Directional correlation measurements for gamma transitions in ^{127}Te

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The directional correlation of coincident γ transitions in ^{127}Te has been measured following the β^- decay of ^{127}Sb ($T_{1/2}=3.9$ d) using Ge(Li)-Ge(Li) and Ge(Li)-NaI(T1) gamma spectrometers. Measurements have been carried out for 14 gamma cascades resulting in the determination of multipole mixing ratios $\delta(E2/M1)$ for 15 γ transitions. The present results permitted a definite spin assignment of $\frac{7}{2}$ for the 785 keV level and confirmation of several previous assignments to other levels in ^{127}Te. The g factor of the 340 keV ($\frac{9}{2}^-$) level has also been measured using the integral perturbed angular correlation method in the hyperfine magnetic field of a Te in Ni matrix. The results of the g factor as well as the mixing ratio for the 252 keV ($\frac{9}{2}^- \rightarrow \frac{11}{2}^-$) transition support the earlier interpretation of this state as an anomalous coupling state.

I. INTRODUCTION

The low lying levels of odd-A tellurium isotopes $^{125-129}$Te are quite similar in many aspects and have been the subject of numerous experimental and theoretical studies. In particular, levels with spins and parities $\frac{3}{2}^+$, $\frac{1}{2}^+$, $\frac{11}{2}^-$, and $\frac{9}{2}^-$ are populated at low energies in the decay of respective antimony isotopes.[1–3] The placement of some of the levels, their mode of decay, and the logft values also reveal striking similarities. The states with spins and parities $\frac{3}{2}^+$, $\frac{1}{2}^+$, and $\frac{11}{2}^-$ are readily assigned as predominantly $2d_{3/2}$, $3s_{1/2}$, and $1h_{11/2}$ single neutron states, but no such interpretation is possible for the $\frac{9}{2}^-$ level. The lowest $\frac{9}{2}^-$ shell model state $1h_{9/2}$ is expected at a much higher energy across the gap than experimentally observed in these nuclei. An explanation has since been proposed by Kisslinger[4] who suggested that a coupling of three quasiparticles in the $1h_{11/2}$ state can under certain circumstances produce a $\frac{9}{2}^-$ intruder state at considerably lower energy than the single quasiparticle level. Theoretical predictions for the $\frac{9}{2}^-$ state from the Kisslinger model[4] have been verified experimentally in ^{125}Te and ^{127}Te with success.[5–9]

Energy levels of ^{125,127,129}Te isotopes have been extensively studied through the (d,p) (Refs. 10—13), (d,t) (Ref. 14), (^{3}He,α) (Ref. 15), (α,3nγ) (Ref. 16), (p,p′) (Ref. 17), and (t,d) (Ref. 18) reactions. Complimentary studies of the levels populated in these nuclides by beta decay have also been reported.[1–3,19,20] A complete review of the experimental work is given in Ref. 21. Several low lying levels in ^{125}Te and ^{127}Te have fairly well-established spin and parity assignments from all these studies. However, with the exception of ^{125}Te knowledge of the multipole character of the γ rays, connecting the states in ^{127}Te and ^{129}Te is far from complete. For this reason we have undertaken the measurements of the directional correlation of γ transitions in these nuclei from the β^- decay of ^{127}Sb and ^{129}Sb. The results of the ^{129}Sb decay will be discussed elsewhere.

Previous to this study Krane and Steyert[22] carried out the nuclear orientation study of the γ rays emitted by ^{127}Sb. Authors have made spin assignments to some of the levels in ^{127}Te and deduced the multipole mixing ratios for a number of relatively strong γ transitions. More recently, Soares *et al.*[9] have measured the angular correlations of the 445-252 and 291-252 keV gamma cascades in ^{127}Te from the ^{127}Sb decay. There is a disagreement between the results of these two studies for the spin of the 785 keV level. The present investigation was undertaken with a view to measure the directional correlations for several gamma cascades in order to further confirm previous assignments of the spins to the excited states in ^{127}Te and to obtain the multipole mixing ratios for a number of additional γ transitions in this nucleus. The angular correlation measurements of ^{127}Te γ rays have been carried out from the β^- decay of ^{127}Sb ($T_{1/2}=3.9$ d) using the Ge(Li)-Ge(Li) and Ge(Li)-NaI(Tl) spectrometers. In addition, we have also measured the g factor of the 341 keV level using the integral rotation method and hyperfine magnetic field of Te nuclei in a Ni matrix. A similar measurement was reported by Soares *et al.*[9] where the hyperfine field of a Te in Fe was used.

II. EXPERIMENTAL

The radioactive sources of ^{127}Sb were prepared by chemically separating the antimony from the fission products of uranium. Approximately 1 g of uranyl nitrate hexahydrate was irradiated with thermal neutrons at a flux of $\sim 2\times 10^{13}$ n/cm^2/s for 8 h in the IEA-R1 reactor at São Paulo. The antimony activity was chemically separated from the fission products and purified 60 h after the end of irradiation using a procedure similar to one described by Hoffman and Barnes.[23] Finally, the precipitate of Sb_2S_3 was dissolved in two drops of diluted NaOH solution and transferred to a Lucite sample holder.

