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g-FACTOR MEASUREMENTS ON EXCITED STATES IN THE N=82 ISOTONES

John C. Hill and F. K. Wohn
Ames Laboratory USDOE, Iowa State University, Ames, Iowa 50011

A. Wolf* and Z. Berant*
Ames Laboratory USDOE, Iowa State University, Ames, Iowa 50011
and
Brookhaven National Laboratory, Upton, New York 11973

R. L. Gill, H. Mach, and M. Rafailovich††
Brookhaven National Laboratory, Upton, New York 11973

H. Kruse† and B. H. Wildenthal§
Michigan State University, E. Lansing, Michigan 48824

G. Peaslee
SUNY at Stony Brook, Stony Brook, New York 11794

ABSTRACT

A program for the measurement of g-factors for excited states of neutron-rich nuclei at the TRISTAN separator facility is described. Results are given for the 4_1^+ states in the N=82 isotones ^{136}Xe and ^{138}Ba. Systematics for g-factors for 4_1^+ and 6_1^+ states in the N=82 isotones are presented and the results are compared with those of a shell-model calculation. The results are well described using effective proton spin and orbital g-factors.

1. Introduction

A knowledge of g-factors of nuclear excited states is of interest in that features of the nuclear wavefunction are often revealed that cannot be easily determined by other means. A good example is the g-factor measured for the $g(6_1^+)$ state in ^{134}Te by Wolf and Cheifetz[1]. The region around ^{132}Sn has been shown to be one of our best doubly magic regions, therefore features of the low-mass N=82 isotones should be well described by excitations of protons outside of an inert ^{132}Sn core. Such calculations have been carried out by Wildenthal et al.[2,3] and Waroquier and Heyde[4]. Level energies, J^{π} values and spectroscopic factors were well described by the above models.

The g-factor for the 6_1^+ state in ^{134}Te is an exception to the above generalization in that it is not well described by a shell-model calculation involving only extra-core protons. If the ^{132}Sn core were truly inert then the g-factor should be describable in terms of simple excitations of the 51st and 52nd protons. The lowest relevant configuration would be $(g_{7/2})^2$ which gives a calculated $g(6_1^+)$ of 0.491. This is considerably smaller than the experimentally measured value[1] of 0.846±0.025. The calculated $g(6_1^+)$ can be increased by admixture of the $(g_{7/2},d_{5/2})$ configuration. Detailed calculations regarding the structure of the ^{134}Te levels have been carried out by Heyde et al.[5] and Wildenthal and Larson[3]. The 6_1^+ state was calculated to be primarily $(g_{7/2})^2$ with an $(g_{7/2},d_{5/2})$ admixture of 2.3% and 13.7% respectively for Ref. 5) and 3). The corresponding calculated $g(6_1^+)$ in ^{134}Te thus becomes 0.504 and 0.573 respectively. Thus such admixtures cannot account for the measured $g(6_1^+)$.

Wolf and Cheifetz[1] next evaluated the effect of core polarization due to $\pi(g_{9/2}^{-1},g_{7/2})$ and $\nu(h_{11/2}^{-1},h_{9/2})$ excitations using the method of Arima and Horie[6]. This increased $g(6_1^+)$ by 0.192, giving values of 0.696 and 0.765 respectively for the two $(g_{7/2},d_{5/2})$ admixtures given above. This corresponds to a particle-hole admixture in the wave function of 0.4%. A particle-hole admixture of 0.9% would account for the entire deviation of the experimental $g(6_1^+)$ from the $(g_{7/2})^2$ Schmidt value.[1] Heyde et al.[7] have reproduced the experimental $g(6_1^+)$ of ^{134}Te by taking into account core polarization and velocity dependent corrections to the magnetic dipole operator.

In this paper we present another approach. We determine effective proton spin and orbital g-factors from g-factors of two odd-Z nuclei and are able to reproduce observed g-factors for five even-even nuclei.

2. The TRISTAN g-Factor Measurement Facility

TRISTAN is an Isotope Separator On Line (ISOL) system[8] for the study of neutron-rich nuclei far from stability located at the High-Flux Beam Reactor at Brookhaven National Laboratory. Activities are produced by fission by thermal neutrons of ^{235}U which is a component of a target ion source combination. Due to the development of several types of ion sources a large variety of fission product beams are available for study.[8] The layout of the TRISTAN facility is shown in Fig. 1.

