Directional and Polarization Correlation Measurements on Eu^{152m}

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The spins and parities of the 1511-kev level in Sm^{152} and the 1315-kev level in Gd^{152} are discussed on the basis of directional correlation and polarization-direction correlation measurements on the 1389–122 kev and 970–344 kev gamma-gamma cascades, following the decay of 9-hour Eu^{152m}. Both levels have been assigned spin and parity 1^-. In order to check the apparatus on cascades known on the basis of previous measurements, directional and polarization-direction correlation measurements have also been made on the 842–122 kev (from 9-hour Eu^{152m}) and 1409–122 kev (from 12-year Eu^{152}) cascades in Sm^{152}.

INTRODUCTION

EUROPIUM-152 decays by electron capture to levels in the deformed nucleus Sm^{152} and by β decay to levels in Gd^{152} which has a spherical equilibrium shape in the ground state.[1–5] The study of this radioactivity, therefore, offers the possibility of making a direct comparison between two nuclei with very different structures. Of particular interest is the occurrence in both nuclei of odd-parity states which possibly may be interpreted as octupole vibrational states.[6] This has tentatively been suggested for the 963-kev, 1^- state of Sm^{152} and for the 1124-kev, 3^- state state of Gd^{152} (see Fig. 1 for the pertinent parts of the decay scheme, constructed on the basis of other work[1,2,4,5,7] and the results of this investigation). These two states appear to be the lowest odd-parity excitations occurring in the two nuclei. According to the theory[6] the second member of the vibrational spectrum associated with the 3^- state in Gd^{152} should be a 1^- state. This is consistent with what is known about the 1315-kev level in Gd^{152} although there was no direct experimental evidence to support this at the time the present work was initiated.

This communication is concerned with a study of the 1511-kev level in Sm^{152} and the 1315-kev level in Gd^{152} using angular correlation techniques involving measurements of directional and polarization-direction correlations of $\gamma-\gamma$ cascades following the decay of 9.2-hr Eu^{152m}.

As is well known,[8] a directional correlation measurement gives information which restricts the possible choice of spin values which can be assigned to the nuclear energy levels involved in the $\gamma-\gamma$ cascade but it is not sensitive to the parities of the nuclear levels. On the other hand a polarization-direction correlation[8] is sensitive to the electric or magnetic character of the γ ray whose polarization is detected. In addition, the polarization-direction correlation depends on the spin values of the nuclear levels and in cases where the γ ray whose polarization is measured is possibly mixed,[9–13] additional restriction on the possible choice of spin values can be inferred over that given by the directional correlation alone. In this way it may be possible to give a unique interpretation to the spins and parities of the levels studied.

DIRECTIONAL CORRELATION MEASUREMENTS

The directional correlation measurements were performed with two $1\frac{1}{2}$-in.$\times 1\frac{1}{2}$-in. NaI scintillation crystals and a fast-slow coincidence circuit with resolving time set at $2\tau = 1.4\times 10^{-8}$ sec. The measurements

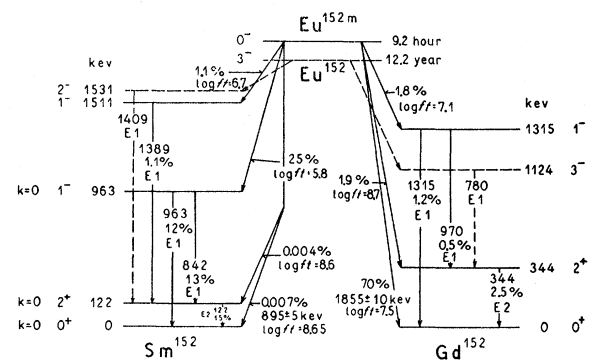

FIG. 1. Partial decay scheme of Eu^{152m} constructed on the basis of references 1, 2, 4, and 7 and the results of this investigation. Pertinent parts of the decay scheme of 12-year Eu^{152} are indicated with dotted lines.[5]

