Angular correlation study of ^{129}I populated in the decay of ^{129}Te

J. De Raedt,* M. Rots, and H. Van de Voorde
Katholieke Universiteit Leuven, Departement Natuurkunde Celestijnenlaan 200 D, 3030 Heverlee, Belgium
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From coincidence measurements on γ-γ cascades following the decay of ^{129}Te^m the existence of a 1047-keV level in ^{129}I is well established. Angular correlation measurements for several cascades give the following values:

281-251-keV cascade: $A_{22}=0.238\pm0.015$, $A_{44}=0.014\pm0.026$;
209-251-keV cascade: $A_{22}=0.234\pm0.012$, $A_{44}=0.011\pm0.022$;
281-278-keV cascade: $A_{22}=-0.048\pm0.014$, $A_{44}=-0.014\pm0.023$;
209-278-keV cascade: $A_{22}=-0.059\pm0.011$, $A_{44}=0.018\pm0.018$;
624-209-keV cascade: $A_{22}=-0.270\pm0.065$, $A_{44}=0.047\pm0.095$;
624-460-keV cascade: $A_{22}=0.151\pm0.009$, $A_{44}=0.003\pm0.012$;
624-478-keV cascade: $A_{22}=-0.290\pm0.025$, $A_{44}=-0.002\pm0.036$;
343-460-keV cascade: $A_{22}=-0.341\pm0.058$, $A_{44}=0.033\pm0.080$.

These values, together with nuclear orientation data, uniquely determine the spin of the excited states at 278 keV ($\frac{3}{2}$) and 860 keV ($\frac{3}{2}$). The mixing ratios $\delta(E2/M1)$ for the different transitions are obtained.

[RADIOACTIVITY ^{129}Te from ^{128}Te(n,γ); measured $\gamma\gamma$ coin, $\gamma\gamma(\theta)$. ^{129}I deduced levels, J, γ-mixing ratios. Enriched target, Ge(Li), NaI(Tl) detectors.]

1. INTRODUCTION

A study of the decay of ^{129}Te by Dickinson, Bloom, and Mann[1] establishes most of the low-energy part of the spectrum of ^{129}I. The spins of several low-lying states are uncertain, especially of the 278.4-, the 487.4-, and the 559.7-keV states. According to Ref. 1, for each of these levels a spin assignment $\frac{5}{2}$ or $\frac{3}{2}$ is possible: they are fed by allowed β decay from the $\frac{3}{2}^+$ ground state of ^{129}Te and decay to the $\frac{7}{2}^+$ ground state and $\frac{5}{2}^+$ first excited state of ^{129}I. The existence of a ground-state transition from the 559.7-keV level is contested by a recent measurement by Mann, quoted by Horen,[2] who gives an energy value of 560.01 keV for this transition. A (^{3}He, d) reaction study by Auble, Ball, and Fuller[3] gives $l=0$, thus $J=\frac{1}{2}$ for a 561-keV level. A recent nuclear orientation study by Silverans, Schoeters, and Vanneste[4] establishes the $\frac{5}{2}$ spin value of the 487.4-keV level. This experiment also favors a $\frac{5}{2}$ spin value of the 559.7-keV level, and excludes a $\frac{1}{2}$ spin value. Angular correlation measurements [with NaI(Tl) detectors] by Gupta and Saha[5] and by Arya and Nicholson[6] give contradicting results.

We used a Ge(Li)-Ge(Li) coincidence setup to measure the angular correlations between the 281- and 209-keV transitions, which feed the 278-keV level, and the 278- and 251-keV transitions to the ground and first excited state. Combining these results with the data from the nuclear orientation measurement should give definite spin assignments as well as $\delta(E2/M1)$ ratios for the considered transitions. A second series of measurements concerned the transitions to and from the 487.4-keV level. These should also give mixing ratios for the decays involved.

2. SPECTROSCOPICAL STUDIES IN ^{129}I

A. Energy and intensity measurement

We have remeasured with good accuracy the energy spectrum of ^{129}Te in the 450–800-keV region. A ^{129}Te source was used, obtained by (n,γ) reaction on ^{128}Te in the BR2 reactor at Mol, Belgium and subsequent separation in the 55° isotope separator of our institute. The measurements were done two months after the irradiation.

We have made a computer fit with Gaussian curves through the different peaks. Taking the energy values of the 459.60 and the 695.98-keV line from Ref. 1, we obtain by linear interpolation the energy values given in Table I. These are in very good agreement with Ref. 1 and, in particular, discard the 560.01-keV value quoted by Ref. 2. From our fit the difference 559.7 − 556.7 keV is given very accurately as 3.02 ± 0.02 keV, independently from the absolute calibration. This means that the energy of the 559.7-keV transition is not in disagreement with a possible ground-state transition from the 559.7-keV level. The intensities of the lines are also obtained from the Gaussian fit. We have taken the intensity ratio 100:64 (Ref. 1) for the 459.6- an

TABLE I. Energy and intensity of ^{129}Te γ rays in the 450–800-keV region. The values marked with (*) are taken from Ref. 1; the other values are obtained by linear interpolation, using our measured values.

