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g factor of the 2_1^+ state in ^{142}Ba

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The g factor of the 2_1^+ state in ^{142}Ba was measured using the time integral perturbed angular correlation technique. The state was populated following the β decay of mass-separated ^{142}Cs produced by thermal neutron fission of ^{235}U. A g factor of 0.48 ± 0.14 was measured. This result is analyzed together with previous results for ^{144,146}Ba, using two different models: the hydrodynamic model including Greiner's correction for different proton and neutron pairing forces, and the interacting boson approximation IBA-2.

In a number of earlier studies,[1,2] the g factors of the 2_1^+ states in the neutron-rich nuclides ^{144,146}Ba and ^{146,148}Ce were measured and interpreted,[3,4] along with known $g(2_1^+)$ values in this region, within the framework of the neutron-proton version of the interacting boson approximation IBA-2. This work resulted in the development of a consistent quantitative description of the behavior of those quantities throughout the transition from spherical to deformed structure which takes place in this mass region. The current paper reports an additional measurement which complements these studies, namely, the $g(2_1^+)$ value for ^{142}Ba. It will be shown that the theoretical description already derived for this region correctly predicts the new result. The applicability of the hydrodynamical approach, as used by Greiner,[5] will also be considered.

Ion beams of mass separated ^{142}Cs obtained by neutron fission of ^{235}U in a thermal ion source[1] at the TRISTAN facility[2] at Brookhaven National Laboratory were used to provide the source of ^{142}Ba. The ion beam was collected on the aluminum layer of an aluminized plastic tape for 3.8 s, then moved into a magnet where the angular correlation pattern was measured for 3.8 s, during which time the next sample was collected. This cycle was repeated throughout the 4-d experiment. The magnetic field was provided by a superconducting magnet with a maximum field strength of 6.25 T at 4.2 K. The direction of the field was reversed in the middle of the experiment so that the shift in the angular correlation pattern could be more easily observed. About 8×10^7 events were collected for each field direction.

The g factor can be determined by measuring the magnitude of the shift, $\Delta\theta$, of the angular correlation in a magnetic field or, as is the case in this experiment and others,[3,4] by measuring the double ratio

$$R^2(\theta)=\frac{I(\theta,B)}{I(\theta,-B)}\Bigg/\frac{I(-\theta,B)}{I(-\theta,-B)}\ , \tag{1}$$

where $I(\theta,B)$ is the intensity at angle θ with field up. By defining this ratio, systematic errors which may arise from different detector efficiencies, geometrical corrections, source strength variations, and time of measurement will cancel. The data were taken using a fixed four-detector system which has been described elsewhere.[6] Coincidences at angles of 150°, 120°, and 90° were obtained and the data at 150° were used to determine the g factor since both the magnitude of $R(\theta)$ and the counting statistics (the 150° angle was repeated three times) were larger. In addition, the data at 150° are less sensitive to systematic errors in the angular positioning of the detectors than those at other angles, and this type of systematic error is not canceled by the double ratio. The other angles were used as consistency checks.

The 2_1^+ state in ^{142}Ba has a half-life of only 0.079 ns (Ref. 7). Thus, it was necessary to use the maximum available magnetic field, 6.25 T, and to use $0^+\rightarrow2^+\rightarrow0^+$ cascades to take advantage of the large associated correlation coefficients (theoretical $a_2=0.357$, $a_4=1.143$) to maximize the effect. In ^{142}Ba there are two excited 0^+ states that are populated strongly enough to be useful: one at 1639.6 keV, the other at 1535.5 keV.[8] To improve statistics, the intensities of the $0^+\rightarrow2^+$ γ rays were summed.

The results of the measurement at each angle are shown in Table I. From these data a value of

$$g(2_1^+)=0.48\pm0.14 \tag{2}$$

is derived for ^{142}Ba as illustrated in Fig. 1. It should be noted that although the standard deviation of the result seems quite large, this is not due to poor counting statistics, but rather to the short half-life. This is evident in Fig. 1 where that short half-life causes the curve of $R(\theta)$ vs g to have a small slope which magnifies the error on R as it is mapped to give the error on g.

