The ratios which appear in column C were computed using new calculations of the internal-conversion coefficients presently in progress at Purdue University.[11,12] These calculations include the effects of finite nuclear size, electron penetration into the nuclear region, and Coulomb screening. In column D the ratios of column C have been corrected for the N-shell contribution by arbitrarily assuming the total N-shell conversion coefficients to be one third as large as the total M-shell coefficients of the new calculation.

The $K/(L+M+\cdots)$ ratio measured in the present investigation is 4.27 ± 0.13. Comparison of this ratio with the values given in column A indicates that the transition is predominantly $E2$ with a small admixture of $M3$. This conclusion is in agreement with previous e^{-}-γ and γ-γ directional correlation measurements.[6,7] When the experimental result is compared to the values of columns B and C, the transition appears to be pure $M3$ while comparison with column D implies an almost pure $M3$ transition with a small possible admixture of $E2$. These latter comparisons are not inconsistent with the results of the forementioned directional correlations and a spin and parity assignment of $\frac{1}{2}^{+}$ for the 436-keV level is implied which is in agreement with shell-model predictions.

TABLE I. Theoretical $K/(L+M)$ internal-conversion ratios for the 355-keV transition in ^{133}Cs.

Multipolarity	A	B	C	D
$M1$	5.45	6.40	6.57	6.22
$E2$	4.31	4.80	5.29	5.07
$M3$	3.73	4.33	4.49	4.24

It should be noted that in any case the present measurement does not compare favorably with predicted $M1$ ratios. The possibility of the transition being 70% $M1$ as suggested by Subba Rao[4] is not supported by this experiment.

ACKNOWLEDGMENTS

The authors would like to thank Professor R. M. Steffen for making the new theoretical ICC values available to them.

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Decay Schemes of the ^{119}Te Isomers*

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The decays of the 4.7-day ^{119m}Te and the 16-h ^{119g}Te have been investigated with the use of Ge(Li) and NaI(Tl) γ-ray detectors, and Si(Li) electron detectors. Coincidence relationships among the γ rays were determined in γ-γ coincidence experiments. It was established that the decay of the 4.7-day ^{119m}Te populates levels at 270.6, 1048.3, 1212.7, 1249.6, 1365.8, 1406.7, 2129.3, 2226.0, 2277.8, 2283.6, and 2360.4 keV in ^{119}Sb; and the decay of the 16-h ^{119g}Te populates levels at 270.6, 644.3, 700.0, 1338.5, 1413.2, 1487.4, 1749.5, and 1821.0 keV in ^{119}Sb. Many spin assignments have been made from present and previously reported internal-conversion-electron data, from logft values, and from γ-γ directional correlation measurements. Trends of the low-lying levels of odd-A antimony isotopes from mass 119 to 125 are discussed and compared with the pairing-plus-quadrupole model for nuclei.

I. INTRODUCTION

In the last few years the low-lying levels of even Z, odd-N nuclides in the neutron-shell region $50<N<82$ have been extensively studied with the use of (d,p) and (d,t) nuclear reactions.[1–3] The results have been discussed in terms of nuclear models, particularly the treatment by Kisslinger and Sorensen[4] (hereafter designated KS). Spectroscopic information about the odd-Z, even-N nuclides is considerably more difficult

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to obtain. The levels of odd-A antimony isotopes have been recently studied from decay of tellurium and tin isotopes,[5–8] and recently Bassani *et al.*[9] have studied the lowest four states of the odd-A antimony isotopes 113 to 125 by the (^{3}He,d) reaction on Sn targets. The study of the β and γ decay of odd-A neutron-deficient tellurium isotopes to levels of the daughter antimony isotopes offers excellent possibilities for the study of the trends of 51-proton levels as a function of (even) neutron number 64 to 68. A useful feature in ^{119}Te is that it has two long-lived isomers, $11/2^-$ and $\frac{1}{2}^+$, which undergo electron capture to populate a wide variety of spin states in ^{119}Sb.

The work reported here concerns the decay of the 4.7-day ^{119m}Te and the 16-hr ^{119g}Te. The decay of these isomers has been the subject of several previous works,[10–14] the most definite being the NaI(Tl)-scintillation spectroscopic study by Kantele and Fink[13] and the conversion electron work by Svedberg and Andersson.[14]

The Ge(Li) work by Berzins and Kelly[15] was communicated to us during the preparation of this manuscript. The last-named authors suggest levels at 644.1, 699.6, 1328, 1338.7, 1412.8, 1487, 1749.1, and 1820 keV. populated in the decay of the 16-hr ^{119g}Te; and at 270.3, 1048.1, 1212.6, 1249, 1365.8, 1407, 2129, 2225, 2278, 2283, and 2360 keV populated in the decay of the 4.7-day ^{119m}Te. In their scheme, Berzins and Kelly have not made definite spin and parity assignments for most of the levels.

Recently, Singru *et al.*[16] reported on the decay of ^{119m}Te and assigned levels at 270, 1048, 1212, 1365, 2281, 2292, 2349, and 2365 keV, not in good agreement with the work of Berzins and Kelly.[15]

In this work, with additional measurements of internal conversion coefficients and directional correlations between coincident γ rays, we were able to make more definite spin and parity assignments. These investigations were performed independently at Massachusetts Institute of Technology (MIT) and at Washington University (WU), and are reported jointly.

II. EXPERIMENTAL PROCEDURES

A. Production of the ^{119}Te Activities

The ^{119m,g}Te samples were produced by the (α,n) reaction at the MIT and WU cyclotrons on 10–50 mg samples of tin oxide enriched to $>95.6\%$ in ^{116}Sn. The maximum ^{4}He-ion energy was kept below 18 MeV to avoid the (α,$2n$) reaction. In the majority of cases, the tellurium samples were purified radiochemically. Small amounts of the 17-day ^{121g}Te were produced and the 506- and 575-keV γ rays associated with its decay were seen in old samples. No other interfering activities were observed.

The following radiochemical purification procedures were employed at WU. The SnO_2 samples were sublimed with tenfold weight of NH_4I. The product was dissolved in 6M HCl solution containing Te(IV) +Te(VI) mixed carriers and Sb(III) hold-back carrier. Te(IV) and Sb(III) were oxidized with NaOCl solution, and the tellurium was reduced to elemental state with hydrazinium chloride under a stream of SO_2 gas. The elemental Te was centrifuged, dissolved, and the purification repeated.

Carrier-free Te samples for electron counting were prepared at WU by carrying out the Te purification procedure using Se as nonisotopic carrier. The selenium was removed by volatilization of the bromide. The tellurium activity was finally electroplated on platinum.

At MIT, thin ^{119m,g}Te samples were produced by fusing the bombarded SnO_2 with sodium carbonate and sulfur powder. The fused material was dissolved in hot water, Te carrier was added, and Te was precipitated from 6N HCl solution. Te was then dissolved with conc. HNO_3 and aliquots taken for sources. Thin sources were prepared by evaporation of small parts of the solution on glass backing.

B. Counting Equipment

For γ-ray counting, both Ge(Li) and NaI(Tl) detectors were employed. The Ge(Li) detectors at MIT had active volumes of 1.2 and 5.0 cm^3, with full widths at half-maximum (FWHM) 2.3 and 3.5 keV for the γ rays from a ^{137}Cs source, respectively. The Ge(Li) detector at WU had an active volume of 1.2 cm^3 and the FWHM was 5.0 keV for the γ rays from a ^{137}Cs source. The NaI(Tl) detectors used were integrally mounted 7.6×7.6 cm crystals.

In the γ-γ coincidence measurements a Ge(Li) and a NaI(Tl) detector were used. The coincidence resolving times employed were typically 50 to 100 nsec.