The γ spectrometer used the combination of 45 cm^3 true Co-axial Ge(Li) detector either with a 7.6 cm$\times$7.6 cm NaI(Tl) detector or another Ge(Li) detector of 35 cm^3. The automatic γ spectrometer and the associated electronics used in the measurements are described elsewhere.[24]

The measurements were carried out at angles from 90° to 270° in steps of 30° with the Ge(Li)-NaI(Tl) detector combination and at 90° and 180° with the Ge(Li)-Ge(Li) combination. Counting from a single source was for a period of 7 d, after which a new source was prepared. A total of 20 sources were used for the entire experiments.

The single channel analyzer (SCA) windows were set to include the photopeaks of 252, 412, 473, and 686 keV as well as the region of 500–600 keV in the NaI(Tl) detector spectrum. The gate settings in the Ge(Li)-Ge(Li) measurements were at the 252 and 604 keV photopeaks. The intensities of the coincident γ rays were measured from the Ge(Li) detector spectra recorded at various angles and corrected for the chance coincidences and the source decay during the measurements. The chance coincidences were determined separately for each gate setting. The effects of Compton scattered radiation of higher energy coincident γ rays included in the window setting were negligible in most cases (see the detailed decay scheme in Ref. 21) and were determined in a few cases by setting the window at a slightly higher energy side and repeating the measurement. For example, the 445-252 keV cascade measured from the 445 keV gate setting needed correction for Compton scattering of the 584 keV γ ray which is also in coincidence with the 252 keV γ ray. This was determined by setting a narrow gate around 490 keV and measuring the 252 keV gamma coincidences. Similarly, the 291-252 keV cascade measured from the 252 keV gate has a contribution from the Compton scattering of 543 keV radiation giving 293 keV gamma coincidences (unresolved from the 291 keV γ ray). This contribution was measured with a narrow gate setting around 300 keV. A reasonably good agreement obtained with the A_{22} values measured from two Ge(Li) detectors as well as the results of the 445-252 keV cascade from the 252 keV gate shows that Compton contributions were adequately taken into consideration.

The angular correlation coefficients A_{kk} were determined by a least square fitting procedure in the usual manner and were corrected for the solid angle effects of the detectors.[25,26] These coefficients were subsequently analyzed for the spin assignments to the levels and γ-ray multipole mixing ratios $\delta(E2/M1)$. The convention of Becker and Steffen[27] was used for the phase of the mixing ratio.

The g factor of the 340 keV level was determined by measuring the integral rotation (fixed angle reverse field method) of the 445-252 keV gamma cascade in the hyperfine magnetic field experienced by the Te nuclei in Ni. A dilute alloy of SbNi was prepared by melting together several times $\sim$2 mg of Sb containing $\sim$25 μCi of ^{127}Sb (obtained by reducing the $SbCl_3$ solution with a freshly prepared solution of chromous chloride) and 1 g of 99.99% pure Ni in an induction furnace in vacuum. Finally, the alloy was pressed into a disc of 5 mm$\times$5 mm. It should be mentioned that the measurement of g factor of the 322 keV state of ^{125}Te has been carried out by Cruse *et al.*[5] and Knapec *et al.*[6] using the integral rotation of the 321-177 keV gamma cascade in the decay of ^{125}Sb. Two independent measurements were carried out, (a) with ^{125}Sb as the SbCu alloy or as $SbCl_3$ in solution and using the external magnetic field, and (b) using the hyperfine magnetic field of a Te in Ni. The preparation of the SbNi alloy used in these studies was carried out in a similar manner as in the present work. Using the hyperfine field value of 195$\pm$10 kG (Ref. 28), a good agreement with the external field measurement of the g factor was obtained.

The measurements of the integral rotation were carried out using either two 5 cm$\times$5 cm NaI(Tl) detectors or the combination of a Ge(Li) and a NaI(Tl) detector associated with a fast-slow coincidence system. The Sb(Ni) sample was polarized in an external magnetic field of 5 kG applied perpendicular to the plane of the detectors. The gates on the 445 and 252 keV γ rays were used as the start and stop pulses, respectively, for the time to pulse height converter (TPHC). The time coincidence spectra for the alternate direction of the polarizing field were stored in two different subgroups of the analyzer memory. The field direction was reversed every hour with the two detectors maintained fixed at 135° or 225° with respect to each other. Four independent measurements were carried out in this manner using two different sources.

III. RESULTS

The γ-ray spectrum in the decay of ^{127}Sb obtained with the Ge(Li) detector is shown in Fig. 1(a). Contributions from the 8.6 h ^{128}Sb were negligible; however, the presence of strong γ rays from 12.4 d ^{126}Sb decay was noticed

