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Identical Gamma-Vibrational Bands in ^{165}Ho.

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Abstract

The structure of ^{165}Ho at moderate spins has been investigated by means of Coulomb excitation. Two γ-vibrational bands ($K^\pi = \frac{11}{2}^-$ and $K^\pi = \frac{3}{2}^-$) are observed, with very nearly identical in-band γ-ray energies. Gamma-ray branching ratios are analysed to extract information on Coriolis mixing, and the role of the K quantum number in identical bands is discussed.

1. Introduction

The recent discovery of "identical" (isospectral) superdeformed bands between neighbouring isotopes and isotones [1,2] has lead to a great deal of interest in isospectral bands, both superdeformed and normally deformed. Models have been proposed to explain how these pairs of bands can arise, based on such concepts as pseudospin symmetry [2,3]; complete understanding of the origins of such bands has however proved elusive.

If simpler cases of isospectral bands, such as identical bands in the same nucleus, can be found and understood, this may perhaps assist in obtaining theoretical understanding of the more complex case of identical bands in neighbouring nuclei. One candidate for such a pair of bands is the case of collective γ-vibrational bands built on the rotational ground state band of odd nuclei.

2. Experiment and analysis

The structure of ^{165}Ho at moderate spins has been investigated by means of Coulomb excitation with 5.4 MeV/u ^{209}Bi ions from the TASCC facility at Chalk River. Gamma-gamma coincidences were detected in the 8π spectrometer, composed of 20 Compton-suppressed HPGe detectors around a 71-element BGO ball. Two separate experiments were performed. In the first one, a thick Ho target was used, and 1.6 million γ-γ events were collected with at least 2 HPGe detectors and 3 elements of the BGO ball in coincidence. The target for the second experiment consisted of 2 mg/cm^2 of Ho on a thick gold backing in order to stop the recoiling Ho ions more rapidly. Over 2 million γ-γ events were collected in this experiment, with the same required conditions. No Doppler-shift corrections were applied to the data from either experiment. The reduced stopping time in the gold-backed target allowed observation of typically one to two more transitions at the top of each band.

It should be noted that the beam energy used here is above what would normally be considered "safe" for Coulomb excitation experiments, *i.e.* nuclear excitations and transfer may not be excluded. No attempt has been made to extract absolute transition quadrupole moments, *etc.*; rather, Coulomb excitation has been used simply as a means of populating the states to be studied.

The data were replayed into two-dimensional matrices, and analysed using the code escl8r [4]. Excellent sensitivity was obtained from the use of γ-γ coincidences; cascades of intensity less than 0.1% of the total intensity are easily observable.

3. Results and discussion

The level scheme deduced from the present work is shown in figure 1. In addition to the $\frac{7}{2}^-[523]$ ground band, two γ-vibrational bands are populated. These bands have $K^\pi = \frac{11}{2}^-$ and $K^\pi = \frac{3}{2}^-$, arising from the parallel and anti-parallel alignment of the $K = 2$ γ vibration with the ground band. They are observed to spins of $(\frac{37}{2})$ and $(\frac{33}{2})$, respectively; in previous experiments [5] they were identified to spins of $(\frac{15}{2})$ and $(\frac{13}{2})$. Figure 2 shows gated spectra for these two bands, together with the total projection. Also observed to higher spins than in previous experiments are the $\frac{3}{2}^+[411]$ and $\frac{1}{2}^+[411]$ bands. Two new structures are shown in figure 1, and appear to form a coupled band with large signature splitting; no structural assignment has yet been made for these bands. The ground state band and $K = \frac{11}{2}$ band have also been studied recently by the Rochester group [6].