For pulse-height analysis at MIT a 4096-channel pulse-height analyzer with two 1024-channel analog-to-digital converters (ADC) was used both in singles and coincidence measurements. In a few measurements, a 2048-channel ADC was used. The analyzer was equipped with a digital gate unit, which allowed one to obtain simultaneously eight 512-channel Ge(Li) spectra

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coincident with eight different areas of the spectrum from the NaI(Tl) detector.

At WU, a 4096-channel pulse-height analyzer with two 4096-channel ADC's was used. The analyzer was equipped with a buffer-tape and a read-search control unit, coupled with a magnetic-tape drive. Two-parameter coincidence spectra were recorded in a Ge(Li) ×NaI(Tl) configuration of 1024×256 channels. In order to improve statistics, the two-parameter spectra were integrated to ~40 keV per window-channel on the NaI axis and ~2 keV on the Ge(Li) axis, with the use of the read-search unit.

Conversion-electron spectra were obtained with Si(Li) detectors having areas 0.5 and 2.0 cm^2 at MIT, and 2 cm^2 at WU, and depletion depths 0.5, 2.0 mm, and 3.0 mm, respectively. The energies and intensities of the γ rays were determined by techniques described in Ref. 17.

The fraction of the β^+ decays was determined by measuring the area of the annihilation peak relative to that of γ-ray photopeaks. A ^{22}Na source was used for determination of the relative efficiencies.

The K internal-conversion coefficients α_K were measured using the values[18] for the 279, 662, and 570, 1064 and 1771 keV transitions from sources of ^{203}Hg, ^{137}Cs, and ^{207}Bi as internal standards. The areas of the peaks were used in the determination of the relative intensities.

Directional-correlation studies between coincident cascading γ rays were measured at WU. In these experiments two 7.6-×7.6-cm NaI(Tl) detectors were used and the ratio of the coincidence rate to the singles rate in the stationary detector was determined for events occurring in windows set on the photopeaks. Corrections for chance rate, background, higher-energy components, and finite solid angle were employed.[19]

III. RESULTS

A typical singles spectrum of 16-h ^{119g}Te is shown in Figs. 1 and 2. The γ rays associated with the 4.7-day ^{119m}Te in this energy region are also present. In addition to the well known 644.3-, 700.0-, and 1749.5-keV γ rays, γ rays at 373.7, 787.3, 843.2, 1105.5, 1120.9, 1177.2, 1338.5, 1413.2 keV and possibly at 769.4 keV are seen to be associated with the decay of ^{119g}Te.

The lower- and higher-energy parts of the γ-ray spectrum of 4.7-day ^{119m}Te are shown in Figs. 3 and 4, respectively. These were obtained at a later time, when most of the 16-hr ^{119g}Te had decayed. The assignment of the various peaks to the two isomers was based on decay measurements of photopeak areas and the half-lives obtained were quite close to 16 h and 4.7 days for the ground and metastable states. In addition to the γ rays at 153.0, 163.9, 270.6, 912.3, 942.1, 1048.3, 1096.0, 1136.0, 1212.7, 1365.8, and 2089.7 keV, which correspond to previously reported [13,14] γ rays, γ rays at 115.5, 872.0, 976.4, 979.0, 1012.9, 1081.0, 1249.6, 1311.0, and 2013.0 keV are seen to be associated with the decay of ^{119m}Te. The energies, the relative intensities of the γ rays determined, are shown in Tables I and II. The intensities listed were obtained as averages from several independent spectra. Figure 5 shows a conversion-electron spectrum of ^{119}Te obtained with the 3-mm-deep Si(Li) detector. In Tables I and II we list our measured values for K-shell conversion coefficients α_K for many transitions in the decay of ^{119}Te isomers. We also list α_K values for ^{119m}Te transitions which have been determined by using conversion-electron intensities from Ref. 14 and γ-ray intensities from this work. Determinations have been based on the α_K value of 0.038±0.004 obtained in this work for the 271-keV transition with the use of internal standards.

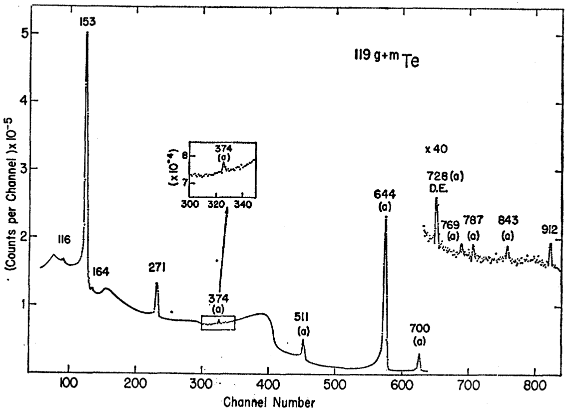

FIG. 1. Low-energy part of singles spectrum of γ rays emitted from $^{119m+g}$Te. The radiations from ^{119g}Te are labeled (a); all others come from ^{119m}Te. The numbers above the peaks correspond to the γ-ray energies in keV.

Coincidence spectra were taken (i) with the analyzer

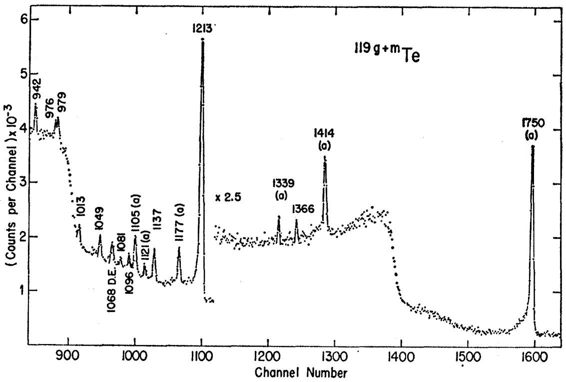

FIG. 2. The higher-energy part of the spectrum from $^{119m+g}$Te, obtained from the same measurement as in Fig. 1.

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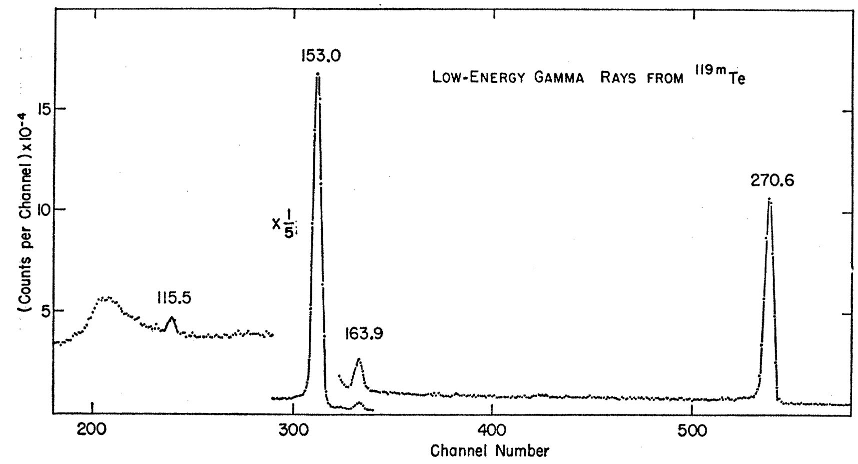

FIG. 3. A singles spectrum showing the low-energy γ rays emitted from ^{119m}Te, after the 16-h ^{119g}Te has decayed away.