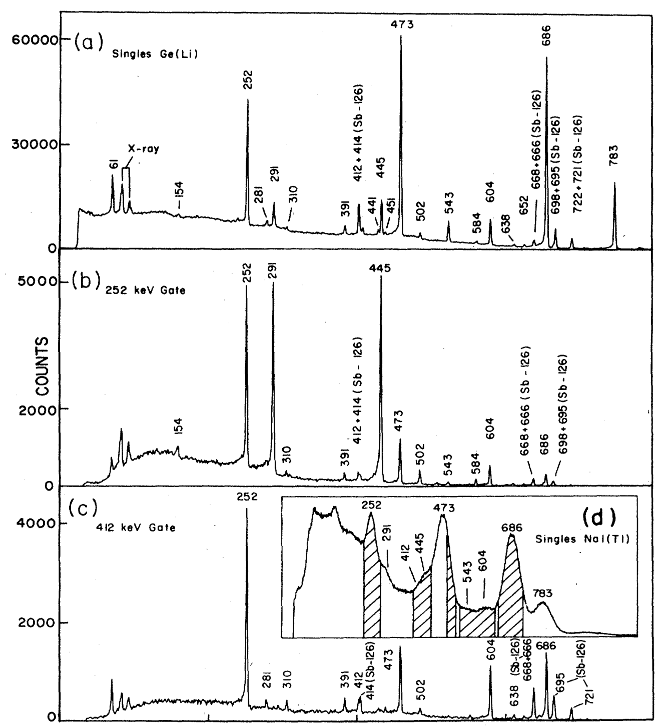

FIG. 1. Direct γ-ray spectrum up to 800 keV in the decay of ^{127}Sb observed with the Ge(Li) detector (a) and the γ-ray spectra in coincidence with the photopeaks at 252 keV (b) and 412 keV (c). In the inset is shown the direct γ-ray spectrum observed with the NaI(Tl) detector with the gate positions indicated (d).

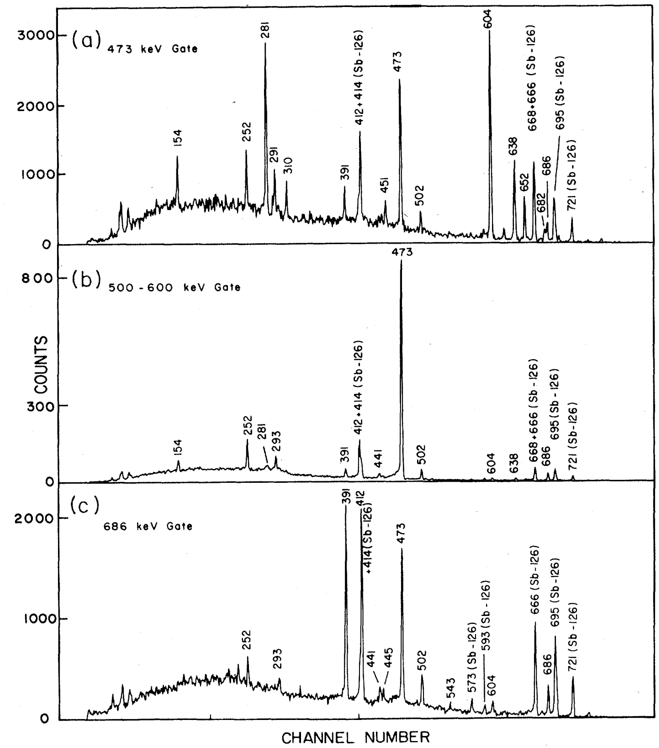

FIG. 2. γ-ray spectra observed in coincidence with the photopeaks at 473 keV (a), 500—600 keV (b), and 686 keV (c).

both in the direct and coincidence spectra. Figure 1(d) shows the γ spectrum from the NaI(Tl) detector with gate positions indicated. Typical examples of γ spectra observed in coincidence with the photopeaks at 252, 412, 473, 500-600, and 686 keV are shown in Figs. 1(b), 1(c), 2(a), 2(b), and 2(c), respectively, representing partial measurements of approximately five days counting period for each grate setting. The directional correlation coefficients A_{kk} corrected for the finite solid angle effects of the detectors are given in Table I. The A_{kk} values from the work of Soares *et al.*[9] are included in this table for comparison. Some typical results of the directional correlation measurements are shown in Fig. 3. The point at 90°

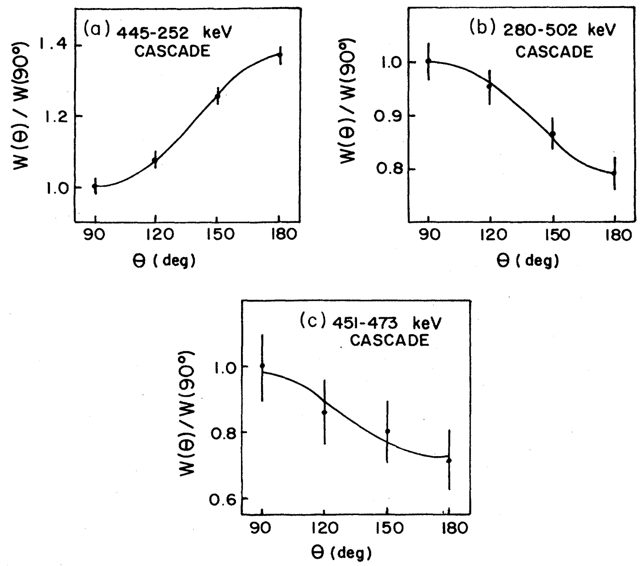

FIG. 3. Directional correlation curves for some gamma cascades typical of (a) intense transitions, (b) intermediate intensity transitions, and (c) weak transitions. Solid curves are the least square fits to the polynomial $W(\theta)=1+A_{22}P_2(\cos\theta)+A_{44}P_4(\cos\theta)$.

TABLE I. Results of directional correlation measurements of transitions in ^{127}Te.

