Systematics of g factors in the neutron-rich ^{142,144,146}Ba isotopes

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The g factor of the 2_1^+ state in ^{142}Ba has been remeasured with higher accuracy. The new result, when combined with recently measured values of $T_{1/2}$ for this state and with $g(2_1^+)$ values in ^{144,146}Ba, clearly indicates that in this region, the proton-neutron interacting boson model gives a much better description of magnetic moments than the hydrodynamical model with the Greiner corrections.

The purpose of this paper is to use recently measured data on magnetic moments of 2_1^+ states in neutron-rich ^{142,144,146}Ba isotopes in order to compare two nuclear models that are commonly used to calculate g factors of collective nuclear states: the hydrodynamical model, and the proton-neutron interacting boson approximation (IBA-2). In the hydrodynamical model, the g factors of excited states are given by the following equations of Greiner:[1]

$$g=\frac{Z}{A}(1-2f) \tag{1}$$

for rotational nuclei and

$$g=\frac{Z}{A}(1-\tfrac{4}{3}f) \tag{2}$$

for vibrational nuclei, where

$$f=N/A(\sqrt{G_p}/G_n-1)\ , \tag{3}$$

and G_p (G_n) are the strengths of the proton (neutron) pairing forces.

An alternative approach for calculating $g(2_1^+)$ in collective nuclei is provided by the proton-neutron version of the interacting boson approximation[2] (IBA-2)

$$g(2_1^+)=(g_\pi N_\pi+g_\nu N_\nu)/N_t\ , \tag{4}$$

where g_π (g_ν) are the proton (neutron) boson g factors, N_π (N_ν) the respective numbers of bosons, and $N_t=N_\pi+N_\nu$. This relation is essentially independent of the parameters in an IBA-2 Hamiltonian. Furthermore, it is important to point out that any differences between the hydrodynamical and the IBA-2 predictions lie, not in the details of the Hamiltonian, but in the basic assumption of equal treatment for all nucleons (hydrodynamical) versus including only valence nucleons (IBA-2). In a recent publication,[3] it was shown that Eq. (4) gives a good description of experimental g factors for a large number of nuclei in the range $A=70-200$. Since the hydrodynamical model[1] also reproduces the gross trends of magnetic moments across the periodic table, it is evident that in order to differentiate between the two models one has to carefully examine fine structure effects. Such effects were indeed found in the $A=150$ region,[4] where they are related to the existence of the $Z=64$ subshell, and for nuclei around $Z=50$.[2] In both cases, the IBA description was found to provide a more adequate description, although in the latter case the only comparison with a geometrical model was for a simple Z/A dependence, without taking into account the reduction in $g(2_1^+)$ due to the different pairing forces between protons and neutrons[1] [Eqs. (1) and (2)].

A good way to differentiate between the two models is to study the N dependence of $g(2_1^+)$ in a series of isotopes. Since in the IBA only the valence particles are taken into account, while in the hydrodynamical model all nucleons are considered, the slope of $g(2_1^+)$ vs N will be different in the two approaches. When sufficiently accurate data are available, it should therefore be possible to distinguish between the models. Sambataro *et al.*[2] have investigated the $g(2_1^+)$ data available at that time for isotopic chains in the range $56\le Z\le 78$, and reported qualitatively better agreement with IBA-type calculations than with Z/A. In this paper we apply the same procedure to the neutron-rich ^{142,144,146}Ba isotopes. $g(2_1^+)$ values for ^{144,146}Ba were measured earlier[5] at the TRISTAN on-line separator[6] using the integral perturbed angular correlation (PAC) method. Recently, a result was reported[7] for ^{142}Ba using the same technique. However, the experimental accuracy did not warrant a meaningful comparison of the two models.

In this work we present the results of a PAC experiment which was undertaken in order to improve the accuracy of $g(2_1^+)$ for ^{142}Ba. The new experimental result is combined with the previous data and with recently reported half-life measurements for the 2_1^+ state. The final value of the g factor now allows a meaningful quantitative comparison of IBA-2 and the hydrodynamical model.

The experiment was carried out at the TRISTAN fission product separator, which operates on-line with the high-flux beam reactor at Brookhaven National Laboratory. The separator provides mass-separated radioactive beams from thermal neutron fission of ^{235}U with relatively high intensities (10^6–10^{10} atoms/sec). In the present experiment, a beam of ^{142}Cs was deposited on an aluminized plastic tape, and then carried inside a superconducting magnet. Since the half-life of the 2_1^+ state is rather short (less than 0.1 nsec, see the following), the maximum available field of 6.25 T was used. The experimental system consisted of four large (80 cm^3 volume) hyperpure Ge detectors. A detailed description of the four-detector system and the associated electronics has been given elsewhere.[8] It enables simultaneous measurement of six angles, which correspond to the six pairs of detectors. In the present experiment we used the 1175-359 and 1280-359 keV cascades in ^{142}Ba in order to determine the g factor of the 359 keV (2_1^+) state. Both cascades are of the $0^+ \to 2^+ \to 0^+$ type. This spin sequence has a very strong anisotropy, and when an external magnetic field is applied, the maximum effect occurs at $\theta \approx 150°$. The detectors were therefore set so that three of the six angles were 150°, two were 120°, and one was 90°. The double ratio

$$R^2(\theta) = \frac{I(\theta,B)}{I(\theta,-B)} \Big/ \frac{I(-\theta,B)}{I(-\theta,-B)} \quad (5)$$