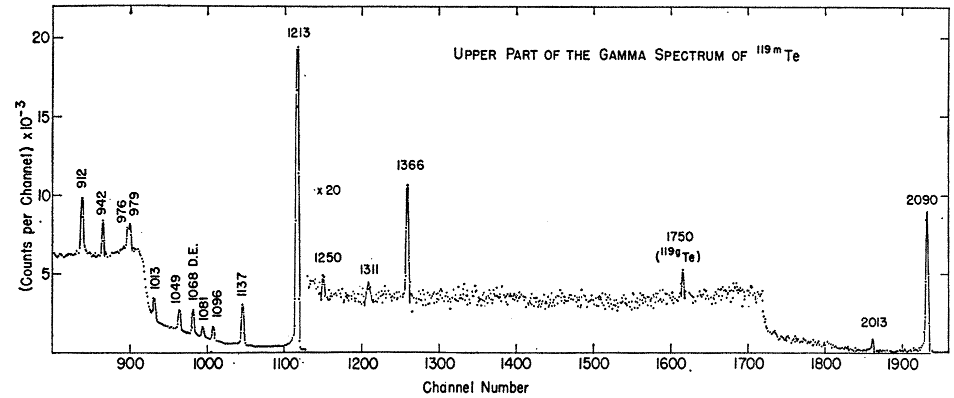

FIG. 4. The higher-energy part of the spectrum from ^{119m}Te after the 16-h ^{119g}Te had practically decayed away.

gated on by pulses from a NaI(Tl) detector and corresponding to the various regions of interest and (ii) with the analyzer operated in a two-parameter configuration NaI(Tl)-Ge(Li), and the consecutive spectra with Ge(Li) for every 40 keV of the NaI(Tl) axis were analyzed. The coincidence spectra presented here correspond to sufficiently large windows to minimize the number of illustrations needed to present the evidence necessary for the construction of the decay scheme. In Figs. 6–8 are shown the spectra taken with the Ge(Li) detector in coincidence with the indicated energy regions in the NaI(Tl) spectra.

In order to obtain more information on the 1213- and 1366-keV levels, we have measured the directional correlation of the γ-γ cascade 153–1213 keV. In Fig. 9 is shown the correlation obtained after correction for

TABLE I. Relative intensities of γ rays following 16-h ^{119g}Te decay. γ-ray singles and conversion electron data.[a]

γ-ray energies (keV)			Relative γ-ray intensities			Measured α_K($x10^3$)			Multi-polarity
MIT	WU	Adopted	MIT	WU	Adopted	MIT	WU	Adopted	
270.6±0.1[b]	270.6±0.1[b]	270.6	0.2	···	0.2	···	···	···	···
373.7±0.9	···	373.7	0.22±0.06	···	0.2	···	···	···	···
643.9±0.5	644.8±0.6	644.3	100	100	100	3.6±0.4	3.6±0.4	3.6±0.4	*M*1, *E*2
699.7±0.5	700.6±0.6	700.0	11.3±0.8	11.8±0.3	11.5	3.0±0.4	3.6±0.5	3.3±0.4	*M*1, *E*2
787.3±0.8	787±5[c]	787.3	0.18±0.04	d	0.2	···	···	···	···
843.2±0.8	845±3[c]	843.2	0.32±0.06	d	0.3	···	···	···	···
1105.4±0.7	1105.6±1.0	1105.5	0.90±0.08	0.56±0.12	0.8	···	···	···	···
1120.9±0.8	···	1120.9	0.21±0.05	d	0.2	···	···	···	···
1177.2±0.8	1177.2±0.7	1177.2	0.91±0.08	1.1±0.4	1.0	···	···	···	···
1338.8±1.0	1338.2±1.0	1338.5	0.21±0.05	0.3±0.2	0.2	···	···	···	···
1413.7±1.0	1412.7±0.9	1413.2	1.0±0.1	1.2±0.1	1.1	···	···	···	···
1749.5±1.0	1749.1±1.0	1749.3	4.2±0.4	4.7±0.2	4.4	···	0.40±0.08	0.40±0.08	*M*1, *E*2

[a] Data obtained at MIT and WU are listed separately.
[b] From Ref. 14.
[c] Seen in coincidence spectra.
[d] Peak seen in coincidence, but not large enough to give a meaningful intensity.

TABLE II. Relative intensities of γ ray following 4.7-day ^{119m}Te decay. γ-ray singles and conversion-electron data.[a]

γ-ray energies (keV)			Relative γ-ray intensities			$\alpha_K \times 10^3$				Multi-polarity
MIT	WU	Adopted	MIT	WU	Adopted	Ref. 14[e]	MIT	WU	Adopted	
115.5±0.6	115±1[c]	115.5	0.7±0.1	1.6±0.8[e]	0.7	···	···	···	···	···
153.0±0.1[b]	153.0±0.1[b]	153.0	99±5	···	99	45±5	46±4	···	46±4	*E*1
163.9±0.1[b]	163.9±0.1[b]	163.9	1.7±0.2	<2.7	1.7	140±60	···	···	140±60	*M*1, *E*2
270.6±0.1[b]	270.5±0.3	270.6	39±2	39±5	39	38±4	38±4	38±5	38±4	*M*1, *E*2
872.0±1.0	···	872.0	0.4±0.1	···	0.4	···	···	···	···	···
912.4±0.7	912.1±1.0	912.3	8.7±1.0	12.8±1.0	10.2	1.3±0.5	···	1.5±0.4	1.4±0.3	*M*1, *E*2
942.1±0.7	942.1±1.0	942.1	7.0±0.5	5.9±0.5	6.5	1.3±0.5	···	2.1±0.6	1.7±0.5	*M*1, *E*2
976.4±1.0	977±1.5[d]	976.4	3.9±0.5	10.0±0.1[d]	3.9	1.0±0.4[f]	···	···	···	···
979.0±1.0		979.0	4.5±0.5		4.5		···	···	···	···
1012.8±0.8	1013±2[c]	1012.9	3.9±0.4	1.3[c]	3.9	1.4±1.0	···	···	1.4±1.0	*M*1, *E*2
1048.5±0.7	1048.0±1.0	1048.3	4.8±0.4	4.6±0.4	4.7	0.9±0.7	···	0.9±0.6	0.9±0.7	*M*1, *E*2
1081.0±0.7	1080.9±1.0	1081.0	2.5±0.3	1.9±0.6	2.3	···	···	0.6±0.3	0.6±0.3	*E*1
1095.7±0.7	1096.3±1.0	1096.0	3.2±0.3	3.6±0.4	3.4	2.7±1.0	···	3.6±0.4	3.3±0.5	*M*2
1136.6±0.7	1135.3±1.0	1136.0	11.3±0.8	12.1±0.6	11.7	0.45±0.30	···	0.53±0.08	0.53±0.08	*E*1
1212.7±0.7	1212.6±1.0	1212.7	100	100	100	0.65±0.06	···	0.69±0.03	0.69±0.03	*M*1, *E*2
1249.6±0.8	···	1249.6	0.20+0.05	···	0.2	···	···	···	···	···
1311.0±1.0	···	1311.0	0.2±0.1	···	0.2	···	···	···	···	···
1365.5±0.8	1366.4±1.0	1365.8	1.9±0.3	2.1±0.3	2.0	···	···	0.81±0.30	0.81±0.30	*E*3
2013.5±1.5	2010±2	2013.0	0.37±0.05	0.70±0.2	0.5	···	···	···	···	···
2089.5±1.0	2091.0±1.0	2089.7	5.6±0.5	6.2±0.6	5.9	···	···	···	···	···

[a] Data obtained at MIT and WU are listed separately.
[b] From Ref. 14.
[c] Obtained from coincidence measurements.
[d] Doublet, 2.5 keV increase in FWHM.
[e] Using conversion electron intensities from Ref. 14 and γ-ray intensities from this work.
[f] Average α_K for two transitions.

chance rate, background, higher-energy components, and finite solid angle. The coefficients A_{22} and A_{44} were obtained by least-squares fitting of the data points.