Gamma cascade (keV)	Gating transition (keV)	A_{22}	A_{44}
584-252	584	−0.072±0.021	0.005±0.033
445-252	252	0.252±0.008	−0.024±0.014
	445	0.235±0.009	0.032±0.014
	252[a]	0.273±0.013	
		0.233±0.014[b]	0.090±0.027
291-252	252	−0.235±0.010	−0.043±0.016
	252[a]	−0.210±0.014	
		−0.342±0.024[b]	0.090±0.046
604-412	604[a]	0.147±0.047	
604-473	473	−0.156±0.010	0.017±0.015
	604[a]	−0.145±0.020	
451-473	473	−0.227±0.065	0.044±0.090
310-473	473	−0.160±0.040	−0.014±0.070
652-502	502	0.120±0.022	0.046±0.035
638-502	502	−0.450±0.018	0.057±0.025
281-502	502	−0.155±0.015	−0.025±0.023
281-441	441	−0.013±0.080	0.026±0.120
293-543	543	0.112±0.040	0.065±0.070
154-543	543	0.052±0.050	0.098±0.070
391-686	686	−0.280±0.012	0.042±0.018

[a]Ge(Li)-Ge(Li) measurement.
[b]Values from Ref. 9.

TABLE II. Multipole mixing ratios of γ transitions in ^{127}Te.

Gamma cascade (keV)	Spin sequence	Mixed transition (keV)	Mixing ratio $\delta(E2/M1)$ This work	Mixing ratio $\delta(E2/M1)$ Previous work
584-252	$\frac{7}{2}(1)\frac{9}{2}(1,2)\frac{11}{2}$	252	$-2.55+0.20$	-1.53 ± 0.24[a]
			or -0.31 ± 0.03	or -0.56 ± 0.10
				-1.61 ± 0.39[b]
445-252	$\frac{7}{2}(1,2)\frac{9}{2}(1,2)\frac{11}{2}$	445	-1.16 ± 0.30	-3.14 ± 0.76[b]
291-252	$\frac{7}{2}(1,2)\frac{9}{2}(1,2)\frac{11}{2}$	291	0.40 ± 0.03	$0.27^{+0.21}_{-0.13}$[a]
				or 6^{+68}_{-3}
				1.87 ± 0.51[b]
604-412	$\frac{5}{2}(1,2)\frac{5}{2}(2)\frac{1}{2}$	604	0.14 ± 0.08	0.00 ± 0.07[a]
			or -2.32 ± 0.50	or 1.65 ± 0.25
	$\frac{9}{2}(2,3)\frac{5}{2}(2)\frac{1}{2}$	604	0.05 ± 0.08	
604-473	$\frac{5}{2}(1,2)\frac{5}{2}(1,2)\frac{3}{2}$		-0.10 ± 0.01	-0.29 ± 0.06[a]
		473		
	$\frac{9}{2}(2)\frac{5}{2}(1,2)\frac{3}{2}$		or -2.50 ± 0.05	or -1.56 ± 0.19
451-473	$\frac{7}{2}(1,2)\frac{5}{2}(1,2)\frac{3}{2}$	451	$0.65^{+0.76}_{-0.12}$	
			or $1.16^{+0.22}_{-0.63}$	
310-473	$\frac{5}{2}(1,2)\frac{5}{2}(1,2)\frac{3}{2}$	310	0.10 ± 0.03	
			or -2.13 ± 0.30	
652-502	$\frac{7}{2}(2)\frac{3}{2}(1,2)\frac{3}{2}$	502	0.34 ± 0.08	
			or 1.50 ± 0.22	
	$\frac{5}{2}(1,2)\frac{3}{2}(1,2)\frac{3}{2}$	502	$0.34^{+0.90}_{-0.24}$	
			or $2.13^{+0.38}_{-0.90}$	
		652	0.24 ± 0.07	
			or $2.08^{+0.26}_{-0.43}$	
638-502	$\frac{5}{2}(1,2)\frac{3}{2}(1,2)\frac{3}{2}$	638	-0.42 ± 0.03	
			or -5.50 ± 0.84	
281-502	$\frac{5}{2}(1,2)\frac{3}{2}(1,2)\frac{3}{2}$	281	-0.09 ± 0.02	
			or 7.80 ± 1.20	
281-441	$\frac{5}{2}(1,2)\frac{3}{2}(1,2)\frac{1}{2}$	441	$0.51^{+0.38}_{-0.22}$	
			or $-18.30^{+14.30}_{-\infty}$	
293-543	$\frac{7}{2}(1,2)\frac{7}{2}(2)\frac{11}{2}$	293	0.12 ± 0.13[c]	
154-543	$\frac{7}{2}(1,2)\frac{7}{2}(2)\frac{11}{2}$	154	0.34 ± 0.21	
			or $-2.30^{+0.81}_{-2.02}$	
391-686	$\frac{9}{2}(1,2)\frac{7}{2}(2)\frac{3}{2}$	391	-0.31 ± 0.02	-0.29 ± 0.14[a]
				or -2.1 ± 0.70
	$\frac{5}{2}(1,2)\frac{7}{2}(2)\frac{3}{2}$	391	0.15 ± 0.02	$0.55^{+0.51}_{-0.19}$[a]
				or $2.8^{+2.5}_{-1.5}$

[a]Values from Ref. 22.
[b]Values from Ref. 9.
[c]Mixing ratio is $\delta(M2/E1)$.

