# Radioactive decay of 2.2-h $^{127}$Sn to levels of $^{127}$Sb†

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High-resolution Ge(Li) detectors have been used to observe $\gamma$-ray singles and coincidence spectra of 2.2-h $^{127}$Sn ($\frac{11}{2}^-$ ground state). Sources of mixed tin isotopes were produced by thermal-neutron fission of enriched $^{235}$U and were chemically separated by solvent extraction and sulfide precipitation. A total of 162 $\gamma$ rays are attributed to the decay of $^{127}$Sn$^g$, and 154 of these transitions have been placed in a $^{127}$Sb level scheme involving 50 excited states. The $\beta$ feeding from $\frac{11}{2}^-$ $^{127}$Sn$^g$ to the $\frac{7}{2}^+$ $^{127}$Sb ground state was determined to be (22 ± 8)% (log$ft$ = 8.0). Spin and parity assignments for $^{127}$Sb levels have been made in many instances. An 11 ± 1-$\mu$sec $\frac{15}{2}^-$ isomeric level in $^{127}$Sb at 1920 keV has been identified. The level structure of $^{127}$Sb is interpreted in terms of the shell model and core-excitation considerations.

RADIOACTIVITY $^{127}$Sn$^g$ (from $^{235}$U fission); measured $E_\gamma$, $I_\gamma$, $t_{1/2}\gamma$, $\gamma$-$\gamma$ coin; deduced $E_\beta$, $I_\beta$, log$ft$. $^{127}$Sb deduced levels, $J$, $\pi$. Enriched target; Ge(Li) detectors.

## I. INTRODUCTION

The study of the radioactive decay of odd-mass neutron-rich Sn isotopes and neutron-deficient Te isotopes offers an important means to characterize systematically the energy levels of odd-mass Sb nuclei. Such studies, utilized in conjunction with various scattering, stripping, and pickup reactions on Sn, Sb, and Te isotopes, make possible a nearly complete characterization of the odd-mass Sb levels below ≈2 MeV.

The Sb isotopes have one proton beyond the closed shell at $Z = 50$, making their level structure particularly easy to interpret. Presumably, careful study of these nuclei will lead to an improved understanding of the long-range residual nucleon-nucleon force. Because of the stability of the nearby Sn and Te isotopes it is possible to study the levels of a large number of Sb nuclei and observe the effects of the changing neutron number on the states available to the odd proton. Stripping [1-3] and pickup[4] reactions on Sn and Te isotopes, respectively, have identified single-particle states of Sb with $113 \leq A \leq 129$, and scattering experiments on stable $^{121}$Sb and $^{123}$Sb have populated a number of collective states.[5,6] Radioactive-decay studies have been reported for the decay[7] of $^{115}$Te to $^{115}$Sb levels, the decay[8] of $^{117}$Te to $^{117}$Sb levels, the decay[9-11] of $^{119}$Te isomers to $^{119}$Sb levels, the decay[12] of $^{121}$Te isomers to $^{121}$Sb levels, the decay[13,14] of $^{123}$Sn isomers to $^{123}$Sb levels, the decay[14-18] of $^{125}$Sn to $^{125}$Sb, and the decay[19,20] of $^{127}$Sn isomers to $^{127}$Sb levels.

Although these studies have characterized the levels below ≈2 MeV in considerable detail, little information above that energy is available. We therefore initiated an investigation of the decay of 2.2-h $^{127}$Sn both for the purpose of extending the systematic studies of the lower levels and to investigate the levels between ≈2 MeV and the $Q_\beta$ energy of ≈3.1 MeV. Preliminary reports of this work have been given,[21] and a report[22] relating specifically to the identification and characterization of the 11-$\mu$sec isomer at 1920 keV has been presented. During the course of this investigation the results of similar but less detailed studies of the decay of both the 2.2-h and 4-min $^{127}$Sn isomers were reported by Helander.[23]

## II. EXPERIMENTAL PROCEDURE

Only two important methods are available for the production of $^{127}$Sn: the $^{130}$Te($n$, $\alpha$)$^{127}$Sn reaction and the separation of Sn from the fission products of heavy elements. The former method has been used with some success[19,23] to prepare low-spin 4-min $^{127}$Sn$^m$ but yields only a small quantity of high-spin 2.2-h $^{127}$Sn$^g$. We therefore prepared our sources by separating Sn from the fission products of $^{235}$U.

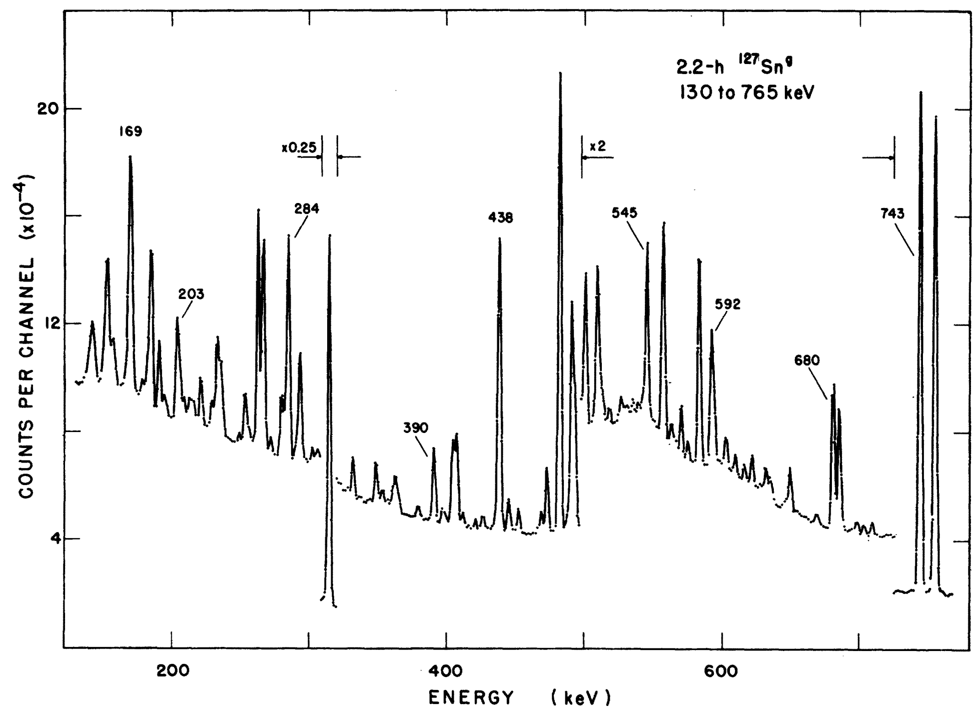


FIG. 1. $\gamma$-ray spectrum between 130 and 765 keV of 2.2-h $^{127}$Sn.

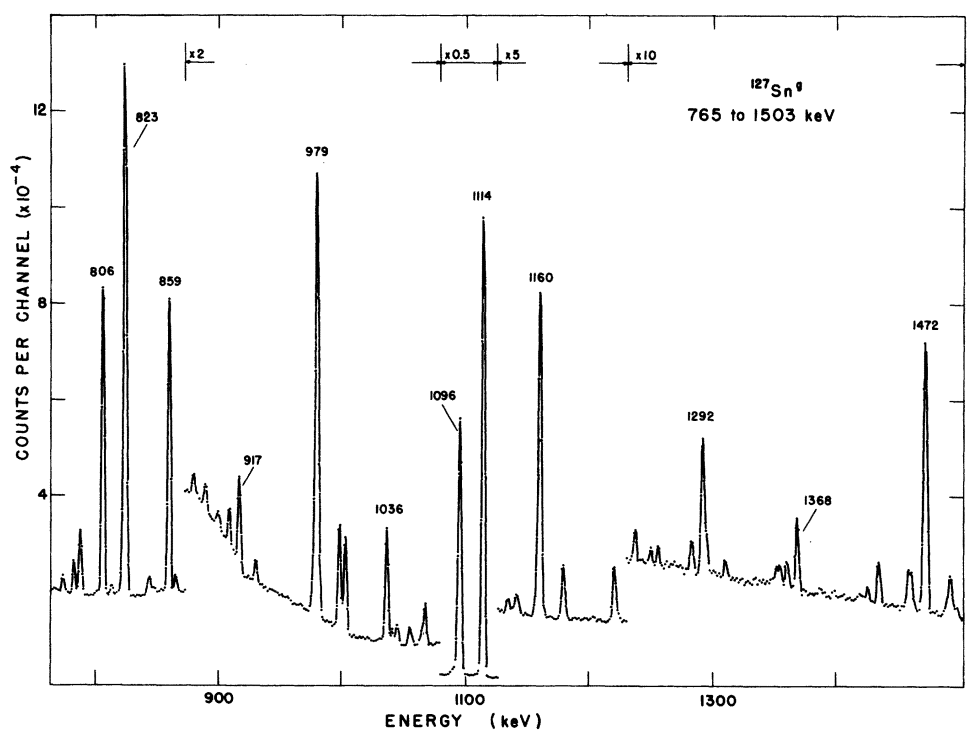


FIG. 2. $\gamma$-ray spectrum between 765 and 1503 keV of 2.2-h $^{127}$Sn.

Sources were produced by irradiating 0.7 mg of 95% enriched $^{235}U$ as a dilute solution of uranyl nitrate in the Massachusetts Institute of Technology reactor at a flux of $2\times10^{13}$ $n$ cm$^{-2}$sec$^{-1}$. Because of the presence of 1-h $^{128}$Sn, irradiation periods of 2 h were used, and the samples were allowed to decay for 6 to 8 h prior to chemical separation. No other contaminants were present as the Sn isotopes with $A>128$ have short half-lives and decay during the delay period, whereas the isotopes with $A\leq 126$ are formed with very small yields in fission.