IV. CONSTRUCTION OF THE DECAY SCHEMES

In Fig. 10 we show the decay schemes for both ^{119}Te isomers based on the results presented above, and below we give arguments for the proposed schemes.

A. Decay of 4.7-day ^{119m}Te

The 1213-keV γ ray is in strong coincidence with the 153-keV γ ray, but it is not in coincidence with the 271-keV γ ray [Figs. 6(c) and (d)]. Either the 1213-keV or the 153-keV γ ray must feed the ground state directly because of the high intensity. The 271-keV does not directly feed any of the levels which de-excite by the latter two γ rays. Because of its high intensity, it must feed directly the ground state. The 271-keV γ ray

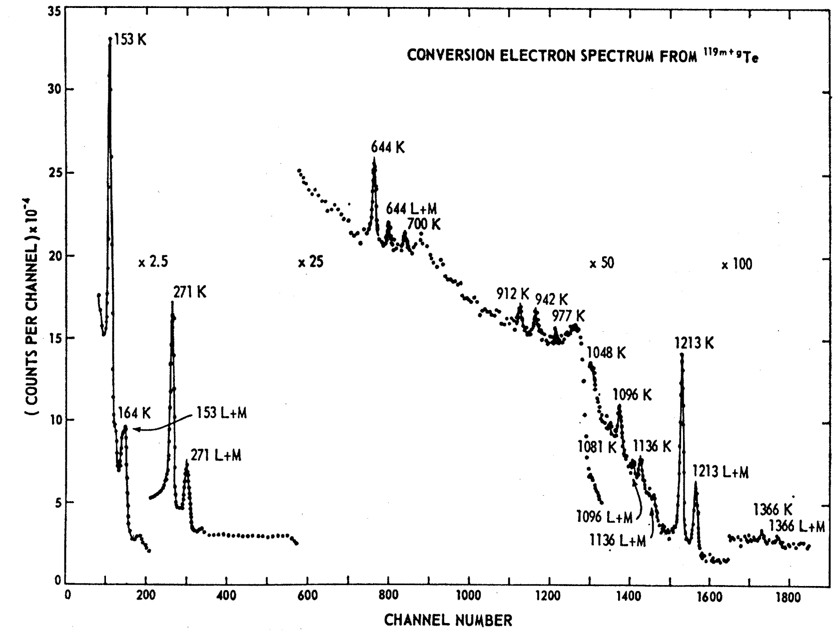

FIG. 5. A Si(Li) spectrum of the conversion electrons emitted from $^{119m+g}$Te. This is a rather late spectrum and only the most intense lines (644*K*, 644 *L*+*M*, and 700 *K*) from ^{119g}Te are seen. The *K* and *L*+*M* lines from the 1096, 1136, 1213, and 1366-keV transitions are clearly seen.

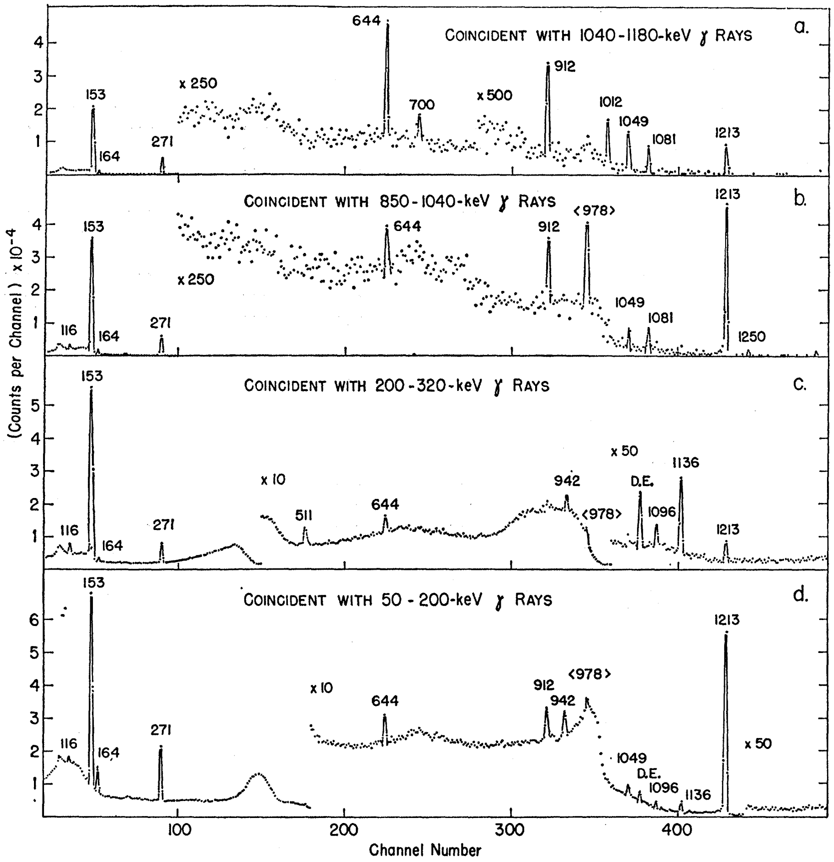

FIG. 6. γ-ray spectra of ^{119m}Te observed with Ge(Li) in coincidence with four different energy regions in the NaI(Tl) detector. The source contained some ^{119g}Te and the 744- and 700-keV γ-rays can be seen. The brackets indicate a doublet.

is in coincidence with the 942.1 keV γ ray. The sum 942.1+270.6 is exactly equal to 1212.7 keV the energy of the strong γ ray. The 153-keV γ ray cannot feed the ground state because the sum of the intensities of the γ rays in coincidence with it exceeds its own intensity. This establishes levels at 270.6, 1212.7, and 1365.8 keV.

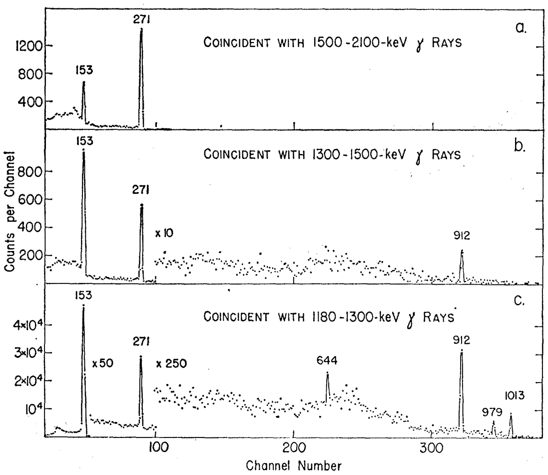

FIG. 7. γ-ray spectra of ^{119m}Te observed with Ge(Li) in coincidence with three different energy regions in the NaI(Tl) detector. These spectra and those of Fig. 6 were taken in one measurement.

The 1365.8 keV γ ray feeds the ground state and is coincident with the 912-keV γ ray. The latter γ ray is also in coincidence with the 153-keV γ ray, so that it can only feed the 1365.8 level and this establishes a level at 2277.8 keV. The 2090-keV γ ray is in coincidence with the 271-keV γ ray, thus establishing a level at 2360.3 keV. The 1213-keV γ ray is in coincidence with 153-, 912-, and 1013-keV γ rays.

