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g factor of the 2_1^+ state of ^{160}Er

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The g factor of the 2_1^+ state of ^{160}Er was measured by perturbed γ-γ angular correlation in a static external magnetic field of 5.82 T. The result, $g(2_1^+) = 0.33(6)$, is discussed within the systematics of g factors of even-even isotopes for the Ba-Pt region.

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The systematic study of g factors of first 2^+ states in heavy even-even nuclei has been a source of interesting nuclear structure information. Stuchbery *et al.* [1] have measured $g(2_1^+)$ for ^{184}Pt, ^{186}Pt, and ^{188}Pt, and, after comparing with other data for the Pt isotopes, found that the values are almost constant in the entire range from ^{184}Pt to ^{198}Pt. The simplest model which predicts a weak mass dependence of g factors is the hydrodynamical model [2]. However, the Pt data show an even weaker mass dependence. An indication for a similar behavior of $g(2_1^+)$ data was recently reported for the Yb isotopes in the range from ^{164}Yb to ^{176}Yb, after measuring $g(2_1^+)$ for ^{164}Yb [3]. In Ref. [3], the systematics of $g(2_1^+)$ for all isotopic chains from Ba to Pt were discussed. It was pointed out that three different trends are observed. For Ba, Ce, Nd, Sm, Gd, W, and Os, i.e., in transitional regions, the g factors vary quite strongly with N. The proton-neutron version of the interacting boson approximation (IBA-2) describes reasonably well the observed behavior for Gd, W, and Os [1]. As the structure becomes more stable, the N dependence becomes weaker and more similar to the hydrodynamical prediction. This trend is observed for Dy and Er, while for Pt and Yb the experimental values of $g(2_1^+)$ are almost constant. In Ref. [3] it was noted that the seniority model [4] predicts constant g factors as a function of nucleon number. However, this model is not expected to be valid in this region due to the large number of valence nucleons. While the reason for the variety of trends for g factor behavior for the Ba-Pt isotopes is not clear and requires a unified interpretation, additional experimental data are needed to extend the systematics in this region.

The purpose of this Brief Report is to present the result of a g factor measurement of the 2_1^+ state in ^{160}Er. The experiment was performed using the setup for g factor measurements [3] installed on one of the beamlines of the tandem accelerator of the Wright Nuclear Structure Laboratory (WNSL) at Yale University. A 96 MeV, ^{18}O beam with a typical on target current of approximately 12 pnA was used to produce the ^{160}Yb isotope via the reaction ^{147}Sm(^{18}O,5n)^{160}Yb. A 1.8 mg/cm^2 target of ^{147}Sm (98% enriched) was used. The ^{160}Yb activity was deposited on a Kapton moving tape and transported to the center of a superconducting coil. Levels in ^{160}Er were populated following beta decay of ^{160}Yb ($T_{1/2} = 4.8$ min) into ^{160}Tm ($T_{1/2} = 9.2$ min) and subsequently into ^{160}Er. The tape was moved cyclically every 30 min. An angular correlation system consisting of eight HpGe detectors with relative efficiencies of 20–25% [compared to a 3in. × 3in. NaI(Tl) detector at 25 cm] was set around the center of the coil. The half-life of the 2_1^+ state of ^{160}Er has been reported [5] to be 0.919(31) nsec, and therefore we used the integral perturbed $\gamma-\gamma$ angular correlation method [6]. More details of the experimental setup and the technique are presented in Ref. [3]. We used an external magnetic field of 5.82 T, close to the maximum of 6 T which is available with our coil. Data were taken for about 109 h with field up and 90 h with field down.

For the determination of the g factor from the data we used the 768–126 keV, $0_2^+ \rightarrow 2_1^+ \rightarrow 0_1^+$ cascade, and calculated the double ratio:

$$R(\theta, B) = \left[\frac{I(\theta, B)}{I(\theta, -B)} \Big/ \frac{I(-\theta, B)}{I(-\theta, -B)}\right]^{1/2}.$$

$I(\theta, B)$ is the coincidence intensity at angle θ and external field B. For a 0–2–0 cascade, the maximum double ratio is obtained at 35° and 145°, and therefore the detectors were set so that 12 of the 28 pairs were at these angles. Three other cascades: 264–126 keV, 728–126 keV, and 861–126 keV were used as a consistency check against systematic errors. In the data analysis, we summed up all coincidence events from detector pairs at angle θ. This was done separately for every θ and each field direction (up and down), taking into account the usual convention [7] relating the position of the detector in which each gamma ray was detected and the direction of the field. We also used the fact that: $I(\theta, B) = I[-(180-\theta), B]$, and added the events at $-(180-\theta)$ to those at angle θ. Two other relations: $I(\theta, B) = I(-\theta, -B)$ and $I(\theta, -B) = I(-\theta, B)$, can be used only when the total beam intensity on target is the