The TRISTAN separator is ideally suited for studies of the validity of the shell model in regions far to the neutron-rich side of stability. Of special interest is the question of whether the regions around neutron-rich ^{132}Sn and ^{78}Ni are truly doubly magic. Mass separation of short-lived fission products is about the only means available to study such nuclei. Study of the ^{132}Sn region at the ISOL facilities, OSIRIS, JOSEF, ISOLDE and TRISTAN have shown it to be one of the best doubly magic regions. Study of the N=50 isotones above ^{78}Ni is planned at TRISTAN which should give some information on the degree to which the ^{78}Ni region is doubly magic.

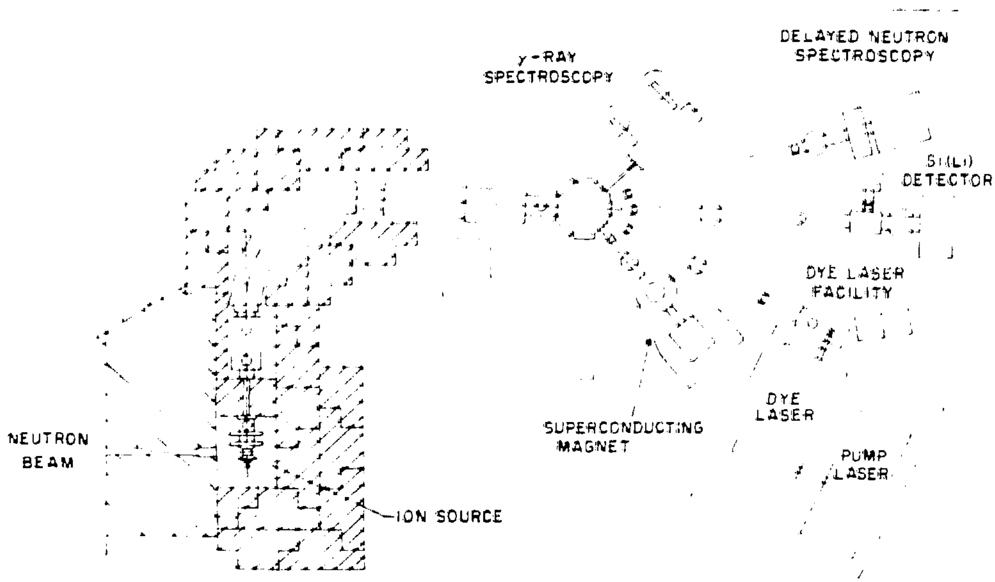

Fig. 1. Layout of TRISTAN separator system.

A system for the measurement of g-factors of nuclear excited states using the technique of perturbed angular correlations (PAC) has been set up on-line to the TRISTAN separator. The initial system used a conventional electromagnet to achieve magnetic fields of up to 2.7T. Results from this system on $g(2_1^+)$ for states in ^{144}Ba and ^{146}Ba have been reported earlier[9]. Recently a superconducting magnet (see Fig. 1) has been installed allowing maximum fields of 6.25T at 4.2°K or 6.75T if the λ- point refrigerator is used to cool the magnet to 2.2°K. Details of this system are given in Ref. 8.

In a typical PAC measurement the TRISTAN ion beam is deposited on an aluminized mylar tape for an appropriate period of time and subsequently moved to a position between the poles of the magnet. Four Ge γ-ray detectors measure γ-γ coincidences in a plane perpendicular to the direction of the magnetic field as shown in Fig. 2. γ-γ coincidences between any of the six pairs of detectors are recorded as address triplets on magnetic tape. The four-detector system has been described in detail elsewhere[10].

