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Evidence for signature-dependent transition rates at large rotational frequencies

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The signature dependence of transition rates has been measured for the first time at and above the rotational frequency of the band crossing. The disappearance of an observed large signature dependence in both level energies and transition rates may be interpreted as a shape change. A large change in the transition rates in the band-crossing region and an apparent signature dependence of $\Delta I = 1$, $E2$ transitions are difficult to understand within the available models.

[NUCLEAR STRUCTURE ^{157}Ho; measured γ-γ coin, $I_\gamma(\theta)$; deduced levels, J, π, δ, branching ratios, $g_K - g_R$.]

Sufficient detailed spectroscopic data are available for even-even and odd-N nuclei so that a systematic picture of quasineutron states is beginning to emerge. In contrast, very few data are available for odd-Z nuclei at the angular frequencies of the lowest-frequency backbend. Such data for odd-Z systems would give information on how the neutron alignment affects the quasiproton configuration. In addition, because of the large intrinsic proton g factors it is possible to deduce magnetic transition probabilities at high spins. This Communication presents such data, which for the first time give a measure of the $M1$ transition rates at and above the angular frequencies of the $i_{13/2}$ neutron band crossings.

The ^{146}Nd(^{15}N,$4n$) reaction at a bombarding energy of 74 MeV has been used to study the decay of ^{157}Ho. The levels of the nucleus ^{157}Ho have been studied earlier by in-beam γ-ray techniques[1] and particle transfer reactions.[2] The decay scheme shown in Fig. 1 is constructed from γ-γ coincidence data obtained using an array of five Compton-suppressed Ge(Li) detectors.[3] Angular distributions of the γ rays, obtained in a separate experiment, are used to establish the multipolarity and $M1$-$E2$ mixing ratios of the cascading transitions.

The level scheme information is transformed to excitation energies in a rotating intrinsic frame (Routhians, e') as a function of the angular frequency $\hbar\omega \approx E_\gamma/2$, using the formalism described in Ref. 4. A plot of the experimentally constructed e''s shown as a function of $\hbar\omega$ for this nucleus is compared with that of ^{155}Ho and ^{159}Ho,[5,6] in Fig. 2. In ^{157}Ho, as in ^{159}Tm,[7] the sizable signature splitting observed for the single-quasiproton Routhians disappears when the $i_{13/2}$ neutrons also are aligned. This produces a small shift (≈ 10 keV) in the crossing frequency between these two bands; however, these crossing frequencies are in general agreement with those of other $N = 90$ isotones. ($\hbar\omega_0 = 0.268$ and 0.278 MeV for the two bands in ^{157}Ho compared with 0.276 and 0.269 MeV for ^{158}Er and ^{160}Yb, respectively,[8] and 0.261 and 0.275 MeV for the favored and unfavored proton bands[7] in ^{159}Tm). Therefore, the odd quasiproton (in contrast to an odd quasineutron) apparently does not significantly affect the magnitude of the neutron pairing-correlation parameter Δ_n (Ref. 8). The yrast bands of the odd-Ho isotopes are based on an $h_{11/2}$ proton configuration. Thus a similar signature-dependent energy splitting and alignment ($\equiv -de'/d\omega$) would be expected if the nuclear shape is independent of the neutron number. A systematic change from larger to smaller alignment and signature splitting is observed with increasing N for the single-quasiproton bands below the backbends (see Fig. 2). The increase in both the alignment and the signature splitting of these single-quasiproton configurations with decreasing neutron number can be explained by an increased low-Ω component in the wave function of the single-quasiproton states. Similarly, the decrease in the signature splitting of the Routhians for the yrast decay sequences in ^{157}Ho above the band crossings indicates less low-Ω components in the quasiproton wave functions when the neutrons are aligned. It is not possible to establish