A remotely operated solvent-extraction apparatus was employed for the tin separation. Pre-equilibrated benzene was used as the extractant and stannic iodide containing the fission-product tin was concentrated in the benzene phase. Tin was back extracted into dilute sulfuric-acid solution. Further purification followed the procedure given by Cowan.[24] For Ge(Li)-Ge(Li) coincidence runs and some singles counts, multiple samples were collected. Up to eight samples were prepared sequentially and were observed over a period of 36 h of continuous counting.

$\gamma$-ray spectra were measured using a multiparameter pulse-height-analyzer system (PHA) and several Ge(Li) detectors. Large detectors with 26- and 45-cm$^3$ active volumes were used [full width at half maximum (FWHM) values of 2.3 and 2.8 keV, respectively, for the 1332-keV $^{60}$Co $\gamma$ ray] as was a small Ge(Li) x-ray detector that had an active volume of $\approx$0.5 cm$^3$ and a FWHM of 750 eV for the 60-keV $^{241}$Am $\gamma$ ray. The PHA and associated electronics[25] enabled both $\gamma$-ray singles spectra and $\gamma\gamma$-coincidence data to be recorded on magnetic tape for later analysis.

The half-life of the 1920-keV level was measured utilizing a $7.6\times7.6$-cm NaI(Tl) detector and an 18-cm$^3$ Ge(Li) detector. Delayed coincidences between the 438-keV $\gamma$ ray [observed with the Ge(Li) detector] and the 1096- and 1114-keV $\gamma$ rays [detected with the NaI(Tl) detector] were recorded. The position of the Ge(Li) energy window was varied in order to confirm the measurement.

## III. RESULTS

The $\gamma$-ray spectrum observed with the 26-cm$^3$ Ge(Li) detector is shown in Figs. 1, 2, and 3, and a portion of the low-energy spectrum observed with the 0.5-cm$^3$ Ge(Li) detector is shown in Fig. 4. A total of 241 peaks were observed, including single-escape (SE), double-escape (DE), x-ray-escape, and sum peaks, and are tabulated in Table I. Half-lives were determined by recording successive spectra on magnetic tape and measuring the areas of each observed peak. 162 $\gamma$ rays are attributed to the decay of $^{127}$Sn. 21 $\gamma$ rays

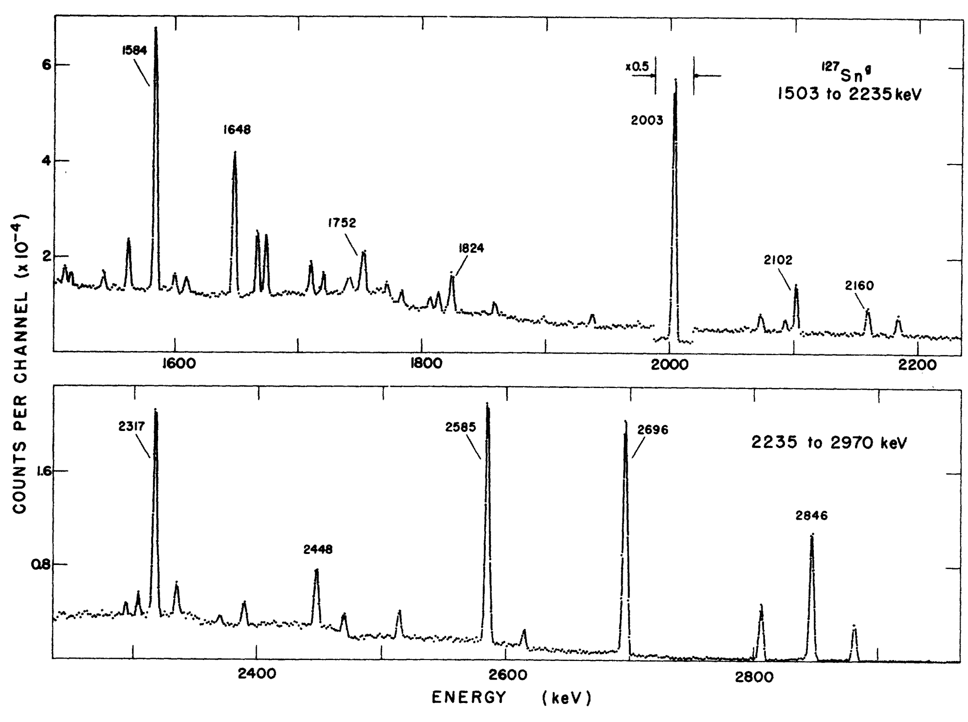


FIG. 3. $\gamma$-ray spectrum between 1503 and 2970 keV of 2.2-h $^{127}$Sn.

were found to decay with 1-h half-lives and are assigned to the transient-equilibrium decay of 1-h $^{128}$Sn and its daughter, 10-min $^{128}$Sb. A total of 19 peaks with intensities <1 are not assigned. The remaining $\gamma$ rays are assigned to such known species as 9.7-day $^{125}$Sn and 3.8-day $^{127}$Sb.

The Ge(Li)-Ge(Li) $\gamma\gamma$-coincidence spectra were analyzed by extracting the coincidence spectra for 47 prominent $\gamma$-ray peaks, as well as neighboring regions to account for Compton backgrounds. Energy gates were set on the spectrum obtained with the 45-cm$^3$ detector, and the spectrum in coincidence with the gated region was retrieved for the 26-cm$^3$ detector. The results obtained are tabulated in Table I. The coincidence spectra obtained by gating on the two most prominent $\gamma$-ray lines are shown in Fig. 5.

The results of the delayed-coincidence measurement for the 438-keV $\gamma$ ray and the 1096- and 1114-keV $\gamma$ rays are shown in Fig. 6 as are comparison data in which the energy gate for the Ge(Li) detector was shifted to the 492-keV peak. The 492-keV peak was chosen as it was known to be in prompt coincidence with the 1096- and 1114-keV $\gamma$ rays and was nearly equal in intensity to the 438-keV line. The resulting decay curve for the 1920-keV level is shown in Fig. 7. The straight line through the data represents a weighted least-squares fit to an exponential function, corresponding to a half-life of $11 \pm 1$ $\mu$sec.

## IV. DECAY SCHEME

The resulting decay scheme is shown in Figs. 8 and 9. A detailed discussion of the placement of each $\gamma$ ray assigned to the decay of $^{127}$Sn is recorded elsewhere,[25] and only level placements are described here. Energy gates were set on those $\gamma$ rays depicted in Figs. 8 and 9 with a dot at their upper end whereas those $\gamma$ rays observed in coincidence spectra are indicated by a dot at their lower end. The $Q_\beta$ of $3.1 \pm 0.1$ MeV[19, 26] restricts $\gamma$ rays above ≈1100 keV to feed levels below 1900 keV and $\gamma$ rays above ≈1800 keV to feed only the ground or first excited state at 491 keV.

The position of the first excited state has been established at 491 keV by the ($d$, $^3$He) studies of

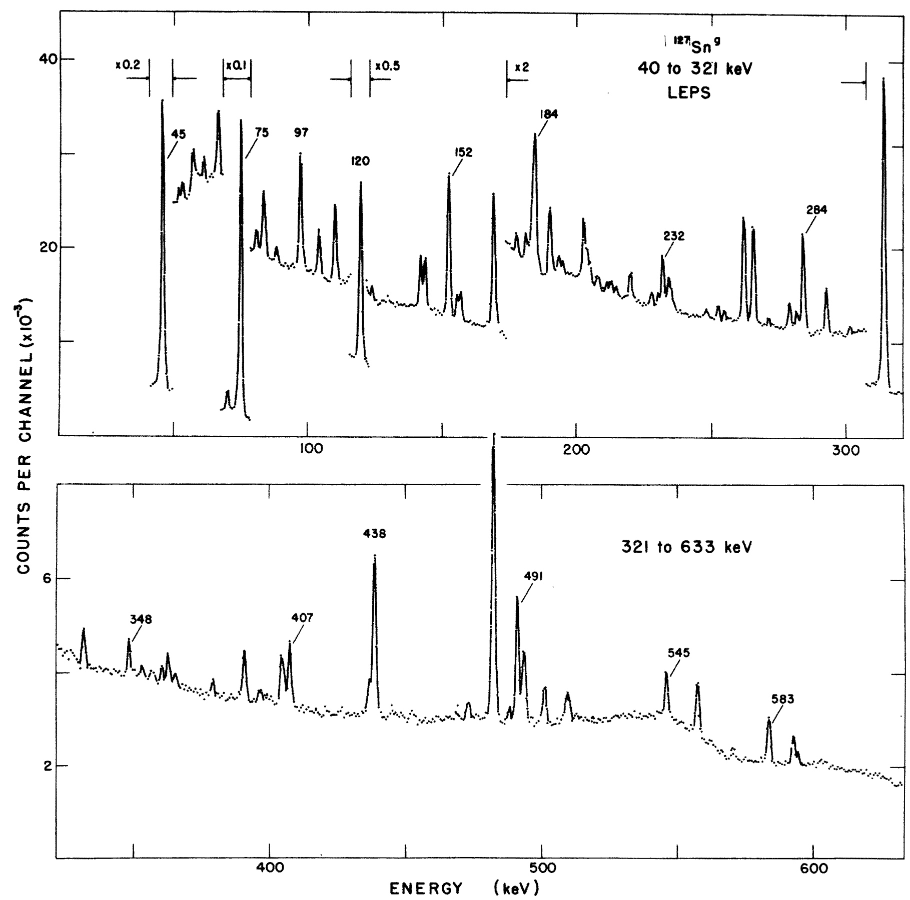


FIG. 4. $\gamma$-ray spectrum between 40 and 633 keV of 2.2-h $^{127}$Sn as observed with the 0.5-cm$^3$ Ge(Li) x-ray detector.

