Measurement of the $E2$ decay branching ratio of the first excited 0^+ state in ^{166}Er

R. L. Gill,[1] C. Barton,[1,2] R. F. Casten,[1,3] and N. V. Zamfir[1,2,4]
[1] *Department of Physics, Brookhaven National Laboratory, Upton, New York 11973*
[2] *Clark University, Worcester, Massachusetts 01610*
[3] *Institut für Kernphysik, Universität Köln, Köln, Germany*
[4] *Institute of Atomic Physics, Bucharest Magurele, Romania*
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Reported measurements of the intensity ratio of the 674.04 and 1379.40 keV γ rays from the 1460 keV 0^+ level in ^{166}Er differ by a factor of 10. This difference is resolved by a new measurement which produces a ratio of 0.024 ± 0.003, in agreement with the majority of measurements. This ratio is important in assessing the two-phonon or β-vibrational nature of the lowest excited $K = 0^+$ band, at 1460 keV, and confirms that its properties differ from those found in the majority of deformed rare earth nuclei.

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The nature of the lowest excited $K = 0^+$ excitations in deformed nuclei has long been of importance in understanding the elementary collective modes of such nuclei. For many years the lowest $K = 0^+$ band has been interpreted as a β vibration. However, recent papers [1,2] have discussed the facts that, in the rare earth region, the properties of the lowest $K = 0^+$ band are *correlated* with those of the γ band [1] and that the predominant $E2$ decay matrix elements of the $K = 0^+$ bands are to the γ *band*, not to the ground band [2]. These observations led to the suggestion [2] that these $K = 0^+$ excitations are phonon excitations built on the γ band.

The ratio $R_{g\gamma} \equiv B(E2: 0^+_{K=0} \rightarrow 2^+_g)/B(E2: 0^+_{K=0} \rightarrow 2^+_\gamma)$ is known experimentally in only a few deformed nuclei because the $\Delta I = -2$, $0^+_{K=0} \rightarrow 2^+_\gamma$ transition is seldom seen due to its low relative energy. Nevertheless, the decay branching ratio of other $K = 0^+$ band transitions can be used to give effective $R_{g\gamma}$ values by multiplying by appropriate ratio of rotational Clebsch-Gordan coefficients. In this way, it is found that, with two exceptions, $R_{g\gamma}$ is in the range 0.0001 to 0.018. The average value is 0.005 and the median is 0.0031. Clearly the $K = 0$ band, in a predominant majority of cases, decays by a large preference to the γ band.

This conclusion focuses attention on the two nuclei that appear to deviate from this pattern, ^{164}Er, where $R_{g\gamma} = 0.52 \pm 0.26$ and ^{166}Er, where the latest Nuclear Data Sheets [3] evaluation leads to $R_{g\gamma} = 1.35 \pm 0.17$. This latter value differs by a couple orders of magnitude from that of most nearby nuclei and suggests that the structure of the lowest $K = 0$ excitation in ^{166}Er is rather different than in other deformed rare earth nuclei.

There is, however, a considerable, and somewhat bizarre, divergence of quoted experimental values for the interband ratio $I_{g\gamma} : I(0^+_{K=0} \rightarrow 2^+_\gamma)/I(0^+_{K=0} \rightarrow 2^+_g)$ for ^{166}Er in the literature. Note that the definition of $I_{g\gamma}$ is inverted relative to $R_{g\gamma}$: large values of one are associated with small values of the other. A number of measurements exist and give values falling in two categories, ~ 0.2 and ~ 0.02, that differ by an order of magnitude. Reference [3] adopts the value 0.0208, giving $R_{g\gamma} = 1.35$ as quoted above. One of the more recent measurements [4], however, gives $I_{g\gamma} = 0.16$, and hence an $R_{g\gamma}$ value of $R_{g\gamma} = 0.15$.

The history of quoted values of $I_{g\gamma}$ for ^{166}Er does not provide much comfort, nor a resolution of this dichotomy of values. An earlier paper by Allab, Azgui, and Ardisson [5] also reports a high ratio $I_{g\gamma} = 0.18$ in a table, but shows a ratio of 0.017 in a figure of the proposed level scheme. To further complicate the situation, Allab, Azgui, and Ardisson claim agreement with the value of 0.22 measured by Reich and Cline [6]. However, the value quoted by Reich and Cline themselves in Ref. [6] was 0.022. Other researchers give results consistent with the lower value: Chand *et al.* [7] report 0.023, and Burson, Goudsmit, and Konijn [8] report 0.032.