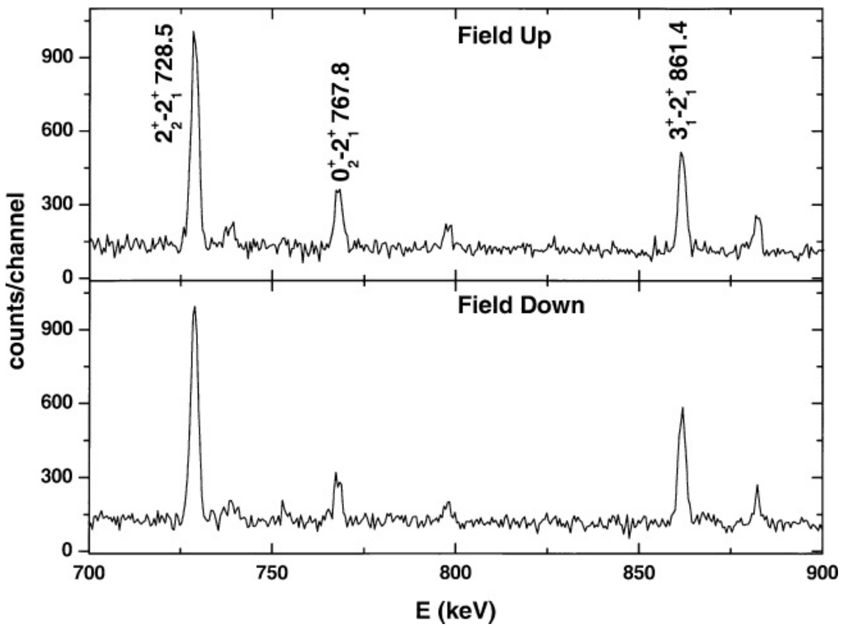

FIG. 1. Part of the background subtracted, γ-γ coincidence spectrum obtained at 145° with field up and field down, when the energy gate was set on the $2_1^+ \to 0_1^+$, 126 keV transition. The energies marked on the peaks are in keV (see text).

same for both field directions. This is usually not the case, and therefore in the final data analysis we used the double ratio as mentioned above. This procedure eliminates normalization corrections. The experimental values of $R(\theta, B)$ for the four cascades analyzed in this work are given in column four of Table I, at angles 145° and 180°. The data at 35° were used in calculating the double ratio at 145°.

In Fig. 1 we present the 700–900 keV region of the coincidence spectrum at 145°, gated on the 126 keV, $2_1^+ \to 0_1^+$ transition, with field up and field down. For illustration purposes only, we included in the summation for the spectrum for field up the data at 35° with field down and vice versa, using a crude normalization based on the beam time with field up and field down. Therefore, the spectra in Fig. 1 contain all the statistics obtained in this experiment, relevant for the extraction of the g factor. The time condition on the coincidence requirement was set at about 100 nsec. This relatively wide coincidence gate was possible due to the low counting rate. The effect of reversing the field direction is clearly seen in Fig. 1 for the 768 keV, $0_2^+ \to 2_1^+$, line. For all the other lines, the effect is much smaller, as expected (see Table I).

TABLE I. The values of the double ratio $R(\theta, B)$ obtained from the coincidence data for several cascades of ^{160}Er (see text).

Cascade (keV)	Spin sequence	Angle (deg)	$R_{\rm exp}(\theta, B)$	$R_{\rm calc}(\theta, B)^{\rm a}$
768–126	$0^+ - 2^+ - 0^+$	145	1.570(10)	–
728–126	$2^+ - 2^+ - 0^+$	145	1.02(4)	$1.09(1)^{\rm b}$
861–126	$3^+ - 2^+ - 0^+$	145	0.88(6)	$0.91(2)^{\rm b}$
264–126	$4^+ - 2^+ - 0^+$	145	0.98(3)	1.03(1)
768–126	$0^+ - 2^+ - 0^+$	180	1.03(2)	1.00
728–126	$2^+ - 2^+ - 0^+$	180	0.95(9)	1.00
861–126	$3^+ - 2^+ - 0^+$	180	0.99(13)	1.00
264–126	$4^+ - 2^+ - 0^+$	180	0.95(8)	1.00

[a]The values of $R_{\rm calc}$ and its error bars, where given, were obtained using the value $g_{\rm exp} = 0.33(6)$ (see text).
[b]The double ratio was calculated assuming pure $E2$ character for the first transition of the cascade.