Energy (keV)	Intensity
459.60 ± 0.05 *	100 *
487.40 ± 0.05	18.7 ± 0.1
531.86 ± 0.05	1.25 ± 0.01
551.71 ± 0.10	0.060 ± 0.004
556.70 ± 0.05	2.34 ± 0.01
559.71 ± 0.05	0.22 ± 0.01
624.43 ± 0.05	1.15 ± 0.01
671.96 ± 0.05	0.50 ± 0.01
695.98 ± 0.05 *	64 *
701.82 ± 0.05	0.50 ± 0.01
705.70 ± 0.10	0.09 ± 0.01
729.62 ± 0.05	15.2 ± 0.1
741.02 ± 0.05	0.99 ± 0.02
768.77 ± 0.05	0.11 ± 0.01

695.98-keV lines as calibration. There is some discrepancy with Ref. 1 for the weaker lines at 551.7, 559.7, and 701.8 keV.

B. Coincidence measurements

In order to investigate the existence of a 1047-keV level as a possible origin of the 559.7-keV transition, we have made Ge(Li)-Ge(Li) coincidence measurements.

Coincident spectra with four windows in the 551–585-keV region are shown in Fig. 1; they clearly show that the 559.7-keV line is coincident with both the 460- and 487.4-keV lines. The intensities of the 559.7-460-keV and of the 559.7-487.4-keV coincidences, normalized to $I_{460} = 100$, are 0.054 and 0.012, respectively. This corresponds to an intensity $I_{559.7} = 0.062 \pm 0.009$, which is much weaker than the measured intensity in the direct spectrum $I_{559.7} = 0.22$. Noting that the coincidences were taken with an angle of 180° between the detectors, a systematic error due to angular correlation is possible. However, this correction could not be large enough to explain the discrepancy. The most plausible explanation seems that the 559.7-keV line is a doublet; one of these is a possible ground-state decay from the 559.7-keV level, the second a transition between a level at 1047 keV and the 487.4-keV level.

Coincidence spectra with γ rays in the 270-280-keV region (Fig. 2) show more evidence for this level at 1047 keV. A 769-keV transition coincident with the 278-keV region indicates that the 1047-keV level decays directly to the $\frac{3}{2}^+$ 278.4-keV level (and not to the $\frac{7}{2}^+$ 768.9-keV level, as we can conclude from the nonobservation of a 278-741-keV coincidence). The coincidences in this region also reveal the existence of several other until now unreported lines, which are summarized in Table II. All these lines fit very well in the decay scheme (Fig. 3). One notes that they form doublets or triplets with other more intense lines.

TABLE II. γ rays observed in the coincidence spectra and not reported in Dickinson's scheme (Ref. 1). The intensities are deduced from the coincidence intensities, taken at 180°, and may have a systematic error. First column values are taken from the coincident spectra.

Energy (keV)	Attribution (keV)	Intensity ($I_{460} = 100$)
281 ± 1	1050.4-768.7	0.012 ± 0.003
281 ± 1	1111.7-829.9	0.021 ± 0.004
560 ± 1	1047 -487.4	0.062 ± 0.012
701.5 ± 0.5	1260.8-559.6	0.017 ± 0.003
732.8 ± 0.5	1292.2-550.6	0.006 ± 0.003
769.6 ± 0.5	1047.5-278.4	0.028 ± 0.006

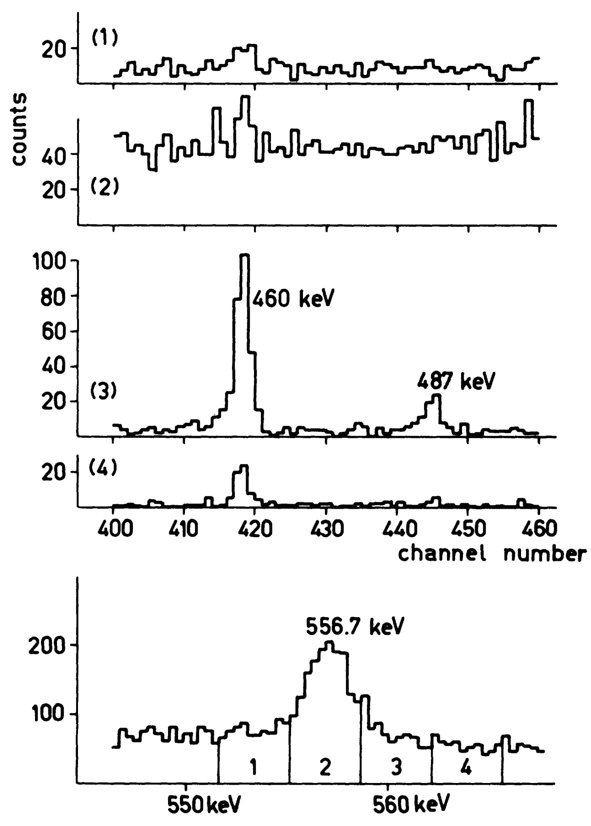

FIG. 1. Coincident spectra with four windows (1) to (4) in the 551-565-keV region.