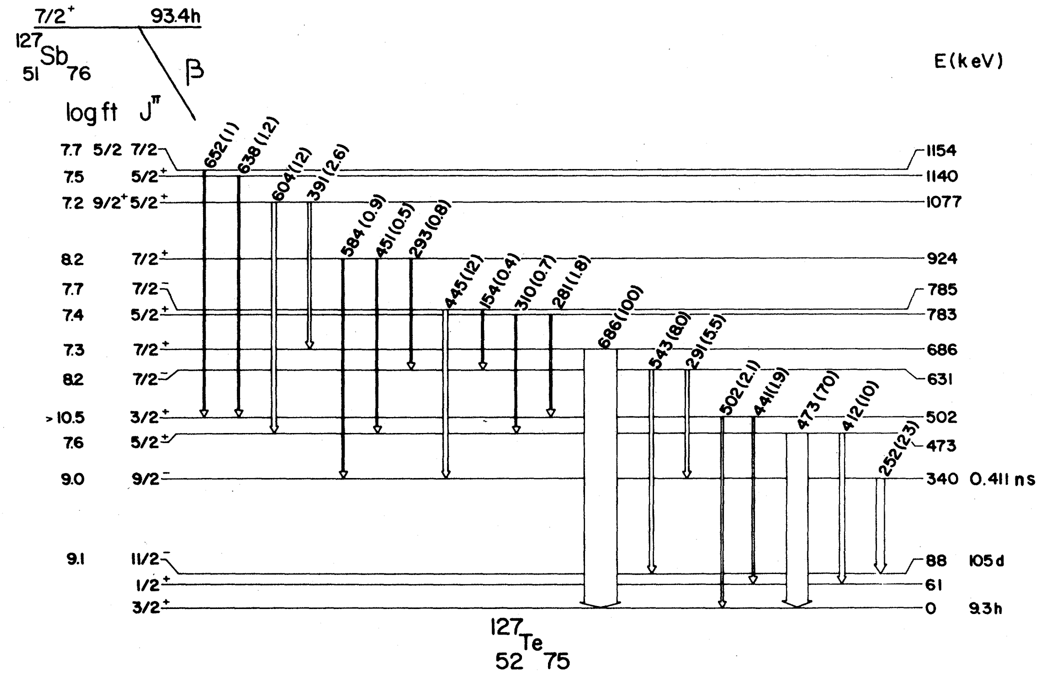

FIG. 4. Partial decay scheme of ^{127}Sb to the levels in ^{127}Te.

has been normalized to unity in each case. Experimental points are shown with respective error bars, and the solid curve is the least square fit of the experimental data to the function

$$W(\theta)=1+A_{22}P_2(\cos\theta)+A_{44}P_4(\cos\theta) .$$

The multipole mixing ratios for the γ transitions together with the spin sequences considered most consistent with the observed directional correlation data, the decay properties, and the results of other studies, are presented in Table II. The mixing ratios were determined by the usual χ^2 analysis as a function of δ and the results are compared with those obtained by Krane and Steyert[22] and Soares *et al.*[9] A partial energy level scheme of ^{127}Te taken from the results of Ragaini *et al.*[3] is shown in Fig. 4. Only γ transitions of interest in this study are shown. The spin and parity assignments consistent with the present results and other available data are included in this figure.

TABLE III. Values of $\omega\tau$ for the 340 keV state of ^{127}Te in Te(Ni) alloy.

	NaI(Tl)-NaI(Tl)	Ge(Li)-NaI(Tl)
$\omega\tau(225°)$	-0.111 ± 0.053	-0.110 ± 0.040
$\omega\tau(135°)$	$+0.131\pm0.016$	$+0.106\pm0.021$
$\lvert\mathrm{av}(\omega\tau)\rvert$	0.114 ± 0.018	
τ (ps)	593 ± 24[a]	
B_{eff} (kG)	190 ± 10[b]	
g	-0.218 ± 0.033	
	-0.214 ± 0.014[a]	

[a]Reference 9.
[b]Reference 28. The hyperfine field value (195±10 kG) corrected for the magnetization of Ni at room temperature (−10 kG) as well as for the external polarizing field (+5 kG).

The results of the g-factor measurements for the 340 keV state are summarized in Table III. Error in the g factor includes the statistical error as well as the errors in lifetime[9] and the hyperfine field.[28]

Spins and parities of the ground state, the first excited state at 61 keV, and the isomeric state at 88 keV in ^{127}Te are fairly well established as $\frac{3}{2}^+$, $\frac{1}{2}^+$, and $\frac{11}{2}^-$, respectively, from the reaction work[10–12,14] as well as the decay studies.[3] The spin and parity of the individual levels and the results of present directional correlation measurements are discussed below.

A. The 340 keV level

This level has a $\frac{9}{2}^-$ assignment established from the decay studies,[3] odd mass Te systematics, and the nuclear orientation work.[22] Three gamma cascades 584-252, 455-252, and 291-252 keV involving this state as the intermediate level have been measured in the present study. The spin and parity of the 924 keV level is known to be $\frac{7}{2}^+$ from decay studies and the reaction work,[10,11] and the present angular correlation result of the 584-252 keV cascade is quite consistent with the $\frac{7}{2}^+$-$\frac{9}{2}^-$ $\frac{11}{2}^-$ sequence. As will be seen later, the results of the 293-543 and 451-473 keV cascade also clearly indicate a $\frac{7}{2}$ spin for the 924 keV level. Assuming the 584 keV transition as $E1$ [correspondingly similar 321 keV transition in ^{125}Te is mostly $E1$ (Ref. 29)], the mixing ratio of the 252 keV transition is obtained as $\delta(252)=-2.55\pm0.20$ or -0.31 ± 0.03.