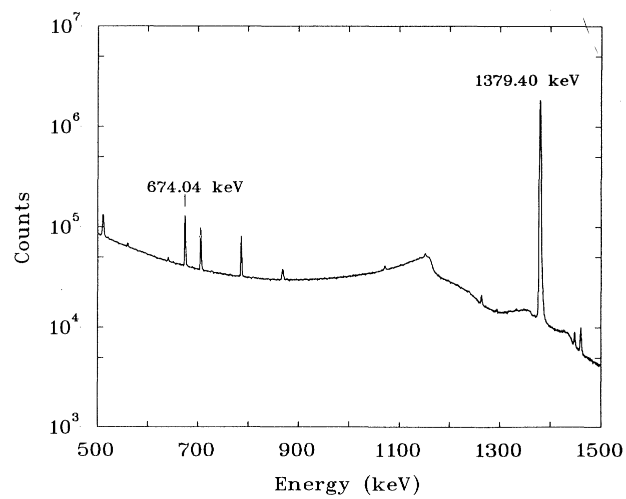

FIG. 1. A portion of the γ-ray spectrum obtained from the β^- decay of ^{166}Ho to levels in ^{166}Er.

Since the resolution of this inconsistency has direct impact on the interpretation of $K = 0$ excitations in deformed nuclei as β-vibrational or two-phonon modes, an experiment was undertaken to remeasure the relative intensities of the 674 and 1379 keV γ rays in ^{166}Er. The purpose of this Brief Report is to present the result of that measurement, and to comment on its implications.

The states of interest were populated through the β^- decay of ^{166}Ho ($t_{1/2} = 26.80$ h), which was produced by the (n,γ) reaction on a target of natural holmium oxide. The irradiation was done at the High Flux Beam Reactor at Brookhaven National Laboratory, utilizing a low intensity ($7\times10^6\ n_{\rm th}/{\rm cm}^2\,{\rm sec}$), external thermal neutron beam at the H1B facility. A thick target (0.75 cm) containing 15 g of Ho_2O_3 was placed in the beam for a period of 2 days. The sample was then removed and counted for a period of 48 h, using a 30% HPGe (hyperpure Ge) detector with $\sim$ 2.0 keV resolution full width at half maximum at 1.33 MeV. Approximately 6.96×10^5 counts were collected for the 674 keV γ ray and 1.71×10^7 counts were collected for the 1379 keV γ ray. The data are shown in Fig. 1, from which it is clear that the 1379 keV line is roughly 2 orders of magnitude stronger than the 674 keV line.

The absolute efficiency of the detector was measured with a National Bureau of Standards calibrated ^{152}Eu source. The efficiency was determined to be 0.014 ± 0.001 at 647 keV, and 0.0079 ± 0.0007 at 1379 keV. Since a thick target was used, it was necessary to measure the absorption of the γ rays of interest in the target material. This was accomplished by measuring the attenuation of the 661.6 keV γ ray from ^{137}Cs and the 1332.5 keV γ ray from ^{60}Co through the holmium target. The absorption coefficient was determined to be 0.136 ± 0.002 cm^{-1} at 662 keV and 0.0606 ± 0.0003 cm^{-1} at 1332 keV. Using the half thickness of the target, the transmission was determined to be $(94.8 \pm 1.2)\%$ and $(97.4 \pm 0.6)\%$ at 674 and 1379 keV, respectively.

After applying the above corrections to the data collected, an intensity ratio of $I(674)/I(1379) \equiv I_{g\gamma} = 0.024 \pm 0.003$ was determined. This is consistent with the value reported in the most recent evaluation [3] and with the majority of measurements. It disagrees, however, by nearly a factor of 10 with the recent measurement of Ref. [4]. The discrepant values given in the literature would appear to be typographical errors in placing the decimal point.

The large value of $I_{g\gamma}$ for ^{166}Er established by the present measurement gives an $R_{g\gamma}$ value of $R_{g\gamma} = 1.16 \pm 0.15$. This value does not indicate an enhanced decay to the γ band and therefore confirms that this 0^+ state should not be counted as a two-phonon excitation (a phonon excitation of the γ band). This result shows that ^{166}Er (and ^{164}Er to a lesser extent) differ qualitatively in the decay of their lowest $K = 0$ excitations from other deformed rare earth nuclei. Clearly, such anomalous behavior is interesting and argues for new efforts at a microscopic understanding.

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