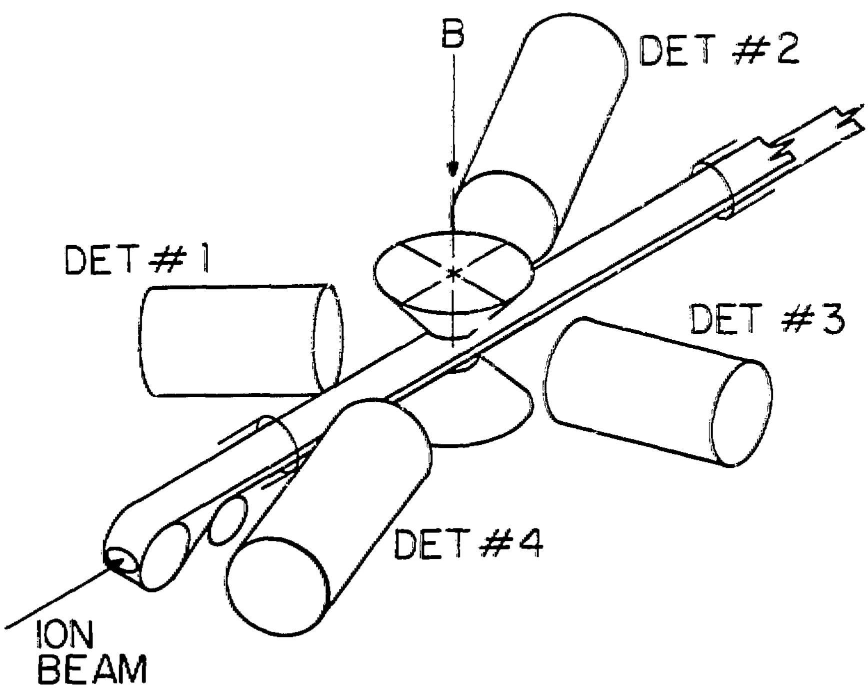

Fig. 2. Schematic diagram of the PAC experimental system.

3. Measurement of $g(4_1^+)$ for ^{136}Xe and ^{138}Ba

The measurement of $g(4_1^+)$ was carried out by observing appropriate γ-γ cascades between levels in ^{136}Xe and ^{138}Ba populated in the β^- decay of ^{136}I and ^{138}Cs respectively. The activities were produced by a FEBIAD-type ion source[8]. The magnetic field was 1.72 and 1.83 T for the Xe and Ba measurements respectively. The integral PAC method was used since the 4_1^+ state half-lives are 1.32 and 2.17 ns respectively[11,12] for ^{136}Xe and ^{138}Ba. For each isotope, an unperturbed angular correlation measurement to determine the coefficients A_{22}, A_{44} in the Legendre polynomial expansion and a time-integral perturbed angular correlation measurement to determine the g-factor were carried out. For each experiment, a different set of angles between the detector pairs was chosen. For the unperturbed correlations, the detectors were set in such a way that angles of 90°, 105°, 120°, 135°, 150° and 165° were obtained between the various pairs. For the perturbed correlations, the detectors were set so that between four pairs we had 130° (for ^{136}Xe) or 140° (for ^{138}Ba). For the particular γ-γ correlations which were used to determine the g-factors of these nuclei, the expected effect is nearly maximal at these two angles. We thus had about four times more statistics per unit time as compared with a two-detector system.

Partial decay schemes of ^{136}Xe (Ref. 13) and ^{138}Ba (Ref. 14) which are relevant to the present work are given in Fig. 3. No γ-γ correlations have been reported to date for ^{136}Xe. For ^{138}Ba, some spin assignments were obtained from γ-γ correlation measurements.[15] We measured unperturbed γ-γ correlations for some of the cascades in Fig. 3. The coefficients A_{22}, A_{44} of the polynomial expansion are given in Table I. In the case of ^{138}Ba, our results agree with those of Basinger et al.[15] and confirm their spin assignments. The results for the 381-1313 and 197-381 cascades(keV) in ^{136}Xe are consistent with $4^+-2^+-0^+$ and $6^+-4^+-2^+$ assignments, respectively. The A_{22}, A_{44} coefficients for the 750-381 cascade in ^{136}Xe are consistent with the spin sequences $3-4^+-2^+$ or $5-4^+-2^+$. The J=3 possibilitiy can be ruled out since a γ transition is observed from this level to the 6_1^+ but not the 2_1^+ state.[13] We therefore assign 5 for the J of the 2444-keV level.

