states thought to be of this character would be strictly forbidden. As can be seen from Table II, transitions to these states appear to be inhibited but the radiative widths are finite and significant. It is impossible to say whether this violation of implied selection rules results from inaccuracies in the description of the initial or final states or both.

Because of the apparent regularities observed in corresponding transitions in *W* and *Hf* isotopes,[20,21] the predicted ratios for the [510] $\frac{1}{2}^-$ band were also calculated for this model. The calculated results indicate that the intensity of the transition to the $J=\frac{3}{2}^-$ state should be approximately two orders of magnitude larger than that of the transition to the $J=\frac{1}{2}^-$ state. This is at complete variance with the experimental results, which exhibit ratios similar to that observed for Er^{167}. Also, in Dy^{165} the radiative width to the $J^\pi=\frac{3}{2}^-$ member of the [521] $\frac{1}{2}^-$ band is approximately 70% of that of the γ ray to the $J^\pi=\frac{1}{2}^-$ level.[15] This value would require a much smaller deformation (≈ 0.2) for Dy^{165} than is consistent with the systematics. In addition, transitions to vibrational states in this nucleus occur with radiative strengths up to 40% of that of the [521] $\frac{1}{2}^-$ level. It must be concluded, therefore, that although the concept of a direct radiative process occurring from the channel region of the reaction phase space provides a rather detailed description of the Er^{176} spectrum, it fails to explain the observations in the ratio $\Gamma_\gamma([510]\,\frac{3}{2}^-)/\Gamma_\gamma([510]\,\frac{1}{2}^-)$ and is not consistent with the data observed in Dy^{165}.

ACKNOWLEDGMENTS

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Conversion-Electron Particle Parameters in the Decay of Eu^{152} and Eu^{154}†

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The internal conversion-electron particle parameters of several fast low-energy *E*2 transitions in the deformed nuclei Sm^{152} and Gd^{154} were determined by comparing the e^--γ directional correlations and γ-γ directional correlations displayed by the same sources. Special attention was paid to eliminating the effects of scattering in the source, and the corrections caused by the presence of extranuclear perturbations of the directional correlations were carefully studied. The results are: 0.122-MeV transition in Sm^{152}: $b_2(E2,K)=1.60\pm0.05$, $b_2(E2,L^-)=1.03\pm0.05$; 0.245-MeV transition in Sm^{152}: $b_2(E2,K)=1.72\pm0.07$; 0.344-MeV transition in Gd^{154}: $b_2(E2,K)=1.57\pm0.13$; 0.123-MeV transition in Gd^{154}: $b_2(E2,K)=1.37\pm0.07$. The two particle parameters of the 0.122-MeV ground-state transitions in Sm^{152} are about 15% lower and that of the 0.123-MeV ground state-transition in Gd^{154} is 25% lower, than the theoretical predictions for finite-size nuclei. The particle parameters of the 0.245-MeV and of the 0.344-MeV transitions agree with the theoretical values within experimental errors.

I. INTRODUCTION

IN recent years experimental conversion-electron particle parameters for pure *E*2 transitions have been reported which show significant deviations from the theoretical values.[1] These discrepancies from a well-established theory are difficult to explain. Recently, more accurate calculations[2] of conversion-electron particle parameters for finite-size nuclei including higher-order effects indicated that even large nuclear deformations cannot explain the observed discrepancies. In view of these difficulties, it seemed desirable to re-examine the experimental results and to investigate the "anomalous" conversion-electron particle parameters, taking into account all possible effects which could cause systematic errors.

The observed "anomalous" conversion particle parameters are all smaller than the theoretical predictions. Thus the effects of scattering of the conversion electrons in the source and the attenuation of the directional correlation by extranuclear perturbations could be offered as possible explanation of the observed discrepancies.

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* Present address: Bir-Zeit College, Bir-Zeit, Jordan.
[1] J. H. Hamilton, E. F. Zganjar, T. M. George, and W. H. Hibbits, Phys. Rev. Letters 14, 567 (1965).
[2] H. C. Pauli, Ph.D. thesis, University of Basel, Switzerland, 1966 (unpublished); D. Imboden, M. S. thesis, University of Basel, 1966 (unpublished).

In the present investigation, a special effort was made to eliminate scattering effects, and the attenuation of the directional correlations was carefully studied by comparing the e^{-}-γ directional correlation with the corresponding γ-γ directional correlation, using the same sources.

