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DISCLAIMER

LIFETIMES AND g-FACTORS IN DECOUPLED BANDS[*]

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Abstract:

Lifetime and g-factor measurements on the $I = j + 2$ state in the decoupled bands of ^{157}Er and ^{159}Er are shown to be in agreement with those expected from the rotation-aligned coupling scheme. Such measurements provide a general way to differentiate this coupling scheme from the better-known weak- and strong-coupling schemes.

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Recently, a number of decoupled bands have been reported in odd-mass nuclei in various regions of the nuclear chart,[1] and an interpretation of these bands as examples of the rotation-aligned coupling scheme has been suggested.[2] If this interpretation is correct for nuclei in the "vibrational" regions, it indicates a greater importance of collective rotation than was previously thought to be likely in nuclei having such small deformations. Studies of the electromagnetic properties of these bands can be helpful in distinguishing among the possible coupling schemes, namely, weak, strong, and rotation-aligned. It is the purpose of the present paper to report such a study in the decoupled bands of the light Er nuclei.

The odd-mass Er isotopes were chosen for this study because the lifetimes and the g-factors of the even-even Er nuclei are known,[3,4] and these are essential for comparison. Lifetimes of the 17/2 (j + 2) and 21/2 (j + 4) members of the decoupled bands in ^{157}Er and ^{159}Er have been measured using the recoil-distance Doppler-shift method. From the lifetimes determined for ^{157}Er, the g-factor of the $17/2^+$ state was calculated by analyzing time-integral PAD data taken during experiments to determine[4] g-factors in the even-even Er nuclei.

In the lifetime measurements, an ^{40}Ar beam from the Berkeley 88" cyclotron was used to bombard self-supporting targets of ^{122}Sn and ^{124}Sn about 850 μg/cm^2 thick. The beam energy was 171 MeV, near the maximum of the excitation functions for the (^{40}Ar,5n) reactions. Since some γ transitions of ^{158}Er were also seen in the spectra obtained, their lifetimes were determined for comparison with the previous results,[3] but the accuracy was poorer in these even-even measurements, because the beam energy was not optimized for the 4n reaction. The ratios, (unshifted intensity)/(unshifted + Doppler-shifted intensity), for the transitions of interest at each plunger distance were obtained and analyzed with a computer program that fits three cascading gamma transitions simultaneously, and allows for another cascade of three transitions to feed the group being determined. A plot of the experimental ratios vs. plunger distance for ^{157}Er is shown in Fig. 1. The recoil velocity was determined to be $v/c = (2.10 \pm 0.02)\%$.

The results are summarized in Table I, and the B(E2) values obtained are compared with those in the neighboring even-even Er nuclei in Fig. 2. The B(E2) values in the odd-mass nuclei are considerably larger than the average values in the even-even nuclei. This indicates that these states in the odd-mass nuclei are not examples of weak coupling, as such a coupling scheme requires that these reduced transition probabilities be identical to those of the core, i.e., the neighboring even-even nuclei. However, both the rotation-aligned and the strong-coupling schemes lead to larger B(E2) values, much closer to the observed ones. For strong-coupling, the B(E2) is given by,

$$B(E2;\ I_i K \rightarrow I_f K) = \frac{5e^2}{16\pi}\ Q_o^{\ 2}\ \langle I_i\ 2\ K\ 0 | I_f K\rangle^2\quad . \tag{1}$$

The assumption that the value of Q_o for the odd-mass nucleus is the average of those in the neighboring even-even isotopes leads to the values shown in Table I for several choices of K.