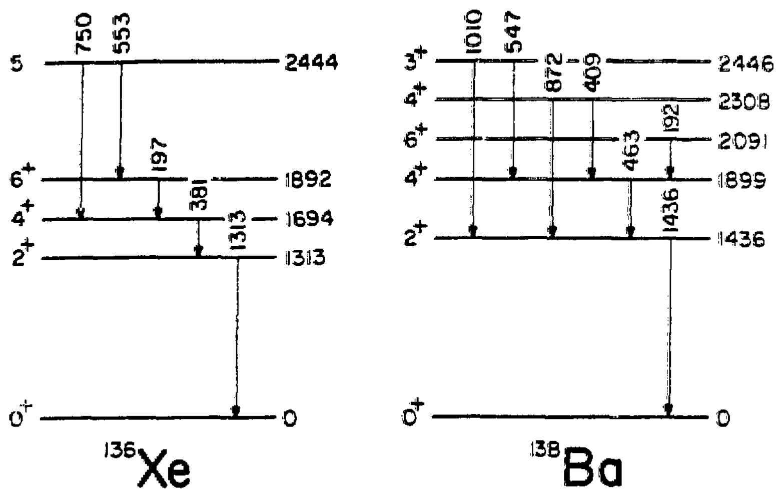

Fig. 3. Partial decay schemes of ^{136}Xe and ^{138}Ba.

TABLE I. Results of the unperturbed angular correlation measurements.

Isotope	Cascade (keV)	Present results[a] A_{22}	A_{44}	Spin sequence
^{136}Xe	381-1313	0.083±0.015	-0.02 ±0.02	$4^+-2^+-0^+$
	197-381	0.080±0.020	0.004±0.020	$6^+-4^+-2^+$
	750-381	-0.410±0.010	0.003±0.030	$5-4^+-2^+$
^{138}Ba	409-463	0.192±0.010	-0.02 ±0.03	$4^+-4^+-2^+$
	409-(463)-1436	0.194±0.004	-0.008±0.020	$4^+-4^+-2^+-0^+$
	872-1436	0.126±0.020	-0.006±0.030	$4^+-2^+-0^+$
	1010-1436	-0.096±0.032	0.014±0.045	$3^+-2^+-0^+$
	547-(463)-1436	-0.034±0.010	0.001±0.014	$3^+-4^+-2^+-0^+$

[a] A_{22} and A_{44} are the coefficients of the Legendre polynomials $P_2(\cos\theta)$ and $P_4(\cos\theta)$, respectively.

The half-lives of the $4_1{}^+$ states in ^{136}Xe and ^{138}Ba are suitable for integral perturbed angular correlation measurements.

of their g-factors. Experimentally, we measured the double ratio

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

where $I(\theta,B)$ is the number of counts for the given γ-γ cascade at angle θ with magnetic field B up. The advantage of using this ratio is that it does not depend on normalization involving detector efficiency, geometry, beam intensity and counting time with field up and down. Several sources of systematic errors are thus eliminated.

The angular correlation coefficients were corrected for solid angle attenuation using information given by Camp and van Lehn.[16)] The magnetic field at the site of the Xe or Ba nuclei (stopped in the aluminized tape) was taken to be equal to the applied magnetic field. Extranuclear perturbations from electric field gradients are not expected because of the cubic structure of aluminum. Also, many unperturbed correlations have been measured to date using aluminized mylar tape and good agreement with theoretical values was found. This indicates that extranuclear perturbations, if at all present, are smaller than the statistical errors.

For a given γ-γ correlation, $R(\theta)$ has a maximum at an angle θ_{max}, which depends on A_{22} and A_{44}. $\theta_{max} \approx 145^{o}$ for the cascades considered in this work. The results for $R(\theta)$ for ^{136}Xe and ^{138}Ba are given in Table II along with the g-factors which were deduced using known formulas for perturbed angular correlations.[17)]

TABLE II. Results of the perturbed angular correlation measurements.

Isotope	Cascade	$R(\theta)$	$g(4_1^+)$
$^{136}Xe^{a}$	750-381	0.868±0.033	
	750-(381)-1313	0.844±0.030	0.80±0.15
$^{138}Ba^{b}$	409-463	1.094±0.010	
	409-(463)-1436	1.097±0.013	0.80±0.14

^{a}B=1.72 T, $\theta = 130^{o}$.

^{b}B=1.83 T, $\theta = 140^{o}$.