B. The 473 keV level

This level is known to have a $\frac{5}{2}^+$ spin and parity assignment.[3,10–12,14,22] Present angular correlation results of the 604-412 and 604-473 keV gamma cascades are also consistent with the $\frac{5}{2}$ spin for the 473 keV level but permit $\frac{5}{2}$ or $\frac{9}{2}$ spin values for the 1077 keV level. The 604-412 keV cascade was measured using two Ge(Li) detectors with the gate setting at 604 keV photopeak in order to avoid the interference from the 667 keV γ ray. The A_{22} value from the present measurement gives $\delta(604)=0.14\pm0.08$ or -2.32 ± 0.50 for the $\frac{5}{2}$-$\frac{5}{2}$-$\frac{1}{2}$ spin sequence and pure quadrupole for the $\frac{9}{2}$-$\frac{5}{2}$-$\frac{1}{2}$ sequence. Since A_{44} was not measured in this case, it is not possible to eliminate either of the δ values in the first sequence. The sign of $\delta(604)=+1.65\pm0.25$ as quoted in Ref. 22 appears to be in error since the sign convention in this work is the same as used in the present study. Signs of several other mixing ratios quoted in Ref. 22 and determined in the present work are in complete agreement. Note especially that the signs of δ values for the 391 keV transition determined from the 391-686 keV cascade correlation agree with those determined in Ref. 22. The 604-473 keV cascade was measured both from the two Ge(Li) detector setup and the Ge(Li)-NaI(Tl) setup and the A_{22} values from both measurements are in agreement. The above values of the mixing ratios of the 604 keV transition were used in calculating the $\delta(473)$; the results are -0.10 ± 0.01 or -2.50 ± 0.05.

C. The 502 keV level

A large logft value of ≥ 10.5 in the beta decay,[3] and the results of the (d,p) (Refs. 10 and 11) reaction as well as the systematics[1] of similar levels in ^{125}Te and ^{129}Te strongly suggest a $\frac{3}{2}^+$ assignment for the 502 keV level. The present results of the 281-502, 638-502, 652-502, and 281-441 keV cascades are consistent with a $\frac{3}{2}$ or $\frac{5}{2}$ assignment for the 502 keV level, but a somewhat better fit was obtained for the $\frac{3}{2}$ value. With the $\frac{3}{2}$ spin value for this level and $I=\frac{5}{2}$ for the 783, 1140, and 1154 keV levels (spin value derived from the earlier studies and in agreement with the present results as will be seen later), we have analyzed the results of 281-502, 638-502, and 652-502 keV cascades in the following way: In a computer search program the A_{kk} coefficients for the three cascades were compared with the theoretical coefficients for all possible combinations of (1,2) mixing parameter δ for all four gamma transitions involved, and for the errors in the coefficients which are given in Table I we found only one region of agreement where a common mixing ratio was obtained for the 502 keV transition in all the three cascades analyzed. The calculated mixing ratios for the 281, 502, 638, and 652 keV transitions are given in Table II.

D. The 631 keV level

Beta decay studies[3] assigned this level as $\frac{9}{2}^-$ or $\frac{11}{2}^-$. However, the results of nuclear orientation study[22] and the angular correlation measurements[9] do not agree with this assignment and a $\frac{7}{2}^-$ value was suggested. Nuclear Data Sheets[21] also propose a $(\frac{7}{2}^-)$ assignment for the 631 keV level. The A_{22} coefficient for the 291-252 keV cascade both from the Ge(Li)-Ge(Li) and Ge(Li)-NaI(Tl) detector measurements in the present study agree with each other but differ from the value obtained by Soares *et al.*[9] The present results permit both $\frac{7}{2}$ and $\frac{11}{2}$ spin values for the 631 keV level. Very poor agreement was obtained for the $\frac{9}{2}$ value. Furthermore, the $\frac{11}{2}$ spin value was ruled out from the combined results of the 293-543 and 154-543 keV cascades. With the $\frac{7}{2}$ assignment we obtained $\delta(291)=0.40\pm0.03$ or 1.42 ± 0.50. The larger δ value was discarded because of a poor fit to the data.

E. The 686 keV level

Based on the beta decay studies[3] this level was assigned a spin and parity of $\frac{7}{2}^+$. The results of nuclear orientation study[22] permit $\frac{5}{2}^+$ or $\frac{7}{2}^+$, but the authors adopted the $\frac{7}{2}^+$ value considering the gamma branching intensity. The present angular correlation of the 391-686 keV cascade is quite consistent with the $\frac{7}{2}$ assignment. A poor fit was obtained for the $\frac{5}{2}$ value for the 686 keV level. However, the data permit both $\frac{5}{2}$ and $\frac{9}{2}$ spin values for the 1077 keV level. The mixing ratios for the 391 keV transition are given in Table II. The solutions corresponding to the larger $|\delta|$ values require a large negative A_{44} in disagreement with the experimental value and are not considered.

F. The 783 keV level

This level has a well-established spin and parity value of $\frac{5}{2}^+$ from all the previous studies.[3,10–12] Three gamma cascades 281-502, 281-441, and 310-473 keV measured in the present study are quite consistent with the $\frac{5}{2}^+$ assignment for this level. The mixing ratios of 281, 310, and 441 keV transitions were obtained using the already known values of $\delta(473)$ and $\delta(502)$ (see Table II).