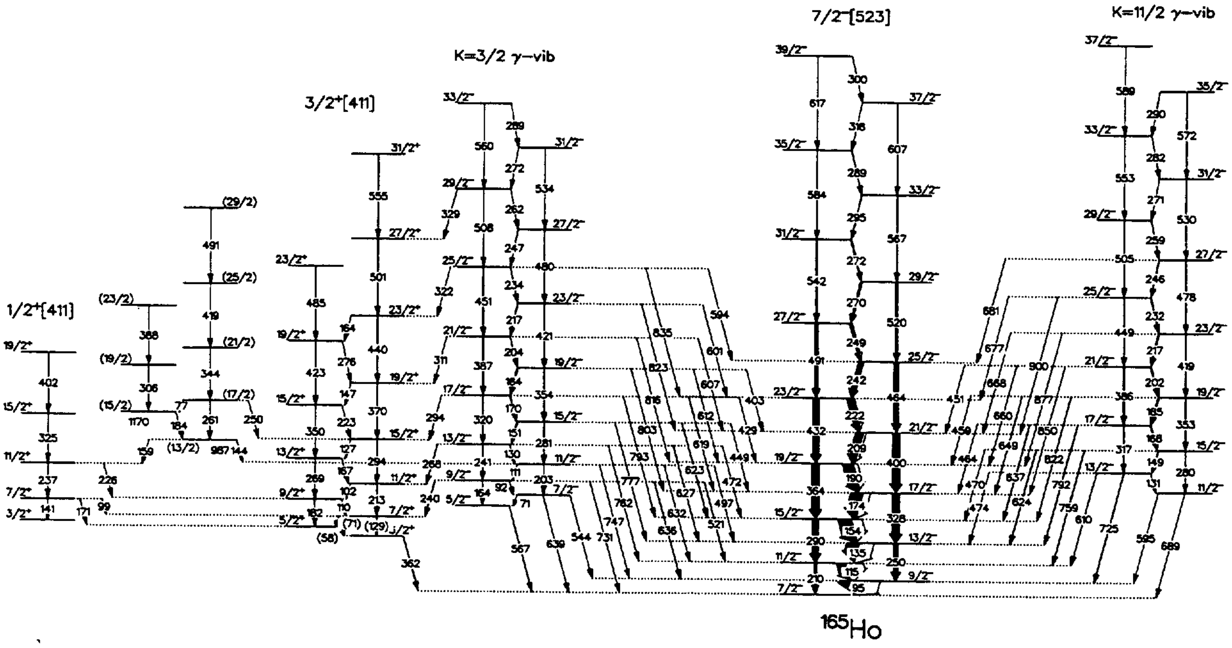

Figure 1: Partial level scheme of ^{165}Ho, as observed in the present work.