The γ_1-γ_2 directional correlation involving no higher multipoles than $L=2$ can be written in the form[3]

$$W(\theta)=1+G_{22}A_2(\gamma_1)A_2(\gamma_2)P_2(\cos\theta)+G_{44}A_4(\gamma_1)A_4(\gamma_2)P_4(\cos\theta). \quad (1)$$

The attenuation factors G_{kk} take into account possible perturbations of the directional correlation by extranuclear interactions in the intermediate nuclear state of the γ-γ cascade. In all cases of the present investigation, the resolving time τ_0 of the coincidence analyzers was much larger than the lifetime τ of the intermediate nuclear states and therefore the integral attenuation factor $G_{22}(\infty)$ (in the notation of Ref. 4) can be used, which is independent of the timing characteristics of the electronics.

If, instead of, e.g., γ_2 a conversion electron from the X shell is observed and if the γ_2 transition is a pure $(L\pi)$ multipole transition, the γ-e^{-} directional correlation is given by[3]

$$W(\theta)=1+b_2(L\pi,X)G_{22}A_2(\gamma_1)A_2(\gamma_2)P_2(\cos\theta)+b_4(L\pi,X)G_{44}A_4(\gamma_1)A_4(\gamma_2)P_4(\cos\theta). \quad (2)$$

Theoretical computations of the electron particle parameters $b_2(L\pi,X)$ are available.

The $b_4(L\pi,K)$ particle parameters is related to $b_2(L\pi,K)$ by the recurrence relation

$$b_4(L\pi,K)=1+\frac{10L(L+1)-30}{3L(L+1)-30}(b_2(L\pi,K)-1). \quad (3)$$

Sliv and co-workers calculated $b_2(L\pi,X)$ for the K and L shells including static finite-nuclear-size effects.[5] More recently Pauli and co-workers[2,6] computed the conversion particle parameters for the K, L, and M shells, taking into account higher-order effects.

The transitions of interest in this investigation are the 0.122-MeV $E2$ transition in Eu^{152} and the 0.123-MeV $E2$ transition in Gd^{154}. The experimental K-shell conversion coefficients of these two transitions agree, in general, with the theoretical values within the rather large experimental error limits ($\pm10\%$).[7] Two recent measurements,[8,9] however, seem to indicate that the values of α_K for the two transitions are about 10% larger than the theoretical ones. The observed L_{II}/L_{III}

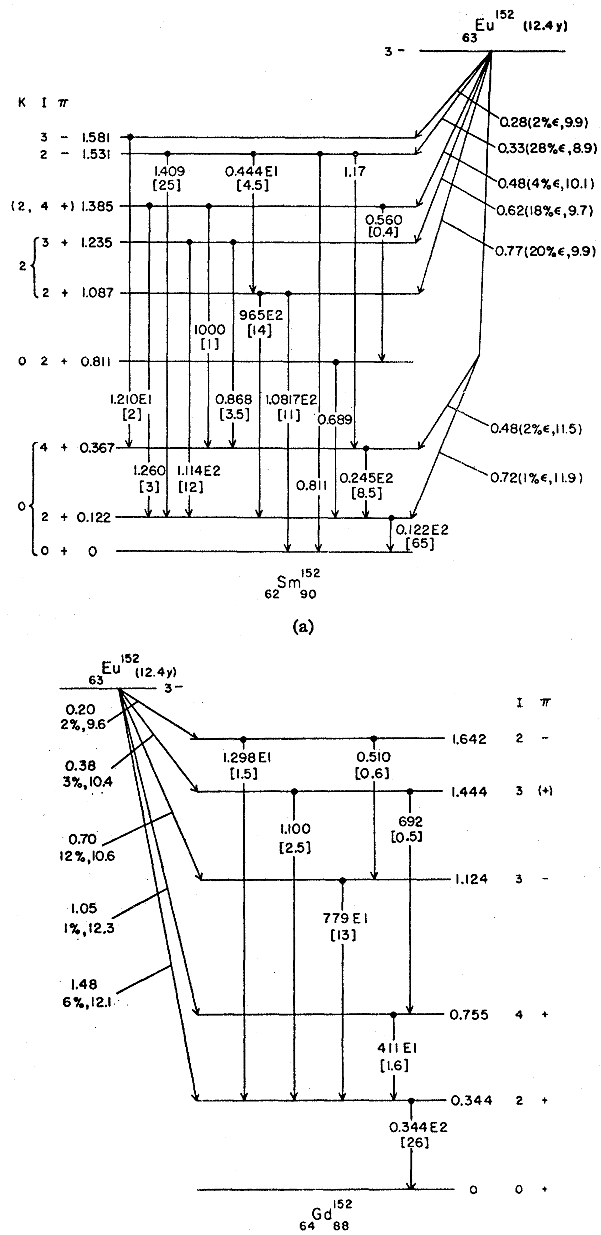

FIG. 1(a). Decay of 12.4y Eu^{152} to Sm^{152}.
(b) Decay of 12.4y Eu^{152} to Gd^{152}.