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[1] L. Grodzins and H. Kendall, Bull. Am. Phys. Soc. Ser. II, 1, 163 (1956).
[2] O. Nathan and M. A. Waggoner, Nuclear Phys. 2, 548 (1957).
[3] G. T. Wood and O. Nathan, *Comptes Rendus du Congrès International de Physique Nucléaire, Paris, July, 1958*, edited by Guggenberger (Dunod, Paris, 1959), p. 861.
[4] Marklund, Nathan, and Nielsen (to be published).
[5] O. Nathan and S. Hultberg, Nuclear Phys. 10, 118 (1959).
[6] Alder, Bohr, Huus, Mottelson, and Winther, Revs. Modern Phys. 28, 432 (1956).
[7] Alburger, Ofer, and Goldhaber, Phys. Rev. 112, 1998 (1958).
[8] L. C. Biedenharn and M. E. Rose, Revs. Modern Phys. 25, 729 (1953).
[9] G. T. Wood, Ph.D. thesis, Washington University, June, 1956 (unpublished); and P. S. Jastram and G. T. Wood, Phys. Rev. 100, 1238(A) (1955).
[10] C. F. Coleman, Phys. Rev. 103, 647 (1956); and Nuclear Phys. 5, 495 (1958).
[11] P. H. Stelson and F. K. McGowan, Phys. Rev. 105, 1346 (1957).
[12] Jastram, Wood, and Hurley, Bull. Am. Phys. Soc. Ser. II, 3, 65 (1958).
[13] G. T. Wood and P. S. Jastram, Bull. Am. Phys. Soc. Ser. II, 3, 65 (1958).

were performed for three angles between the counters, 90°, 135°, and 180°, and were fitted by an expansion in Legendre polynomials, $1+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)$. The directional correlation coefficients, A_2 and A_4, were adjusted to fit the measured distribution and are given in Table I for the four cascades measured. For all four cascades a $\frac{1}{2}$-mm thick Cd absorber was used before the counter detecting the lower energy photon in order to reduce K-capture x-rays. A 3-mm Pb absorber was used before the counter detecting the higher energy photon to absorb 122-kev photons in addition to the x-rays. In the case of the 970–340 kev cascade a lead shield was positioned between the counters to reduce spurious coincidences due to Compton scattering. Corrections were applied for source decay, for random background counts, for coincidences due to 12-year Eu^{152}, and for the finite angular resolution of the counters. The 842–122 kev cascade has been previously studied by Grodzins.[1] The present results are consistent with his assignment of spins $1-2-0$ to the levels involved in this cascade. The 1415–122 kev cascade in the 12-year Eu^{152} was measured in order to further check the apparatus and the results agree with Ofer's measurements[14] and are consistent with his assignment of spins $2-2-0$ to the levels in this cascade.

