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V.d. Non-Adiabatic Effect on the Collective g-Factors and K-Forbidden M1 Transitions in ^{166}Er

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(Presented by H. Ikegami)

As a result of efforts of both theoretical and experimental physicists on the magnetic properties of the collective states, it appears that differences may exist in g-factors between different excited states even in the same vibrational or rotational band. However, the quoted experimental errors are usually so large that one can't make a final assessment of the problem.

The principal aim of the present study is to settle the experimental situation for the rotational levels of the ground state in ^{166}Er by making an accurate precession measurement for the 4^+ excited state. Another aim is to measure the M1 admixture in the interband transition related to the 4^+ state and to examine what kind of K impurities are responsible for the K-forbidden M1 transition.

Active samples of 1200 y ^{166}Ho were prepared by neutron irradiation of Ho-metal targets which were then converted into the form of $HoCl_3$ after some chemical purification. The γ-ray source used was an aqueous solution of these samples. The precession measurements were performed by the time-integral method applied to the angular correlation between the 810 and 184 keV γ-rays which are the transitions in the cascade: $5^+(K=2) \rightarrow 4^+\ (K=0) \rightarrow 2^+(K=0)$, (see Fig. 1). A 7.56 cm × 7.56 cm NaI(Tl) crystal and a 27 cm³ Ge(Li) detector were used for the 184 and the 810 keV γ-rays, respectively, (see Fig. 2). A magnetic field was applied to the source perpendicular to the detection plane. The coincidence spectra at eight angles of the NaI detector between 90° and 220° were recorded in the 128 channel sub-memories of a 4096-channel pulse height analyzer. The measuring time interval was 10 min and the field direction was reversed after every 48 hours of measurement. Four independent runs were carried out for slightly different settings of the apparatus. The measurement involved 4800 hours of data accumulation and the total number of coincident counts was about 15 million. After some geometrical corrections and a small correction for the time dependent attenuation effect[1] were made, the results from the four measurements, seen in Fig. 3, were averaged and the following values were obtained for the $5^+ \xrightarrow{810\gamma} 4^+ \xrightarrow{184\gamma} 2^+$ cascade in ^{166}Er:

$$A_4/A_2 = 0.349 \pm 0.015$$

and

$$\omega\tau/\beta = (6.20 \pm 0.21) \times 10^{-3}$$

for $H_{ext} = 25.4 \pm 0.3$ kOe, where β is the paramagnetic correction factor for the Er^{3+} ion.[2] These values are in agreement with those of Bodenstedt's group.[1] Now we obtain the quantity g/Q_{00}^2, hereafter called the "reduced spin rotation," as