In the rotation-aligned coupling scheme, the decoupled-band B(E2) values are given by,

$$B(E2;\ I_i\alpha = j \rightarrow I_f\alpha = j) = \frac{5e^2}{16\pi}\ Q_o^{\ 2} \Big| \sum_{K,K'} a_K\, a_{K'}\, \langle I_i\ 2\ K\ K - K' | I_f K'\rangle \Big|^2\quad , \tag{2}$$

where $a_K = d^j_{jK}(\pi/2)$ and j is 13/2 for these Er nuclei. Keeping only the collective (K = K') terms leads to: B(E2; 17/2 → 13/2)/B(E2; 2 → 0) = 1.47 and B(E2; 21/2 → 17/2)/B(E2; 4 → 2) = 1.10; clearly the I = j + 2 → I = j transition is the most sensitive one for distinguishing among these coupling schemes. In Fig. 2 the calculated B(E2) values for the decoupled transitions are shown as dashed lines. The solid lines, drawn to connect the data for the even-even nuclei, show the weak-coupling limit since these are the same. It can be seen that weak coupling is rather far from the observed results, rotation alignment comes within about 15%, and strong coupling comes even closer for low values of K.

In the earlier measurement[4] of the g-factors in ^{156}Er, ^{158}Er, and ^{160}Er, a time-integral PAD measurement was made using the strong hyperfine field acting on the highly-charged ions recoiling in vacuum. In these studies it was apparent that some γ rays from the odd-mass Er nuclei did not show any perturbation of their angular distribution, presumably due to their having very small g-factors. For example, the ratio of the anisotropy, W(0°)/W(90°), of the self-supporting target (from which the recoils escape into vacuum and experience large hf fields) to the anisotropy of the Pb-backed target (in which the recoils stop quickly and do not experience large hf fields for a significant time) for the $17/2^+ \rightarrow 13/2^+$ ($\tau_m = 74.2$ ps) transition in ^{157}Er is 0.98±0.07, while, for comparison, the ratio for the $2^+ \rightarrow 0^+$ ($\tau_m = 47.9$ ps) transition in ^{156}Er is 0.73±0.05. Clearly, in the odd-mass case there is very little perturbation of the angular distribution of the recoils in vacuum even though the time τ_m is long. The value of the integral attenuation coefficient, $\overline{G_2(\infty)}$, that can be extracted for the above $17/2 \rightarrow 13/2$ transition is 0.96±0.07, and this is quite insensitive to the assumptions used in its determination. Since the lifetime of the $17/2^+$ state has been determined in the present experiment, we can deduce an upper limit on its g-factor.

The measured $\overline{G_2(\infty)}$ can be related to the g-factor of the state using the theory of Abragam and Pound,[5] in which $\overline{G_2(\infty)}$ is expressed as

$$\overline{G_2(\infty)} = \frac{1}{1 + 2\omega^2\,\tau_m\,\tau_c} \quad , \tag{3}$$

where τ_m is the nuclear lifetime, τ_c is the correlation time of the fluctuating field, and $\omega = gH_{hf}\mu_N/\hbar = 4.8 \times 10^3\, gH_{hf}$ is the Larmor frequency. As discussed in Ref. 4, we used $H_{hf} = 41 \pm 7$ MG and $\tau_c = 3$ psec. The upper limit for the g-factor of the $17/2^+$ state in ^{157}Er was thus determined to be 0.08. However, since I is rather large, (17/2), the I-J dependence, which was discussed in Ref. 4, should probably be included in the perturbation factor. In this case our result for the 17/2$^+$ state of ^{157}Er is $|g| = 0.05\pm0.05$. This can be compared with the calculated values, using g_s(effective) = 0.6 g_s(free), $g_R = 0.40$, and $g_\ell = 0$ for neutrons; weak coupling, -0.04; strong coupling, +0.18, +0.38, and +0.35 for K = 1/2, 3/2, and 5/2; and rotation-aligned, -0.02. The experimental result is in agreement with either the weak-coupling or rotation-aligned calculation, but not with the strong-coupling one.

Only the rotation-aligned wave functions give reasonable agreement for both types of measurement made here. The energy levels of these nuclei are also in best agreement with this scheme, though it is clearly only approximate, especially for ^{159}Er. The reason the measured B(E2) values are ~ 15% higher than the rotation-aligned ones is not clear. It could be due to experimental error, or to slightly larger deformations for the odd-mass nuclei, or to some other effect not yet considered. More measurements are needed to clear up this point.