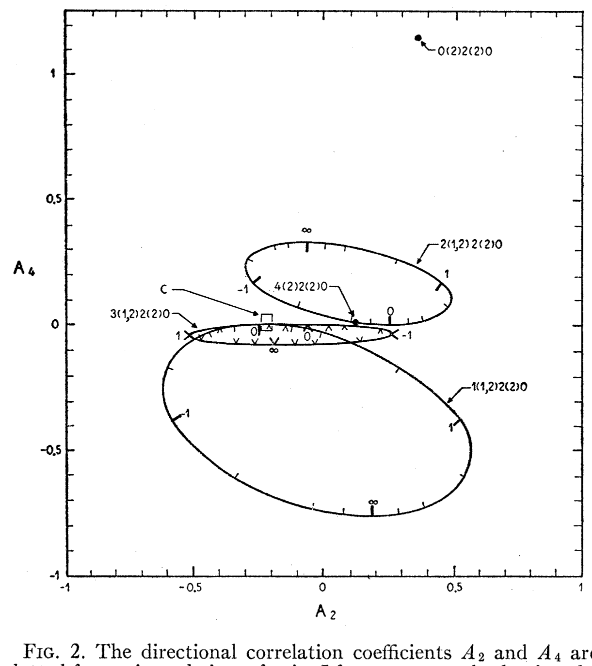

FIG. 2. The directional correlation coefficients A_2 and A_4 are plotted for various choices of spin J for $\gamma-\gamma$ cascades having the spin sequence $J-2-0$. The possibility of mixtures is considered for $J=2$, 3, and 4 and the curves for these spin values are parametric in the quadrupole to dipole mixing ratio δ. Markers are placed along the curves to indicate the points for $\delta=0$, ±0.1, ±0.2, ±0.5, ±1, ±2, ±5, ±10, and ∞ but only the values 0, ±1, and ∞ are labeled. A rectangle is plotted to show the experimental limits on the measurement of Cascade C (see Table I). The corresponding rectangle for Cascade D lies within the rectangle plotted for Cascade C.

[14] S. Ofer, Nuclear Phys. 4, 477 (1957).

TABLE I. The results of directional correlation measurements on cascades following the decay of 12-year Eu^{152} (Cascade A) and 9-hour Eu^{152m} (Cascades B, C, D). The results are given in terms of A_2 and A_4, the coefficients of expansion in Legendre polynomials. The errors quoted are standard deviations and do not account for possible systematic errors.

Cascade			A_2	A_4
A	Sm^{152}	1409–122 kev	$+0.250\pm0.017$	-0.009 ± 0.032
B	Sm^{152}	842–122 kev	-0.231 ± 0.013	$+0.004\pm0.018$
C	Sm^{152}	1389–122 kev	-0.221 ± 0.019	$+0.006\pm0.028$
D	Gd^{152}	970–344 kev	-0.226 ± 0.014	$+0.009\pm0.021$

The measured directional correlation functions for the three Cascades B, C, D are all identical within the experimental limits. The measured directional correlation coefficients for the unknown Cascades C and D are compared in Fig. 2 with the theoretical values for different spin choices $J-2-0$ ($J=0$, 1, 2, 3, 4) to the levels involved in these cascades. The use of this form of representation was discussed previously in references 10, 12, and 13. The curves are parametric in δ, the ratio of the quadrupole to dipole reduced matrix elements.[8] The experimental limits on A_2 and A_4 for Cascade C are indicated by the rectangle on Fig. 2. The corresponding rectangle for Cascade D is omitted for the sake of clarity, but lies within the rectangle for Cascade C. It is seen that the measurements are consistent with the spin values 1 or 3 for the initial states but not with spin 0, 2, or 4. If in either case the spin of the initial state is 1, the first transition of this cascade must proceed by an almost pure dipole radiation with δ^2, the ratio of the quadrupole to dipole transition probabilities, less than 0.001. However, the slight deviation of the experimental results from the theoretical value $A_2=-0.25$ for a pure dipole transition may also be explained by small extranuclear attenuation effects.[14] If the spin of the initial state is 3, the first transition proceeds by a mixed dipole-quadrupole radiation with the mixing ratio $\delta^2=0.035\pm0.005$.

POLARIZATION-DIRECTION CORRELATION MEASUREMENTS

The polarization-direction correlation apparatus consisted of four scintillation counters using NaI(Tl) crystals mounted on RCA-6342 photomultiplier tubes arranged as shown in Fig. 3. The direction of one γ ray in the cascade is determined by the "direction detector," Counter 1. Both polarization and direction are determined for the other γ ray by the "polarization detector" consisting of Counters 2, 3, and 4. Here, Compton scattering is the polarization sensitive process. The scattering occurs in the scintillation crystal of Counter 2 and the scattered γ ray may be detected in either Counters 3 or 4. Counters 3 and 4 can rotate together about the axis of Counter 2 but are fixed relative to each other so that the planes defined by Counters $2-3$ and $2-4$ are perpendicular. The polarization sensitivity of Compton scattering to a