4. Shell-Model Interpretation of g-Factors in the N=82 Isotones

All g-factors which have been measured for 4_1^+ states in the N=82 isotones are given in Table III along with those for the 6_1^+ states in ^{134}Te and ^{138}Ba. Table III also gives the results of a shell-model calculation for the above g-factors. Wavefunctions for the states of interest were obtained from a shell-model calculation which was carried out for the N=82 nuclei ^{133}Sb to ^{148}Dy. The model space consisted of all $g_{7/2}$, $d_{5/2}$, $d_{3/2}$, $s_{1/2}$, and $h_{11/2}$ configurations outside of a closed ^{132}Sn core. The only restrictions were that a maximum of four protons were allowed in the $h_{11/2}$ orbit, and that only configurations with overall seniority less than or equal to 4 were considered. Values for the individual matrix elements of the two-body Hamiltonian and for the single-particle energies were fitted using a set of approximately 150 well-determined energy levels for the N=82 isotones. A description of this fit, and the detailed results of the shell model calculation will be reported by two of us (HK and BHW) in a future publication.

TABLE III. Measured and calculated g-factors for states in the N=82 isotones.

nucleus	J^π	g(experimental)	Calculated with free proton g-factors	Calculated with effective proton g-factors[a]
^{134}Te	6^+	0.846±.025[b]	0.55	0.82
^{136}Xe	4^+	0.80±.15[c]	0.58	0.84
^{138}Ba	4^+	0.80±.14[c]	0.67	0.90
	6^+	0.98±.02[d]	0.83	1.01
^{140}Ce	4^+	1.11±.04[e]	0.99	1.11

[a] g'_ℓ =1.12 and g'_s =4.12.

[b] Ref. 1.

[c] This work

[d] Ref. 18.

[e] Ref. 19.

It has been established[1] in the case of the g-factor for the 6_1^+ state in ^{134}Te that the use of configuration-mixed shell-model wavefunctions along with free proton spin and orbital g-factors is not sufficient to give the correct $g(6_1^+)$. We have chosen to indirectly incorporate core polarization effects by determining one set of effective proton orbital and spin g-factors g'_ℓ and g'_s. These were determined by fitting the ground state g-factors for ^{139}La and ^{141}Pr, which are $g(7/2^+)=2.78$ and $g(5/2^+)=4.28$, respectively,[20] to the configuration-mixed wavefunctions. These wavefunctions are very pure for the ground states of ^{139}La and ^{141}Pr which is consistent with spectroscopic factors obtained from single-proton transfer reactions.[21] Fits to the experimental g-factors for ^{139}La and ^{141}Pr yield $g'_\ell=1.12$ and $g'_s=4.12$.

The above effective proton g-factors g'_ℓ and g'_s were next used to calculate the g-factors for the 4_1^+ states in ^{136}Xe, ^{138}Ba, and ^{140}Ce and the 6_1^+ states in ^{134}Te and ^{138}Ba using the appropriate configuration-mixed wavefunctions. The results are given in Table III. The known $g(4_1^+)$ values can all be reproduced using one pair of effective proton g-factors that adequately describe the core polarization effects for all 4 nuclei. It is interesting to examine the contributions of the various components of the wavefunctions to the magnetic moments of the 4_1^+ states in ^{136}Xe and ^{138}Ba. This is illustrated in Fig. 4. In both cases more than 75% of the contribution to the g-factor comes from a single component of the wavefunction.

The ^{136}Xe components shown in Fig. 4 are:

(a) $(g_{7/2})^4_4$, (b) $(g_{7/2})^2_4\,(d_{5/2})^2_0$, (c) $(g_{7/2})^3_{7/2}\,(d_{5/2})^1_{5/2}$,

(d) $(g_{7/2})^2_4(h_{11/2})^2_0$, (e) $(g_{7/2})^2_4(d_{3/2})^2_0$, (f) $(g_{7/2})^3_{5/2}(d_{3/2})^1_{3/2}$,

(g) $(g_{7/2})^2_0\,(d_{5/2})^2_4$, (h) $(g_{7/2})^1_{7/2}\,(d_{5/2})^3_{5/2}$.

For ^{138}Ba the components shown in Fig. 4 are:

(a) $(g_{7/2})^6_4$, (b) $(g_{7/2})^4_4(d_{5/2})^2_0$ (c) $(g_{7/2})^5_{7/2}(d_{5/2})^1_{5/2}$,

(d) $(g_{7/2})^3_{7/2}(d_{5/2})^3_{5/2}$, (e) $(g_{7/2})^4_4(h_{11/2})^2_0$, (f) $(g_{7/2})^4_0(d_{5/2})^2_4$,

(g) $(g_{7/2})^2_4(d_{5/2})^4_0$, (h) $(g_{7/2})^4_4(d_{3/2})^2_0$, (i) $(g_{7/2})^3_{7/2}(d_{5/2})^1_{5/2}$.