G. The 785 keV level

The decay studies[3] assigned the spin of $\frac{7}{2}$ or $\frac{9}{2}$ for this level. The results of nuclear orientation studies[22] determined the spin and parity as $\frac{9}{2}^-$, while the angular correlation results of Soares *et al.*[9] indicated a $\frac{7}{2}$ assignment. The present results of the 445-252 keV cascade were analyzed for the $\frac{7}{2}$-$\frac{9}{2}$-$\frac{11}{2}$ and $\frac{9}{2}$-$\frac{9}{2}$-$\frac{11}{2}$ spin sequences. Figure 5 shows the results of χ^2 analysis for the two-spin sequence as a function of the mixing ratio of the 445 keV transition. The quantity χ^2 is given by

$$\chi^2=\sum_{i=1}^{4}|[W(\theta)_i^{expt}-W(\theta)_i^{\rm th}]/\epsilon_i|^2\,,$$

where $W(\theta)_i^{\rm exp}$ is the experimental correlation at each of the four angles and ϵ_i is the error on $W(\theta)_i^{\rm expt}$. A clearly better fit was obtained for the first sequence thereby establishing the spin of the 785 keV level as $\frac{7}{2}$. The mixing ratio of the 445 keV transition is obtained as -1.16 ± 0.30 using the mixing ratio of the 252 keV transition as given in Table II. It should be mentioned that the result of the 154-543 keV cascade is also in agreement with the $\frac{7}{2}$ spin assignment for the 785 keV level, and when combined with the result of the 293-543 keV cascade it eliminates the $\frac{11}{2}$ spin possibility for the 631 keV level.

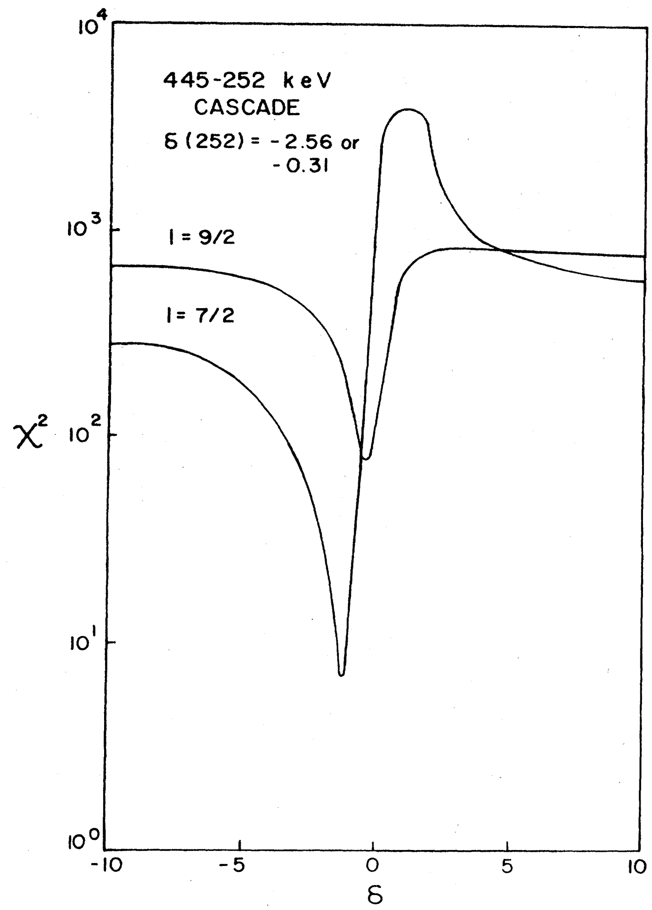

FIG. 5. Comparison of the experimental and calculated values for the angular correlation of the 445-252 keV gamma cascade. The curves are for the two spins of the 785 keV level.

H. The 924 keV level

The decay studies[3] and the reaction work[10–12,14] strongly suggest a $\frac{7}{2}^+$ assignment for this level. The nuclear orientation results,[22] although consistent with this assignment, do not rule out other spin values. Combined results of the 584-252, 451-473, and 293-543 keV cascades indicate clearly a $\frac{7}{2}$ spin value for this level. The result of the 293-543 keV cascade rules out the $\frac{5}{2}^+$ assignment as the 293 keV transition then would have an unreasonably large $M2$ admixture in the $E1$ transition. Similarly, the result of the 584-252 keV cascade shows that a $\frac{5}{2}$ spin for the 924 keV level results in either pure $M1$ or mostly $E2$ 252 keV transition in disagreement with the findings of both Krane and Steyert[22] and Soares *et al.*[9]

I. The 1077 keV level

The results of the decay studies[3] and the nuclear orientation work[22] limit the spin and parity of this level as $\frac{5}{2}^+$ or $\frac{9}{2}^+$. Three gamma cascades 391-686, 604-473, and 604-412 keV were measured in the present study. In the case of the 391-686 keV cascade a poor fit to the data was obtained for the $\frac{7}{2}$ spin assignment of the 1077 keV level. The spin values of $\frac{5}{2}$ or $\frac{9}{2}$ are permitted by the results of all the three cascades.

J. The 1140 and 1154 keV levels

The spin and parity of the 1140 keV level is known to be $\frac{5}{2}^+$ from previous studies.[3,10–12,14,22] The 1154 keV level was assigned as $\frac{5}{2}$ or $\frac{7}{2}$ from the decay studies[3] with no indication of parity. The angular correlation results of the 638-502 and 652-502 keV cascades from the present study do not add further information on the spins of the above levels except that they are not in disagreement with these assignments.