[3] H. Frauenfelder and R. M. Steffen, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965), Chap. XIX.

[4] R. M. Steffen and H. Frauenfelder, in *Perturbed Angular Correlations*, edited by E. Karlsson, E. Matthias and K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1964).

[5] I. M. Band, M. A. Listengarten, L. A. Sliv, and J. E. Thun in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1965).

[6] H. C. Pauli, Tables of Internal Conversion Coefficients and Particle Parameters for the K, L, and M shells (to be published).

[7] S. Swarnagowri and M. K. Ramaswamy, Proc. Indian Acad. Sci. **62**, 34 (1966).

[8] E. F. Zganjar and J. H. Hamilton, in *Internal Conversion Processes*, edited by J. H. Hamilton (Academic Press Inc., New York, 1966), p. 253.

[9] J. F. W. Jansen, J. H. Hamilton, and E. F. Zganjar, in *Internal Conversion Processes*, edited by J. H. Hamilton (Academic Press Inc., New York, 1966), p. 257.

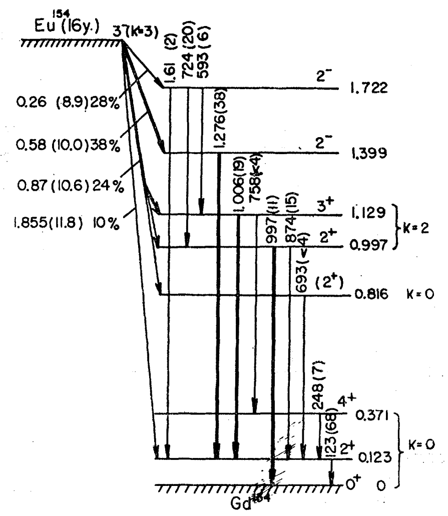

FIG. 2. Decay of Eu^{154}.

subshell ratios are in good agreement with theory. There is an indication, however, that the observed L_I/L_{II} and L_I/L_{III} ratios are about 6% larger than the theoretical predictions.[10] Such deviations have been observed systematically for low-energy $E2$ transitions in deformed nuclei.[11]

Both the particle parameters and the conversion coefficients depend on the same radial matrix elements.[12] The particle parameters, however, depend on the ratio of the radial matrix elements, whereas the conversion coefficients are proportional to the sum of the squares.

The K-shell conversion-electron particle parameters for the 0.122- and 0.245-MeV transitions in Sm^{152} and for the 0.344-MeV transition in Gd^{152} following the dual decay of Eu^{152} (see Fig. 1) were measured. For the 0.122-MeV transition, the L-shell particle parameter was also observed. The K-shell particle parameter of the 0.123-MeV transition in Gd^{154} following the decay of Eu^{154} (Fig. 2) was determined. All these transitions are enhanced pure $E2$ transitions; hence, penetration effects should give negligible contributions. The results, however, show conclusively that the conversion particle parameters for the ground-state transitions of 0.122-MeV energy in Sm^{152} and of 0.123-MeV energy in Gd^{154} are about 20% lower than the theoretical prediction. The conversion particle parameters for the 0.245-MeV transition in Sm^{152} and for the 0.344-MeV transition in Gd^{152}, on the other hand, agree, within the limits of error, with theory.

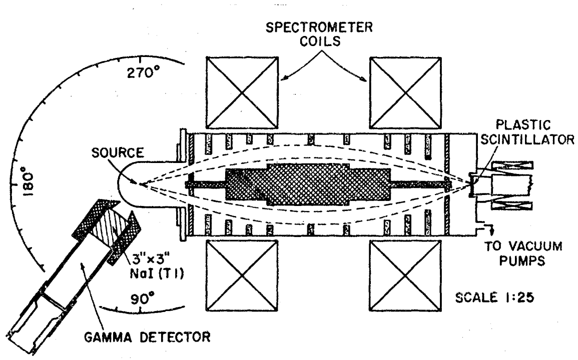

FIG. 3. Diagram of e^-—γ directional correlation apparatus.

