connecting the odd-$(I+\frac{1}{2})$ levels in the $\frac{1}{2}^+[411]$ band have been identified up to spin $\frac{29}{2}$ without ambiguity; the $\frac{7}{2}^+$ band has been modified above the $\frac{25}{2}^+$ level; several interband $\Delta K = 3$ transitions ($\frac{1}{2}^+[411] \rightleftharpoons \frac{7}{2}^+[404]$) have been observed by means of γ-γ coincidences.

With the use of the formulas defined in Ref. 5,

$$\bar{R}^2 = (\vec{I} - \vec{j})^2,$$

$$R^2 = I(I+1) - K^2 + (-)^{I+1/2}\,a(I+\tfrac{1}{2})\,\delta_{K,1/2},$$

$$2J/\hbar^2 \approx R^2/\Delta E, \quad (\hbar\omega)^2 \approx (\Delta E/\Delta R)^2,$$

and the values of ΔE taken in the level scheme (Fig. 1), we have plotted the quantity $2J/\hbar^2$ versus $(\hbar\omega)^2$ for the four bands of ^{165}Tm and also for the ground band of ^{164}Er and ^{166}Yb in Fig. 2.

On this figure, we observe that (a) the $\frac{1}{2}^+$, $\frac{7}{2}^+$, and $\frac{7}{2}^-$ rotational bands backbend at rotational frequencies slightly lower than in even-even neighboring nuclei; (b) the $R = I - j$ values necessary to reach the backbending point in these bands are lower ($R > 11$) than in the even-even nuclei ($R > 14$); (c) the $\frac{1}{2}^-[541]$ band does not backbend for rotational frequency values as high as $(\hbar\omega)^2 = 0.112$.

The last point, also observed in the case of ^{167}Lu,[5] implies that the $h_{9/2}$ protons are strongly involved in the mechanism of backbending, in agreement with the rotation-alignment model.[1] It is surprising to note that the $\frac{7}{2}^-[523]$ band backbends because the $h_{11/2}$ protons also seem to satisfy the conditions for Coriolis decoupling of a nucleon pair. The angular momentum j has a high value, $j = \frac{11}{2}$; the matrix element $\langle\Omega\pm 1|j_\pm|\Omega\rangle$ has a mean value of 4.8 for $\beta = 0.3$ (3.8 for $h_{9/2}$). The different behaviors of these two subshells might result from their respective locations compared with the Fermi level. The low-Ω states of the $h_{11/2}$ are far from the Fermi level, while in the case of the $h_{9/2}$, only the low-Ω states are filled, i.e. the Ω states for which the Coriolis interaction is the strongest. The situation is probably similar to the one observed in Os by Lieder[12] who suggests that the backbending in $^{181-182}$Os is due to the $h_{9/2}$ protons and not to the $i_{13/2}$ neutrons. In this case, the states near the Fermi level are the $\frac{9}{2}^+[624]_n$ and the $\frac{1}{2}^-[541]_p$. Consequently the $h_{9/2}$ protons occur with Ω values much lower than those of the $i_{13/2}$ neutrons.

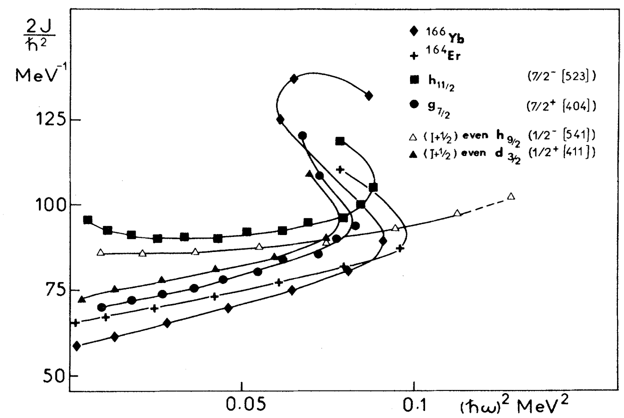

FIG. 2. $2J/\hbar^2$ versus $\hbar^2\omega^2$ for the observed bands in ^{165}Tm and for even-even ^{164}Er and ^{166}Yb.