TABLE I. $\gamma$ rays observed in decay of fission-product tin samples. (w) implies that the $\gamma$ ray was weakly observed in the coincidence spectrum.

| $E$ [a] (keV) | $I$ [c] | Transition [b] From | To | Coincident $\gamma$ rays or identification |
|---|---|---|---|---|
| 15.3 | | | | Ge x-ray escape peak |
| 16.4 | | | | Ge x-ray escape peak |
| 19.8 | | | | Ge x-ray escape peak |
| 25.2 | 7.4 | | | Sn x ray |
| 26.3 | 70 | | | Sb x ray |
| 28.5 | 1.1 | | | Sn x ray |
| 29.7 | 13 | | | Sb x ray |
| 32.1 | 1.5 | | | 1 h, $^{128}$Sn-$^{128}$Sb [d] |
| 34.9 | 0.10 | | | Not placed |
| 35.8 | | | | Ge x-ray escape peak |
| 45.7 | 4.5 | | | 1 h, $^{128}$Sn |
| 46.9 | 0.21 | | | Not placed |
| 51.5 | 0.05 | | | Not placed |
| 52.8 | 0.10 | | | Not placed |
| 56.9 | 0.15 | | | Not placed |
| 60.9 | 0.14 | | | $^{127}$Sb |
| 66.4 | 0.38 | 2004 | 1937 | |
| 70.3 | 1.0 | 1991 | 1920 | |
| 75.0 | 14 | | | 1 h, $^{128}$Sn |
| 80.7 | 0.1 | | | 1 h, $^{128}$Sn-$^{128}$Sb |
| 83.4 | 0.50 | | | Not placed |
| 88.1 | 0.11 | | | Not placed |
| 97.2 | 1.2 | 2222 | 2124 | 124, 169, 184.7, 204, 234.3, 279, 860, 1096 |
| 104.1 | 0.50 | 2456 | 2352 | 348, 397(w), 2003 |
| 110.1 | 1.0 | 2456 | 2346 | 124, 143.7, 203, 205, 235.3, 282, 391, 426(w), 860, 1096 |
| 119.7 | 5.7 | 2110 | 1991 | 156.9, 181, 235.3, 263, 266, 293, 332 405.0 |
| 124.0 | 0.2 | 2346 | 2222 | 97, 110, 284, 293, 823(w) |
| 141.9 | 1.1 | 2501 | 2358 | 438 |
| 143.7 | 1.3 | 2346 | 2202 | 110, 184.0, 208(w), 211.5, 282, 293 |
| 152.5 | 3.5 | | | 1 h, $^{128}$Sn |
| 155.6 | 0.6 | 2093 | 1937 | 493, 823, 1114 |
| 156.9 | 0.7 | 2530 | 2373 | 120, 190, 263, 452(w) |
| 169.2 | 5.3 | 2124 | 1955 | 97, 184.7, 234.3, 249(w), 279, 332, 405.0, 514, 540, 860, 1096 |
| 170.3 [e] | 0.2 | 2373 | 2202 | 266, 282 |
| 178.0 | 0.3 | 2530 | 2352 | 348 |
| 181.1 | 0.4 | 2554 | 2373 | 120, 263 |
| 184.0 [e] | 1.2 | 2530 | 2346 | 143.7, 203, 205, 235.3, 391, 860, 1096 |
| 184.7 [e] | 2.9 | 2406 | 2222 | 97, 169, 232, 284, 302(w), 823, 860, 1096, 1114 |
| 190.1 | 1.5 | 2110 | 1920 | 156.9, 235.3, 263, 266 |
| 193.5 | 0.4 | | | 1 h, $^{128}$Sb |
| 195.0 | 0.2 | 2696 | 2501 | 545(w) |
| 202.8 | 2.0 | 2140 | 1937 | 110, 184.0, 205, 293, 361, 446, 622 823, 1114 |
| 204.1 | 0.6 | 2124 | 1920 | 97, 332, 405 |
| 205.2 | 0.6 | 2346 | 2140 | 110, 184.0, 203, 220, 293 |
| 208.0 | 0.4 | 2554 | 2346 | 143.7(w), 391 |
| 211.5 [f] | 0.3 | 2202 | 1991 | 143.7, 293 |
| 212.9 [f] | 0.3 | 2150 | 1937 | 823 |
| 215.0 [f,g] | 0.2 | 2317 | 2102 | 2102 |
| 220.4 | 0.8 | 2140 | 1920 | 205, 293, 361, 446, 622 |
| 228.4 | 0.5 | 2587 | 2358 | 438 |
| 230.5 | 0.3 | | | 1 h, $^{128}$Sn-$^{128}$Sb |

TABLE I *(Continued)*

| $E$[a] (keV) | $I$[c] | Transition[b] From | To | Coincident $\gamma$ rays or identification |
|---|---|---|---|---|
| 232.2 | 2.2 | 2639 | 2406 | 184.7, 284, 469, 823, 1114, 1292 |
| 234.3 | 1.4 | 2456 | 2222 | 97, 169, 284, 823, 860, 1096, 1114 |
| 235.3 | 0.7 | 2346 | 2110 | 110, 120, 184.0, 190, 293 |
| 248.6 | 0.2 | 2373 | 2124 | 169(w), 266(w) |
| 253.0 | 1.1 | | | $^{127}$Sb |
| 255.3[f] | 0.3 | 2530 | 2275 | 1160.4 |
| 262.5 | 6.1 | 2373 | 2110 | 120, 156.9, 181, 190, 266 |
| 266.2 | 5.6 | 2639 | 2373 | 120, 170, 190, 249(w), 263, 282, 452 |
| 271.5 | 0.3 | 2275 | 2004 | 2003 |
| 279.3 | 1.5 | 2501 | 2222 | 97, 169, 284, 823, 1114 |
| 282.0 | 1.4 | 2202 | 1920 | 110, 143.7, 170, 266, 293 |
| 284.3 | 7.0 | 2222 | 1937 | 124, 184.7, 232, 234.3, 279, 366, 823, 1114 |
| 292.9 | 3.3 | 2639 | 2346 | 120, 124, 143.7, 203, 205, 211.5, 220, 235.3, 282, 391, 426, 860, 1096 |
| 301.7 | 0.3 | 2222 | 1920 | 184.7(w) |
| 305.9 | 0.2 | 2762 | 2456 | 501(w) |
| 314.2 | 55 | | | 1 h; $^{128}$Sb |
| 331.7 | 1.2 | 2456 | 2124 | 120, 169, 204, 860, 1096 |
| 348.4 | 1.3 | 2352 | 2004 | 104, 178, 2003 |
| 353.3 | 0.3 | 1937 | 1584 | 491, 1584 |
| 357.0 | 0.5 | 1471 | 1114 | 1114 |
| 360.6 | 0.5 | 2501 | 2140 | 203, 220 |
| 362.7 | 1.1 | 2456 | 2093 | 979.2, 998, 1114 |
| 365.5 | 0.5 | 2587 | 2222 | 284, 823 |
| 378.9 | 0.5 | 2530 | 2150 | 1036 |
| 390.5 | 3.3 | 2346 | 1955 | 110, 184.0, 208, 293, 860, 1096 |
| 396.9 | 0.9 | 2352 | 1955 | 104(w), 860, 1096 |
| 404.4 | 3.4 | | | 1 h, $^{128}$Sn-$^{128}$Sb |
| 405.0[e] | 1.2 | 2530 | 2124 | 120, 169, 204, 860, 1096 |
| 407.1 | 4.0 | 2501 | 2093 | 491, 509.0, 979.2, 998, 1093, 1096 1114, 1584 |
| 411.4 | 0.3 | | | $^{127}$Sb |
| 420.7 | 0.4 | | | Not placed |
| 425.7 | 0.6 | 2346 | 1920 | 293, 110(w) |
| 435.7 | 2 | | | 1 h, $^{128}$Sn-$^{128}$Sb |
| 438.2 | 16 | 2358 | 1920 | 141.9, 228 |
| 444.7[e] | 1.2 | 2762 | 2317 | 2317 |
| 446.3[e] | 0.6 | 2587 | 2140 | 203, 220 |
| 452.1 | 1.0 | 2373 | 1920 | 156.9(w), 266 |
| 468.7 | 1.2 | 2406 | 1937 | 232, 823, 1114 |
| 472.6 | 3.2 | | | $^{127}$Sb |
| 482.0 | 31 | | | 1 h, $^{128}$Sn |
| 487.5 | 1.2 | 2805 | 2317 | 2317 |
| 490.9 | 14.0 | 491 | 0 | 353, 407, 493, 509.0, 917, 976.1, 980.3, 1003, 1093, 1135, 1159.2, 1221, 1611, 1813 |
| 493.2 | 8.2 | 2587 | 2093 | 155.6, 491, 509.0, 979.2, 998, 1096, 1114, 1584 |
| 500.7 | 4.0 | 2456 | 1955 | 306(w), 860, 1096 |
| 509.0[e] | 3.8 | 2093 | 1584 | 407, 491, 493, 774(w), 1093, 1584 |
| 509.7[e] | 2.0 | 2447 | 1937 | 823, 1114 |
| 513.9[e] | 0.7 | 2639 | 2124 | 169 |
| 518.2 | 0.5 | 2456 | 1937 | 823 |
| 527.3[g] | 0.4 | | | Sum peak, 46 + 482 keV, $^{128}$Sn |
| 528.5[e-g] | 0.3 | 2631 | 2102 | 2102 |
| 530.6[e-g] | 0.3 | 2805 | 2275 | 1160.4 |
| 539.6[e,f] | 0.6 | 2664 | 2124 | 169 |