In Fig. 2 we present the calculated value of the double ratio at 145° as a function of the g factor, for a 0–2–0 cascade, and the known lifetime of the 2_1^+ state. The experimental value of $R(145°, B)$ from Table I, 1.57(10), is also shown in Fig. 2 with its error bar. The value of the g factor is extracted from Fig. 2:

$$g_{\rm exp}(2_1^+) = 0.33(6).$$

This value of the g factor was used to calculate the expected double ratio R for the other cascades in Table I. The results are given in the last column of this table. We also note that at 180° there is no perturbation effect, and therefore the value of

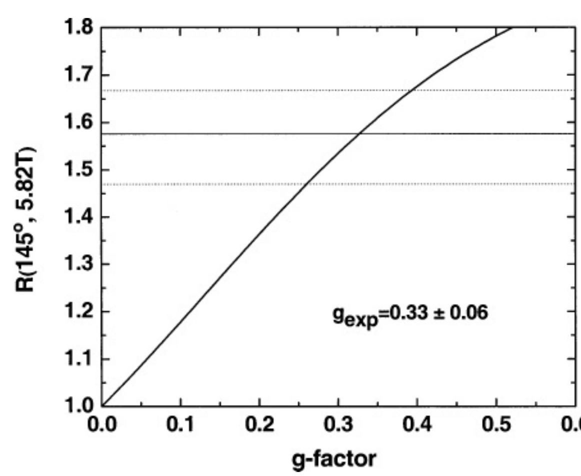

FIG. 2. The calculated double ratio $R(145°, 5.82\,{\rm T})$ vs the g factor, and the experimental double ratio for the 768–126 keV, $0_2^+ \to 2_1^+ \to 0_1^+$ cascade.

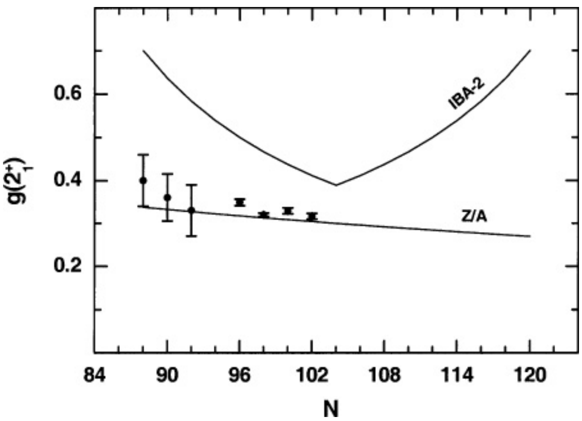

FIG. 3. Systematics of $g(2_1^+)$ data for the Er isotopes. The results for $N = 88$, 90 and $N = 96$–102 are from the tables of Raghavan [10] and Stone [11]. The value at $N = 92$ is from this work. The prediction of the IBA-2 model [8] and the Z/A trend of the hydrodynamical model [2] are also presented.

R should be 1.00 for all cascades. We see that the values in column 4 are consistent, within their experimental errors, with the calculated values in column 5. This may be considered as evidence that no serious systematic errors are present.

We now briefly discuss the present result in view of the systematics of known g factors for other Er isotopes. In Fig. 3 we present the known data, together with the result from this work, as a function of neutron number. We see that the overall trend of the data is consistent with the rather weak dependence on N predicted by the hydrodynamical model [2]. The much stronger N dependence predicted by the analytical formula of IBA-2 [8], or by any other valence nuclear model, is not consistent with the results. The simplest interpretation of this beahvior is that in the Er isotopes most or all nucleons participate in the nuclear motion, as opposed to cases such as Gd, W, and Os, where the data indicate that mostly the valence nucleons are responsible for the magnetic moments [1,3]. Furthermore, as mentioned already, the Pt and Yb isotopes exhibit a very flat dependence on N, as if the addition of neutrons to the nucleus does not affect its magnetic moment. Another possible interpretation for the weak or almost constant dependence on N for the Er, Yb, and Pt isotopes is that there is a saturation of contributions to the g factor in some regions, similarly to what occurs for $B(E2)$ values [9]. While there is no obvious microscopic rationale for any of these scenarios, or for the different behavior of different elements, the present result, analyzed in the context of the existing data, provides information on the collective nuclear behavior in this region. A better understanding of the reasons for this behavior and the different trends observed in the various isotopic chains warrants more theoretical work.

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