In summary, we have measured $g(4_1^+)$ for ^{136}Xe and ^{138}Ba and created systematics for $g(4_1^+)$ in the N=82 isotones. The results for the known $g(4_1^+)$ and $g(6_1^+)$ are well described by calculations employing configuration-mixed shell-model wavefunctions and effective proton spin and orbital g-factors that account in an empirical fashion for core polarization effects.

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*Present address: Physics Department, Nuclear Research Centre, Beer Sheva, Israel.

††Present address: Physics Department, Weizmann Institute of Science, Rehovoth, Israel.

†Present address: Telco Research Corporation, 1818 Division Street, Nashville, Tennessee 37203.

§Present address: Physics Department, Drexel University, Philadelphia, Pennsylvania 19104.

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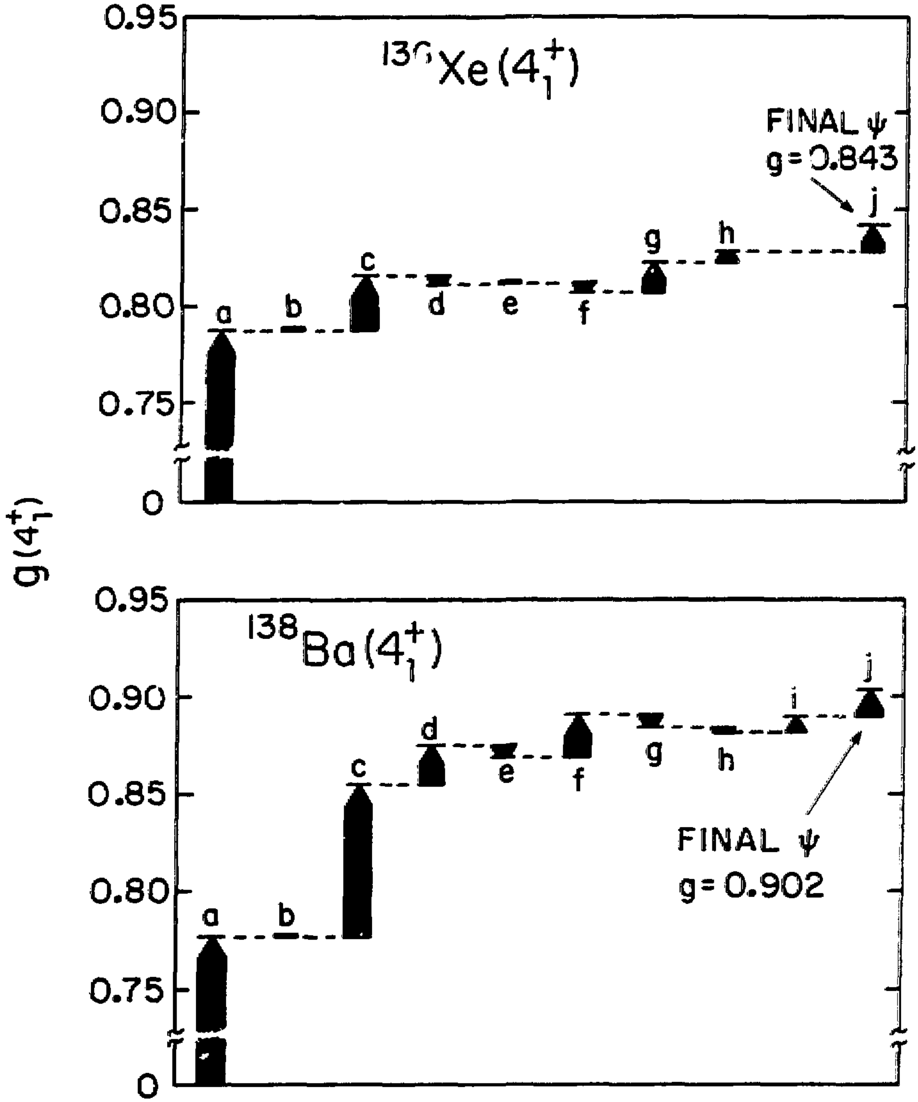

Fig. 4. Contributions to $g(4_1{}^+)$ in ^{136}Xe and ^{138}Ba from various components of the $4_1{}^+$ wavefunction. See text above for details.