II. SOURCE PREPARATION AND EXPERIMENTAL PROCEDURE

The sources were prepared by depositing Eu^{152} and Eu^{154} on a 680-μg/cm^2 Al foil in the Argonne National Laboratory isotope separator. The Eu introduced into the ion source of the isotope separator was enriched to 95% in Eu^{152} or Eu^{154}, respectively. Hence, effectively doubly mass-separated samples were used. In order to reduce the penetration depth of the ions in the Al backing, the ions were decelerated to a few hundred electron volts which resulted in a penetration depth of less than 0.01 μg/cm^2 of Al. The thickness of the invisible deposits was less than 1 μg/cm^2.

The isotope-separated samples were then irradiated in the Argonne reactor at a flux of 5×10^{13} neutrons/cm^2 sec for several weeks. In the case of Eu^{154}, a high neutron flux must be avoided in order to avoid double and triple neutron capture. In addition, the measurements on the Eu^{154} source were started more than three months after irradiation in order to allow the 15.2-day Eu^{156} activity to decay. The radioactivity induced in the Al backing was completely negligible.

The e^--γ and γ-e^- directional correlations were measured with the equipment shown in Fig. 3. The conversion electrons were focused by a magnetic double-lens spectrometer onto a plastic scintillator, which was viewed by an RCA-6342 photomultiplier. The γ radiation was detected in a 3×3 in. NaI(Tl) scintillation crystal connected through an 8-in. lightpipe to a photomultiplier. The γ detector was laterally shielded by a 1-in.-thick Pb cylinder to prevent detection of γ radiation scattered from the face of the lens spectrometer. For low-energy γ rays (E_γ L150 keV), the scintillation counter was replaced in some experiments by a 2-mm-thick lithium-drifted Ge detector.

The γ-γ directional correlations were measured with two 3×3 in. NaI(Tl) scintillation detectors. The γ(0.245 MeV)-γ(0.122 MeV) directional correlation in Sm^{152} was also measured with two 5-mm-thick lithium-drifted Ge detectors.

The coincidence rates were determined at seven angles and corrected for chance coincidences and for coincidences caused by competing cascades. The later contribution, which was of considerable importance in most cases investigated, was determined by observing the co-

[10] R. Stepic, M. Bogdanovic, and M. Mladjenovic, in *Internal Conversion Processes*, edited by J. H. Hamilton (Academic Press Inc., New York, 1966), p. 507.

[11] P. Erman, G. T. Emery, and M. L. Perlman, Phys. Rev. **147**, 858 (1966).

[12] L. C. Biedenharn and M. E. Rose, Rev. Mod. Phys. **25**, 729 (1953).

TABLE I. Gamma conversion-electron correlation measurements and particle parameters.

Isotope	Cascade (keV)	$G_{22}A_{22}$	$G_{44}A_{44}$	$b_2(E2,X)_{\rm exp}$	$b_2(E2,X)_{\rm th}$	$\frac{b_2(E2,X)_{\rm exp}}{b_2(E2,X)_{\rm th}}$	Reference
Sm^{152}	245γ–$122K$	0.140±0.003	0.018±0.009	1.61±0.15	1.89	0.85±0.07	a
		0.142±0.006	−0.028±0.011	1.65±0.17	1.89	0.87±0.09	b
	1410γ–$122K$	0.275±0.005	0.010±0.015	1.60±0.05	1.89	0.85±0.03	a
		0.237±0.007	0.017±0.022	1.90±0.07	1.89	1.00±0.04	c
	245γ–$122L$	0.08 ±0.01		0.92±0.14	1.25	0.74±0.11	a
	1410γ–$122L$	0.188±0.009	0.012±0.020	1.09±0.06	1.25	0.88±0.05	a
	245γ–122γ	0.138±0.004		1.59±0.16	1.72	0.92±0.09	a
		0.090±0.012	0.022±0.026	1.05±0.16	1.72	0.61±0.09	b
	869γ–$245K$	0.258±0.024[d]	0.150±0.030[d]	1.74±0.07[e]	1.72	1.01±0.04	a
		0.231±0.008	0.129±0.023	1.76±0.08	1.72	1.02±0.05	c
Gd^{152}	779γ–$344K$	−0.116±0.006		1.57±0.13	1.60	0.98±0.08	a
		−0.115±0.013		1.58±0.17	1.60	0.99±0.11	b
Gd^{154}	1278γ–$123K$	0.195±0.005	0.008±0.012	1.37±0.07	1.88	0.73±0.04	a
		0.178±0.005	−0.009±0.012	1.41±0.07	1.88	0.75±0.04	b
		0.164±0.003	0.006±0.01	1.88±0.06	1.88	1.00±0.03	c
	1278γ–$123L$	0.112±0.016		0.88±0.13	1.25	0.70±0.10	f