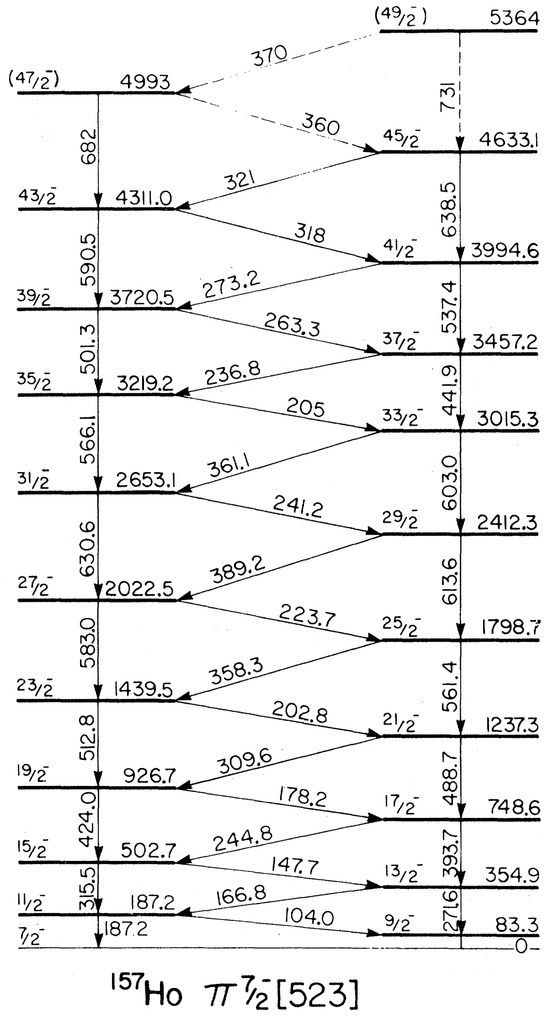

FIG. 1. Partial level scheme for ^{157}Ho.

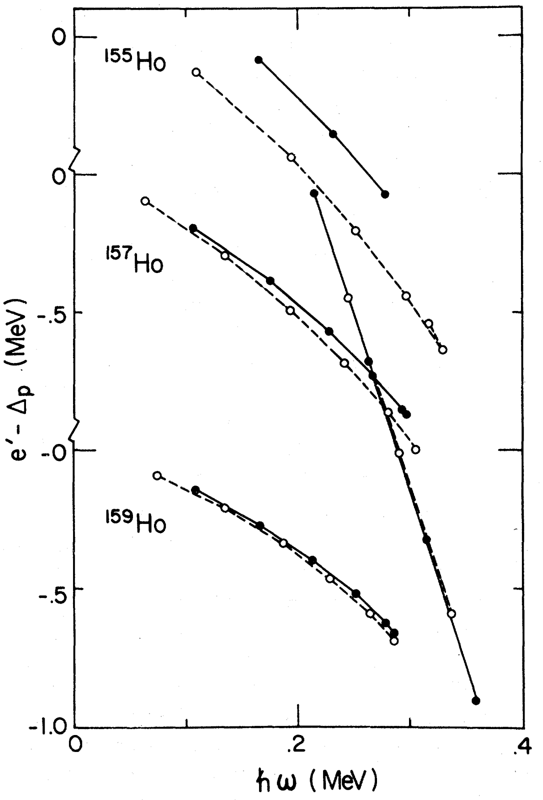

FIG. 2. Experimental Routhian, e', as a function of $\hbar\omega$ for the yrast bands, based on the $\frac{7}{2}^{-}[523]$ orbital, of ^{155,157,159}Ho. The solid and open circles correspond to transitions in the $\alpha=\frac{1}{2}$ and $-\frac{1}{2}$ bands, respectively. A reference frame (Ref. 4) of moment of inertia $\mathscr{I}=\mathscr{I}_0+\mathscr{I}_1\omega^2$ with $\mathscr{I}_0=10$, 20, and 26 MeV$^{-1}\hbar^2$ and $\mathscr{I}_1=120$, 90, and 90 MeV$^{-3}\hbar^4$ has been subtracted for ^{155}Ho, ^{157}Ho, and ^{159}Ho, respectively.

definitively the physical basis of the increased low-Ω component in these single-quasiproton configurations; however, either a decrease in ϵ_2 or an increase in ϵ_4 will bring the low-Ω quasiproton configurations nearer to the Fermi surface.