Directly connected with backbending, the anomalous branching ratios observed for high-spin levels in the $\frac{7}{2}^-[523]$ rotational band appear. From these branching ratios, $(g_K - g_R)/Q_0$ experimental values can be deduced. In Fig. 3, we have reported the values of $(g_K - g_R)/Q_0$ which can be deduced without ambiguity due to complex γ rays. In spite of a strong Coriolis coupling, we may deduce, for levels with spin I lower than $\frac{27}{2}$, a mean value of $(g_K - g_R)/Q_0 = 0.12$. For states above backbend, we observe a fast and strong variation of this ratio (0.153 and 0.245 for $I = \frac{32}{2}$ and $I = \frac{35}{2}$ respectively). Such an effect is not surprising if we consider that the Coriolis antipairing model as well as the rotation-alignment model predict a strong variation of the g_R factor at the backbend.[13,14] Moreover the values of the intrinsic gyromagnetic factor g_K for the upper

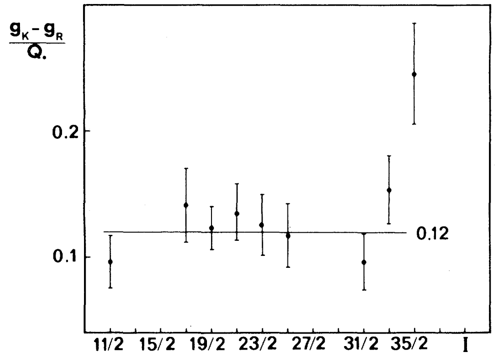

FIG. 3. Variation of the experimental $(g_K - g_R)/Q_0$ ratio in the $\frac{7}{2}^-$ [523] rotational band.

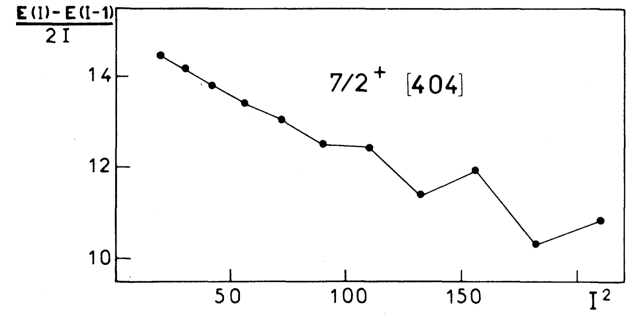

FIG. 4. Plot of $[E(I) - E(I-1)]/2I$ versus I^2 for the $\frac{7}{2}^+$ [404] rotational band.

part of the band correspond to that of the "supra" band while that of the lower part of the band, i.e. $g_K = 1.26$, corresponds to the $\frac{7}{2}^-$[523] band.[15] The simultaneous change of the three quantities g_K, g_R, and Q_0 makes it very difficult to explain the variation of the ratio $(g_K - g_R)/Q_0$. A similar effect has been observed for the $\frac{7}{2}^-$ [523] band in the ^{159}Ho.[16]