γ ray initially plane polarized and having a given energy and angle of scattering is characterized by the "asymmetry ratio," R, which for point detectors is defined as the ratio of the Klein-Nishina differential cross sections for scattering in planes perpendicular to parallel, respectively, to the initial plane of polarization. In the actual apparatus the asymmetry ratio can be defined as the ratio of coincidence rates $2-4$ to $2-3$ for a beam of γ rays incident on Counter 2 with plane of polarization in the plane of Counters $2-3$. The asymmetry ratio of the apparatus is, of course, reduced over the ideal case due to the finite angular resolution of the counters and the fact that the γ rays may scatter more than once in the scatterer crystal. NaI was employed for the scatterer crystal since it gives approximately three times greater Compton scattering cross section than organic crystals such as anthracene. It is possible to use NaI in the experiments reported here since the photons whose polarizations are detected are of sufficiently high energy (842 to 1409 kev) that they are not strongly absorbed by photoelectric effect in the crystal. NaI is also more convenient since the photopeaks can be used for pulse-height calibration. As seen in Fig. 3 the angle between the direction and polarization detectors is fixed at 90° since this angle gives the maximum polarization effect for the $\gamma-\gamma$ cascades investigated in this work.

A block diagram of the fast-slow coincidence arrangement is shown in Fig. 4. The last three dynode voltages of each photomultiplier are stabilized against high counting rates by replacing the last three resistances in the photomultiplier voltage divider by 150-volt neon tubes.[15] Fast pulses are taken directly from each photomultiplier collector through RG 114 cable into a Hewlett Packard Wide Band Amplifier 460 A. In the

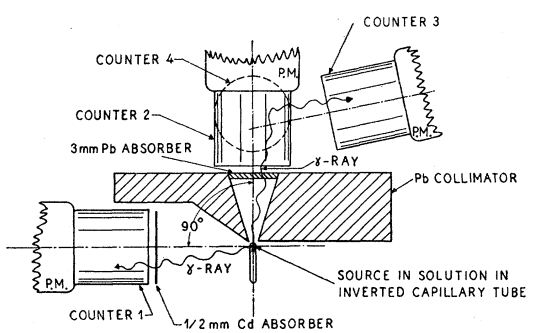

FIG. 3. A diagram of the counter arrangement used in the polarization-direction correlation experiments. Counter 1 is the direction detector. Counters 2, 3, and 4 make up the polarization detector with Compton scattering taking place in Counter 2. The axis of Counters 3 and 4 which detect the scattered γ rays are shown lying in planes parallel and perpendicular, respectively, to the plane defined by the axes of Counters 1 and 2. Counters 3 and 4 can be rotated together through 90° to the point where Counter 4 has the position shown by Counter 3 in the diagram. All four counters employed NaI(Tl) scintillation crystals in these experiments. P.M.: Photomultiplier.

[15] R. Stump and H. E. Talley, Rev. Sci. Instr. **25**, 1132 (1954).

fast coincidence circuit input, pulses are shaped and added and coincidences are selected with a biased germanium diode in a conventional manner. The slow pulses on each counter come from the last dynode of the photomultiplier through a cathode follower and are coupled directly without amplification to pulse-height selectors. Pulses from Counters 2, 3, and 4 are added in pairs $2+3$ and $2+4$. The sum spectra give full energy peaks having pulse height and width equal to the corresponding photopeaks in Counter 2.[10] Then energy selection is obtained in the polarization detector by picking out the appropriate full energy peak with a pulse-height selector. The pulses from Counters 3 and 4 trigger integral discriminators biased low. In addition, pulses from Counter 2 are pulse-height selected with a relatively wide window. Thus, limits on the distribution of scattering angles in the scatterer crystal are defined for a given photon energy. Also with pulse-height selection on Counter 2, one can eliminate spurious scattering of photons from Counters 3 and 4 to Counter 2. As shown in Fig. 4 the outputs of the fast coincidence circuits, F 234 and F 12, and the pulse-height selectors $S1$, $S2$, $S3$, $S4$, $S2+3$, $S2+4$ are combined in slow coincidence circuits ($2\tau\sim 0.4$ μsec) giving fast-slow coincidences $1-2$, $2-3$, $2-4$, $1-2-3$, and $1-2-4$.