The 1013-keV is not in coincidence with the 153-keV γ ray and this means that it must feed the 1212.7-keV level, thus establishing a level at 2226.0 keV. The 271-keV γ ray is seen to be in coincidence with the following γ rays: 164, 942, 1096, 1136, 2090, and the γ rays in the doublet 978 keV. The sum 270.6+1096.0 agrees, within experimental error (<1 keV), with the assignment of a level at 1365.8 keV. The sum 270.6 +979.0+115.5 is within experimental error equal to 1365.8 keV and this in turn suggests a level at 1249.6 keV. This assignment is supported by the observed weak 1249.6-keV γ ray, a crossover to the ground state. The weak 116-keV γ ray is seen to be enhanced in the spectrum coincident with the region 850–1040 keV in NaI, which is consistent with the above assignment. The rather strong coincidence of the 1136-keV γ ray with the 271-keV γ ray places a level at 1406.6 keV. The members of the doublet 976.4 and 979.8 keV are in

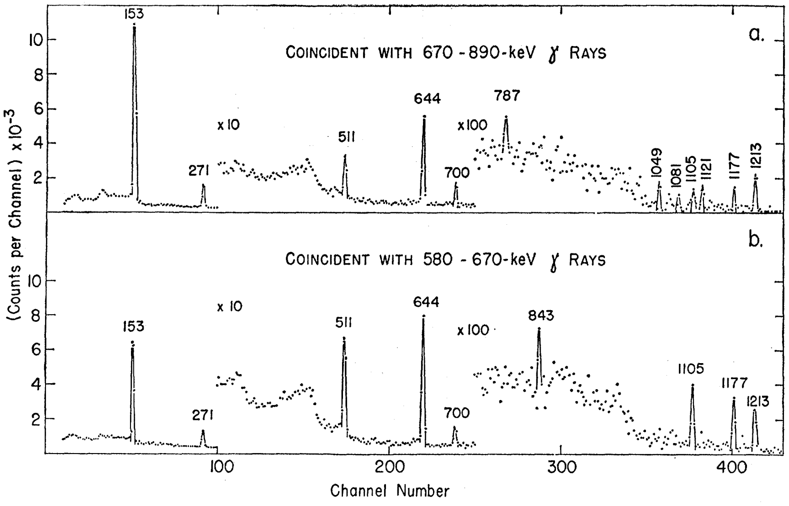

FIG. 8. γ-ray spectra from a newly prepared source of $^{119m+g}$Te taken with a Ge(Li) detector in coincidence with two energy regions in the NaI(Tl) detector.

coincidence with each other. This confirms the level at 2226.0 keV. The 153-keV γ ray is in coincidence with the 164- and the 1048-keV γ rays, none of which is in coincidence with the 1213-keV γ ray [see Fig. 7(c)]. The 164–1048 cascade must therefore originate from the 1212.7-keV level. Since the 1048 is the more intense, we place a level at 1048.3 keV. The 1081-keV γ ray is coincident with the 1048-keV γ ray. This is confirmed from the two-parameter spectrum where the 1081-keV γ-ray intensity peaks in the (1028–1060)-keV NaI window, while the 1048-keV γ-ray peaks in the (1060–1095)-keV NaI window. This establishes a level at 2129.3 keV. The very weak 2013-keV γ ray was not seen in the coincidence spectra, perhaps because of low efficiency at this energy. This γ ray is likely to feed either the ground or the 271-keV level. We prefer the latter choice on arguments based on log*ft* values, giving a level at 2283.6 keV. The two weak γ rays at 872 and 1311 keV were not seen in coincidence with others. On grounds of energy sum rules, we have placed them between the levels at 2277.8 and 1406.6, and 2360.3 and 1048.3 keV.

B. Decay of 16-h ^{119g}Te

The 644-keV γ ray is so intense that it must feed the ground state. The 700-keV γ ray is not in coincidence with the 644-keV γ ray and because of its large intensity it must feed the ground state. The 644-keV γ ray is in coincidence with the 843-, 1105-, and 1177-keV γ rays [Fig. 8(b)]. This establishes levels at 1487.4, 1749.5, and 1821.0 keV. The 700-keV γ ray is in coincidence with the 787- and 1121-keV γ rays [Fig. 8(a)]. This confirms the presence of levels at 1487.4 and 1821.0 keV. The level at 1749.5 keV also de-excites directly to the ground state by a 1749.3-keV γ ray, in excellent agreement with the energy sum rule. The weak γ ray at 373.7 keV was assigned to feed the 271-keV level on the basis of the excellent agreement with the sum rule for 644.3. Neither the 1339- nor the 1413-keV γ ray was seen in the coincidence spectra and both were therefore assigned to feed the ground state. It is unlikely that these γ rays feed either of the 644- or 700-keV levels because this would place levels too high in energy to be populated in β decay by any observable amount. A weak γ ray at 769.4 was seen in the "singles" spectra (see Fig. 1) but not in coincidence with other γ rays. A possible placement of this γ ray could be between the 644.3- and 1413.2-keV levels.

V. ASSIGNMENT OF SPINS AND PARITIES

We have measured the percentage of total positron emission in the ^{119m}Te decay and found it to be $\leq 0.3\%$. We have also measured the positron branching to the levels in ^{119}Sb from the decay of ^{119g}Te to be 2.8%. From coincidence spectra, we have estimated that 2.5% goes to the 644-keV level and 0.3% to the 700-keV

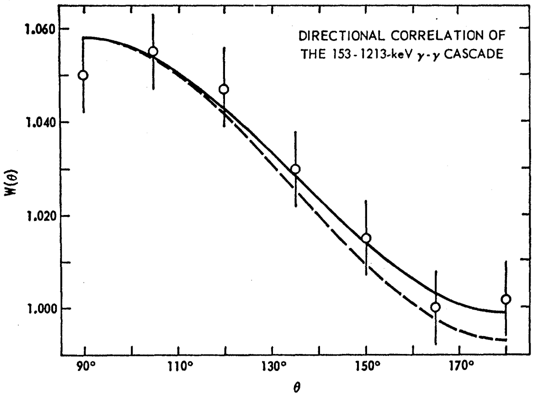

FIG. 9. A directional correlation for the 153–1213 keV γ-γ cascade. The solid line is the least-squares fit to the experimental points that gave -0.065 ± 0.006 and 0.0006 ± 0.0060 for A_{22} and A_{44}, respectively. The broken line is obtained from theory with -0.0714 and 0 for A_{22} and A_{44} for a pure sequence $11/2(1)\ \frac{9}{2}(2)\ \frac{5}{2}$.