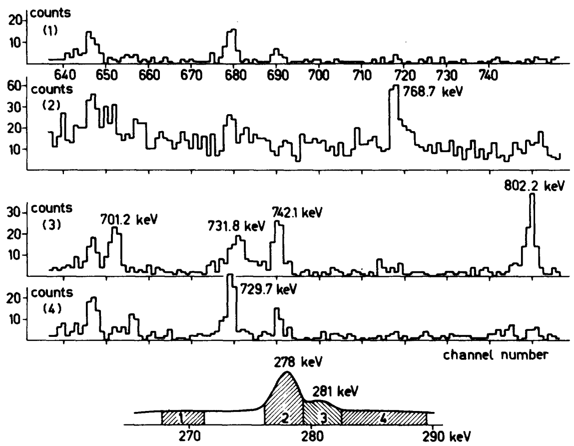

FIG. 2. Coincident spectra with four windows (1) to (4) in the 270-285-keV region.

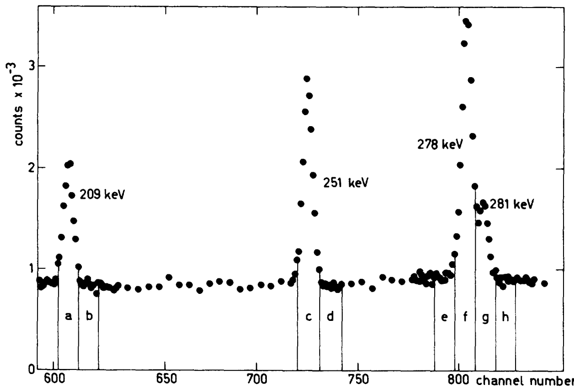

FIG. 4. Selected windows for the angular correlation measurement of the (281-251)-, (281-278)-, (209-251)-, and (209-278)-keV cascades.

3. ANGULAR CORRELATION OF THE (209, 281)-(251, 278)-keV CASCADES

A. Source and apparatus

A liquid solution of Te in hydrochloric acid was used as source in a 2 × 10-mm cylindrical (Lucite) container. In our measurement we used a coincidence setup with two 30-cm^3 true coaxial Ge(Li) detectors and an 8000-word PDP 8L computer for data registration. For the registration of the coincidences the spectrum of one of the detectors was divided into eight regions corresponding to the peaks at 209 and 251 keV and a region immediately on their right side, and to the peaks at 278 and 281 keV and regions around them (Fig. 4). For each of these eight regions the coincident spectrum of the second detector was stored, as well as the total number of chance coincidences.

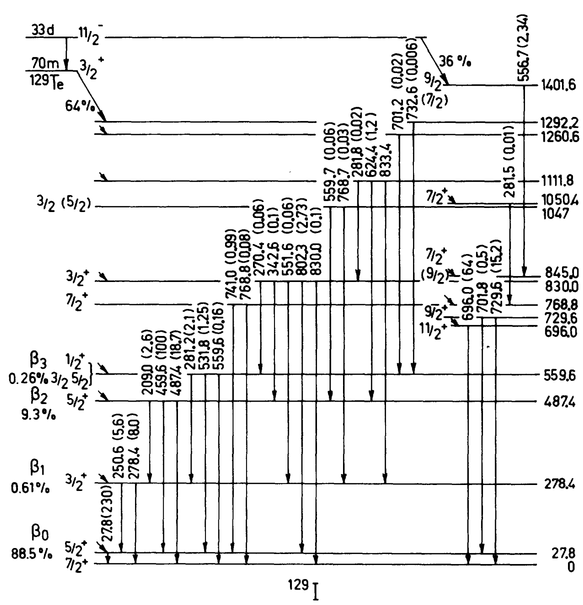

FIG. 3. Decay scheme of ^{129}Te based on our data and data in Ref. 1. Lines which are not of interest in this study are not shown.

B. Results and corrections

We measured at angles of 90, 120, 150, and 180° between the two detectors. The detectors

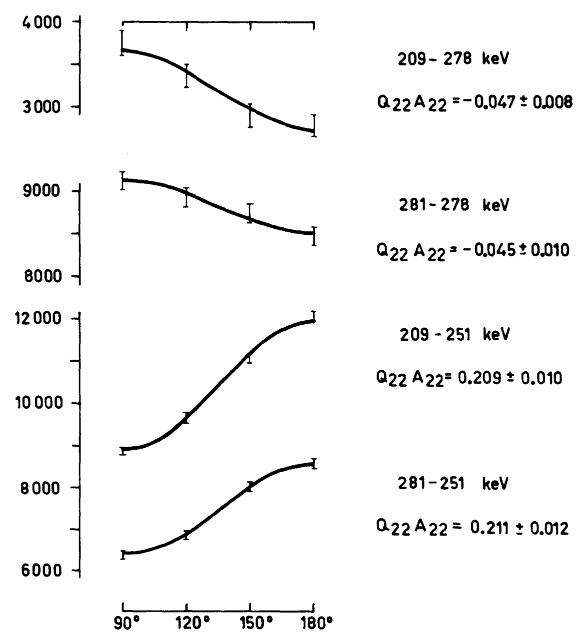

FIG. 5. Measured angular correlation of the (281-251)-, (281-278)-, (209-251)-, and (209-278)-keV cascades. The corrected coincidence numbers are fitted with a two-parameter curve $W(\Theta) = A'_{00}[1 + A_{22}Q_{22}P_2(\cos\Theta)]$.

TABLE III. Angular correlation coefficients resulting from a best fit through the measured data of

(a) $W(\theta)=A'_{00}\,[1+Q_{22}A_{22}P_2(\cos\theta)+Q_{44}A_{44}P_4(\cos\theta)]$,

(b) $W(\theta)=A'_{00}\,[1+Q_{22}A_{22}P_2(\cos\theta)]$.