TABLE I *(Continued)*

| $E$[a] (keV) | $I$[c] | Transition[b] From | Transition[b] To | Coincident $\gamma$ rays or identification |
|---|---|---|---|---|
| 545.4 | 6.0 | 2501 | 1955 | 195(w), 860, 1096 |
| 557.3 | 8.3 | | | 1 h, $^{128}$Sn |
| 563.4[e] | 0.4 | 2501 | 1937 | 823, 1114 |
| 565.8[e,g] | 0.3 | 2150 | 1584 | 1584 |
| 570.1 | 1.5 | 2664 | 2093 | 979.2, 998(w), 1114 |
| 575.4 | 0.6 | | | >2 h, contamination |
| 583.3 | 8.4 | 2587 | 2003 | 823, 889, 1114, 2003 |
| 592.3 | 5.3 | 2530 | 1937 | 823, 1114 |
| 594.3 | 1.3 | | | 1 h, $^{128}$Sb |
| 602.4 | 1.1 | | | >2 h, contamination; and sum peak, 46+557 keV, $^{128}$Sn |
| 609.5 | 0.8 | 2530 | 1920 | |
| 616.1 | 0.6 | 2554 | 1937 | 823, 1114 |
| 621.9 | 1.2 | 2762 | 2140 | 203, 220 |
| 631.6[e,g] | 1.4 | 2587 | 1955 | 860, 1096 |
| 634.9[e,g] | 0.7 | 2785 | 2150 | 1036 |
| 649.1 | 2.1 | 2587 | 1937 | 823, 1114 |
| 668.6 | 0.5 | 2762 | 2093 | 979.2(w) |
| 680.4 | 6.2 | | | 1 h, $^{128}$Sn-$^{128}$Sb |
| 684.8 | 4.0 | | | $^{127}$Sb |
| 697.5 | 0.4 | | | $^{127}$Sb |
| 702.6 | 0.4 | 2805 | 2102 | 2102 |
| 708.7 | 0.5 | 2664 | 1955 | 860 |
| 743.3 | 57 | | | 1 h, $^{128}$Sb |
| 753.9 | 56 | | | 1 h, $^{128}$Sb |
| 759.1[f,g] | 0.4 | 2762 | 2004 | 2003 |
| 773.7 | 1.1 | 2867 | 2093 | 509.0(w), 979.2, 1114(w) |
| 782.6 | 1.8 | | | $^{127}$Sb |
| 787.7 | 4.5 | | | 1 h, $^{128}$Sb |
| 805.9 | 21.7 | 1920 | 1114 | 1114 |
| 823.1[e] | 28 | 1937 | 1114 | 124(w), 155.6, 184.7, 203, 212.9, 232, 234.3, 279, 284, 366, 469, 509.7, 518, 563, 583, 592, 616, 649, 848(w), 899(w), 930, 1114 |
| 824.7[e] | 16 | 1920 | 1096 | 1096 |
| 844.0 | 1.5 | | | 1 h, $^{128}$Sb |
| 847.6[g] | 0.5 | 2785 | 1937 | 823(w) |
| 859.5 | 21.0 | 1955 | 1096 | 97, 110, 169, 184.0, 184.7, 234.3, 293, 332, 391, 397, 405.0, 501, 545, 632, 709, 912, 1096 |
| 865.0 | 0.9 | 2785 | 1920 | |
| 879.4 | 0.7 | | | >2 h, contamination |
| 889.0 | 0.9 | 2004 | 1114 | 583, 1114 |
| 898.8[g] | 0.5 | 2835 | 1937 | 823(w) |
| 908.3 | 1.3 | | | 1 h, $^{128}$Sb |
| 912.4 | 0.3 | 2867 | 1955 | 860, 1096 |
| 916.5 | 3.1 | 2501 | 1584 | 491, 1093, 1584 |
| 929.7 | 0.9 | 2867 | 1937 | 823, 1114 |
| 976.1[e-g] | 2 | 2447 | 1471 | 491, 980.3, 1471 |
| 979.2[e] | 19 | 2093 | 1114 | 363, 407, 493, 570, 669(w), 774, 1114 |
| 980.3[e,f] | 2 | 1471 | 491 | 491, 976, 1159.2 |
| 981.4 | 1 | | | DE (2003) |
| 997.9 | 5.1 | 2093 | 1096 | 363, 407, 493, 570(w), 1096 |
| 1002.6 | 4.6 | 2587 | 1584 | 491, 1093, 1584 |
| 1027.9 | 0.1 | | | Sum peak, 169+860 keV |
| 1036.1 | 5.2 | 2150 | 1114 | 379, 635, 1114 |
| 1041.0[g] | 0.3 | | | 1 h, $^{128}$Sb |
| 1044.9 | 0.7 | 2140 | 1096 | 1096 |
| 1055.5[e,f] | 0.6 | 2150 | 1096 | 1096 |

TABLE I *(Continued)*

| $E$ [a] (keV) | $I$ [c] | Transition [b] From | To | Coincident $\gamma$ rays or identification |
|---|---|---|---|---|
| 1057 [e-g] | 0.5 | | | Sum peak, 314 + 743 keV, $^{128}$Sb |
| 1064.6 [e-g] | 1.0 | 2160 | 1096 | 1096 |
| 1067.2 | 2.6 | | | $^{125}$Sn; and sum peak, 314 + 754 keV, $^{128}$Sb |
| 1089.0 [f,g] | 1 | | | $^{125}$Sn |
| 1093.3 [e,g] | 10 | 1584 | 491 | 407, 491, 509.0, 917, 1003 |
| 1095.6 [e] | 51 | 1096 | 0 | 97, 110, 169, 184.0, 184.7, 234.3, 293, 332, 391, 397, 405.0, 493, 501, 545, 632, 825, 860, 912, 998, 1045, 1056, 1065, 1179, 1360, 1434, 1458, 1600, 1667, 1710, 1751 |
| 1114.3 | 100 | 1114 | 0 | 155.6, 184.7, 203, 232, 234.3, 279, 284, 357, 363, 407, 469, 493, 509.7, 563, 570, 583, 592, 616, 649, 774(w), 806, 823, 889, 930, 979.2, 1036, 1142, 1160.4, 1237, 1292, 1368, 1473, 1648, 1720, 1753 |
| 1134.5 | 0.3 | 2846 | 1711 | 491, 1221 |
| 1142.0 | 0.5 | 2256 | 1114 | 1114 |
| 1159.2 [e,g] | 2.4 | 2631 | 1471 | 491, 980.3, 1471 |
| 1160.4 [e] | 6.3 | 2275 | 1114 | 255, 531, 1114 |
| 1179.2 | 1.3 | 2275 | 1096 | 1096 |
| 1220.5 | 1.4 | 1711 | 491 | 491, 1135 |
| 1237.4 | 0.3 | 2352 | 1114 | 1114 |
| 1250.1 | 0.1 | | | Sum peak, 391 + 860 keV |
| 1256.2 | 0.2 | | | <2 h, unidentified |
| 1264.0 | 0.2 | | | Sum peak, 169 + 1096 |
| 1283.3 | 0.5 | | | <2 h, unidentified |
| 1292.1 | 2.0 | 2406 | 1114 | 232, 1114 |
| 1295.5 | 0.4 | | | DE (2317) |
| 1310.5 | 0.2 | 2406 | 1096 | |
| 1354.6 | 0.3 | | | <2 h, $^{128}$Sb |
| 1360.3 | 0.4 | 2456 | 1096 | 1096 |
| 1368.4 | 1.4 | 2483 | 1114 | 1114 |
| 1387.1 | 0.1 | | | Sum peak, 407 + 979 keV |
| 1399.0 | 0.1 | | | Sum peak, 284 + 1114 keV |
| 1419.6 | 0.1 | | | $^{125}$Sn |
| 1425.7 | 0.2 | | | DE (2448) |
| 1434.4 | 0.8 | 2530 | 1096 | 1096 |
| 1458.4 [e,g] | 0.7 | 2554 | 1096 | 1096 |
| 1460.3 [g] | 0.3 | | | $^{40}$K, background |
| 1471.2 [e,g] | 2.0 | 1471 | 0 | 976.1, 1159.2 |
| 1472.5 [e] | 3.3 | 2587 | 1114 | 1114 |
| 1491.9 | 0.8 | | | SE (2003) |
| 1497.1 | 0.3 | | | Sum peak, 743 + 754 keV, $^{128}$Sb |
| 1511.4 | 0.2 | | | <2 h, unidentified |
| 1516.2 | 0.2 | | | <2 h, unidentified |
| 1542.7 | 0.2 | 2639 | 1096 | |
| 1551.3 [f] | 0.1 | | | Unidentified |
| 1562.8 | 0.9 | | | DE (2585) |
| 1584.3 | 4.7 | 1584 | 0 | 353, 407, 493, 509.0, 566, 917, 1003 |
| 1600.0 | 0.4 | 2696 | 1096 | 1096 |
| 1610.8 | 0.4 | 2102 | 491 | 491 |
| 1647.8 | 2.7 | 2762 | 1114 | 1114 |
| 1666.5 | 1.3 | 2762 | 1096 | 1096 |
| 1673.7 | 1.1 | | | DE (2696) |
| 1709.9 | 0.7 | 2805 | 1096 | 1096 |
| 1720.0 | 0.5 | 2835 | 1114 | 1114 |
| 1740.8 | 0.5 | | | <2 h, unidentified |
| 1750.7 [e,g] | 0.5 | 2846 | 1096 | 1096 |