In the present work we have shown that measurements of lifetimes and g-factors for the appropriate states in odd-mass nuclei can differentiate among weak-coupling, rotation-aligned, and strong-coupling schemes. These measurements are relatively easy to make, and can be applied rather generally to identify the type of coupling in particular nuclei. Application to ^{157}Er and ^{159}Er shows that the rotation-aligned description is the most accurate one for these nuclei. A preliminary lifetime for the $I = 15/2 \rightarrow I = j = 11/2$ transition in ^{125}La, compared with that of the $2 \rightarrow 0$ transition in ^{124}Ba, is also close to the rotation-aligned value, and distinctly shorter than the weak-coupling value. It will be interesting to make these measurements on other "decoupled" bands in regions of low deformation.

We would like to thank D. Clark, J. Bowen, and the operating crew of the 88" cyclotron for providing the ^{40}Ar beam, and we express our appreciation to P. O. Tjøm who helped in some parts of this experiment. One of us (K.N.) would like to thank the Japanese Society for the Promotion of Science for financial aid which made his participation possible, and another (D.P.) would like to thank the University of Munich.

FOOTNOTES AND REFERENCES

[*] Work performed under the auspices of the U. S. Atomic Energy Commission.

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Table I. Summary of the lifetime measurement.

						Theory		
Nucleus	Transition	E_γ(keV)	$T_{1/2}$(ps)	α	B(E2) in $e^2 \times 10^{-48} cm^2$	weak	strong	rotation aligned
^{157}Er	$17/2^+ \rightarrow 13/2^+$	267	49.0±2.5	0.098	0.78±0.04	0.46	K = 1/2 0.76 K = 3/2 0.75 K = 5/2 0.69	0.68
	$21/2^+ \rightarrow 17/2^+$	415	5.3±0.5	0.026	0.84±0.08	0.67	K = 3/2 0.76	0.74
^{159}Er	$17/2^+ \rightarrow 13/2^+$	209	95±5	0.222	1.23±0.06	0.70	K = 1/2 1.15 K = 3/2 1.14 K = 5/2 1.05	1.03
	$21/2^+ \rightarrow 17/2^+$	351	8.2±0.9	0.042	1.25±0.12	0.98	K = 3/2 1.11	1.08
^{158}Er	$2^+ \rightarrow 0^+$	192.7	260±20 (300±15)[a]	0.283	0.64±0.06 (0.55±0.03)[a]	0.58±0.03[b]		
	$4^+ \rightarrow 2^+$	335.7	19±3 (14.4±.72)[a]	0.050	0.67±0.10 (0.87±0.05)[a]	0.81±.04[b]		