The amplitude of low-Ω components in the wave function also is expected[9,10] to influence the $M1$ transition matrix elements in such a way that the $I(\alpha=\frac{1}{2})\leftrightarrow I-1(\alpha=-\frac{1}{2})$ (type A of Ref. 10) is reduced and the $I(\alpha=-\frac{1}{2})\leftrightarrow I-1(\alpha=\frac{1}{2})$ (type B of Ref. 10) is enhanced compared to the strong coupling rotational model. Even without knowing the absolute transition rates it is possible to compare $M1$ rates to the inband $E2$ rates within each signature

$$\frac{B(M1)(\text{type A})}{B(E2)\alpha=\frac{1}{2}}$$

and

$$\frac{B(M1)(\text{type B})}{B(E2)\alpha=-\frac{1}{2}}$$

through the experimentally observed branching ratios

$$\lambda_I=\frac{T_\gamma(I\to I-2)}{T_\gamma(I\to I-1)}\quad .$$

The dependence of λ on the $\Delta I=1$ $B(E2)$ type A or B is negligible,[11] and the intrinsic quadrupole moment is expected to be independent of signature. It also is possible by means of a measured mixing ratio

$$\delta_I=\frac{\langle I\,\|M(E2)\|\,I-1\rangle}{\langle I\,\|M(M1)\|\,I-1\rangle}$$

to compare the $M1$ rates to the $E2$ cross band transitions (types A and B). If a definite K value is assumed, the branching and mixing ratios can be reduced[12] to the ratios $(g_K-g_R)/Q_0$, where the Q_0 is the intrinsic quadrupole moment which could, in principle, also be signature dependent. The sign of $(g_K - g_R)$ is determined from the mixing ratio δ_I assuming a positive value of Q. The $(g_K - g_R)$ values deduced from the branching and mixing ratios, assuming $Q_0 = 7$ e b and $K = \frac{7}{2}$, are plotted in the lower and upper parts of Fig. 3, respectively, as a function of the angular frequency $\hbar\omega$. A very pronounced signature splitting is observed in the $(g_K - g_R)$ values obtained from branching ratios in these bands up to the band crossing. In the region of the band crossing, the magnitude of $(g_K - g_R)$ apparently increases dramatically for both signatures. (This could be an effect of a drastic decrease in Q_0.) Above the band crossing the signature splitting is greatly reduced, and the values of $(g_K - g_R)$ for both bands approach that of the $\alpha = \frac{1}{2}$ band at low $\hbar\omega$. The values of $(g_K - g_R)$ deduced from mixing ratios agree with the values obtained from branching ratios for the $\alpha = \frac{1}{2}$ band, as seen from the upper part of Fig. 3; no signature splitting is observed. A lower value of K applied in the analysis, assuming rigid rotation, would increase the magnitude of $(g_K - g_R)$, but not affect the signature splitting deduced from the branching ratios λ. Since the mixing ratio δ in the rigid rotor description does not depend on K, the agreement observed between the $(g_K - g_R)$ values obtained from λ and δ for the transitions from the $\alpha = +\frac{1}{2}$ positive signature state would be destroyed if a lower K value is applied.

From these results it seems necessary to assume a signature dependence in both the $M1$ and $E2$, $I \rightarrow I-1$ (but not in the $E2$, $I \rightarrow I-2$) transition probabilities below the band crossings. It is possible to qualitatively understand the signature dependence in the $M1$ transitions. Calculated $M1$ transition rates[10] for shapes (ϵ_2, ϵ_4) and pairing (Δ_p) necessary to reproduce the observed signature splitting and alignments below the band crossings in the Routhian (Fig. 2) do show a pronounced signature dependence. This signature dependence, however, increases with $\hbar\omega$ and is smaller than observed over the total region below the band crossings. Above the band crossing the lack of observed signature dependence in both excitation energy and $M1$ transition rates is consistent with, and probably is the result of, a shape change which, according to the data, must take place quite suddenly at the band crossing. Such a sudden change in shape has been predicted[13] to occur at a specific I in nuclei around $N = 90$. In contrast, it is not possible to even qualitatively describe the apparent signature dependence in $E2$, $I \rightarrow I-1$ transitions. The small dependence predicted[11] is in the opposite direction of that observed.