TABLE I *(Continued)*

| $E$[a] (keV) | $I$[c] | Transition[b] From | To | Coincident $\gamma$ rays or identification |
|---|---|---|---|---|
| 1752.8[e,g] | 0.7 | 2867 | 1114 | 1114 |
| 1771.2 | 0.3 | | | <2 h, unidentified |
| 1783.4 | 0.3 | | | DE (2806) |
| 1806.3 | 0.2 | | | SE (2317) |
| 1812.8 | 0.3 | 2304 | 491 | 491 |
| 1824.1 | 0.9 | | | DE (2846) |
| 1858.5 | 0.2 | | | DE (2881) |
| 1898.1 | 0.2 | | | <2 h, unidentified |
| 1919.8 | 0.1 | | | Sum peak, 806 + 1114 keV and 825 + 1096 keV |
| 1936[g] | 0.1 | | | SE (2448) |
| 1937.3 | 0.2 | 1937 | 0 | |
| 1974.6 | 0.2 | | | >2 h, contamination |
| 2003.4 | 14.0 | 2004 | 0 | 104, 272, 348, 583, 759 |
| 2073.5 | 0.5 | | | SE (2585) |
| 2093.3 | 0.2 | 2093 | 0 | |
| 2102.4 | 1.3 | 2102 | 0 | 215, 529, 703 |
| 2126.5[f] | 0.07 | | | Unidentified |
| 2150.3 | 0.09 | 2150 | 0 | |
| 2160.0 | 0.8 | 2160 | 0 | |
| 2184.5 | 0.6 | | | SE (2696) |
| 2294.3 | 0.1 | | | SE (2806) |
| 2304.2 | 0.3 | 2304 | 0 | |
| 2317.4 | 2.9 | 2317 | 0 | 445, 488 |
| 2335.1 | 0.4 | | | SE (2846) |
| 2369.7 | 0.1 | | | SE (2881) |
| 2389.5 | 0.3 | 2881 | 491 | |
| 2447.5 | 0.9 | 2447 | 0 | |
| 2470.0 | 0.3 | 2470 | 0 | |
| 2513.9 | 0.3 | 2514 | 0 | |
| 2584.9 | 4.1 | 2585 | 0 | |
| 2614.2 | 0.2 | | | ThD, background |
| 2695.9 | 4.3 | 2696 | 0 | |
| 2805.7 | 1.0 | 2805 | 0 | |
| 2846.4 | 2.5 | 2846 | 0 | |
| 2881.1 | 0.7 | 2881 | 0 | |

[a] Unless otherwise stated, uncertainty in energies is 0.3 keV below about 100 keV, 0.4 keV between about 100 and 1800 keV, and 0.5 keV at energies above this.
[b] In $^{127}Sb$ unless otherwise indicated; $\gamma$-ray half-lives are within 15% of 2.2 h.
[c] Uncertainty in relative $\gamma$-ray intensities is 10% or 0.1, whichever is greater. For $\gamma$ rays below 100 keV, uncertainty is 20%.
[d] The 1-h half-life $\gamma$ rays were from the transient-equilibrium decay of 1-h $^{128}Sn$ and 10-min $^{128}Sb$. Specific assignments for these $\gamma$ rays were made where possible.
[e] $\gamma$-ray energy and relative intensity were determined from coincidence spectra. Uncertainty in relative intensity is 20% or 0.2, whichever is greater.
[f] $\gamma$-ray intensity was too low to permit half-life determination.
[g] Uncertainty in energy is 0.7 keV.

TABLE II. Theoretical half-lives (Ref. 28) for the 806-, 825-, and 1920-keV $\gamma$ rays.

| $E_\gamma$ (keV) | Multipolarity $E1$ | $M1$ | $E2$ | $M2$ | $E3$ | $M3$ | $E4$ | $M4$ |
|---|---|---|---|---|---|---|---|---|
| 806 | 0.52 fsec | 46 fsec | 43 psec | 0.96 nsec | 5.7 $\mu$sec | 57 $\mu$sec | 1.1 sec | 6.2 sec |
| 825 | 0.49 fsec | 43 fsec | 38 psec | 0.86 nsec | 4.9 $\mu$sec | 48 $\mu$sec | 0.87 sec | 5.1 sec |
| 1920 | 0.039 fsec | 3.4 fsec | 0.56 psec | 13 psec | 13 nsec | 0.13 $\mu$sec | 0.44 msec | 2.5 msec |

Auble, Ball, and Fulmer.[4] The two states at 1096 and 1114 keV are established by the strong intensities of two $\gamma$ rays of those energies and the absence of any coincidences between them (see Fig. 5).

The level at 1471 keV is placed on the basis of the 491- by 980-, 976- by 980-, 976- by 1471-, and 980- by 1159-keV coincidences as well as the absence of the 1471.2-keV ray in coincidence spectra for the 491-, 1096-, and 1114-keV $\gamma$ rays. The levels of 1584 and 1711 keV are placed on the basis of strong 491- by 1093- and 491- by 1221-keV $\gamma$-ray coincidences and the absence of the 1093- and 1221-keV $\gamma$ rays in 1096- and 1114-keV gates.

Of the 44 levels above 1.8 MeV, 16 are established by the presence of $\gamma$ rays whose energy values are too large to feed into the states at 1096 or 1114 keV. Although several of these $\gamma$ rays are low enough in energy to populate the level at 491 keV, no coincidences were observed for these $\gamma$ rays, and the intensity of the 491-keV $\gamma$ ray is accounted for by the $\gamma$ rays that were observed in its coincidence spectrum. These levels are located at 1937, 2004, 2093, 2102, 2150, 2160, 2304, 2317, 2447, 2470, 2514, 2585, 2696, 2805, 2846, and 2881 keV. From coincidence spectra, an additional 15 levels located at 1920, 1955, 2140, 2256, 2275, 2352, 2406, 2456, 2483, 2530, 2554, 2587, 2762, 2835, and 2867 keV are determined to feed one or both of the levels at 1096 and 1114 keV.

Of the remaing 13 levels, 12 are established by two or more observed coincidences. Coincidence of the $\gamma$ rays at 284, 563, and 848 keV with the 823-keV $\gamma$ ray establishes levels at 2222, 2501, and 2785 keV, respectively. Coincidences of the $\gamma$ rays at 169, 391, and 709 keV with the 860-keV $\gamma$ ray establish levels at 2124, 2346, and 2664 keV, respectively. The level at 2631 keV is established by the observed coincidence of the 1159-keV $\gamma$ ray and 1471-keV $\gamma$ ray, and the level at 2639 keV is established by the strong 232- by 1292-, 266- by 263-, and 293- by 391-keV $\gamma$-ray coincidences.

The levels at 2110, 2202, and 2358 keV decay predominantly to the isomer at 1920 keV, although delayed-coincidence evidence is available only for the 438-keV $\gamma$ ray which depopulates the 2358-keV

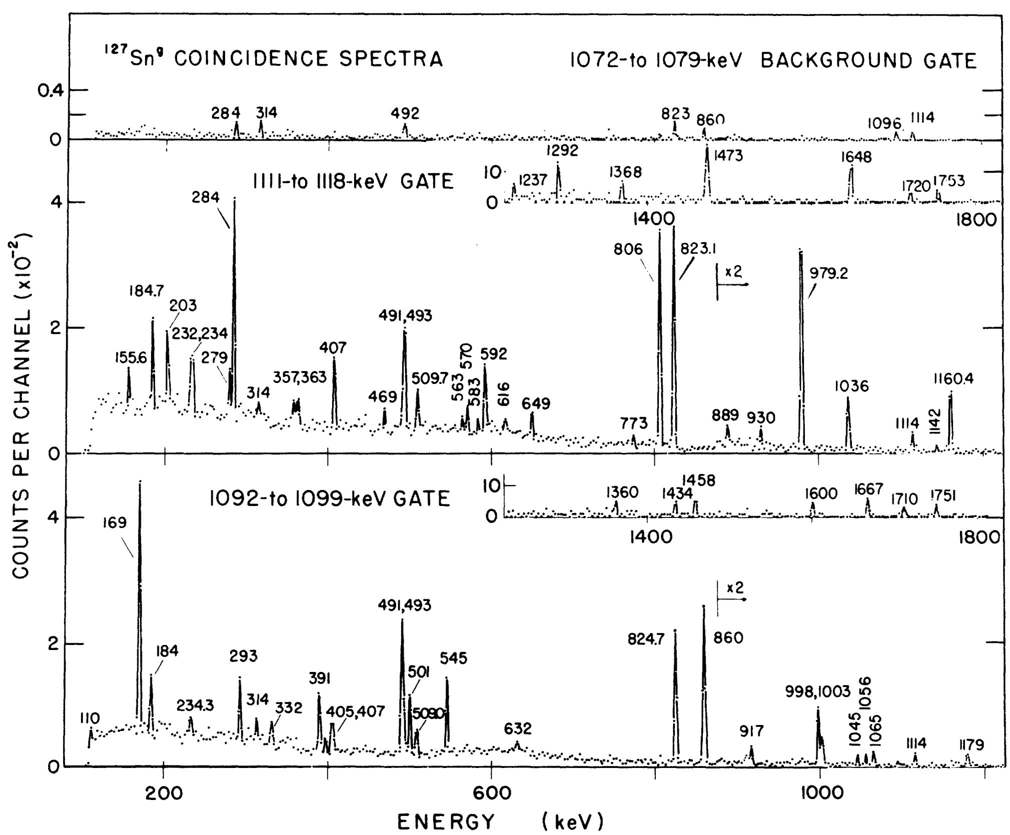


FIG. 5. The $^{127}$Sn$^g$ 26-cm$^3$ Ge(Li) spectra coincident with the 1072- to 1079-keV, 1111- to 1118-keV, and 1092- to 1099-keV regions of the 45-cm$^3$ Ge(Li) spectrum.