For one of the runs an antipile-up circuit[16] was added to the system. Pile-up events are first detected in the mixed train of pulses from Counters 1 and 2. A pile-up event may be due to two pulses originating in the same counter (either 1 or 2) or to single pulses from the two counters piling up when mixed. Should there be a fast-slow coincidence $1-2$ associated with one of the pulses in the pile-up event, it will be rejected by an anticoincidence circuit. The pile-up detection is accomplished in the following way. Pulses from the fast outputs of Counters 1 and 2 are differentiated, mixed by addition, amplified, and limited. A single pulse at the limiter output consists of a positive spike of 0.1 microsecond duration followed by a negative undershoot. A Schmidt trigger circuit is turned on by the first pulse in a pile-up event and is turned off at the time when the slow outputs of Counters 1 and 2 become cleared of pulses. Finally the Schmidt trigger output is delayed by 0.1 microsecond and pile-up events are detected as coincidences between these delayed pulses and the fast limiter output. Thereby, most of those events which would otherwise be incorrectly counted as to pulse height are eliminated. This is of value particularly in polarization-direction correlation experiments where it is often necessary to use high counting rates ($\sim$100 000/sec total counting rate per channel) in order to achieve reasonable triple coincidence counting rates.

In order to make the measurement of a polarization-direction correlation, the numbers of coincidence counts

[16] The author is indebted to Dr. R. E. Bell for the idea of developing an antipile-up circuit, and for its basic design.

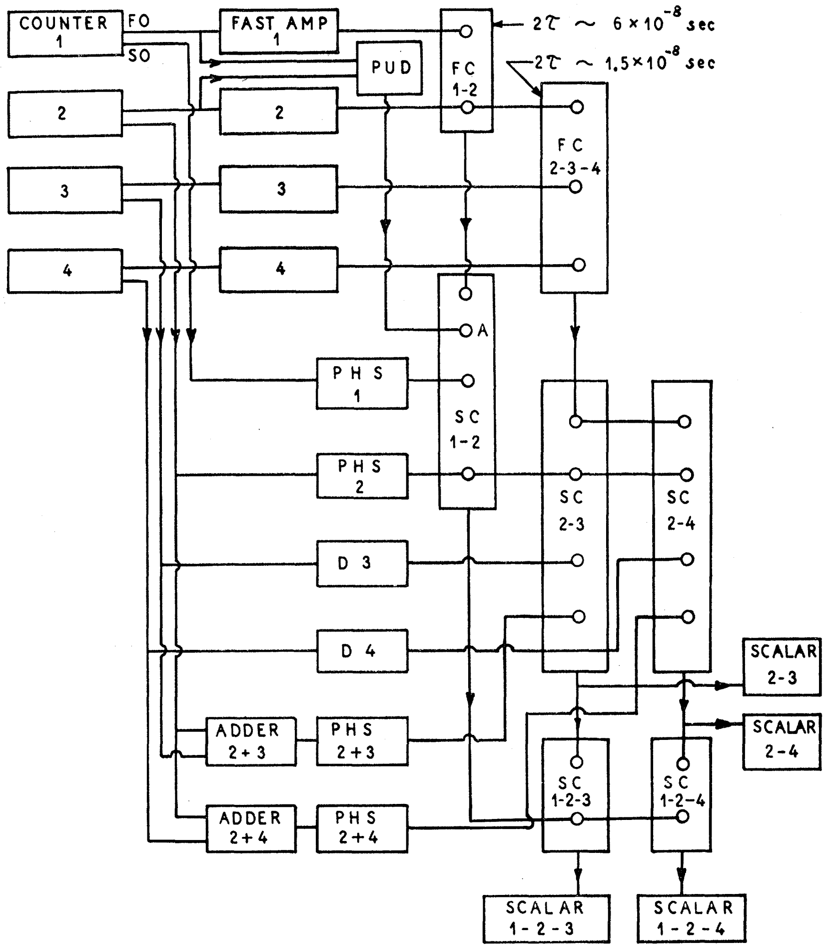

FIG. 4. A block diagram of the polarization-direction correlation electronics. FC: fast coincidence circuit, SC: slow coincidence circuit, PHS: pulse-height selector, D: discriminator, PUB: pile-up detector, A: anticoincidence input, FO: fast output, SO: slow output. In the upper right-hand corner of the figure the numbers 6 and 1.5 should be reversed; i.e., the upper term should read 1.5×10^{-8} sec, and the lower term should read 6×10^{-8} sec.