Cascade (keV)	A_{22a}	A_{44a}	A_{22b}
281-251	0.238 ± 0.015	0.014 ± 0.026	0.239 ± 0.014
209-251	0.234 ± 0.012	0.011 ± 0.022	0.237 ± 0.011
281-278	-0.048 ± 0.014	-0.014 ± 0.023	-0.051 ± 0.011
209-278	-0.059 ± 0.011	0.018 ± 0.018	-0.054 ± 0.009

were carefully shielded against backscattering from the 459.6- and 487.4-keV γ rays. The results were corrected for centering errors and for chance coincidences. The Compton background below the peaks was subtracted using a linear interpolation method.[7] These correlations are illustrated in Fig. 5. The expansion coefficients are obtained from a fit[8] of

$$W(\theta)=A'_{00}+A'_{22}P_2(\cos\theta)+A'_{44}P_4(\cos\theta)$$

and from $A_{KK}Q_{KK}=A'_{KK}/A'_{00}$, where Q_{KK} accounts for the effect of finite solid angle and source size. A two-parameter analysis ($A_{44}=0$) was also made and gives excellent fits as shown in Fig. 5. The results are given in Table III.

C. Analysis

1. *Notation*

Throughout this article we use the following notations for a cascade $J_1(\gamma_1)J_2(\gamma_2)J_3$:

$$A_{KK}(\gamma_1,\gamma_2)=B_K(\gamma_1)A_K(\gamma_2)\quad\text{with } K=2,4$$

$$B_K(\gamma_1)=\frac{F_K(11J_1J_2)-2\delta(\gamma_1)F_K(12J_1J_2)+\delta^2(\gamma_1)F_K(22J_1J_2)}{1+\delta^2(\gamma_1)},$$

$$A_K(\gamma_2)=\frac{F_K(11J_3J_2)+2\delta(\gamma_2)F_K(12J_3J_2)+\delta^2(\gamma_2)F_K(22J_3J_2)}{1+\delta^2(\gamma_2)},$$

where $\delta(\gamma)=\langle f\|E2\|i\rangle/\langle f\|M1\|i\rangle$. We note that in this notation δ is independently defined for the initial and the final γ ray in a cascade. These mixing ratios are the same as the ones given by Krane and Steffen.[9] The anisotropy of γ rays from oriented nuclei is indicated by $U_2A_2(\gamma)$. U_2 contains the effect of the unobserved intermediate radiation and is specified further in the text.

2. *Analysis with $J_{278}=\frac{5}{2}$*

The possible spin assignments for the 278-keV level are $\frac{3}{2}$ and $\frac{5}{2}$. Assuming $J_{278}=\frac{5}{2}$, each γ ray in the considered cascades has mixed $(E2,M1)$ multipolarity. The measured angular correlation gives a relation between the mixing ratios $\delta(E2/M1)$ of each γ ray involved. Since the measured A_{44} coefficients are small and consistent with $A_{44}=0$, they do not impose a severe restriction on the δ values. We can combine the results of two cascades involving the same γ ray in order to restrict further the allowed region of consistency. However, no definite spin assignment can be made from the correlation measurement alone. We compare our results with those of the orientation measurement (Ref. 4). Using the relations resulting from the (209-251) and (281-251) cascades, we calculate $U_2A_2(251)$, the anisotropy of the 251-keV γ ray for oriented ^{129}Te. We assume the intermediate β transitions to be pure Gamow-Teller and take the feeding modes of the 278-keV level from Ref. 1, neglecting the smaller feeding modes. This gives $U_2=[0.63U_2(\beta_1)+0.21U_2(\beta_2)U_2(209)+0.16U_2(\beta_3)U_2(281)]$. The coefficients U_2 are given by Yamazaki,[10] in our case $U_2(\beta)=U_2(\frac{3}{2}\,1j_F)$ and $U_2(\gamma)=[U_2(j_i\,1j_F)+\delta^2U_2(j_i\,2j_F)]/(1+\delta^2)$. Assuming $J_{560}=\frac{1}{2}$, we obtain $U_2A_2(251)=-0.26\pm0.02$ for $\delta(281)=-0.27$, or $U_2A_2(251)=-0.23\pm0.02$ for $\delta(281)=-0.99$. Similarly, for the assumptions $J_{560}=\frac{3}{2}$ or $\frac{5}{2}$ we find negative values of $U_2A_2(251)$ in the whole region of $\delta(251)$ allowed by the angular correlation measurements. These results are not compatible with the measured $U_2A_2(251)=0.224\pm0.029$.[4] The neglected terms as well as possible Fermi contributions would not affect this result. So the spin value $J_{278}=\frac{5}{2}$ can be rejected.

3. *Analysis with $J\,(278)=\frac{3}{2}$*

Since the spin ($\frac{3}{2}$) of the intermediate state does not allow A_{44} terms in the angular correlation, we use the two-parameter-fit values of A_{22} given in Table III, Eq. (b). We use a least-squares method in order to obtain values of the coefficients

TABLE IV. Values of U_2A_2 for different γ rays, compatible with the (209, 281)-(251, 278) correlation data and with a $\frac{3}{2}$ spin assignment for the 278-keV level.