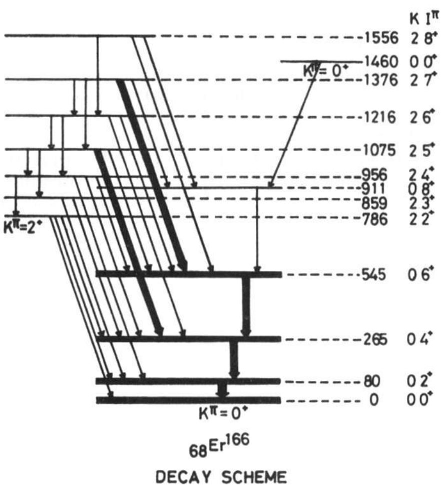

Fig. 1

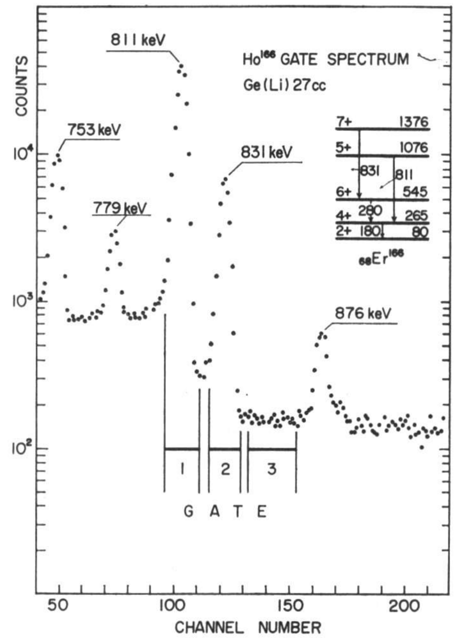

Fig. 2

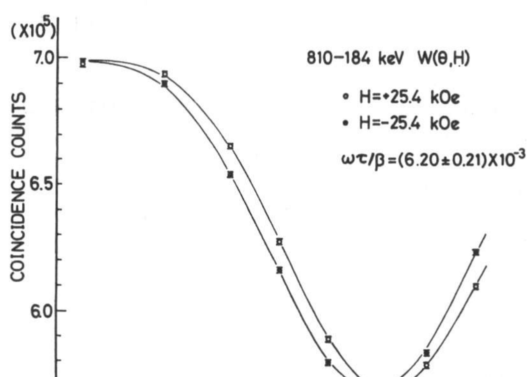

Fig. 3

$$(g/Q_{00}^2)_{4^+} = (5.05 \pm 0.18) \times 10^{-3}\ \text{barn}^{-2}$$

where Q_{00} is the intrinsic quadrupole moment of the ground rotational band. If a mean-life value of 0.171 ± 0.08 ns is adopted by averaging previous measurements, we get

$$g_{4^+} = 0.299 \pm 0.017.$$

The value for the reduced spin rotation may be compared with the result for the 2^+ state, as obtained from Mössbauer measurements and life-time data;

$$(g/Q_{00}^2)_{2^+} = (5.43 \pm 0.07) \times 10^{-3}\ \text{barn}^{-2}\ .$$

Table I.

	Method	$\omega\tau/\beta$	τ (s)	Q_0^2 (barn^2)	g	g/Q_0^2 (barn^{-2})	Reference
	Mössbauer				0.305(15)		1
	Mössbauer				0.312(10)		2
2^+	Mössbauer				0.31 (3)		3
	Mössbauer				0.318(10)		4
	Average		$2.66(\ 2) \times 10^{-9}$ a)	57.8(5)	0.313(3)	$5.43(\ 7) \times 10^{-3}$	
	$\gamma\gamma(\theta, \mathrm{H})$	0.0117(8)	$1.76(10) \times 10^{-10}$ b)		0.266(24)		5
4^+	$\gamma\gamma(\theta, \mathrm{H})$	0.0062(2)	$1.71(\ 8) \times 10^{-10}$ c)	(59(3))	0.299(17)	$5.05(18) \times 10^{-3}$ d)	present result

a) Average of values from refs. 7–18.
b) Average of values from refs. 6 and 14.
c) Average of values from refs. 14 and 18.
d) Derived directly from value.

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Thus it is found that there is a possible decrease in the reduced spin rotation (g/Q_{00}^2) of about (7.0 ± 3.6) % for the 4^+ state with respect to the 2^+ state. (see Table I) Such a deviation in the reduced spin rotation is, of course, attributed to non-adiabatic effects which imply coupling between rotation, vibration and particle motions.

To investigate these effects further, M1-admixtures were determined precisely for the K-forbidden 810-keV and 830-keV transitions in the cascades $5^+(K=2) \xrightarrow{180\gamma} 4^+(K=0) \xrightarrow{184\gamma} 2^+(K=0)$ and $7^+(K=2) \xrightarrow{830\gamma} 6^+(K=0) \xrightarrow{280\gamma} 4^+(K=0)$, respectively. The ratio of coefficients in the angular correlation functions after correction is:

$$A_2/A_4 = 0.438 \pm 0.027$$

for the 830γ-280γ cascades, as illustrated in Fig. 4 together with the result of the 810γ-184γ cascade given above. The multipole mixing parameter δ is expressed as:

$$\delta^{-2} = W(\mathrm{M1})/W(\mathrm{E2})$$

$$\delta^{-1} = -1.20\, E_\gamma^{-1}(in\ \mathrm{MeV}) \frac{\langle i \| \mathscr{M}(\mathrm{M1}) \| f \rangle (\text{in n.m.})}{\langle i \| \mathscr{M}(\mathrm{E2}) \| f \rangle\ (\text{in e} \cdot \text{b})}\,.$$

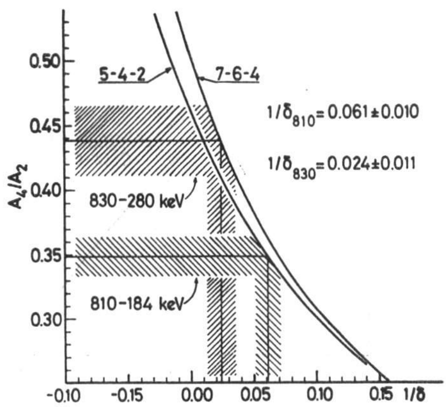

Fig. 4

Here, W(M1) and W(E2) are the M1 and E2 transition rates. An A_2/A_4 plot, shown in Fig. 4, yields

$$\delta^{-1}(810 \text{ keV}) = +0.061 \pm 0.010$$

and

$$\delta^{-1}(830 \text{ keV}) = +0.024 \pm 0.011 \ .$$

These values are in agreement with results of Reich and Cline.[3]