N_{23}, N_{24}, N_{123}, and N_{124} are recorded on scalers for runs involving two positions of the Counters 3 and 4. In the first position the planes defined by Counters $2-3$ and $1-2$ are parallel and in the second position these planes are perpendicular. For the first position we compute the ratio of normalized triple coincidence counting rates $S(1)=(N_{123}/N_{23})/(N_{124}/N_{24})$ and for the second the ratio $S(2)=(N_{124}/N_{24})/(N_{123}/N_{23})$. In first order the ratios $S(1)$ and $S(2)$ should be independent of variation of counter efficiency associated with electronic drift and should be equal provided the pulse-height selection is approximately the same for the $2-3$ and $2-4$ coincidence combinations. However, should there be a small difference between the ratios N_{123}/N_{23} and N_{124}/N_{24} (apart from statistical variations) when measured in successive runs in which Counters 3 and 4 have the same position, then this asymmetry will cancel in the geometric mean quantity $S=[S(1)S(2)]^{\frac{1}{2}}$. If there is no polarization effect, $S=1$. This procedure described here using two counters instead of one to detect the scattered radiation has the advantage of giving greater stability against electronic drift in addition to doubling the rate of data taking. Moreover, the results are independent of source decay during the runs.

The measured quantity S is to be compared with the corresponding theoretical value obtained from the relation $S=(p+R)/(pR+1)$, where p is the ratio of probabilities of polarization parallel to perpendicular with respect to the plane of the two radiations for the gamma-ray detected in the polarization detector and R is the asymmetry ratio of the polarization detector. The quantity p can be calculated from the formula and tables of Rose[8] for various assignments of spin to the levels involved in the cascasde.

In order to compare theory with experiment it is necessary to know the asymmetry ratio, R of the apparatus for the photon energies involved. Although R can be calculated from the Klein-Nishina formula for Compton scattering, the calculation is made difficult due to the finite sizes of the detectors and the effect of double or higher order scattering. In these experiments R was determined experimentally by measuring the polarization-direction correlations of two known cascades, the 1409–122 kev cascade in the 12-year decay of Eu^{152} and the 842–122 kev cascade in the 9-hour decay of Eu^{152m}. The levels involved in these cascades have been studied previously from directional correlations and internal conversion measurements and have been assigned spins and parities $2^-(E1)2^+(E2)0^+$,[14,2] and $1^-(E1)2^+(E2)0^+$,[1–3] respectively. From the polarization-direction correlations of these cascades, R was determined for the photon energies 1409 and 842 kev. An interpolation with respect to energy is used to determine R for other photon energies intermediate to the above. The polarization-direction correlation results for the known and unknown cascades are presented in Table II.

From the measured values of S, the quantity p is calculated for the unknown Cascades C and D. The quantity p, so determined, is compared with the theoretical possibilities in Fig. 3. Here, p is plotted *versus* the directional correlation coefficient A_2[13] for the various possibilities of spin sequence $J-2-0$ where $J=0$, 1, 2, 3, and 4. The curves are parametric in the quadrupole to dipole mixing ratio δ. For $p>1$, $1/p$ is plotted *versus* A_2 instead of p. From the comparison of theory with the polarization-direction correlation results in Fig. 5, it is possible to rule out some of the possibilities consistent with the directional correlation measurements alone. From Fig. 2 it was seen that the