J_{559}	(281)	$U_2A_2(251)$	$U_2A_2(278)$	$U_2A_2(281)$
$\frac{5}{2}$	-0.225	0.208 ± 0.029	-0.046 ± 0.000	-0.565 ± 0.046
$\frac{5}{2}$	∞	0.143 ± 0.020	-0.032 ± 0.000	-0.132 ± 0.064
$\frac{3}{2}$	3.66	0.140 ± 0.020	-0.031 ± 0.000	-0.084 ± 0.014
$\frac{3}{2}$	0.57	0.151 ± 0.021	-0.033 ± 0.000	-0.194 ± 0.004
$\frac{1}{2}$	/	0.152 ± 0.022	-0.033 ± 0.000	0

$A_2(251)$, $B_2(281)$, and $B_2(209)$ which have to satisfy the relations $A_2(\gamma_2)B_2(\gamma_1) = A_{22}(\gamma_1\gamma_2)$, where $A_2(278) = -0.143$ for the unique $E2$ transition $(\frac{3}{2}-\frac{7}{2})$. These values are $A_2(251) = 0.648 \pm 0.091$, $B_2(281) = 0.368 \pm 0.052$, and $B_2(209) = 0.366 \pm 0.051$. From these we deduce the following δ values:

$$\delta_{251} = 0.53^{+0.16}_{-0.12} \text{ or } 3.54^{+2.0}_{-1.1},$$

$$\delta_{209} = -0.22 \pm 0.05 \text{ or } \delta < -19 \text{ or } \delta > 28,$$

$$\delta_{281} = -0.23 \pm 0.05 \text{ or } \delta < -18 \text{ or } \delta > 29 \text{ for } J_{559} = \tfrac{5}{2},$$

$$= 0.57^{+0.07}_{-0.06} \text{ or } \delta = 3.6^{+0.8}_{-0.6} \text{ for } J_{559} = \tfrac{3}{2},$$

$$= -0.08 \pm 0.03 \text{ or } \delta = 2.09 \pm 0.14 \text{ for } J_{559} = \tfrac{1}{2}.$$

Using these values we calculate the anisotropies of the different γ rays from oriented $^{129}Te^{g}$ for comparison with the data of Ref. 4.

Anisotropy $U_2A_2(209)$. The different δ values give $A_2(209) = 0.756 \pm 0.066$ for $\delta(209) = -0.22$, or $A_2(209) = 0.176 \pm 0.083$ for $|\delta(209)| > 19$; $U_2 = U_2(\beta_2) = 0.748$. Only the first δ values agree with the measured $U_2A_2(209) = 0.507 \pm 0.046$.

Anisotropy $U_2A_2(251)$. The results for the the expected anisotropy $U_2A_2(251)$ are shown in Table IV for the different possible spin values of the 559-keV state, and for the different values of $\delta(281)$. We have excellent agreement with the experimental $U_2A_2 = 0.224 \pm 0.029$ when we accept $J(559) = \frac{5}{2}$ and $\delta(281) = -0.22$. However, considering the approximations used in calculating U_2 we may not exclude the other possibilities. Indeed, including small Fermi contributions we would have to replace $U_2(\beta) = U_2(\frac{3}{2}1\frac{3}{2}) = 0.2$ by $U_2(\beta) = (0.2 + \langle F/GT\rangle^2)/(1 + \langle F/GT\rangle^2)$ which would increase the expected U_2A_2.

Anisotropies $U_2A_2(278)$ and $U_2A_2(281)$. These are also given in Table IV. As is seen, $U_2A_2(281)$ is strongly dependent on the spin of the 559-keV level and the δ value of the 281-keV transition. It could be used to determine both. However, the measurement of Ref. 4 does not separate the 278- and 281-keV γ rays. The sum value $U_2A_2 \times (278 + 281) = 0.0 \pm 0.03$ is consistent with each set of spin and δ values.

4. ANGULAR CORRELATION OF THE (343, 624)-(209, 460, 487)-keV CASCADES

A. Source and apparatus

The source was similar to the one used in the preceding measurement. ^{110}Ag impurities were eliminated chemically by adding and precipitating AgCl. The apparatus was a system consisting of one fixed 7.6-cm × 7.6-cm NaI(Tl) and two moving Ge(Li) detectors perpendicular to each other. This system, and its electronics, is an extension of the one used in the previous measurement. In the spectrum recorded by the moving Ge(Li)