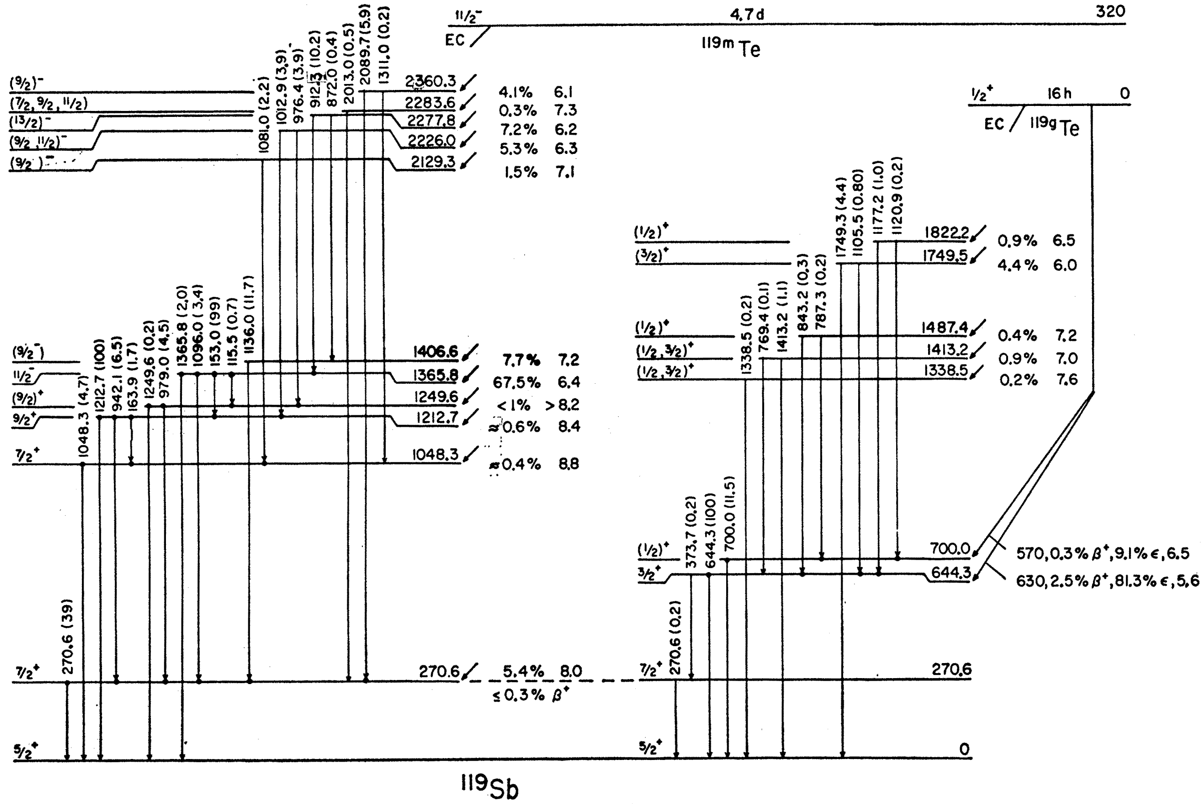

FIG. 10. Proposed decay schemes for the 4.7-day ^{119m}Te (left), and the 16-h. ^{119g}Te (right). The conventions used are those of *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Offices, National Academy of Sciences—National Research Council, Washington 25, D. C.), except that all energies are given in keV.

level. An upper limit to the isomeric transition for the ^{119m}Te is established to be $\leq 0.1\%$ by measuring an upper limit for the intensity ratio of the 644-keV γ ray to the 1213-keV γ ray in an old ^{119}Te source.

Log *ft* values for the β transitions shown in Fig. 10 from both the ^{119}Te isomers were calculated with the use of Moszkowski's nomogram.[20] For this purpose the values of 2.61 MeV[13] and 2.29 MeV[10] for the electron-capture Q value Q_{EC} to the ground state for decay of ^{119m}Te and ^{119g}Te were employed, respectively. The discussion of the character of the β decays is given below, together with the assignment of the spins from the internal-conversion data. The conversion coefficients presented in Tables I and II, when compared to the values of Sliv and Band,[21] suggest the most probable multipolarities for most of the transitions involved, as shown in the last columns of Tables I and II.

From systematics in the neighboring odd-A antimony isotopes it is well established that the two lowest states are $\frac{7}{2}^+$ and $\frac{5}{2}^+$. Since the first excited state is fed significantly in the decay of $11/2^-$ ^{119m}Te (log*ft* of 8.0, first-forbidden unique) it should be $\frac{7}{2}^+$, and therefore the ground state should be $\frac{5}{2}^+$. From measurements of the directional correlation in the cascade 153, 1213 keV we obtained the values -0.065 ± 0.006 and 0.0006 ±0.006 for the coefficients A_{22} and A_{44} in

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

The solid line in Fig. 9 was constructed using these values for the coefficients.

Assuming for this cascade a spin sequence $11/2(1)$ $\frac{9}{2}(2)\frac{5}{2}$ without any admixtures we calculate from theory[22] -0.0714 and 0 for A_{22} and A_{44} (broken line in Fig. 9), in good agreement with experiment.

Another alternative spin sequence which could fit the directional correlation results is $\frac{9}{2}(1)11/2(3)\frac{5}{2}$, with some quadrupole admixture in the transition $\frac{9}{2}$ to $11/2$. This assignment can be ruled out because of log*ft* values and internal-conversion coefficients. The internal-conversion coefficients agree with the assignment $E2$ and $E1$ for the 1213- and 153-keV transitions, respectively, and this establishes the parities $11/2^-$ and $\frac{9}{2}^+$ for the 1366- and 1213-keV levels and $\frac{5}{2}^+$ for the ground state. Further the α_K for the 1366-keV transition is consistent with $E3$ in agreement with the assignments above.

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[20] S. A. Moszkowski, Phys. Rev. 82, 35 (1951).

[21] L. A. Sliv and I. M. Band in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Seigbahn (North-Holland Publishing Company, Amsterdam, 1965), p. 1639.

[22] M. Ferentz and N. Rosenzweig in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Seigbahn (North-Holland Publishing Company, Amsterdam, 1965), p. 1687.

The α_K values for the 164-, 942-, and 1048-keV transitions indicate the assignments $M1$ or $E2$ for these. The 1048-keV level could be then $(\frac{5}{2}, \frac{7}{2}, \text{or } \frac{9}{2})^+$. We rule out $\frac{9}{2}^+$ because the 1366-keV level would feed it in that case by an $E1$ transition. We do not see such a transition of 317.5 keV. Because the 1048-keV level is fed by an $E1$ transition from the 2129-keV level the spin of the 1048-keV level can be limited to $\frac{7}{2}$.

The conversion-coefficient data are not conclusive for the 979-keV transition, because the doublet 978 keV was not resolved in the conversion electron spectra. The average value for α_K for this doublet suggests that one of these could be $E1$ and the other $M1$ or $E2$. The most likely assignment for the 1250-keV level is $\frac{9}{2}^+$ because this level is fed by the 116-keV γ ray from the $11/2^-$ state at 1366 keV and it decays to the $\frac{5}{2}^+$ ground state as well as to the $\frac{7}{2}^+$ first excited state. The assignment $11/2^+$ is ruled out because this would give a ratio ($E2$, 1250–271)/($M3$, 1250–0) for single-proton transitions[23] of 5×10^5, which is 2×10^4 times higher than the experimental ratio, suggesting that the 1250-keV γ ray should not have been seen. The assignment $\frac{9}{2}^+$ for this 1250-keV level is preferred because it gives a ratio ($E2$, 1250–0)/($M1$, 1250–271) of 3×10^{-3} for single-proton transitions[23] compared to the measured 0.04. Such enhancements of rates of $E2$ over M1 are common in this region.[24,25]

The level at 1407 keV is very interesting. We have repeated the measurement of the internal conversion coefficient for the 1136-keV transition and found it to be $(5.3\pm0.8)\times10^{-4}$, compared to theoretical values of 4.2×10^{-4} for $E1$ and 9.4×10^{-4} for $E2$.[21] This indicates an assignment of $\frac{9}{2}^-$ for the 1407-keV level. Such a low-lying $\frac{9}{2}^-$ state is rather unusual.

The α_K for the 912-keV transition indicates $M1$ or $E2$ for this transition. The logft value for β decay to the 2278-keV level is low, suggesting an allowed β decay, thus limiting the spin value for this level to $(\frac{9}{2}, 11/2, 13/2)^-$. However, the lack of decay of this strong level to any of the $\frac{9}{2}^+$ lower lying states would eliminate the $(\frac{9}{2}, 11/2)^-$ values, leaving the $13/2^-$ as a possibility. The value of the spin and parity of the 2360-keV level can be limited to $\frac{9}{2}^-$ if the β decay to this level, with a logft value of 6.1, is taken as allowed, and the fact that only the $\frac{7}{2}^+$ levels at 271 and 1048 keV are fed from this de-excitation. The value for α_K for the 1013-keV transitions indicates $M1$ or $E2$. A positive parity assignment for the level at 2226-keV is unlikely because (i) the logft value of 6.3 is quite low compared to the values for lower-lying levels populated by first-forbidden β decays, and (ii) the uncertainties on the α_K values are too large to strongly support such an assignment. In addition, the average α_K for the doublet at 976 and 979 keV suggests that one of these is $E1$. We therefore prefer $(\frac{9}{2}, 11/2)^-$ as the possible spin and parity for the 2226-keV level on the basis of the logft value.