level. Prompt coincidences between the 438-keV $\gamma$ ray and the 142- and 228-keV $\gamma$ rays were also observed. The 190-keV $\gamma$ ray depopulating the 2110-keV level is in coincidence with the $\gamma$ rays at 235 and 263 keV, and the 212- and 282-keV $\gamma$ rays depopulating the 2202-keV level are in coincidence with $\gamma$ rays at 144 and 293 keV. The level at 2373 keV decays predominantly to the isomeric and the 2110-keV levels. The 452- and 263-keV $\gamma$ rays which depopulate the 2373-keV level are coincident with the 157- and 266-keV $\gamma$ rays.

The placement of a level at 1991 keV is dictated by the strong coincidences between the 120-, 263-, and 266-keV $\gamma$ rays. Other consistent coincidence evidence established the placement of the 266- and 263-keV $\gamma$ rays as depopulating levels at 2639 and 2373 keV, respectively. As the 120-keV $\gamma$ ray cannot be placed as feeding the 2639-keV level, it must proceed from the 2110-keV level to the 1991-keV level. A weak $\gamma$ ray is observed in singles spectra at 70 keV and is placed between the 1990-keV level and the isomer at 1920 keV. No coincidence data were observed for the 70-keV $\gamma$ ray because of the lower level energy cutoff. As the 70-keV transition must be sufficiently internally converted to carry the intensity of the 266-, 263-, and 120-keV $\gamma$-ray cascade,[27] it must therefore be delayed,[28, 29] and the lifetime of the nuclear level must be $\gtrsim 1$ $\mu$sec. Because of the observed prompt coincidences between the 120-keV $\gamma$ ray and the 263- and the 266-keV $\gamma$ rays, the reverse placement of the 120- and 70-keV $\gamma$ rays (with a resulting level at 2040 keV) can be precluded.

The absolute percentage strengths of the $\beta$ transitions to $^{127}$Sb levels have been determined by establishing the relative amount of $^{127}$Sb daughter in a 2.2-h $^{127}$Sn sample at several parent half-lives past the last Sb chemical separation. By observing the relative $\gamma$-ray activity from the $^{127}$Sn source and deducing the total relative $^{127}$Sn activity from the equations of radioactive decay and growth, it is found that $(22 \pm 8)\%$ of the 2.2-h $^{127}$Sn decays proceed to the ground state of $^{127}$Sb.

## V. SPIN AND PARITY ASSIGNMENTS

The spin and parity assignments of the isomers of $^{127}$Sn are proposed on the basis of systematic trends, the yields in the $(n, \alpha)$ reactions, and the $\beta$-decay patterns of the two isomers. Systematic evidence strongly favors two $^{127}$Sn isomers with spins of $\frac{11}{2}^-$ and $\frac{3}{2}^+$. Such isomers are observed in isotopic $^{123}$Sn and $^{125}$Sn and isotonic $^{129}$Te. Furthermore, if the lowering of the $\frac{11}{2}^-$ level with respect to the $\frac{3}{2}^+$ level continues in $^{127}$Sn as it has

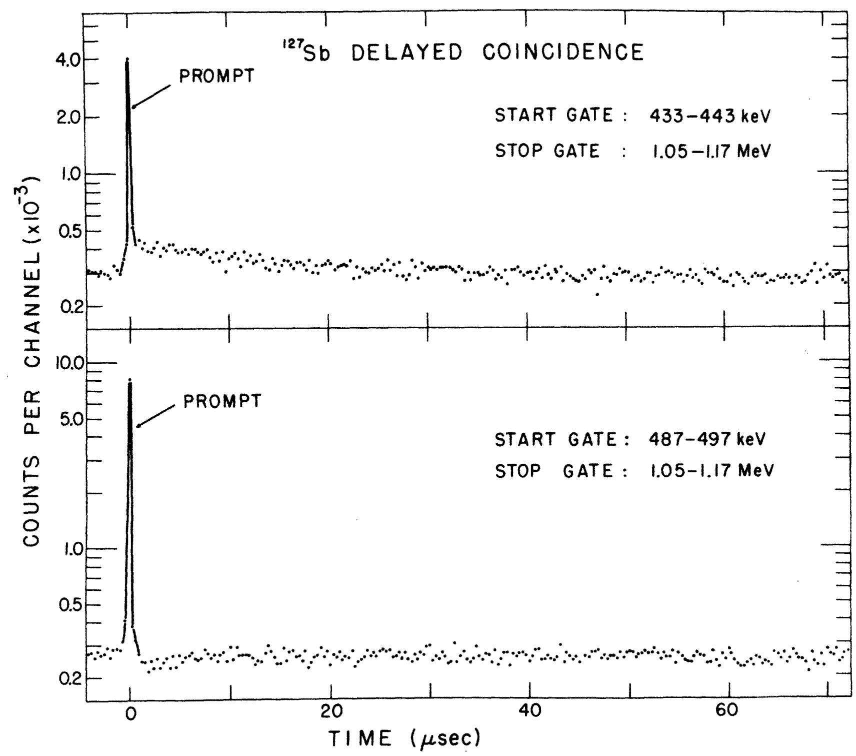


FIG. 6. Time spectra obtained in the half-life determination for the 1920-keV isomeric level in $^{127}$Sb.

for the tin isotopes 117 through 125, then it follows that the low-spin isomer is the excited state and probably lies no more than ≈0.1 MeV above the ground state. The short-lived 4-min isomer was found by Kauranen[19] to be formed predominantly in the $^{130}$Te($n$, $\alpha$)$^{127}$Sn reaction and to decay strongly to the 491-keV level in $^{127}$Sb whose spin and parity of $\frac{5}{2}^+$ are established by the $^{128}$Te($d$, $^3$He)-$^{127}$Sb studies by Auble, Ball, and Fulmer.[4] Hence it is clearly the $\frac{3}{2}^+$ isomer. The long-lived isomer observed in this study showed no $\beta$ decay to the $\frac{5}{2}^+$ level at 491 keV but showed a (22 ± 8)% branch to the $\frac{7}{2}^+$ ground state of $^{127}$Sb. The resultant log$ft$ value of 8.0 is consistent with a first-forbidden unique $\beta$ transition of ≈3.1 MeV and thus with an $\frac{11}{2}^-$ assignment for 2.2-h $^{127}$Sn. Additional levels were observed at 776 ± 10 keV ($\frac{3}{2}^+$), 1180 ± 10 keV ($\frac{1}{2}^+$), 2260 ± 10 keV ($\frac{9}{2}^+$), 2530 ± 10 keV ($\frac{1}{2}^-$), and 2790 ± 10 keV ($\frac{3}{2}^-$) by Auble, Ball, and Fulmer[4] but are not clearly identified with any of the levels observed in this work.

The levels at 1096 and 1114 keV are restricted to spin and parity values of $\frac{7}{2}^+$, $\frac{9}{2}^+$, and $\frac{11}{2}^+$ by their prompt $\gamma$ transitions to the ground state, the lack of observed $\beta$ feeding in the decay of the 4-min $\frac{3}{2}^+$ $^{127}$Sn isomer,[19, 23] and their $\gamma$ feeding from numerous higher-lying levels with spin values of $\frac{9}{2}$, $\frac{11}{2}$, or $\frac{13}{2}$. The levels at 1471, 1584, and 1711 keV are further restricted to only $\frac{7}{2}^+$ or $\frac{9}{2}^+$ assignments by their $\gamma$ branching to the $\frac{5}{2}^+$ level at 491 keV. Levels exist in $^{125}$Sb at similar energies and show similar $\gamma$ feeding and decay properties. Angular-correlation studies in $^{125}$Sb have

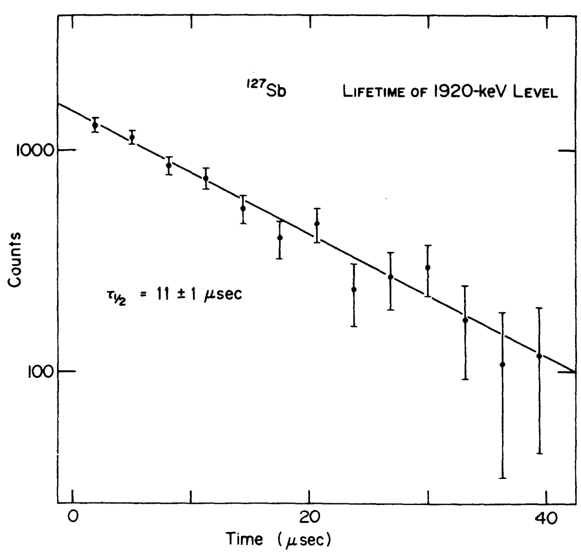


FIG. 7. Time spectrum obtained in the half-life determination for the 1920-keV isomeric level in $^{127}$Sb after having corrected for random events.