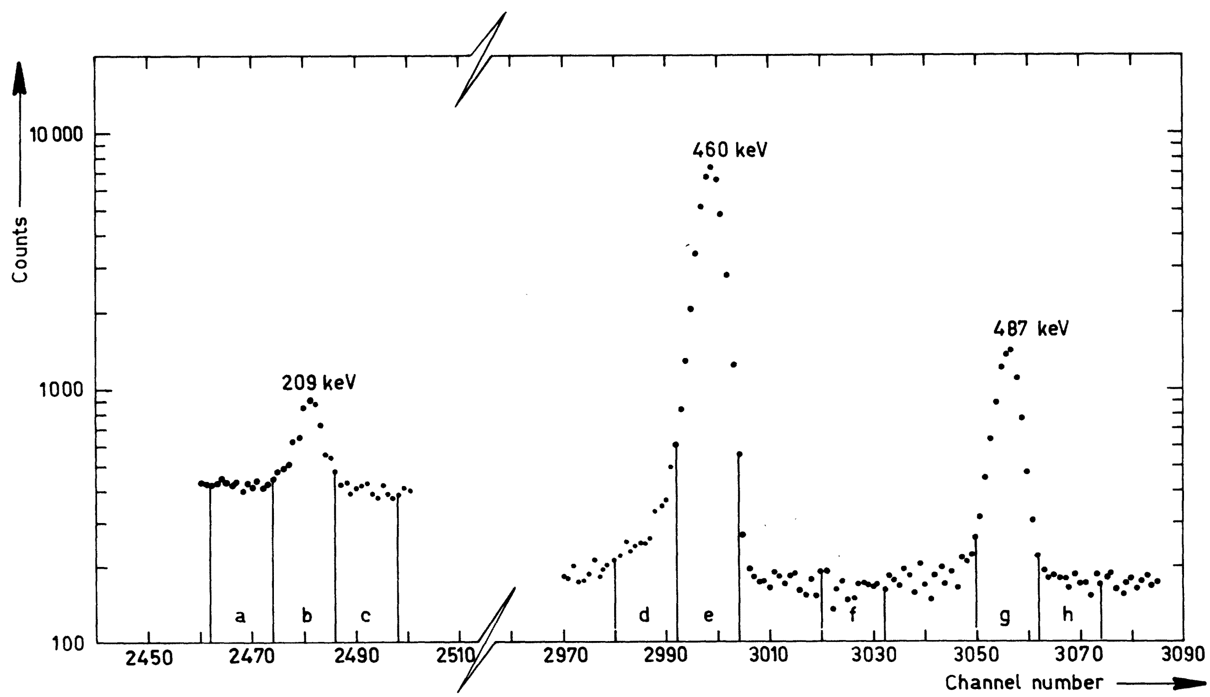

FIG. 6. Part of the Ge(Li) spectrum showing the selected windows around the peaks at 209, 460, and 478 keV for the angular correlation measurement with the 624- and 343-keV γ rays.

detectors, eight regions were selected, as shown in Fig. 6, around the 209-, 460-, and 487-keV γ lines which deexcite the 487-keV level. For each region the coincident NaI spectrum between 250 and 800 keV, as well as the total number of chance coincidences in this region, were stored.

B. Measurement and corrections

The relative intensities of the γ rays which feed the 487-keV level are indicated in Fig. 3. We measured coincidences between the 624- and 342-keV transitions to this level and the 487-, 460-, and 209-keV transitions from this level. The Compton background below the peaks in the Ge(Li) detector gives contributions to the coincidences. For the 460- and 487-keV peaks this is mainly due to remaining ^{110}Ag impurities; for the 209 peak the main contribution comes from the two higher peaks. In this last case the Compton background is very large.

The measured coincidences were corrected for centering errors and chance coincidences

TABLE V. Angular correlation coefficients resulting from a best fit through the corrected data of

$$W(\theta)=A'_{00}\,[1+Q_{22}A_{22}P_2(\cos\theta)+Q_{44}A_{44}P_4(\cos\theta)]\,.$$

The cascades indicated "350"-460 and "410"-460 are the correlations between the regions a and b of Fig. 4(d) and the 460-keV γ ray.

Cascade (keV)	A_{22}	A_{44}
624-487	−0.290 ± 0.025	−0.002 ± 0.036
624-460	0.152 ± 0.008	0.003 ± 0.012
624-209	−0.270 ± 0.065	0.047 ± 0.095
"350"-460	−0.078 ± 0.020	0.033 ± 0.027
"410"-460	0.142 ± 0.032	0.031 ± 0.043
343-460	−0.341 ± 0.058	0.033 ± 0.080

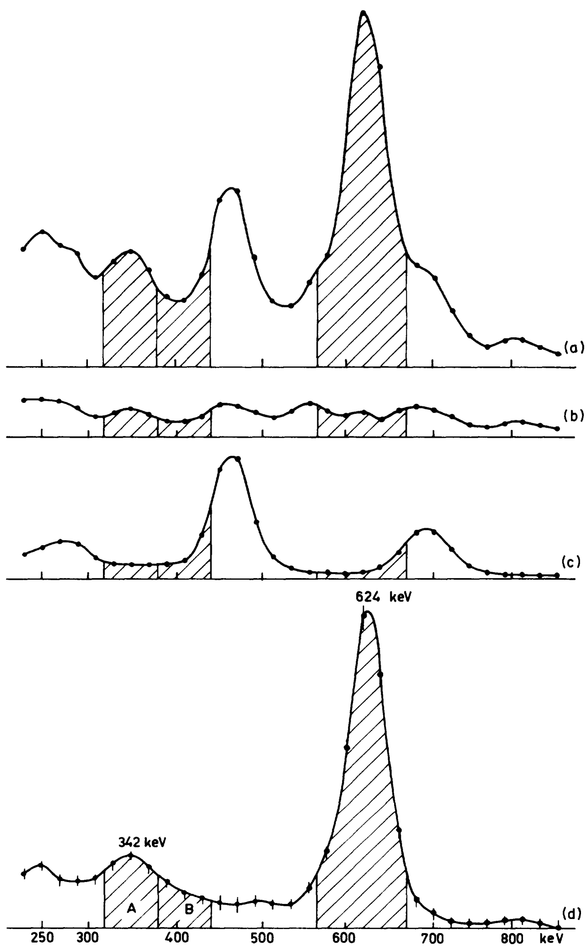

FIG. 7. Coincident NaI spectrum with the 460-keV γ ray, illustrating the different corrections: (a) measured coincident spectrum; (b) mean value of the coincident spectra with regions about the peak; (c) chance coincident spectrum deduced from the direct spectrum and the total number of chance coincidences; (d) corrected spectrum a − b − c.