The logft value of 7.1 for the population of the 2129-keV level suggests either a first-forbidden or an allowed β decay. The measured α_K value for the 1081-keV transition indicates an $E1$ assignment and therefore negative parity. Because of the feeding of the 1048-keV level the possible spin may be limited to $(\frac{9}{2})^-$. The lack of feeding to the lowest $\frac{7}{2}^+$ state should be noticed.

The evidence for definite spin and parity assignments of the levels populated on the β decay of the 16-h ^{119g}Te is rather limited. Our α_K values for the 644-, 700-, and 1750-keV transitions are consistent with the assignment $M1$ or $E2$. This information together with the logft values support $(\frac{1}{2}, \frac{3}{2})^+$ for the levels at 644, 700, and 1750 keV. The former two decay to the $\frac{5}{2}^+$ ground, but only the 644-keV level was seen to decay to the $\frac{7}{2}^+$ 271-keV level. Assuming $\frac{3}{2}^+$ for the 644-keV level we calculate a ratio ($M1$, 644–0)/($E2$, 644–271) or 6×10^5 for single-proton transitions,[23] compared to 5×10^2 from experiment. Enhancements of $E2$ over $M1$ transitions of the order 10 to 1000 are not uncommon and we therefore would prefer the spin $\frac{3}{2}^+$ for the 644-keV level. The value $\frac{3}{2}^+$ for the 700-keV level cannot be ruled out on the basis of the experimental evidence, but from nuclear systematics it is very likely that the value is $\frac{1}{2}^+$. No negative-parity low-spin states are expected at energies up to 1800 keV and therefore it may be assumed that all β decays are of the allowed type. States of $\frac{5}{2},^+$ would require second-forbidden β decays and are thus excluded. The 1821-keV level decays only to the 644- and 700-keV levels probably by $M1$ transitions. In this case we calculate the ratios ($E2$, 1821–0)/($M1$, 1821–644) of 5×10^{-2}, and ($M1$, 1821–0)/($M1$, 1821–644) of 30 for single-proton transitions.[23] A spin of $\frac{1}{2}^+$ could be assigned to this level on the basis of these ratios and the lack of decay to the ground state. The 1750-keV level can be either $\frac{1}{2}^+$ or $\frac{3}{2}^+$. On the basis of single-proton transition ratios we prefer the value $\frac{3}{2}^+$ with assumed $M1$ transitions as opposed to $\frac{1}{2}^+$ which would require 10^3 enhancement of $E2$ over $M1$ for the 1750- and 1106-keV transitions. The assignment of $\frac{1}{2}^+$ for the 1487-keV level can be made on the same arguments presented for the 1821-keV level. The levels at 1413 and 1339 keV decay exclusively to ground, thus supporting a $\frac{3}{2}^+$ assignment, although the value $\frac{1}{2}^+$ cannot be excluded.

VI. INTERPRETATION OF THE LEVELS

Our work is in good agreement with that of Berzins and Kelly.[15] Our measurements give support to all their levels except one at 1328 keV. We suggest also in our work that in ^{119g}Te decay the 644-keV level decays to the $\frac{7}{2}^+$ state at 271 keV with a 374-keV γ ray which they do not see. This transition suggests the

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[23] D. H. Wilkinson, in *Nuclear Spectroscopy*, edited by F. Ajzenberg-Selove (Academic Press Inc., New York, 1960), p. 860.

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[25] W. B. Walters, C. E. Bemis, Jr., and G. E. Gordon, Phys. Rev. **140**, B268 (1965).

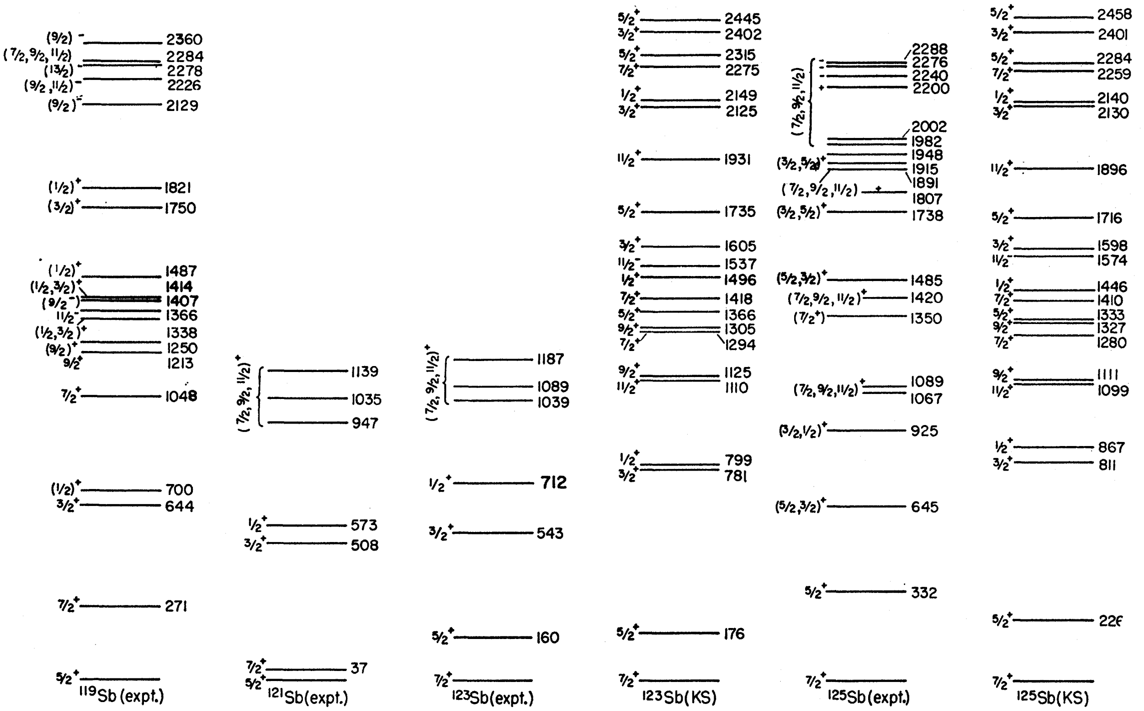

FIG. 11. Low-lying levels of the odd-A Sb isotopes 119 to 125. The experimental information is from this work and Refs. 5–8. The levels for ^{123}Sb and ^{125}Sb predicted by Kisslinger and Sorensen (Ref. 4) are also given.

assignment $\frac{3}{2}^{+}$ for the 644-keV level (see above). Using conversion electron and angular correlation data, we give more definitive assignments for spins and partites for many ^{119}Sb levels obtained in the decay of the ^{119}Te isomers.