From Table I we see that the values of $R(\theta)$ at 90° and 120° are consistent with what we expect for a g factor of

TABLE I. Results for the g factor of ^{142}Ba. $R(\theta)$ is an average of the data for each angle measured. The data for the 1176-359 keV and 1280-359 keV cascades were summed. The last column gives the values of $R(\theta)$ calculated for a g factor of 0.48.

θ	$R(\theta)$ experimental	g factor	$R(\theta)$ for $g=0.48$
90	0.988 ± 0.029		1.000
120	1.009 ± 0.033		0.963
150	1.074 ± 0.022	0.48 ± 0.14	1.074

0.48 and a 0^+-2^+-0^+ cascade. This indicates that systematic errors, if present, are smaller than the statistical errors.

We will now discuss the present result for ^{142}Ba together with the $g(2_1^+)$ values for ^{144,146}Ba measured previously.[3] We use two models: (a) the hydrodynamic model with Greiner's correction[5] and (b) IBA-2.

The simpler version of the hydrodynamic model predicts $g=Z/A$ for collective nuclear states. Greiner has shown,[5] however, that the different pairing forces of protons and neutrons can change that value. More specifically, the larger pairing force for protons implies a smaller deformation for protons than for neutrons, which in turn implies that the neutron and proton degrees of freedom no longer rotate in phase with each other. The tensorial character which results from the g factor gives rise to a reduction in the Z/A estimate for g_R, as well as to transitions between excited states.

For the ground band of rotational nuclei, Greiner obtains

$$g_R=\frac{Z}{A}(1-2f)\ , \tag{3}$$

while the analogous treatment for vibrational nuclei yields

$$g_R\approx\frac{Z}{A}(1-\tfrac{4}{3}f)\ . \tag{4}$$

Here f is given by

$$f\approx\frac{N}{A}(\sqrt{G_p/G_n}-1)=\frac{N}{A}(\sqrt{\beta_n/\beta_p}-1)\ . \tag{5}$$

In Eq. (5) G_p and G_n are the strength of the pairing forces for protons and neutrons, respectively. Nilsson and Prior[10] have suggested values of $G_n=18/A$ MeV and $G_p=25/A$ MeV, while Marschalek and Rasmussen[11] have found $G_n=20/A$ MeV and $G_p=30/A$ MeV. In our calculations we have used the former values since they appear to give slightly better agreement with the data. The results for both the vibrational and rotational calculations are shown in Fig. 2. The transition between vibrational and rotational structure would be expected to take place between ^{142}Ba and ^{144}Ba, as indicated by the dotted line in Fig. 2.

Another model which can be used to interpret the data is IBA-2. According to this model, a 2_1^+ state which is fully symmetric with respect to interchange of neutron and proton degrees of freedom has a g factor given by:[12]

$$g(2_1^+)=g_\pi\frac{N_\pi}{N_t}+g_\nu\frac{N_\nu}{N_t}\ , \tag{6}$$

where N_π and N_ν are the number of proton bosons and neutron bosons, respectively, $N_t=N_\pi+N_\nu$, and g_π and