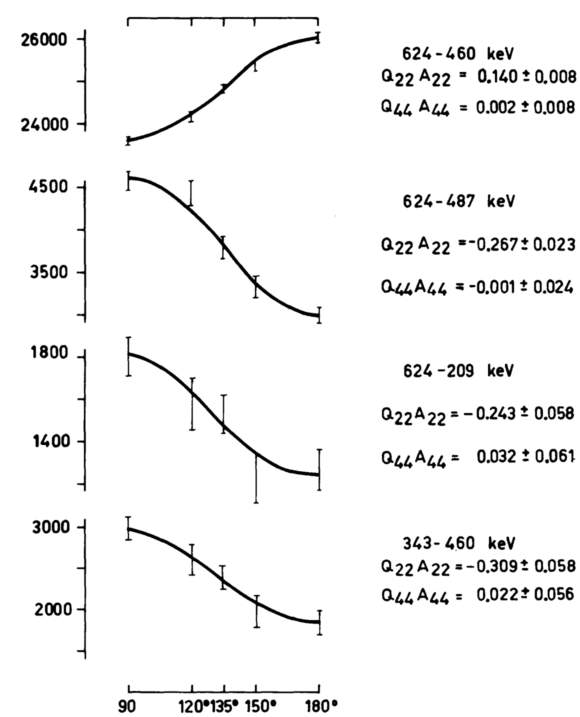

FIG. 8. Measured angular correlation of the (624-460)-, (624-487)-, (624-209)-, and (343-460)-keV cascades. The fitted curves are

$$W(\Theta)=A'_{00}\,|1+A_{22}Q_{22}P_2(\cos\Theta)+A_{44}Q_{44}P_4(\cos\Theta)|,$$

with the indicated $A_{22}Q_{22}$ and $A_{44}Q_{44}$ values.

were subtracted. The Compton contributions were subtracted, using the coincidences with the side windows around each peak. All these corrections are illustrated in Fig. 7. The deduced A_{22} and A_{44} coefficients are given in Table V.

C. Analysis

1. 624-487-keV and 624-460-keV cascades

The spin of the 1112- and 487-keV levels are known to be $\frac{5}{2}$ (Ref. 4). We thus have to analyze a $\frac{5}{2}-\frac{5}{2}-\frac{5}{2}$ and a $\frac{5}{2}-\frac{5}{2}-\frac{7}{2}$ correlation. As in Sec. 3A2 the analysis gives relations between δ(624), δ(460), and δ(487).

Combining our measurement with the A_2 values from Ref. 4 we get $B_2(624) = -0.423 \pm 0.061$. This corresponds to $\delta(624) = +0.01 \pm 0.06$ or $-1.66^{+0.25}_{-0.21}$. Only the first value gives consistency with the measured $U_2A_2(624) = -0.39 \pm 0.20$ (Ref. 4).

2. 624-209 cascade

As noted above, due to the relative weakness of the 209 transition and to the large corrections, our measurement gives rather unaccurate values of A_{22} and A_{44}. These, however, confirm the consistency of the previous results. Indeed, from Sec. 4C1 we have $B_2(624) = -0.423 \pm 0.061$ and from Sec. 3C3 $A_2(209) = 0.756 \pm 0.066$, which gives

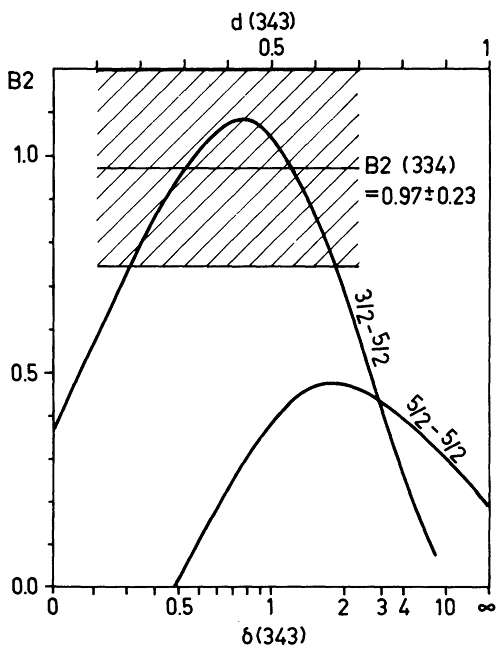

FIG. 9. $B2$ versus $d = \delta/(1+|\delta|)$ plot for the 343-keV transition, showing the experimental value and theoretical curves for $\frac{3}{2}$-$\frac{5}{2}$ and $\frac{5}{2}$-$\frac{5}{2}$ transitions.

$A_{22}(624\text{-}209) = -0.320 \pm 0.054$, in good agreement with the measured value $A_{22} = -0.276 \pm 0.067$.