[a] Present work.
[b] Reference 1.
[c] Reference 13.
[d] Reference 14.
[e] Calculated from b_4.
[f] Reference 15.

incidence spectrum with a gated multichannel analyzer and by setting the single-channel analyzer windows immediately below and above the photopeaks of interest. Great care was taken to assure that the window settings were the same in the e^--γ and γ-γ directional correlation experiments. The corrections for competing cascades were particularly important in the γ-γ measurement with the Ge detectors due to the presence of a backscattering peak just under the photoelectric peak of interest.

The directional correlation coefficients $G_{kk}A_k(\gamma_1)\times A_k(\gamma_2)$ and $G_{kk}b_k(L\pi)A_k(\gamma_1)A_k(\gamma_2)$ were determined by a least-squares fit to the functions (1) and (2).

III. RESULTS AND DISCUSSION

A. Summary of the Results

The results of the present investigation of conversion-electron particle parameters for pure $E2$ transitions are summarized in Table I. Experimental results obtained by other groups, where available, are included for comparison.

It is interesting to note that, in general, the present results of the e^--γ directional correlation measurements agree with those reported by the Stockholm group.[13] The present γ-γ directional correlation measurements, however, yielded considerably larger directional correlation coefficients (by about 20%) as compared to the results of the Stockholm group (see Table II). The present γ-γ directional correlation results agree with those of the Vanderbilt group,[1] where available. The e^--γ directional measurements of the latter group are in reasonably good agreement with the results of the present investigation, except for the case of the e_K^-(0.245 MeV)-γ(0.122 MeV) directional correlation in Sm^{152}, where the present investigation yielded a much larger directional correlation coefficient. It should be mentioned that the different source compositions used

TABLE II. γ–γ correlation measurements.

Isotope	Cascade (keV)	Theory A_{22}	Theory A_{44}	Liquid sources A_{22}	Liquid sources A_{44}	Solid sources $G_{22}A_{22}$	Solid sources $G_{44}A_{44}$	G_{22}	Reference
Sm^{152}	245γ–122γ	0.102[a]	0.009[a]	0.111±0.014	0.007±0.015				b
						0.087±0.008	0.002±0.001	0.87±0.07	c
						0.086±0.008	0.013±0.016	0.84±0.08	d
	1410γ–122γ			0.225±0.007	0.01±0.01				b
						0.172±0.004	0.005±0.007	0.78±0.04	c
						0.144±0.005	0.011±0.010	0.64±0.03	e
	869γ–245γ					0.165±0.010	−0.174±0.012		c
						0.136±0.013	−0.143±0.020		e
Gd^{152}	779γ–334γ	−0.071[f]	0[f]						
						−0.074±0.005	0.000±0.008		c
						−0.073±0.003			d
Gd^{154}	1278γ–123γ			0.251±0.039	0.000±0.045				b
						0.142±0.007	0.001±0.010	0.57±0.09	c
						0.127±0.005	0.007±0.008	0.51±0.08	d
						0.087±0.003	0.000±0.006	0.35±0.06	e

[a] Calculated for pure $E2$, $E2$, $4^+\rightarrow 2^+\rightarrow 0^+$ transitions.
[b] P. Debruner and W. Kündig, Helv. Phys. Acta 33, 395 (1960).
[c] Present work.
[d] Reference 1.
[e] Reference 13.
[f] Calculated for pure $E1$, $E2$, $3^-\rightarrow 2^+\rightarrow 0^+$ transitions.

[13] L. Holmberg, V. Stefansson, and B. G. Petterson, Nucl. Phys. **A96**, 33 (1967).

by the various groups may result in different attenuation factors G_{kk} and give rise to differing directional correlations.