The behavior of the $(g_K - g_R)/Q_0$ values in the band-crossing region also presents a distinct problem. A decrease in $B(E2)$ value of the magnitude observed [provided the $(g_K - g_R)$ value does not change markedly[14]] can only be expected if the interaction between the crossing bands is extremely small. In such a case only one transition should be affected in contradiction with the experimental situation, where the apparent $B(E2)$ decrease is spread over at least three transitions.

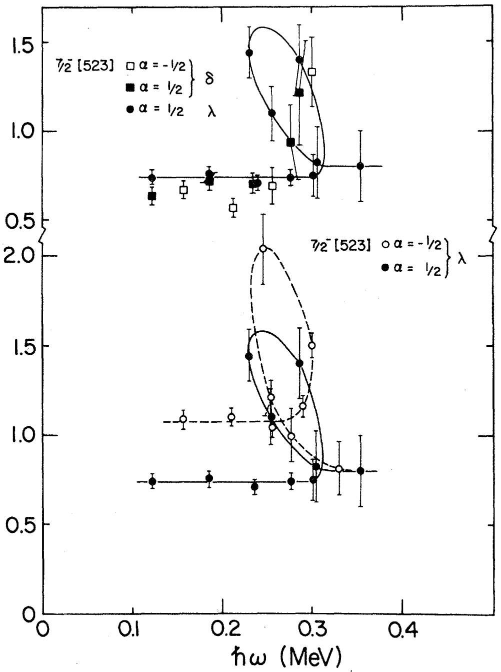

FIG. 3. The quantity $(g_K - g_R)$ as a function of $\hbar\omega$. The solid and open squares are the values calculated from the experimental mixing ratios δ for transitions I $(\alpha = \frac{1}{2}) \rightarrow I-1$ $(\alpha = -\frac{1}{2})$ and I $(\alpha = -\frac{1}{2}) \rightarrow I-1$ $(\alpha = \frac{1}{2})$, respectively, from the expression

$$\frac{(g_K - g_R)}{Q_0} = \frac{E_\gamma(I \rightarrow I-1)\ \mathrm{keV}}{5.36 \times 10^2[(2I-2)(2I+2)]^{1/2}} \frac{1}{\delta} .$$

The solid and open circles are the values calculated from the experimental branching ratios λ for transitions I $(\alpha = \frac{1}{2}) \rightarrow I-1$ $(\alpha = -\frac{1}{2})$ and $I(\alpha = -\frac{1}{2}) \rightarrow I-1$ $(\alpha = \frac{1}{2})$, respectively, from the expression

$$\left| \frac{g_K - g_R}{Q_0} \right| = \frac{E_\gamma(I \rightarrow I-1)\ \mathrm{keV}}{5.36 \times 10^2[(2I+2)(2I-2)]^{1/2}} \times \left[\left(\frac{E_\gamma(I \rightarrow I-2)}{E_\gamma(I \rightarrow I-1)} \right)^5 \frac{F(I,K)}{\lambda} - 1 \right]^{1/2}$$

with

$$F(I,K) = \frac{(2I+2)(2I-2+2K)(2I-2-2K)}{4(2K)^2(2I-1)} .$$

A value of $Q_0 = +7$ e b has been assumed for the intrinsic quadrupole moment. The sign of $(g_K - g_R)$ is determined from δ to be positive.

In summary, a signature dependence is observed consistently in both excitation energy and transition strength of $I \rightarrow I-1$ transitions. The magnitude of this signature dependence is a probe of nuclear wave function, which is dependent on the nuclear shape. Therefore, a shape change is postulated to take place at the band crossing in ^{157}Ho in contrast to ^{159}Ho, where there is neither signature dependence in the excitation energies (Fig. 2) nor in the $B(M1)$ values.[6] The apparent signature dependence in the $B(E2,\ I \rightarrow I-1)$ transitions is not quantitatively understood. Likewise, the spread in reduced $B(E2,\ I \rightarrow I-1)$ values over several states presents a puzzle. Systematic data of similar type might prove valuable in tracing the nuclear wave functions to more detail than recent comparisons to cranked shell-model calculations can provide.[4]

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