3. 343-460-keV correlation

The analysis of this cascade is difficult due to the weakness of the 343-keV line and the fact that the contributions from the Compton spectrum of the 624-keV line are quite important. We have considered two regions in the NaI(Tl) spectrum (Fig. 7): (a) the region of the 343-keV peak (between 320 and 380 keV), and (b) the region immediately to the right (between 380 and 440 keV). For each region A_{22} and A_{44} values are given in Table V. Region (b) corresponds to part of the Compton spectrum of the 624-keV line. The correlation measured with this region agrees very well with the values from the photopeak measurement. Region (a) also contains a large contribution from the Compton spectrum. To estimate this contribution we suppose the Compton spectrum to be constant between 350 and 410 keV and subtract both regions [(a)−(b)] to obtain the true 343-460 correlation. This leads to the values

$$A_{22}(343-460) = -0.341 \pm 0.058\ ,$$

$$A_{44}(343-460) = 0.033 \pm 0.080\ .$$

From the A_{22} value and $A_2(460) = -0.348 \pm 0.054$ we deduce $B_2(343) = 0.971 \pm 0.225$. This corresponds to $\delta(343) = 0.74^{+1.04}_{-0.52}$ for a spin value $J_{830} = \frac{3}{2}$. This is shown in Fig. 9 in a B_2 versus δ plot. This plot also shows the effect of possible systematic errors due to a bad estimation of the Compton contribution from the 624-460 cascade. A lower estimate of this contribution would shift the B_2 value downwards and give a larger δ region. A higher estimate would reduce this δ region; the mean value of δ would not be affected. A spin value $J_{(830)} = \frac{5}{2}$ would not give an agreement with the experimental B_2 values.

5. DISCUSSION

The spins of the 278.4-keV level and of the 829.9-keV level have been well established to be $\frac{3}{2}$. Another level at 559.7 keV remains difficult to identify: part of a 559.7-keV line has been shown to originate from a new level at 1047 keV; however, the intensity of this 1047-487-keV transition, measured in coincidence with the 460-keV transition, is about 3 times smaller than that of the 559.7-keV line in the direct spectrum. This indicates that the 559.7-keV line is a doublet. The remaining part could be a transition to the $\frac{7}{2}^+$ ground state from the 559.7-keV level which then would have a spin value $\frac{3}{2}$ or $\frac{5}{2}$. In this case this level would not be the $\frac{1}{2}^+$ state at 561 keV

TABLE VI. $\delta(E2/M1)$ mixing ratios deduced from the angular correlation measurements for different transitions.

Transition (keV)	j_i-j_F	$\delta(E2/M1)$ values
209	$\frac{5}{2}-\frac{3}{2}$	-0.22 ± 0.05
251	$\frac{3}{2}-\frac{5}{2}$	$0.53^{+0.16}_{-0.12}$ or $3.5^{+2.0}_{-1.1}$
278	$\frac{3}{2}-\frac{7}{2}$	Pure $E2$
281	$\frac{1}{2}-\frac{3}{2}$	-0.08 ± 0.03 or 2.09 ± 0.14
	$\frac{3}{2}-\frac{3}{2}$	$0.57^{+0.07}_{-0.06}$ or $3.6^{+0.8}_{-0.6}$
	$\frac{5}{2}-\frac{3}{2}$	-0.23 ± 0.05 or $\delta < -18$ or $\delta > 29$
343	$\frac{3}{2}-\frac{5}{2}$	1.02 ± 0.80
642	$\frac{5}{2}-\frac{5}{2}$	0.01 ± 0.06

observed in (^{3}He, d) reactions by Auble, Ball, and Fuller.[3] Theoretically two such levels with spin $\frac{1}{2}$ and spin $\frac{5}{2}$ would fit well in the decay scheme proposed by Vanden Berghe.[11] The new observed level at 1047 keV decays to the $\frac{3}{2}^+$ state at 278 keV and to the $\frac{5}{2}^+$ state at 460 keV. Since no transitions to a $\frac{7}{2}$ state were observed, a spin value $\frac{3}{2}$ seems more likely than $\frac{5}{2}$.

The $\delta(E2/M1)$ mixing ratios deduced from our angular correlation measurements are summarized in Table VI; all these ratios, except for the 624.4-keV transition, are very large compared to the single-particle estimates which range from 8.5×10^{-3} to 2.5×10^{-2} in the 209–624-keV region. Our results do not agree with previous results.[5,6] We believe this is due to errors inherent to NaI, NaI measurements; the internal consistency of our measurements was checked several times.

A problem arises concerning the 460-27-keV correlation which we have not measured. From the $\delta(460)$ value consistent with our measurement and Ref. 4, and from the $\delta(27)$ value from Bemis and Fransson[12] and the sign determination of the latter δ by de Waard, Reintsema, and Pasternak[13] we deduce an expected $A_{22}(460\text{-}27)$ value

$$A_{22}(460\text{-}27) = -0.0308^{+0.0032}_{-0.0024} \, .$$

This value is in disagreement with previous experiments by Sanders,[14] who measured $A_{22}(460\text{-}27) = -0.0148 \pm 0.0029$ and by Makariuniene and Makariunas,[15] who give $A_{22}(460\text{-}27) = 0.056 \pm 0.018$. As these results are well outside the quoted errors, new experimental data would be welcome.

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*Aangesteld Navorser N. F. W. O.

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