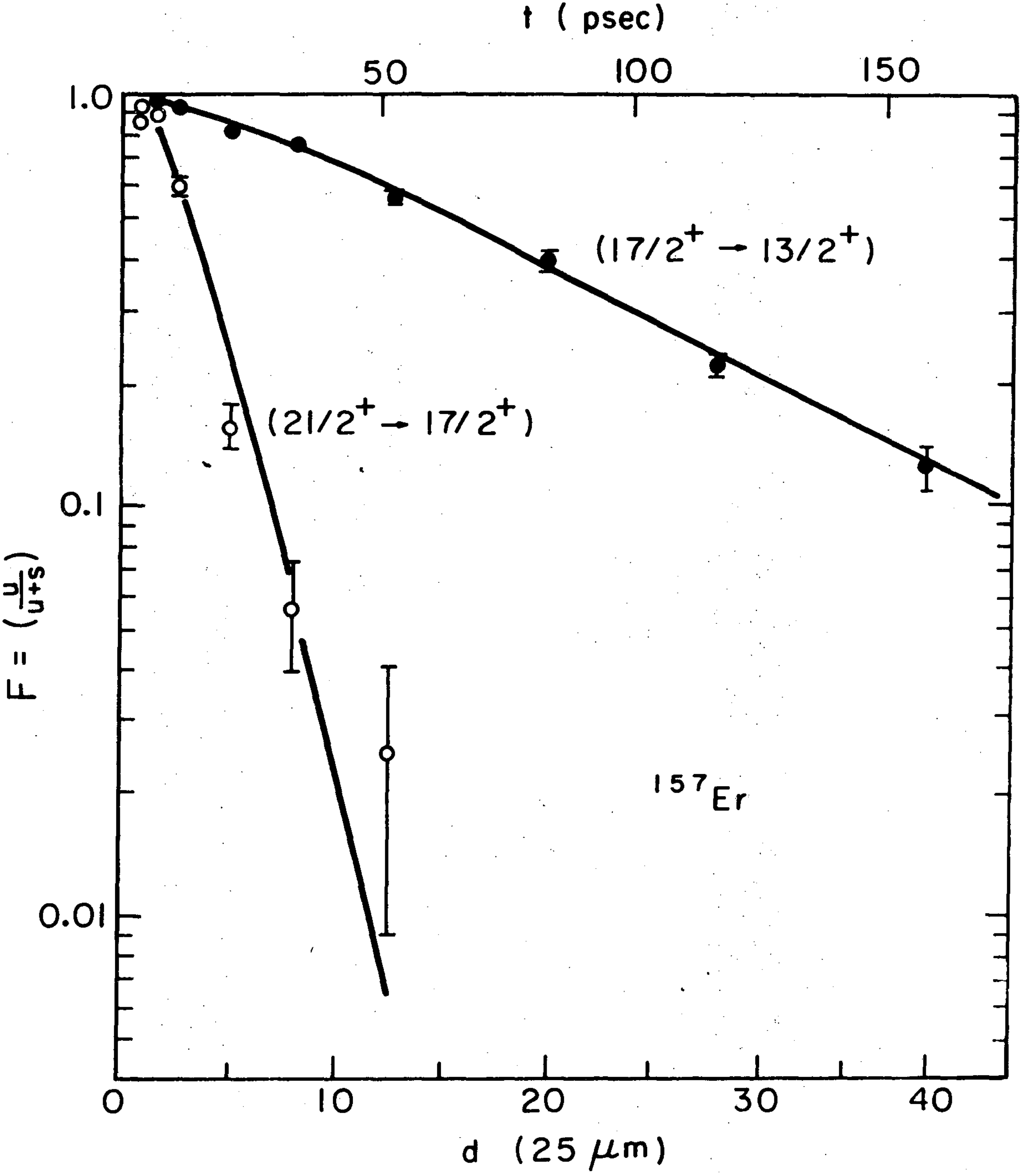
[a] Values in Ref. 3.

[b] Adopted values; weighted value by (1/ε), where ε is the error.

FIGURE CAPTIONS

Fig. 1. The fraction of unshifted intensity, F, vs. target-plunger distance for the 17/2 → 13/2 and 21/2 → 17/2 transitions of ^{157}Er. The distance is given in units of 25 μm, and a scale in psec is shown at the top. The lines are the computer fits to the data.

Fig. 2. Plots of B(E2) vs. A. The solid curves correspond to weak-coupling (even-even) values, and the dashed curves to rotation-aligned ones. The crosses and circles correspond to measured values in even-even and odd-mass nuclei, respectively.