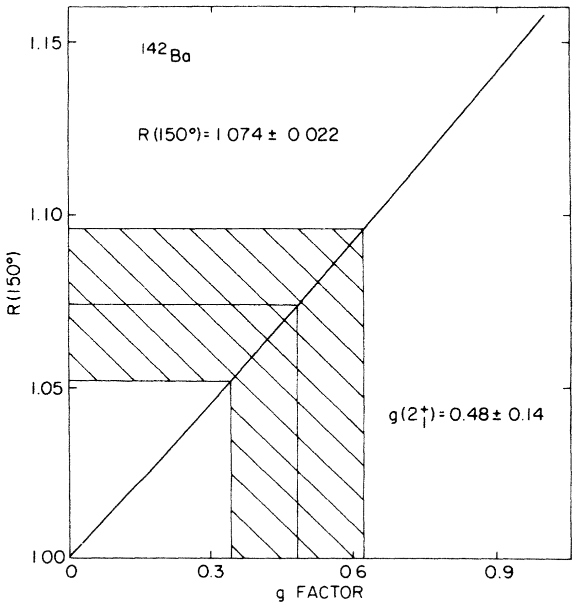

FIG. 1. $R(\theta)$ vs $g(2_1^+)$ calculated for a $0^+\rightarrow2^+\rightarrow0^+$ cascade, with $\theta=150°$ and $T_{1/2}=0.079$ ns for the 2_1^+ state. The shaded region shows the derivation of the resulting g factor and error from the measured $R(150°)$.

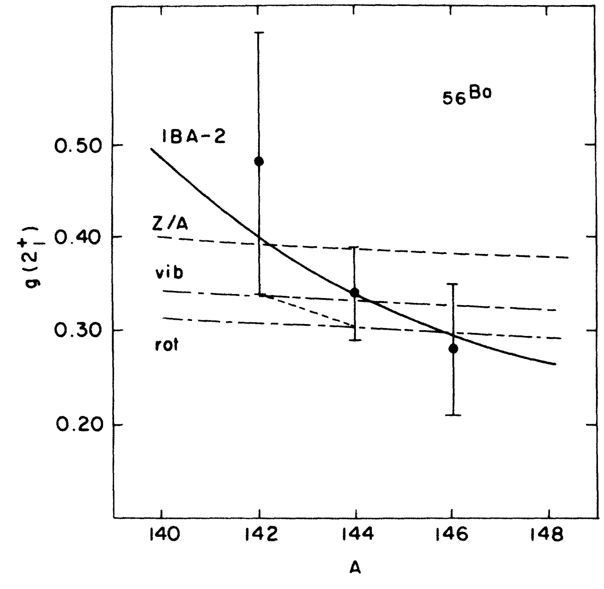

FIG. 2. $g(2_1^+)$ values for Ba compared to hydrodynamical and IBA-2 calculations. The dashed line is the Z/A dependence, the dot-dashed line includes Greiner's correction with the dotted line showing the transition from vibrational to rotational structure. The solid line is the IBA-2 calculation based on Eqs. (6) and (7).

g_ν are the g factors of a single proton boson and neutron boson, respectively.

Previous IBA-2 analyses[9] of the g factors of 2_1^+ states for a large number of nuclei in the $A=150$ region showed that constant values of g_π and g_ν may be used, specifically,

$$\begin{aligned} g_\pi &= 0.63 \pm 0.04 \ , \\ g_\nu &= 0.05 \pm 0.05 \ . \end{aligned} \tag{7}$$

These values of g_π and g_ν, together with Eq. (6), can thus be used to calculate $g(2_1^+)$ for the Ba isotopes, and the results are presented in Fig. 2. In particular, for ^{142}Ba a value of $g(2_1^+)=0.40$ is obtained, consistent with the results of the current experiments. We note that the IBA-2 model predicts a more rapid decrease of $g(2_1^+)$ with A than the hydrodynamic model. This is due to the fact that since g_ν is consistent with zero, Eq. (6) predicts a dependence N_π/N_t based on valence nucleon number, rather than on total nucleon number. In addition, the IBA model is independent of the structure of the Hamiltonian, and hence does not require the somewhat *ad hoc* change from a vibrational to rotational description.

Nevertheless, it is clear from Fig. 2 that the experimental results presented here are not sufficiently accurate to distinguish between the IBA-2 and the hydrodynamical calculations. However, it is equally evident that the difference between the predictions of the two approaches becomes far more significant for ^{140}Ba, so that a measurement of $g(2_1^+)$ for that nucleus would provide a more sensitive test.

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