This attenuation effect, however, should affect the γ-γ and the e^--γ directional correlations in the same way and the experimental values of the particle parameters $b_2(E2)$ should be independent of the source composition, if the γ-γ and e^--γ directional correlations are measured with the same sources. These considerations are correct if the conversion-electron transition succeeds the γ transition. If the conversion-electron transition precedes the γ radiation, the effects of the recoil of the conversion electron, which is larger than the recoil of the corresponding γ ray, on the surrounding of the decaying nucleus and the influence of the hole created by the conversion process in the electron shell should be considered. Since some of the intermediate states involved in our measurements have lifetimes in the nanosecond region these effects could, in principle, cause an attenuation of the directional correlation by extranuclear effects which would be different for the e^--γ cascade as compared to the γ-γ cascade. In the present measurements, the decaying nuclei were embedded in a metallic surrounding (Eu ions in Al). It is known that in metals the atomic shell recovers very rapidly (in less than 10^{-10} sec), and no evidence of an effect of the recoil on the attenuation has been seen in a metal source.

The attenuation coefficients of the particular sources used in the present measurements are listed in column 9 of Table II. For their computation, the unperturbed directional correlation must be known. For those cascades where the unperturbed directional correlation is not well known or where differing experimental results have been reported, the theoretical values for the correlation coefficients were used. These results are listed in columns 3 and 6 of Table II.

The experimental conversion-electron particle parameters $b_k(E2,X)$ for $E2$ transitions, which were computed from the various directional correlation measurements, are listed in column 5 of Table I.

The theoretical values of the particle parameters (column 6 of Table I) were calculated on the Purdue IBM-7094 computer using an internal conversion parameter program, prepared by H. C. Pauli, which allows one to calculate higher-order effects caused by the finite charge distribution of the nucleus. For the $E2$ transitions of interest in our investigation, however, the higher-order effects are negligibly small. Also, variations of the nuclear radius by $\pm 10\%$ resulted in a negligible influence on the particle parameters. Similarly, a theoretical estimate of the effects of deformations of the nuclear charge distribution on the particle parameters revealed that such effects change the theoretical values of the particle parameters by less than 2%.

B. Individual Transitions

1. The 0.122-MeV Transition in Sm^{152}

This transition is an enhanced $E2$ transition between the 2^+ excited and 0^+ ground state of a $K=0$ rotational band. The K-shell particle parameter was determined by two different directional correlation measurements.

The measurement of the γ(0.245 MeV)-K(0.122 MeV) directional correlation yields for the particle parameter of the 0.122-MeV transition

$$b_2(E2,K)_{\text{exp}}=1.61\pm0.15\,.$$

The relatively large error is caused by the large corrections from contributing cascades in both the γ-γ and γ-e^- directional correlation measurements. The γ-γ as well as the γ-e^- results are in good agreement with those reported by Hamilton *et al.*[1]

The γ(1.41 MeV)-K(0.122 MeV) directional correlation gives more reliable results, since the corrections for competing cascades are small. The particle parameter $b_2(E2,K)$ for the 0.122-MeV transitions extracted from these measurements is

$$b_2(E2,K)_{\text{exp}}=1.60\pm0.05\,.$$

The results of the two measurements are in excellent agreement, but they are substantially lower than the theoretical prediction:

$$\frac{b_2(E2,K)_{\text{exp}}}{b_2(E2,K)_{\text{theory}}}=0.85\pm0.03\,.$$

During the course of this investigation a value of $b_2(E2,K)_{\text{exp}}$ of 1.90 ± 0.07, in agreement with theory, was reported by Holmberg *et al.*[13] However, the values of the γ-γ directional correlation parameters as measured by Holmberg were substantially lower than the present values (see Table II).

The experimental L-shell particle parameter for this transition was also determined in two different directional correlation experiments and shows a similar deviation from the theoretical value. The weighted average of the experimental results is $b_2(E2,L)_{\text{exp}}=1.03\pm0.05$, which implies

$$b_2(E2,L)_{\text{exp}}/b_2(E2,L)_{\text{theory}}=0.83\pm0.04\,.$$

The fact that the energies of the conversion electrons from the K and the L shell are quite different ($E_K=77$ keV and $\bar{E}_L=115$ keV, respectively) indicates that source scattering effects cannot be responsible for the deviations. This possibility was further checked by placing the source with its plane at 90° and at 45° with respect to the spectrometer axis. The results obtained with the two source positions were identical. Judging from the negligible thickness of the isotope-separator-produced sources, no scattering effects are expected at all for electron energies above 50 keV.