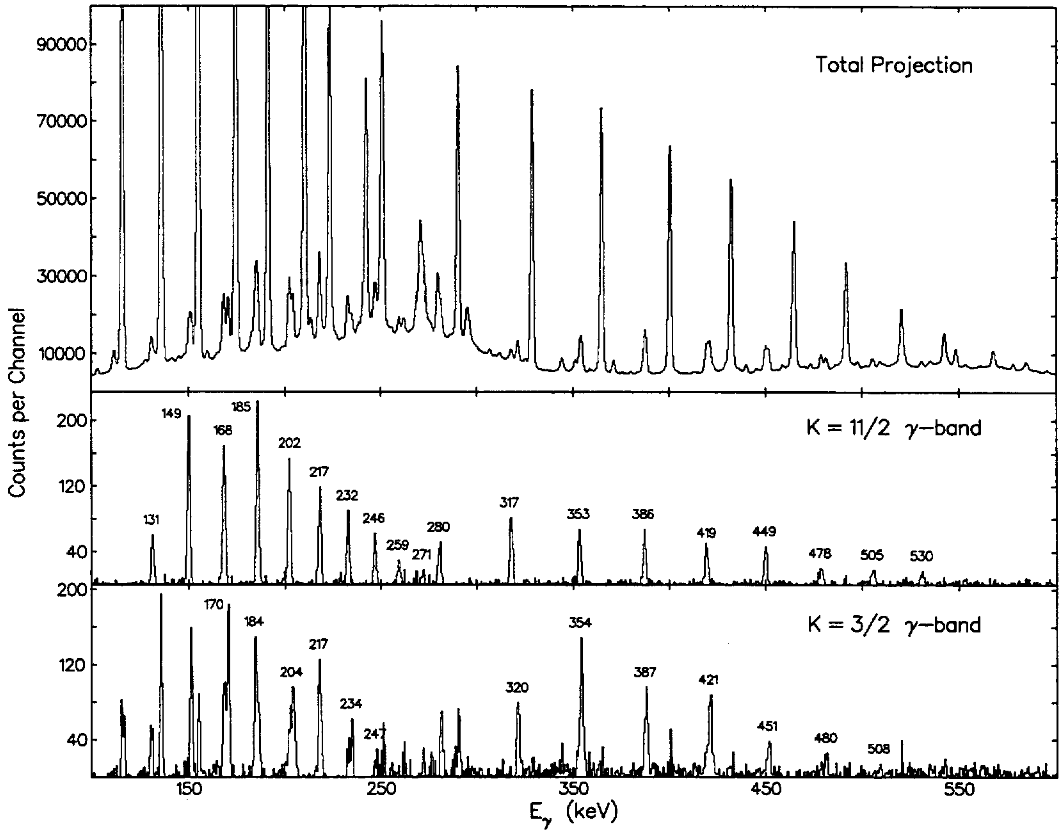

Figure 2: Spectra gated on transitions from the $K=\frac{3}{2}$ and $K=\frac{11}{2}$ γ-vibrational bands, together with the total projection spectrum, from the experiment with the gold-backed target.

Many transitions are observed from the decay of the γ bands to the ground band; for $K=\frac{3}{2}\to K=\frac{7}{2}$ we observe transitions with $J\to J+1, J\to J$ and $J\to J-1$, while for $K=\frac{11}{2}\to K=\frac{7}{2}$ we observe $J\to J, J\to J-1$ and $J\to J-2$.

If these transitions were between pure-K states, any M1 admixture would be forbidden by the $\Delta K\leq\lambda$ selection rule. If we assume that the transitions are indeed pure E2, then we can use the observed branching ratios to calculate B(E2;$K\to K\pm2$)/B(E2; $K\to K$) ratios. The results of such a calculation, using preliminary values of the branching ratios, show a range of ratios that cover three orders of magnitude. If we extract ratios of transition quadrupole moments from these B(E2) ratios, we can also make a (modified) Mikhailov plot of

$$\frac{Q_T(K\to K\pm2)}{Q_T(K\to K)}=\sqrt{\frac{B(E2;K\to K\pm2)}{B(E2;K\to K)}}\,\frac{<J_i\ \ K\ \ 2\ \ 0\mid(J_i-2)\ \ K>}{<J_i\ \ K\ \ 2\ \ \pm2\mid J_f\ \ K\pm2>}$$

versus $J_f(J_f+1)-J_i(J_i+1)$, as shown in figure 3.

In a Mikhailov plot [7], the value of the slope provides a measure of the strength of the Coriolis mixing. M. Matsuzaki, Y. Shimizu and T. Nakatsukasa have recently performed calculations [8,9] using the cranked shell model with RPA and adding a particle-vibration coupling. They extract matrix elements for the E2 strengths from the γ bands to the ground

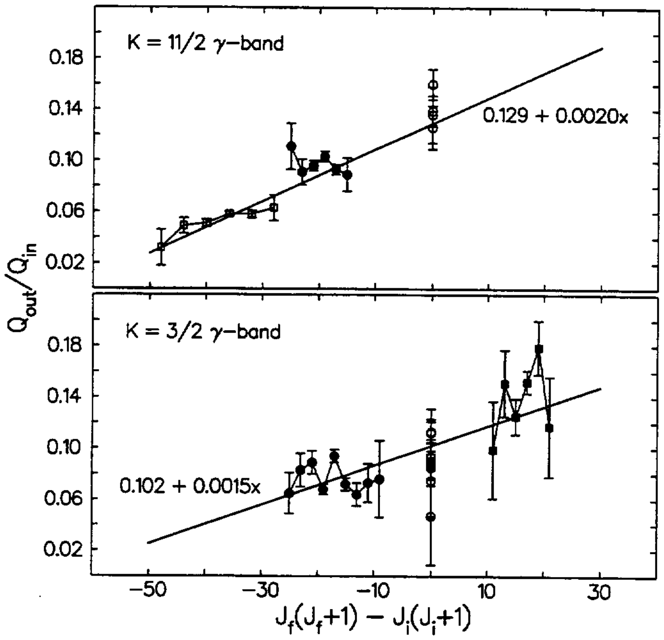

Figure 3: Mikhailov plot of observed ratios of transition quadrupole moments for the two γ bands. The solid lines are least-squares fits to the experimental data, where $x = J_f(J_f+1) - J_i(J_i+1)$.

band. The results are listed together with the experimental numbers in table 1, where the nomenclature

$$Q_T(K \to K) = Q_0$$

and

$$Q_T(K \to K \pm 2) = Q_a + Q_b[J_f(J_f+1) - J_i(J_i+1)]$$

is used. The agreement between the calculated and observed ratios is excellent.