was determined at each angle θ, directly from the total number of coincidence counts with field up, $I(\pm\theta,B)$, and field down, $I(\pm\theta,-B)$. About 2.7×10^8 coincidence events were collected for each field direction. The final values of $R(\theta)$, averaged for all detector pairs at each angle θ, are given in Table I. We have also included in this table the results for the 967-359 keV cascade, for which the spin sequence is 1-2-0, and should therefore give a value $R(\theta) \approx 1.00$ because of the short half-life of the 2_1^+ state and the relatively weak anisotropy of the correlation. The data indeed show $R(\theta)$ values that are close to 1.00 for this cascade, while for the 0-2-0 cascades the effect at 150° is clearly statistically different than 1.00. The fact that all $R(\theta)$ values in Table I, except $R(150°)$ for the 0-2-0 cascades, are consistent with 1.00 provides a good check against systematic errors. In order to extract the g factor from the measured $R(150°)$, the half-life of the state has to be known. In our previous report,[7] we used $T_{1/2}=0.079(6)$ nsec, from the work of Cheifetz *et al.*[9] Recently, two other values became available, from works of Mamane[10] with a ^{252}Cf source, and Mach *et al.*[11] from β-γ coincidence measurements at TRISTAN. All the results for $T_{1/2}$ are summarized in Table II. The weighted average of these results is

$$T_{1/2} = 66(4)\ \text{psec} . \quad (6)$$

TABLE I. Experimental values of the ratio $R(\theta)$ [Eq. (5)] at 90°, 120°, and 150° for the 967-359, 1176-359, and 1280-359 keV cascades from ^{142}Cs$\to$^{142}Ba decay. The results of the 0-2-0 cascades have been summed.

Cascade	Spin sequence	$R(\theta)$ 90°	$R(\theta)$ 120°	$R(\theta)$ 150°
967-359	1-2-0	1.018(12)	1.001(6)	1.000(6)
1176-359 1280-359	0-2-0	1.013(13)	0.981(9)	1.053(6)

TABLE II. Summary of half-life values for the 2_1^+ level in ^{142}Ba.

No.	$T_{1/2}$ (psec)	Reference
1	79(6)	E. Cheifetz *et al.*, Ref. 9
2	58(5)	G. Mamane, Ref. 10
3	64(7)	H. Mach *et al.*, Ref. 11

Using this value of $T_{1/2}$, the ratio $R(150°)$ for the 0-2-0 cascades from Table I, and the angular correlation coefficients corrected for solid angle attenuation following Camp and van Lehn,[12] we obtain now for the g factor of the 359 keV level

$$g(2_1^+) = 0.413(50) . \quad (7)$$

The present error, which includes the uncertainty in $T_{1/2}$, is about three times smaller than the one reported previously.[7] This is primarily due to much better statistics. The weighted average of both results is

$$g(2_1^+) = 0.426(48) . \quad (8)$$

In calculating this final value we have corrected the previous result[7] to take into account the new half-life [Eq. (6)].

In Fig. 1 we present the final result [Eq. (8)] for ^{142}Ba together with the data for ^{144,146}Ba,[5] and the predictions of the hydrodynamical model with Greiner's correction[1] for rotational and vibrational nuclei [Eqs. (1) and (2)] and the IBA-2 model [Eq. (4)]. We used two values of G_p/G_n for calculating the factor f [Eq. (3)]: 1.389 from Nilsson and Prior,[13] and 1.500 from Marschallek and Rasmussen.[14] The lines labeled vib and rot in Fig. 1 are averages of the two calculations for vibrational and rotational nuclei, respectively. For the isotopes under consideration, a transition occurs around $N=90$ from vibrational rotational structure, so both lines are relevant to this discussion.

For the IBA-2 calculation we used

$$g_\pi = 0.63 ,$$

$$g_\nu = 0.05 ,$$

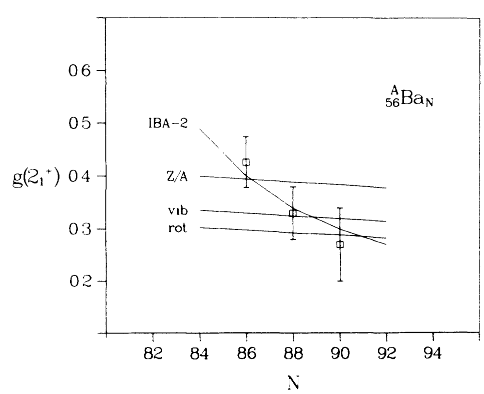

FIG. 1. Experimental values of $g(2_1^+)$ for ^{142,144,146}Ba isotopes and predictions of Z/A, the hydrodynamical model [Eqs. (1) and (2)], and IBA-2 [Eq. (4)].

for the proton and neutron boson g factors. These values were obtained from linear fits to experimental data in the $A=150$ region, as described in Ref. 3.

The importance of the ^{142}Ba value is evident from Fig. 1. At $N=86$, the difference between the hydrodynamical and IBA-2 curves is about 20%. The experimental result is about two standard deviations above the predictions based on Eqs. (1) and (2). On the other hand, it is in very good agreement with the IBA-2 prediction. Moreover, the N dependence of the experimental $g(2_1^+)$ data is much better reproduced by the IBA calculation.

In conclusion, we have shown that accurate values of g factors of 2_1^+ states in collective nuclei can help distinguish between different nuclear models. Specifically, for the neutron-rich Ba isotopes, the IBA-2 provides, with a very simple formula which emphasizes the role of valence nucleons, a better description than the hydrodynamical model.

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