2. The 0.245-MeV Transition in Sm^{152}

Hamilton *et al.*[1] reported a large deviation of the K-shell conversion-electron particle parameter from the theoretical value. The present experimental result is slightly low, but agrees, within limits of error, with the theoretical predictions. The K-particle parameters for this transition were obtained in two different ways. The direct comparison of the K(0.245 MeV)-γ(0.122 MeV) directional correlation with the γ(0.245 MeV)-γ(0.122 MeV) directional correlation yielded the result $b_2(E2,K) = 1.59\pm0.16$. The error is relatively large because of the many corrections for competing cascades which must be applied to the directional correlation measurements.

The particle parameter for the 0.245-MeV transition can also be obtained from the measurements on the 0.869-MeV$-$0.245-MeV cascade. This cascade offers several advantages as compared to the 0.245-MeV $-$0.122-MeV cascade. The intermediate 0.367-MeV state has a short lifetime, $\tau\cong10^{-10}$ sec; hence no attenuation effects are expected. Also, the γ(0.869 MeV -γ(0.245 MeV) directional correlation has a large $P_4(\cos\theta)$ term, which makes a comparison between $b_2(E2,K)$ and $b_4(E2,K)$ possible. The particle parameter $b_2(E2,K)$ can be calculated directly from the coefficients of the $P_2(\cos\theta)$ term in the γ-γ and γ-e^- directional correlations. The $b_2(E2,K)$ can also be computed from Eq. (3) using the experimental value of $b_4(E2,K)$.

The γ(0.869 MeV)-K(0.245-MeV) directional correlation has been measured by Bisgård *et al.*[14] The γ-γ directional correlation coefficients reported in this paper are systematically larger than the values reported by the Stockholm group.[13]

Using our γ-γ directional correlation results for this cascade, which are in agreement with the accepted spin assignments $3^+\rightarrow4^+\rightarrow2^+$, and the mixing ratio $\delta=+6.0$ for the 0.869-MeV transition, we can extract two experimentally independent values for the particle parameter $b_2(E2,K)$ of the 0.245-MeV transition:

$$b_2(E2,K)_{\mathrm{exp\ I}}=1.59\pm0.16$$

and

$$b_2(E2,K)_{\mathrm{exp\ II}}=1.4-\frac{b_4(E2,K)}{2.5}=1.74\pm0.07.$$

The experimental values of $b_2(E2,K)$ extracted from the different measurements agree within experimental error. The weighted average of the measurements yields $b_2(E2,K)_{\mathrm{exp}}=1.72\pm0.07$, which is in good agreement with the theoretical value $b_2(E2;K)_{\mathrm{theory}}=1.72$. The same conclusion was reached by the Stockholm group,[13] although their γ-γ directional correlation is markedly different from the one measured in the present investigation.

[14] K. M. Bisgård, K. B. Nielsen, and J. Sodemann, Phys. Letters 7, 57 (1963).

3. The 0.344-MeV Transition in Gd^{152}

The 0.344-MeV ground-state transition in Gd^{152} is an enhanced $E2$ transition from a first 2^+ vibrational state. All indications point toward a spherical shape of the Gd^{152} nucleus in the lower excited states. The K-shell particle parameter of this transition was obtained by observing the γ-e^- and γ-γ directional correlation of the 0.779-MeV$-$0.344-MeV cascade. The experimental value, $b_2(E2,K)_{\mathrm{exp}}=1.57\pm0.13$, agrees well with the theoretical value, $b_2(E2,K)_{\mathrm{theory}}=1.60$, in accordance with the results reported by the Vanderbilt group.[1]

4. The 0.123-MeV Transition in Gd^{154}

The Gd^{154} nucleus is strongly deformed. The 0.123-MeV transition is an enhanced $E2$ transition to the ground state of a $K=0$ band. The lifetime of the 0.123-MeV excited state in Gd^{152} is comparable to the lifetime of the 0.122-MeV level in Sm^{152}. Hence it is important that the particle parameter is extracted from the γ-γ and γ-e^- directional correlations performed with the same source. The K-shell particle parameter extracted from the present measurements is

$$b_2(E2;k)=1.37\pm0.07,$$

in good agreement with the particle parameter reported by the Vanderbilt group,[1] although the latter group's anisotropy values are slightly lower than the present results, probably due to a different attenuation in the source. The results reported here are considerably different from the measurements reported by the Stockholm group.[13]

The experimental K-shell particle parameter for the 0.123-MeV transition in Gd^{154} disagrees strongly with the theoretical value:

$$b_2(E2,K)_{\mathrm{exp}}/b_2(E2,K)_{\mathrm{theory}}=0.73\pm0.04.$$

The result reported recently by Zganjar and Hamilton[15] for the $b_2(E2,L)$ parameter $b_2(E2,L)=0.88\pm0.13$ supports this conclusion. In this case the ratio

$$\frac{b_2(E2,L)_{\mathrm{exp}}}{b_2(E2,L)_{\mathrm{theory}}}=0.70\pm0.10$$

is in good agreement with the corresponding ratio for the b_2 parameters for the K-conversion electrons.