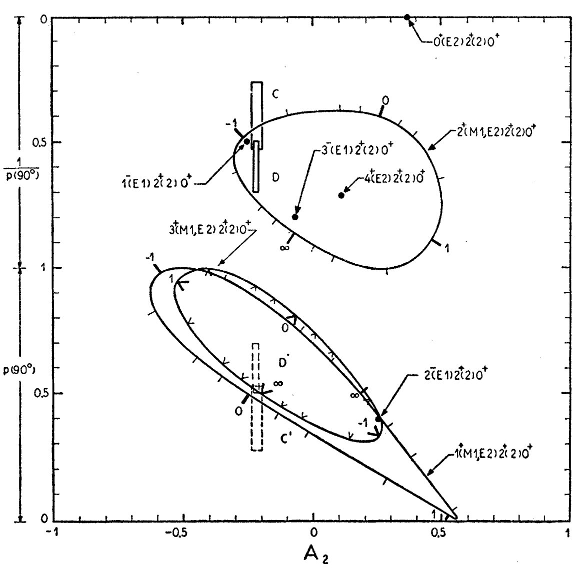

FIG. 5. The polarization-direction correlation function, p, is plotted for an angle of 90° between the cascade photons *versus* the directional correlation coefficient, A_2, for gamma-gamma cascades having the spin sequence $J-2-0$. The possibility of mixtures is considered for $J=2$, 3, and 4 and the curves are parametric in the quadrupole to dipole mixing ratio δ. Markers are placed along the curves to indicate the points for $\delta=0$, ±0.1, ±0.2, ±0.5, ±1, ±2, ±5, ±10, and ∞, but only the values 0, ±1, and ∞ are labeled. Rectangles are plotted to show the experimental limits of the measurements of p and A_2 for the Cascades C and D (see Table II). The rectangles labeled C' and D' are the mirror images about the $p=1$ axis (i.e., $p_c=1/p_c'$) of the rectangles C and D, respectively. By comparing the rectangles C' and D' with the theoretical curves it is possible to consider the cascades in which the first transition has the opposite parity change from the one indicated by the label on each curve.

TABLE II. Polarization-direction correlation results for cascades in 12-year Eu^{152} (Cascade A) and 9-hour Eu^{152m} (Cascades B, C, and D). The polarization and direction detectors subtend an angle of 90° on the source. For Cascades A and B, R is calculated from S which is measured and p which is calculated from the known spin values. In Cascades C and D, R is obtained by interpolation in photon energy of the values determined from Cascades A and B for energies 1409 and 842 kev, respectively. Then $1/p$ is calculated from the measured S and the computed R. These experiments were performed with a $\frac{1}{2}$-mm Cd absorber before Counter 1 in order to reduce K-capture x-rays and a 3-mm Pb absorber before Counter 2 to absorb both the 122-kev photons and the x-rays.

Cascade	p (theory)	S (experiment)	R	$1/p$ (calculated)
A. Pol. 1409–Dir. 122 kev	0.4	1.26±0.03	1.73	···
B. Pol. 842–Dir. 122 kev	2	0.78±0.01	2.19	···
C. Pol. 1389–Dir. 122 kev	···	0.79±0.04[a]	1.74	0.40±0.13
D. Pol. 970–Dir. 344 kev	···	0.84±0.04	2.07	0.60±0.10

[a] For this measurement of Cascade C an antipile-up circuit was used in order to reject pile-up events which were present due to high counting rates. Two measurements made without the use of the antipile-up circuit gave $S=0.90\pm0.04$ and $S=0.91\pm0.04$.

directional correlation measurements could be fitted if spins and parities $1^\pm-2^+-0^+$ or $3^\pm-2^+-0^+$ are assigned to the levels involved in the 1389–122 kev and 970–344 kev cascades. For both of these cascades only the spin and parity assignment $1^-(E1)2^+(E2)0^+$ gives a reasonable fit to the polarization-direction correlation results as is seen in Fig. 5. Consequently, we are led to assign spin 1^- to both the 1511-kev level in Sm^{152} and the 1315-kev level in Gd^{152} and $E1$ to the 1389- and 970-kev transitions emitted from these states.

DISCUSSION

Wood and Nathan[3] searched for the 1315- and 1389-kev K internal conversion lines in the Copenhagen six-gap "orange" type β-ray spectrometer set to an energy resolution of 1%. Only weak indications of these lines were found above the continuous β-ray background of the source. As shown in Table III, these measurements suggested $E1$ for the 1315-kev transition and $M1$ for the 1389-kev transition although the possibility of $E1$ in the later case was not excluded. Marklund *et al.*[4] have measured both the internal and external conversion lines for the 970-, 1315-, and 1389-kev transition in the Uppsala double focussing iron yoke spectrometer used at energy resolutions of

TABLE III. Measurements of K internal conversion coefficients of transitions following the decay of Eu^{152m}.