established spins and parities of $\frac{7}{2}^+$, $\frac{9}{2}^+$, and $\frac{7}{2}^+$ for the levels similar to the levels in $^{127}$Sb at 1471, 1584, and 1711 keV, respectively. In addition to this systematic evidence, we favor these assignments in $^{127}$Sb for reasons that are statistical in nature. Some 40 levels of $^{127}$Sb are known above 1900 keV, most of which are restricted to spin values of $\frac{9}{2}$, $\frac{11}{2}$, and $\frac{13}{2}$ by the log$ft$ values (≤8) of the feeding $\beta$ transitions from the $\frac{11}{2}^-$ $^{127}$Sn parent. From such levels, transitions to a $\frac{7}{2}^+$ level would require generally larger angular momentum change and should be less likely than transitions to $\frac{9}{2}^+$ and $\frac{11}{2}^+$ levels. The proposed $\frac{7}{2}^+$ levels at 1711 and 1471 keV are fed by only one and two $\gamma$ transitions, respectively, whereas the proposed $\frac{9}{2}^+$ level at 1584 keV is fed from five levels. Similarly the levels at 1096 and 1114 keV are fed by 15 and 14 transitions, respectively, which suggests their assignments are $\frac{9}{2}^+$ or $\frac{11}{2}^+$. We also note the presence of two isolated levels near 1 MeV in $^{123}$Sb and $^{125}$Sb with respective assignments of $\frac{9}{2}^+$ and $\frac{11}{2}^+$, in good agreement with theory.[30] Thus, we suggest that the levels in $^{127}$Sb at 1096 and 1114 keV correspond to these two levels.

We have proposed spin and parity of $\frac{15}{2}^-$ for the 11-$\mu$sec isomer of $^{127}$Sb at 1920 keV. In Table II are listed the theoretical single-particle half-lives for decay of the 1920-keV level by various multipole transitions.[28] Spin and parity values for the isomer of $\leq \frac{11}{2}^\pm$ and $\geq \frac{17}{2}^+$ are readily excluded because of the observed $\gamma$-ray deexcitation patterns and because of very strong contradictions between observed and theoretical partial half-lives.[29] However, the selection among the $\frac{13}{2}^\pm$ and $\frac{15}{2}^\pm$ possibilities is more complex. We observed approximately equal transition rates from the isomer to the levels at 1096 and 1114 keV, one of which is presumably $\frac{9}{2}^+$ and the other $\frac{11}{2}^+$. The $\frac{13}{2}^\pm$ possibilities for the isomer are not favored as the $M1$ or $E1$ transition to the $\frac{11}{2}^+$ state near 1.1 MeV would be hindered by 9 and 11 orders of magnitude, respectively. Equally significant is an $E2$ hindrance of ≈$10^6$ from a $\frac{13}{2}^+$ level to the $\frac{9}{2}^+$ level.

A choice of $\frac{15}{2}^+$ would mean a hindrance of ≈$10^6$ for the $E2$ transition to the $\frac{11}{2}^+$ level. Consequently, a $\frac{15}{2}^+$ assignment is unacceptable. Alternatively, a choice of $\frac{15}{2}^-$ would require nearly equal lifetimes from competing $M2$ and $E3$ transitions. The $E3$ hindrance is calculated to be ≈4 and the $M2$ hindrance ≈$2 \times 10^4$. The choice of $\frac{15}{2}^-$ is thus most consistent with known trends concerning observed and theoretical $\gamma$-transition rates.[28, 29]

Spin and parity assignments for the remainder of the observed $^{127}$Sb levels are made where possible and are based on the following: (1) log$ft$

values; (2) $\gamma$ transitions to the $\frac{7}{2}^+$ ground state; (3) $\gamma$ transitions to both the 1096- and 1114-keV levels, at least one of which is presumed to be a $\frac{9}{2}^+$ level; (4) $\gamma$ transitions to the $\frac{5}{2}^+$ first excited level; and (5) $\gamma$ transitions to the $\frac{15}{2}^-$ isomeric level. Those $\beta$ transitions whose $\log ft$ values were $\leqslant 5.9$ were assumed to be allowed transitions with $\Delta J = 0$, 1 and $\Delta\pi$ = no. The $J^\pi$ values so determined are shown in Figs. 8 and 9. The levels at 1937, 2004, and 2093 keV show $\beta^-$ and $\gamma$-decay characteristics remarkably similar to levels in $^{125}$Sb at 1982 keV ($\frac{11}{2}^+$), 2002 keV ($\frac{9}{2}^+$, $\frac{11}{2}^+$), and 1890 keV ($\frac{11}{2}^-$), respectively, and have been tentatively assigned the respective $J^\pi$ values.

## VI. DISCUSSION

Our study of the decay of the $\frac{11}{2}^-$ isomer of $^{127}$Sn has offered an opportunity to examine the character of a large number of states of $^{127}$Sb above $\approx$2 MeV. Owing to the $\approx E^5$ dependence of $\beta$-decay transition rates, the decay of most nuclides involves mainly the population of low-lying states. Consequently very few data have been available as to the density or character of the states of odd-mass Sb nuclides above the neutron pairing energy. In the decay of $\frac{11}{2}^-$ $^{127}$Sn, however, it has been possible to observe $\beta$ branching to 40 states above 1.9 MeV.

Theoretical description of the lower-lying particle-plus-phonon levels has been given by Vanden Berghe and Heyde.[30] Their intermediate-coupling calculations have been found to fit rather well the positions of the lower-lying levels and to account for many of the observed transition rates. At higher energies, however, they utilized only the coupling of the proton to various combinations of quadrupole and octupole collective states. The predicted density of states resulting from this calculation is far lower than the observed density. It is clearly not possible to interpret the structure of the isomeric state, the high level density, the $\beta$-decay properties, and the $\gamma$-decay properties of the levels of $^{127}$Sb utilizing only particle-plus-core

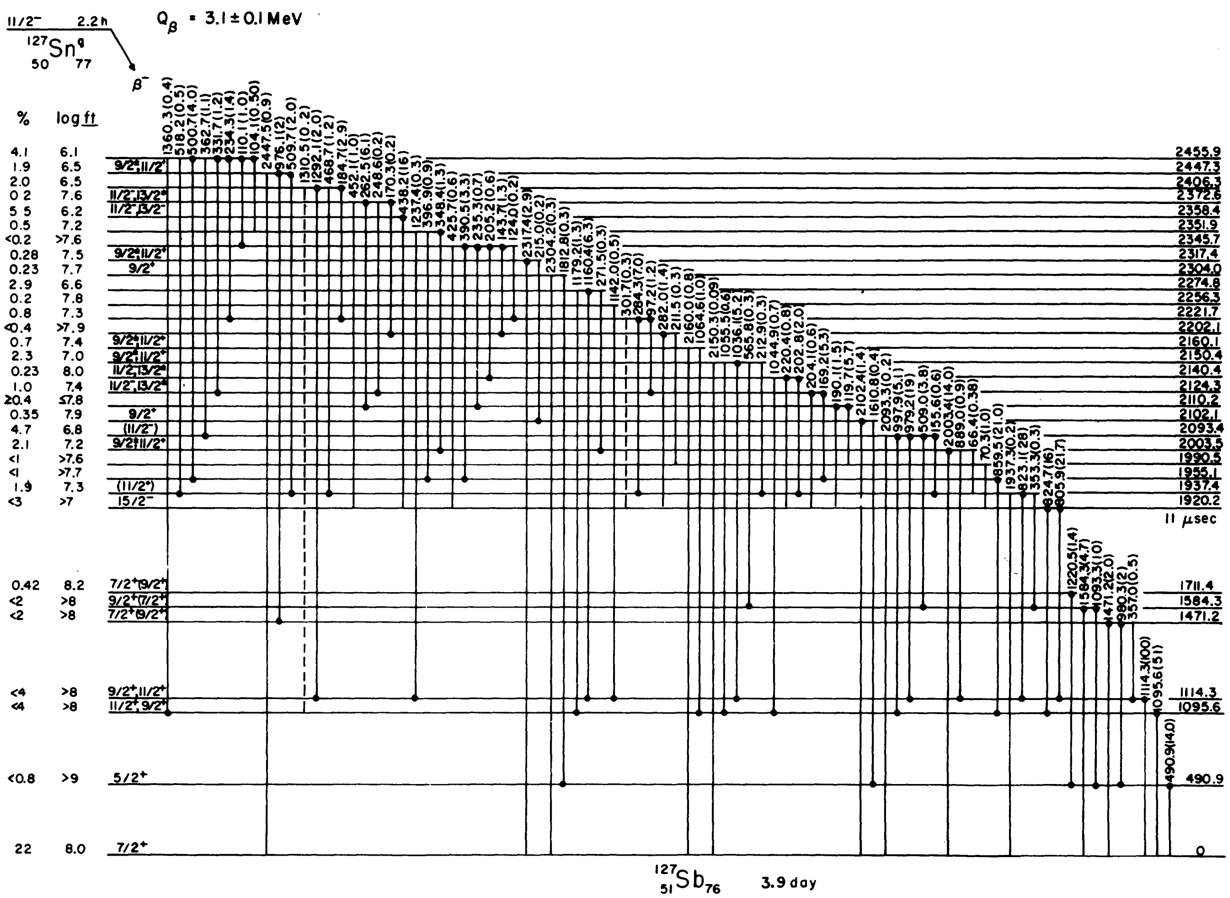


FIG. 8. The partial decay scheme of 2.2-h $^{127}$Sn$^g$ including $\beta$ feedings to levels between ground and 2456 keV.

excitations. Only by including coupling of the proton to the neutron two-quasiparticle levels can many of the features observed in $^{127}$Sb be qualitatively understood.