A detailed study of the $\frac{7}{2}^+$ [404] band shows an interesting effect not observed in previous works[9,10]—the $\Delta K = 3$ coupling between the $\frac{7}{2}^+$ [404] and $\frac{1}{2}^+$ [411] rotational bands. The first surprising fact is the anomalous behavior of the $\Delta E = f(I^2)$ curve, drawn for the $\frac{7}{2}^+$[404] band, shown in Fig. 4. Usually this band is unaffected by the Coriolis interaction and gives a smooth curve, slowly decreasing as a result of the stretching effect. This is not the case for ^{165}Tm (Fig. 4). The second unexpected fact is given by the analysis of the γ-γ coincidences. We find several interband transitions, the first with an $E2$ character (in the case $\frac{7}{2}^+$ [404] $\rightleftharpoons \frac{1}{2}^+$ [411]), the second with an $E1$ character (in the case $\frac{7}{2}^+$ [404] $\to \frac{1}{2}^-$ [541]). In terms of a pure configuration for each rotational state, these transitions would be K forbidden, and would have a negligible intensity compared with those of the $E2$ intraband transitions. To explain these interband transitions one has to assume a mixing $\alpha|\frac{1}{2}^+\rangle + \beta|\frac{7}{2}^+\rangle$ for the considered levels of the $\frac{1}{2}^+$ and $\frac{7}{2}^+$ bands. This $\Delta K = 3$ coupling is mostly important when the energy gap between states of identical spin is small. This is exactly what we observe experimentally: States especially influenced by this effect are the $\frac{19}{2}^+$ for which the gap is only 9.9 keV and the $\frac{23}{2}^+$, $\frac{15}{2}^+$, and $\frac{27}{2}^+$ with energy gaps of 16.2, 22.3, and 23.6 keV, respectively. By use of the intraband $B(E2)$ formula,

$$B(E2, I_i \to I_f) = \tfrac{5}{16} e^2 Q_0^2 (I_i\, 2K0 | I_f K)^2,$$

it is possible to estimate the mixing for the different states. We have made the calculation for the six levels with spin values $\frac{11}{2}^+$, $\frac{15}{2}^+$, and $\frac{19}{2}^+$. We obtain $\alpha_{11/2}^2 = 0$, $\alpha_{15/2}^2 = 11.5\%$, and $\alpha_{19/2}^2 = 66\%$.

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Search for Fragment Emission from Nuclear Shock Waves*

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Energy spectra and angular distributions have been measured of ^{3}He and ^{4}He fragments emitted from Ag and U targets, bombarded with 2.7-GeV protons, and 1.05-GeV/nucleon α particles and ^{16}O ions. All cross sections increase dramatically with projectile mass. No narrow peaks are found in the angular distributions or in the energy spectra.

For central collisions of nuclei at relativistic energies, recent theoretical investigations[1-6] have focused on the question of how large amounts of energy and momentum are transferred from projectile to target nucleons, and on the early events in the evolution of hot, high-density regions as thermal equilibrium is approached. In particular, the formation of squirts of nuclear matter, or of nuclear shock waves[7] carrying large transverse momentum and compressional energy, has been predicted.[2-5] These would be formed in central collisions if the projectile velocity exceeds the nuclear sound velocity $\nu_0 \approx 0.2c$. The models are in disagreement about the angles in the lab system at which emission should occur, some predicting[3,4] a narrow peak at angles ranging from 25° to 45° depending systematically on the incident energy while others anticipate a broad range of forward angles for the fragments.[5] There is agreement, however, as to the expectation that such processes should have a high fragment multiplicity, with energies ranging far above the evaporative domain.

In an experiment with Lexan foil detectors, Crawford *et al.*[8] investigated fragments resulting from the interaction of a 2.1-GeV/nucleon ^{12}C beam with Au. Nonevaporative tails in the spectra were observed but angular distributions showed no significant peaks. Kullberg and Otterlund[9] have studied the emission of α particles produced in nuclear emulsions by heavy cosmic-ray nuclei. The angular distributions deviate markedly from evaporation-model predictions at angles around 45°. The authors observe that the high-energy α particles result primarily from high-multiplicity (star event) target fragmentations.[10]

The most provocative experiment thus far is a recent study of prong angular distributions of star events produced in AgCl crystals irradiated with 0.87-GeV/nucleon ^{16}O ions by Baumgardt *et al.*[3] They report the observation of narrow peaking in $d\sigma/d\theta$ at 40°, with an angular width of about 20° full width at half-maximum (FWHM). The prongs analyzed in that experiment are due to protons less than 28 MeV and He nuclei less than 200 MeV/nucleon, with no further discrimination with respect to energy and isotope. The