Transition	$\alpha_K\times10^3$ Wood and Nathan[a]	Marklund *et al.*[b]	Sliv and Band[c] $E1$	$E2$	$M1$
970-kev Gd^{152}	···	1.0±0.5	0.9	2.2	3.6
1315-kev Gd^{152}	<0.7	0.5±0.2	0.6	1.4	2.1
1389-kev Sm^{152}	1.5±0.6	0.4±0.2	0.5	1.1	1.6

[a] See reference 3.
[b] See reference 4.
[c] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Reprt 57 ICCK1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].

0.3–0.4%. As seen in Table III their results are consistent with an assignment of $E1$ to all three transitions in agreement with the present angular correlation work.

The assignment of spin 1^- to the 1511-kev level in Sm^{152} raises the problem why no transition is observed between this level and the ground state. If we consider this state to be described by a pure quantum number $K=1$ then the theory[6] governing branching to levels in a rotational band predicts that the intensities of the 1389-kev and 1511-kev gamma rays should be in the ratio of 0.39 to 1. However, examination of the gamma-ray spectrum both on a scintillation spectrometer[3] and by external conversion in a double focussing spectrometer[17] indicate that the intensity of the 1511-kev crossover gamma-ray is less than 1% of the 1389-kev gamma-ray intensity. There is the possibility that this effect is caused by a mixing interaction between two K-bands. It is presumed that the two 1^- levels at 1511 kev and 963 kev are the lowest energy levels, respectively, of two rotational bands having $K=1$ and $K=0$. Then the 963- and 1511-kev levels which we call α and β, respectively, can be described by mixed wave functions:

$$\Psi_\alpha = a\psi_{M,K=0}{}^{I=1} + b\psi_{M,K=1}{}^{I=1}$$

and

$$\Psi_\beta = a\psi_{M,K=1}{}^{I=1} - b\psi_{M,K=0}{}^{I=1},$$

where a and b are treated as adjustable parameters. We define the "mixing parameter" $x \equiv b/a$ and the ratio of matrix elements between the initial and final intrinsic states χ^i and χ^f, as

$$y \equiv \frac{\sqrt{2}\langle \chi_{K=0}{}^f | M(E1) | \chi_{K=1}{}^i \rangle}{\langle \chi_{K=0}{}^f | M(E1) | \chi_{K=0}{}^i \rangle}.$$

The $\sqrt{2}$ factor in the expression for y comes about as the result of symmetrization of the wave function

$$\psi_{M,K=1}{}^{I=1}.$$

[17] I. Marklund, Nuclear Phys. **9**, 83 (1958).

The following expressions are deduced[18] for the branching of the α and β states to the ground state and first excited states in terms of ratios of reduced transition probabillties:

$$\frac{B[E1, \alpha \to I_f=2, K_f=0]}{B[E1, \alpha \to I_f=0, K_f=0]} = 2\left|\frac{1+\frac{1}{2}xy}{1-xy}\right|^2,$$

and

$$\frac{B[E1, \beta \to I_f=2, K_f=0]}{B[E1, \beta \to I_f=0, K_f=0]} = \frac{1}{2}\left|\frac{1-2x/y}{1+x/y}\right|^2.$$

The observed γ-ray intensities can be fitted if one sets $x=-y=\pm 0.27$. However, to support or reject this result more experimental information is needed. One possibility would be to measure the ratio of the lifetimes of the two 1^- levels. Using the values of x and y found above, the ratio of these lifetimes can be predicted to have the value $\tau_\beta/\tau_\alpha=2.5$. In addition it would be illuminating to determine the energies of the rotational levels built on the two 1^- levels in order to compare with the predicted distortion of the level spacings in rotational bands due to K-band mixing.

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[18] This calculation has been made by Dr. S. G. Nilsson. The author is grateful for the permission to quote the results before publication.