Table 1

Ratios of spin-independent and spin-dependent components of the transition quadrupole moments in ^{165}Ho.

	Experiment	Theory [8,9]
$Q_a/Q_0; K = \frac{11}{2}$	0.13	0.17
$Q_b/Q_0; K = \frac{11}{2}$	0.0020	0.0021
$Q_a/Q_0; K = \frac{3}{2}$	0.10	0.17
$Q_b/Q_0; K = \frac{3}{2}$	0.0015	0.0025

One striking aspect of the data is that these two γ-vibrational bands are isospectral, *i.e.*, have very nearly identical γ-ray energies for the in-band transitions originating from states of the same spin. A plot of the incremental alignment [3] between the two bands is shown

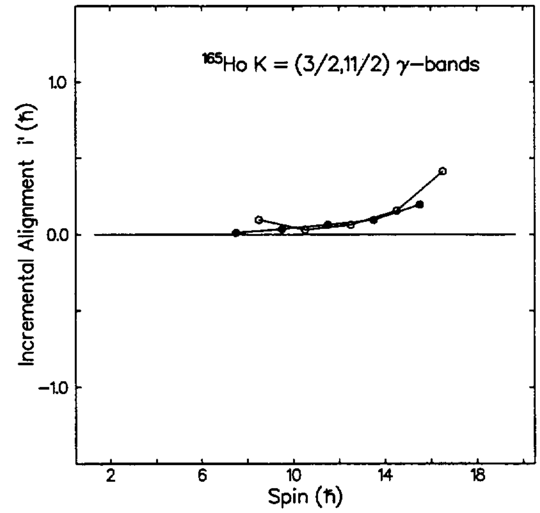

Figure 4: Incremental alignment between the two γ-vibration bands in ^{165}Ho.

in figure 4; values are less than 0.1 $\hbar$ below spin 29/2, at which point the bands appear to enter a backbending region.

These isospectral bands arise through a simple recoupling of the collective and single-particle degrees of freedom, rather than through the addition or removal of nucleons. The recoupling changes the direction of the total angular momentum vector, and thus the value of K. In a one-dimensional cranking model [10], the different K-values result in very different rotational frequencies, and thus alignments, for the two bands; see for example figure 5. The recoupling of the vibration, however, should not change its alignment, and thus in such a model it is very difficult to understand how the two bands could be isospectral.

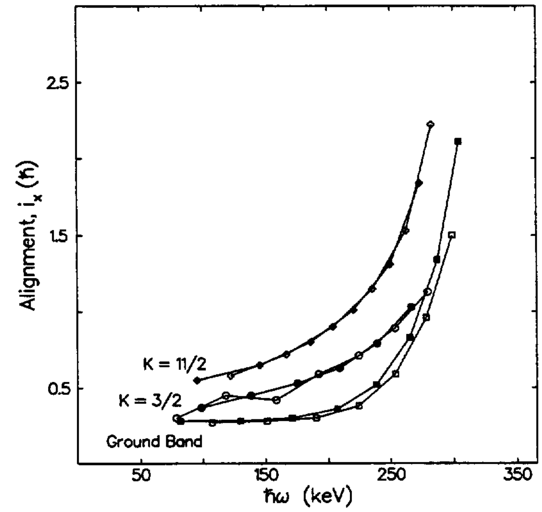

Figure 5: Alignments of the two γ bands, extracted from the data using the normal cranked shell model methodology, and subtracting a reference with Harris parameters $J_0 = 44.5$ MeV$^{-1}\hbar^2$ and $J_1 = 110$ MeV$^{-3}\hbar^4$.

In a tilted-axis or three-dimensional cranking model [11], the rotational frequency is simply defined as one-half of the the in-band E2 transition energy, and is thus identical for isospectral bands. This clearly allows a better explanation of the observed results. Nevertheless, an intuitive semiclassical picture would have the deformed nucleus exhibiting different moments of inertia as it rotates about different axes. Thus it appears that these bands show a striking example of strong coupling, where the moment of inertia is unaffected by the vibrational coupling, *i.e.*, is independent of the value of the K quantum number.

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