K. The g factor of the 340 keV level

The g factor of the 340 keV level has been previously determined by Soares *et al.*[9] by measuring the integral perturbed angular correlation of the 445-252 and 291-252 keV cascades in the hyperfine magnetic field of Te nuclei in Fe ($H_{\rm hf}=681$ kG). A similar measurement was reported by the group at the University of Leuven (private communication to Soares *et al.*[9]) in which the integral rotation was measured by the method of fixed angle (135°) and reverse field. There is a considerable difference in the value of $\omega\tau$ in the two experiments. Since the large hyperfine field of Te might cause attenuation of the angular correlation affecting principally the later experiment, we decided to remeasure this g factor using the smaller hyperfine field of Te in Ni ($H_{\rm hf}\approx 195$ kG). The results presented in Table III are in excellent agreement with those of Soares *et al.*

IV. DISCUSSION

Attempts to understand the ^{127}Te level scheme have achieved moderate success. According to the shell model, the lowest energy orbitals available to the odd neutron in ^{127}Te are $2d_{3/2}$, $3s_{1/2}$,and $1h_{11/2}$ in agreement with the experimental observation of the ground state as $\frac{3}{2}^+$ and first two excited states as $\frac{1}{2}^+$ and $\frac{11}{2}^-$. The higher energy positive and negative parity levels are thought to arise mainly from the quasiparticle-phonon coupling such as $2_1^+\otimes d_{3/2}$, $2_1^+\otimes s_{1/2}$, and $2_1^+\otimes h_{11/2}$. By considering a pairing plus quadrupole force interaction with the spherical core, Kisslinger and Sorensen[30] (KS) were able to obtain a spectrum of the excited states of ^{127}Te in fair agreement with the observed level scheme.

A significant failure of the KS (Ref. 30) model was, however, the lack of a predicted $\frac{9}{2}^-$ state which appears at 340 keV in ^{127}Te. Such states also occur at relatively low energy in ^{125}Te (321 keV) (Ref. 1) and ^{129}Te (464 keV).[2] The lowest single particle $\frac{9}{2}^-$ state is expected at about 1 MeV in the model. A later calculation by Kisslinger[4] showed that a coupling of three quasiparticles to $j-1$, where j is the quasiparticle orbital spin, would lead to a level whose energy would not be too much higher than that of the single quasiparticle state j itself. The properties of such an "intruder" state are (i) a vanishing $M1$ transition probability between the $(j)^3_{j-1}$ and $(j)^1_j$ states, because the two-quasiparticle $M1$ operator vanishes if the states are pure, and (ii) the g factor of the three-

TABLE IV. $B(E2)$ values for $\frac{9}{2}^- \rightarrow \frac{11}{2}^-$ transitions and the g factors of the $\frac{9}{2}^-$ states in ^{125,127}Te compared to theoretical predictions.

	$B(E2)$ (e^2 10^{-50} cm^4)		$g(\frac{9}{2}^-)$	
Nucleus	Expt.	Calc. (Ref. 33)	Expt.	Calc. (Ref. 33)
^{125}Te	11.5(5) (Ref. 34)	10.5	−0.202(16) (Ref. 6) −0.204(7) (Ref. 5)	−0.21
^{127}Te	11.8(6)[a]	8.2	−0.214(14) (Ref. 9) −0.218(33)[a]	−0.22

[a]This work: Value calculated using $\delta(252) = -2.55 \pm 0.20$ and the half-life of the 341 keV level $T_{1/2} = 411 \pm 17$ ps (Ref. 9).

quasiparticle state $J-1$ should be equal to that of the single particle state with spin j.

Whereas the measured g factors of the 340 keV ($\frac{9}{2}^-$) state and the 88 keV ($\frac{11}{2}^-$) state[31] in ^{127}Te as well as the 321 keV ($\frac{9}{2}^-$) and the 145 keV ($\frac{11}{2}^-$) states in ^{125}Te (Refs. 5–8) are in reasonable agreement with the model predictions, the $E2$ multipole component in the $\frac{9}{2}^- \rightarrow \frac{11}{2}^-$ transitions does not seem to dominate as strongly as expected. The nonzero $M1$ transition probability can be explained[32] by assuming the photon admixture of the $\frac{11}{2}^-$ state as well as the single particle admixture of the $\frac{9}{2}^-$ state. However, such mixing is expected to be small and $M1$ transitions should still be observed with much reduced intensity compared to the single particle estimates. The retardation factors for the $M1$ transitions are 250 and 2300 W.u., respectively, for the 177 and 252 keV transitions in ^{125}Te and ^{127}Te. The results of the g factors and the mixing ratios $\delta(E2/M1)$ thus support to a large extent the interpretation of the $\frac{9}{2}^-$ states in ^{125}Te and ^{127}Te as the three-quasiparticle states. More recently, Kuriyama *et al.*,[33] in somewhat more refined calculations using the dressed three-quasiparticle modes, have also predicted the g factor of the $\frac{9}{2}^-$ state and a strongly enhanced $E2$ transition probability for the $\frac{9}{2}^- \rightarrow \frac{11}{2}^-$ transition in excellent agreement with the experiment. Experimental results are compared with the theoretical predictions in Table IV for the ^{125,127}Te nuclei.

Although the spin and parity assignments to a number of levels in ^{127}Te are known from previous studies, the present results confirm and establish more conclusively these assignments. The spin of the 785 keV has been established as $\frac{7}{2}$. In addition, the γ-ray multipole mixing ratios for a number of transitions have been determined, some of them confirming the previous results. An important result of the present study is the further experimental confirmation of the three-quasiparticle interpretation of the 340 keV ($\frac{9}{2}^-$) state given by Kisslinger.[4]

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