IV. CONCLUSIONS

The experimental conversion-electron particle parameters for the ground-state transitions of the $K=0$ rotational bands in Sm^{152} and Gd^{154} deviate considerably from the theoretical values.

[15] E. F. Zganjar and J. H. Hamilton, in *Internal Conversion Processes*, edited by J. H. Hamilton (Academic Press Inc., New York, 1966), p. 485.

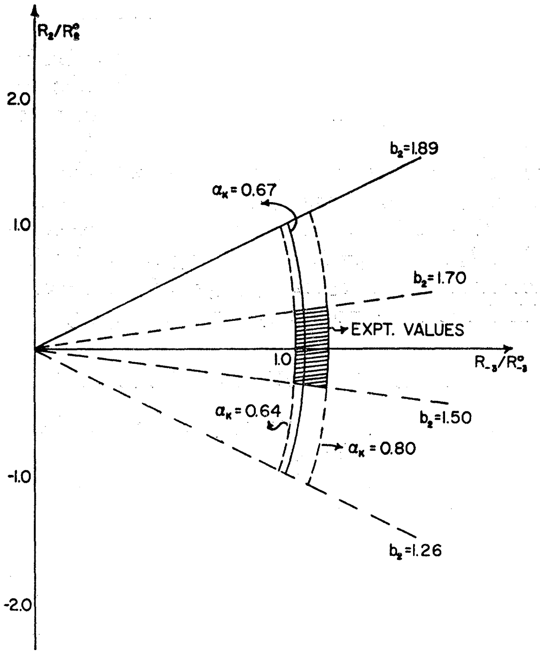

FIG. 4. The K-particle parameter and K-conversion coefficient for the 0.122-MeV transition in Sm^{152} as a function of the imaginary parts of the radial matrix elements R_{+2} and R_{-3}. Values of R_{+2} and R_{-3} are normalized to $R_{+2}{}^\circ$ and $R_{-3}{}^\circ$ given by the theory of Rose (Refs. 12 and 16).

Since both transitions occur in strongly deformed nuclei, one is tempted to ascribe the deviations to the nonspherical nuclear charge distributions. Theoretical estimates, however, indicate that these effects are too small to explain the large discrepancies. In addition, the K-shell particle parameter of the 0.245-MeV transition in Sm^{152} should then also be affected by the nonspherical nuclear charge distribution, since this transition occurs in the same rotational band as the "anomalous" 0.122-MeV transition. It is to be noted, however, that the experimental errors in this case are too large to give evidence of deviations that are smaller than about 5%.

In Fig. 4, the K-particle parameter and K-conversion coefficient for the 0.122-MeV transition in Sm^{152} are plotted as a function of the imaginary parts of the radial matrix elements R_{+2} and R_{-3} in the notation of the reference.[16] The inclusion of the real parts, which are of the order of a few percent, will not significantly alter the conclusions drawn from the graph. The dashed area in the figure selects values of R_{+2} and R_{-3} which are in agreement with both the measured K-particle parameter and the K-conversion coefficient for the 0.122-MeV transition. The point with coordinates (1.0; 1.0) corresponds to the values $b_2(122K)$ and $\alpha_k(122)$ as tabulated by Rose.[12,16]

It can be seen from the figure that in order to get the agreement between the measured particle parameter and conversion coefficient for the 0.122-MeV transition in Sm^{152} one must seriously reduce the R_{+2} radial matrix element (with respect to its theoretical value). The same conclusion can be drawn from a similar graph for the 0.123-MeV $E2$ transition in Gd^{154}. In both cases the R_{-3} radial matrix element is practically not affected.

The "anomalous" particle parameters seem to be related to the fact that the transition energies in the two "anomalous" cases are small. It would be desirable to study systematically particle parameters of low-energy transitions (about 0.1 MeV) is nondeformed nuclei. However, the $E2$ transitions in spherical nuclei that are convenient for such measurements have, in general, considerably higher energies (about 0.25-MeV).

The possibility that low-energy internal conversion particle parameters in rare-earth atoms are affected by the unfilled $4f$ shell should perhaps also be explored.

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[16] M. E. Rose *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).