XBL743-2672

Fig. 1

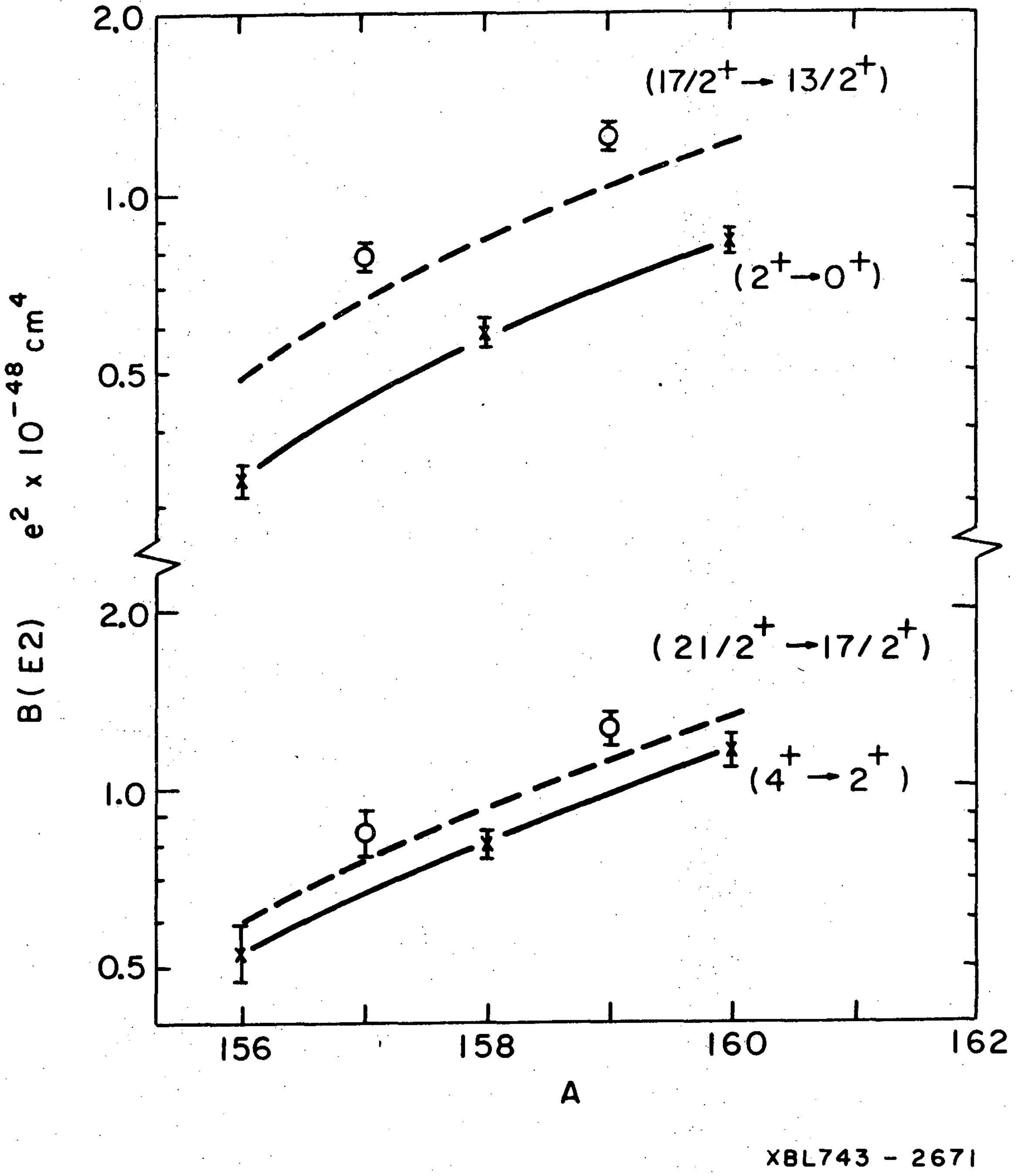

2.0
1.0
0.5
2.0
1.0
0.5
$B(E2)\ e^2 \times 10^{-48}\,cm^4$
$(17/2^+ \rightarrow 13/2^+)$
$(2^+ \rightarrow 0^+)$
$(21/2^+ \rightarrow 17/2^+)$
$(4^+ \rightarrow 2^+)$
156
158
160
162
A
XBL743 - 2671

Fig. 2

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