Now, we discuss the observed I-dependence of the reduced spin rotations and the related K-forbidden M1 transitions. Under the assumption that the direct or the second order mixing between bands with $K = 2$ and 0 is the only important one, we expect,

$$\Delta \equiv \frac{(g/Q_{00}^2)_{I^+} - (g/Q_{00}^2)_{2^+}}{(g/Q_{00}^2)_{2^+}} = 8[I(I+2) - 8]\varepsilon_2^2 \cdot \frac{g_K - g_R}{g_R}$$

$$\delta^{-2}\begin{pmatrix} I+1 \\ K=2 \end{pmatrix} \rightarrow \begin{matrix} I \\ K=0 \end{matrix}\Bigg) = 27.7E_\gamma^{-2}(in \text{ MeV})(I-1)^2 I(I+2)\left(\frac{g_K - g_R}{Q_{20}}\right)^2 (\varepsilon_2)^2 \ .$$

With the following values of the I-independent parameters: $\varepsilon_2 = 1.2 \times 10^{-3}$, $Q_{00} = 1.6Q_{20} = 7.5 \pm 0.5$ b and $|g_K - g_R| = 0.11$,[3] we find the following: $\Delta = 0.006\%$, $\delta^{-2}(810\gamma) = 7.2 \times 10^{-6}$ and $\delta^{-2}(830\gamma) = 3.8 \times 10^{-5}$, which are from two to three order of magnitude smaller than the present experimental results.

The I-dependence of the collective g-factors revealed by the present study has been predicted by Sano and Wakai[4] using the cranking model with the Coriolis anti-pairing effect. In Fig. 5, the present results are compared with their values. The I-dependence of the curve in the figure might be more remarkable if Q_{00} also decreased with I.[5]

A similar microscopic calculation has also been carried out by Bes *et al.* for the K-forbidden M1 transitions.[6] They assume the $K = 1$ band to be responsible for the M1 admixture and, in an RPA calculation, obtain matrix elements which predict $\delta^{-2}(810\gamma) = 0.090$ and $\delta > 0$ for all $K = 2 \rightarrow 0$ transitions. These results are comparable with the present data and are of the right sign.

In the light of the present study on the collective g-factors and K-forbidden M1 transitions,

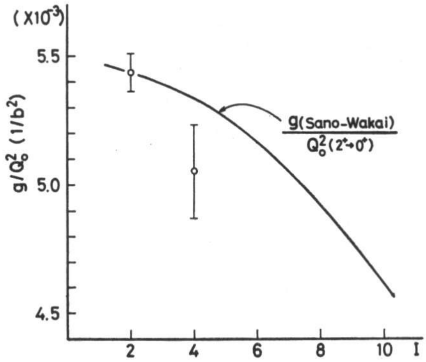

Fig. 5

it is concluded that the role of the Coriolis coupling and the contribution from the $K = 1$ band or the core polarization are of particular importance in the magnetic properties of collective states.

Further study on the g-factor of the 6^+ state in ^{166}Er is now in progress.

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Discussion

L. GRODZINS (MIT): Was the theoretical curve of g_R vs I, with which you compared your experimental values, calculated for ^{166}Er? If so, was it based on the energy levels of ^{166}Er? The curve Prof. Sano showed in his slide was for ^{158}Dy which has a more violent behavior of $\mathscr{T}$ vs I than does ^{166}Er.

IKEGAMI: We got the factors calculated by Prof. Sano and his collaborators, and we divided the calculated g factors by the observed Q_{00} values. However, nobody knows whether the Q_{00}'s decrease or increase with angular momentum.

GRODZINS: Thank you, but the answer that you gave us was not to my question. I would like to ask if the solid curve was based on the energy levels of ^{166}Er.

IKEGAMI: Yes, it was based on ^{166}Er.

GRODZINS: I would note that the Sano-Wakai model is more applicable to high spin than low spin states, and does not fit the latter values particularly well.