In Fig. 11 we have summarized both the experimental and the theoretical information on the low-lying levels of odd-A Sb isotopes 119 to 125 (based on this work and Refs. 5–8). Limited experimental information is available on the ^{121}Sb and ^{123}Sb levels. In this region, the protons are filling single-particle levels $g_{7/2}$, $d_{5/2}$, $h_{11/2}$ $d_{3/2}$, and $s_{1/2}$, approximately in that order. According to the treatment of KS, the pure quasiparticle levels (before consideration of the long-range force) for ^{119}Sb are expected at the energies $g_{7/2}$, 0; $d_{5/2}$, 0.52; $h_{11/2}$, 2.03; $d_{3/2}$, 3.20; and $s_{1/2}$, 3.33 MeV. When the long-range quadrupole force is included, it brings down a number of levels.[4]

One trend is apparent among the experimental levels shown. The $\frac{5}{2}^{+}$ level moves down as the neutron number decreases, and in ^{121}Sb and ^{119}Sb it becomes the ground state. This trend is not reproduced by the pairing-plus-quadrupole calculations, but when a δ interaction between the single proton and the Sb neutrons is taken into account, the energy shift can be reproduced at least qualitatively.[4]

Because of the odd-proton (outside the 50 proton shell) character of the Sb isotopes one might expect a weak coupling of the odd proton with at least the 1-phonon states of the even-even core, giving rise to particle-core multiplets, which should lie above the single-particle levels about 1.2 MeV, the phonon energy in ^{118}Sn. Since the ground and first excited states $\frac{7}{2}^{+}$ and $\frac{5}{2}^{+}$ are expected to be primarily single-quasiparticle states (78% and 68% for the corresponding states in ^{123}Sb[4]), two particle-core multiplets should occur. Such states appear in the KS formulations. For example, in ^{123}Sb, the states $11/2^{+}$ and $\frac{9}{2}^{+}$ at 1110 and 1125 keV are almost of pure $(\frac{7}{2}^{+})$-1-phonon character; also the $\frac{9}{2}^{+}$ level at 1305 is almost of pure $(\frac{5}{2}^{+})$-1-phonon character. The $\frac{7}{2}^{+}$ levels at 1294 and 1418 keV in ^{123}Sb have about equal $(\frac{5}{2}^{+})$- and $(\frac{7}{2}^{+})$-1-phonon character. Levels of primarily 1-quasiparticle-2-phonon character are expected to occur above about 2 MeV in ^{123}Sb. The negative-parity state $11/2^{-}$ in ^{123}Sb is expected at 1537 keV and has 64% single-quasiparticle character with a 31% 1-phonon admixture. The next odd-parity state in ^{123}Sb is expected, according to the KS treatment, to be a $\frac{9}{2}^{-}$ state at 3.01 MeV.[4]

Although the experimental information on the ^{119,121,123,125}Sb isotopes is not complete enough to allow for a detailed comparison, it is apparent from Fig. 11 that a number of levels seem to correspond to the levels of the KS treatment. In the case of ^{119}Sb, several remarks can be made for a number of levels. First of all, the $\frac{3}{2}^{+}$ and $\frac{1}{2}^{+}$ levels at 644.3 and 700.0 keV must be heavily phonon mixed. The "core-multiplet" levels associated with the $\frac{5}{2}^{+}$ and the $\frac{7}{2}^{+}$ ground and first excited state should be present in ^{119}Sb also. The levels at 644, 700, 1048, 1213, and 1250 could be explained in this manner.

No $11/2^+$ or $\frac{5}{2}^+$ states were found. Direct β feeding of the $\frac{5}{2}^+$ state is a second-forbidden transition that we do not expect to see. The $11/2^+$ states were not observed probably because of small β feeding. The $11/2^-$ level at 1366 keV is expected to be primarily of single-quasiparticle character.

If the 1407-keV level is indeed $\frac{9}{2}^-$ then this level at such a low energy cannot be explained by KS treatment with the pairing between only like particles and the quadrupole force alone. As Kisslinger[26] has pointed out, a 3-quasiparticle $j-1$ state, made of 3 particles in a half-full j shell, can be lowered considerably by a large diagonal matrix element of the quadrupole force. This effect would be particularly important for large-spin opposite parity states. Such an "intruder" state would be very weakly coupled to the phonon in distinction to the 1-quasiparticle-1-phonon state which would lie at higher energy.

It is therefore tempting to invoke the presence of a 3-quasiparticle state to explain the $\frac{9}{2}^-$ level at 1407 keV. Such a state, however, is difficult to form in ^{119}Sb. The possibility of forming $\frac{9}{2}^-$ from coupling of the ground state $\frac{5}{2}^+$ quasiparticle with the 3- octupole state in the core was also considered. The energy of the 3- state in ^{118}Sn is 2.3 MeV[27] and one would expect that the highest spin states would lie at the energy of the unperturbed state 3- or even higher, unless the multiplet is inverted. If this were the case, then other negative parity states should be present including the $\frac{1}{2}^-$ and $\frac{3}{2}^-$ as possibilities. Candidates for such assignment could be the levels at 1339, 1413, or 1487 keV. However, the latter states and the $\frac{9}{2}^-$ are too low in energy to make this assignment plausible.[28]

Other negative-parity states occur at 2129, 2226, 2278, and 2360 keV, considerably lower than calculated at ^{123}Sb. Some of these states could probably be described as 1 quasiparticle coupled to 1 phonon.

One thing which is apparent in the ^{119}Te decay is generally high log*ft* values for allowed transitions, especially for the decays to the levels at 1339, 1413, and 1487 keV. These transitions belong to the "even jumping" class in the KS treatment and to first order the *ft* is proportional to $(V_{jn}\times V_{jp})^{-2}$, where the V^2's are the occupation probabilities for the parent $\frac{1}{2}^+$ odd neutron and the daughter $\frac{3}{2}^+$ or $\frac{1}{2}^+$ proton levels. For the odd neutron in the parent, $(V_{1/2n})^2$ is ~ 0.7 and for the odd proton in the daughter $(V_{jp})^2$ for $d_{3/2}$ and $s_{1/2}$ proton levels are 0.25 and 0.5, respectively; therefore, this effect does not account for all the observed hindrance.

A possible explanation for the high log*ft* values could be that the wave functions are heavily phonon mixed, as has been suggested previously.[25] From the results of KS we estimate that the parent $\frac{1}{2}^+$ level of ^{119g}Te is 60% pure $\frac{1}{2}^+$ single quasiparticle, with 31 and $<9\%$ contributions from $(\frac{5}{2}^+)$-1-phonon and $(\frac{5}{2}^+, \frac{7}{2}^+,$ etc.)-2-phonon, parts respectively.[4] To first order, the allowed β decay will take place only from the $(\frac{1}{2}^+)$-0-phonon part of the parent state to a similar part $[(\frac{1}{2}^+)$ or $(\frac{3}{2}^+)]$-0-phonon part of the daughter-state wave function, or from the $(\frac{5}{2}^+)$-1-phonon part of the initial state to the $[(\frac{3}{2}^+)$, $(\frac{5}{2}^+)$, or $(\frac{7}{2}^+)]$-0-phonon part of the final state. Unfortunately, we do not have detailed calculations for ^{119}Sb levels, but the calculations for ^{123}Sb and ^{125}Sb suggest that the low-lying $\frac{1}{2}^+$ and $\frac{3}{2}^+$ states are heavily phonon mixed.[4] It should be noted, however, that the log*ft* value for the allowed β decay to the lowest $\frac{3}{2}^+$ level at 644 keV is not hindered. Experimentally, the log*ft* values for the allowed β decay to the lowest $\frac{1}{2}^+$ and $\frac{3}{2}^+$ states are decreasing with neutron number, because log*ft* values for the β decay to these levels are in ^{125}Sb 7.2 and 7.0,[6] in ^{123}Sb 6.8 and 7.0,[6] in ^{121}Sb 6.4 and 7.0[5] and in ^{119}Sb 6.5 and 5.6. Bassani *et al.*[9] have suggested from (He,*d*) work that the single-particle character for these two levels is increasing with decreasing neutron number and this could explain the trend of the log*ft* values.

In summary, the limited amount of data available on the levels of odd-*A* antimony isotopes can be qualitatively well explained with the model of pairing forces plus long-range quadrupole interactions as treated by Kisslinger and Sorensen.[4]

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