Flynn, Beery, and Blair[31] have investigated the structure of $^{126}$Sn through the $^{124}$Sn$(t,p)^{126}$Sn reaction. The first excited state is $2^+$ and lies at 1145 keV, and the second, a $5^-$ level, lies at 2054 keV. The structure of the $\frac{15}{2}^-$ isomer can thus be readily understood as the $g_{7/2}$ proton coupled to the $5^-$ state in the $^{126}$Sn core. The $\gamma$ decay of the isomer to the $\frac{9}{2}^+$ and $\frac{11}{2}^+$ states, in which the $E3$ rate to the $\frac{9}{2}^+$ state is near the single-particle rate and the decay to the $\frac{11}{2}^+$ state also appears to be $E3$, can be interpreted as just the decay of the $5^-$ state in the core to the $2^+$ core state.

The more quantitative question of why the $\frac{15}{2}^-$ state is lower than the other $\pi\nu_1\nu_2$ configurations (the $\frac{17}{2}^-$ in particular) remains to be answered. It is possible that admixture of the $[\pi d_{5/2}(\nu_1\nu_2)_{5^-}]_{15/2^-}$ configuration may be responsible for the lowered position of the $\frac{15}{2}^-$ isomer.

We show in Table III the spins, parities, and configurations expected in $^{126}$Sn between $\approx 2$ and $\approx 3$ MeV. Not all 20 states have been identified in $^{126}$Sn; however, an examination of the structure of $^{124}$Sn and $^{122}$Sn indicates[31, 32] that most of these states are present. In Table IV we show the resultant density of states formed by coupling a $g_{7/2}$ or $d_{5/2}$ proton to the states shown in Table III. 78 states are postulated with spins of $\frac{9}{2}$, $\frac{11}{2}$, and $\frac{13}{2}$ that might lie within 3 MeV of the $^{127}$Sn ground state. Thus the 40 states we observe are about half of the postulated states that could be fed by $\beta$ decay by allowed or first-forbidden nonunique transitions.

The mechanism for $\beta$ decay of the $\frac{11}{2}^-$ isomer to the three-particle $\pi\nu_1\nu_2$ states is viewed simply as a single-particle jump from a core neutron orbital ($\nu_1$) near the Fermi level to the final-state proton orbital, $\pi$, with the initial-state $h_{11/2}$ neutron ($\nu_2$) remaining unchanged. From an examination of the various possible decay paths, we conclude that the strongest $\beta$ transitions should be the allowed transitions to the 12 negative-parity states with

$$[\pi d_{5/2}(\nu_1 d_{3/2}\nu_2 h_{11/2})_{4^-,5^-,6^-,7^-}]_{9/2^-,11/2^-,13/2^-}$$

configurations, the configuration of the initial state being $[(\nu_1 d_{3/2}\nu_1 d_{3/2})_0\nu_2 h_{11/2}]$. We have, in

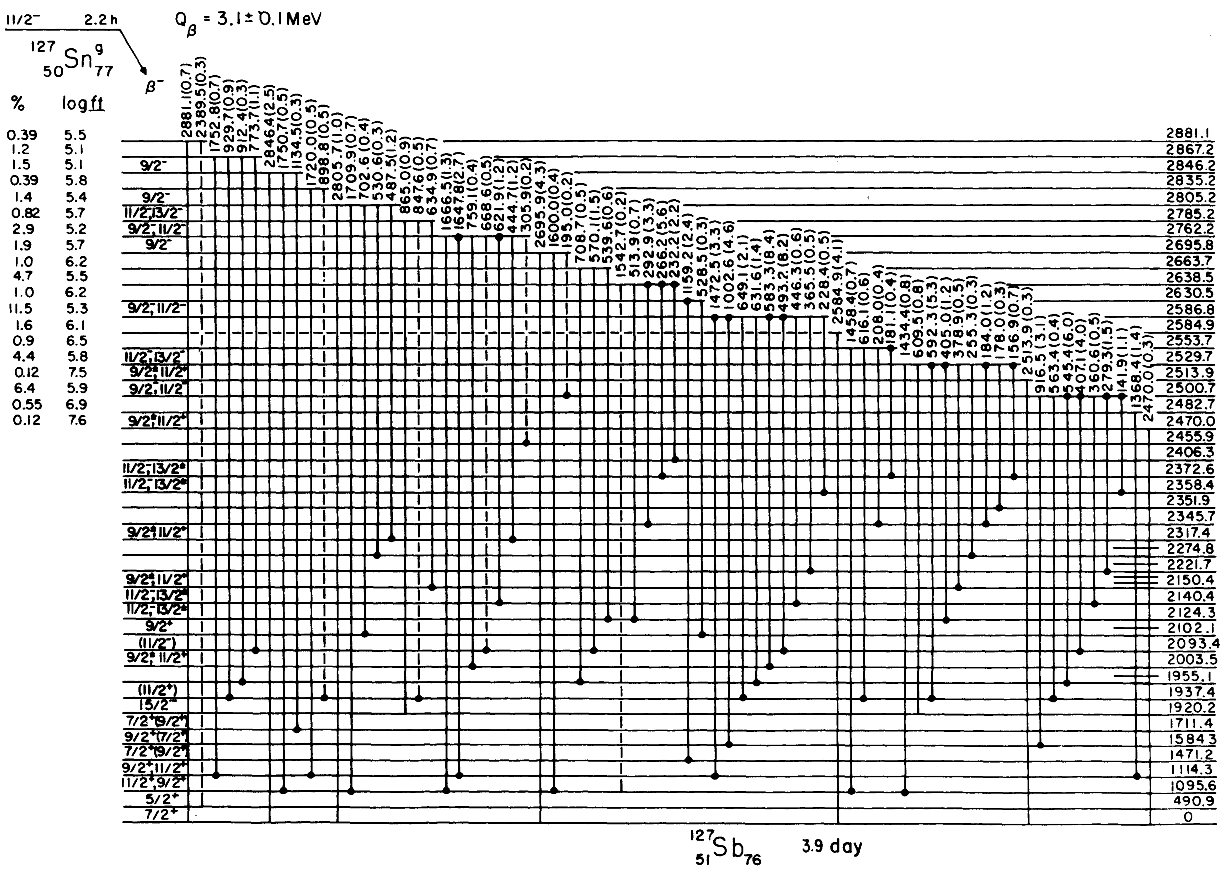


FIG. 9. The partial decay scheme of 2.2-h $^{127}$Sn$^g$ including $\beta$ feedings to levels from 2470 to 2881 keV.

TABLE III. Possible states in $^{126}$Sn between ≈2 and ≈3 MeV.

| Neutron configuration or type of excitation | $J^\pi$ of resultant states | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $(1h_{11/2})^2$ | $0^+$ | | $2^+$ | | $4^+$ | | $6^+$ | | $8^+$ | $10^+$ |
| $(2d_{3/2})^2$ | $0^+$ | | $2^+$ | | | | | | | |
| $(3s_{1/2})^2$ | $0^+$ | | | | | | | | | |
| $(1h_{11/2}2d_{3/2})$ | | | | | $4^-$ | $5^-$ | $6^-$ | $7^-$ | | |
| $(1h_{11/2}3s_{1/2})$ | | | | | | $5^-$ | $6^-$ | | | |
| $(2d_{3/2}3s_{1/2})$ | | $1^+$ | $2^+$ | | | | | | | |
| Two phonon | $0^+$ | | $2^+$ | | $4^+$ | | | | | |
| Octupole | | | | $3^-$ | | | | | | |

fact, identified 12 states with log$ft$ values ≤5.9 (i.e., allowed transitions), although it is somewhat presumptuous to suggest that these are the same states as the 12 indicated above.

The $\frac{15}{2}^-$ isomer is fed from 10 levels. Of these 10, only 2 have observable $\gamma$ branches to the particle-plus-phonon levels below 1.9 MeV (both to the 1095.6-keV state). On the other hand, 32 of the 33 levels which do not feed the isomer have branches to the particle-plus-phonon states. Only the level at 2663.7 keV decays exclusively to levels above the isomer. Furthermore, the lower levels that feed the isomer are themselves fed by the higher-lying levels that also feed the isomer.

Although one expects a certain amount of configuration mixing of the states above 1.9 MeV, it still appears possible to identify particular states in some cases. For example, the state at 2358.4 keV is both strongly fed by $\beta$ decay and decays solely to the isomer and is very likely a $(\pi d_{5/2}\nu_1 d_{3/2}\nu_2 h_{11/12})_{13/2^-}$ state. Also, the 1990.5-keV state which is not fed by $\beta$ decay, and is fed by $\gamma$ decay only by two states that also feed the isomer, may be the $(\pi g_{7/2}\nu_1 d_{3/2}\nu_2 h_{11/2})_{17/2^-}$ state.

TABLE IV. Distribution of states of $^{127}$Sb predicted by zeroth-order core coupling. The excitation states of the $^{126}$Sn core are assumed to be those given in Table III and the valence proton is given the $1g_{7/2}$ and $2d_{5/2}$ shell-model orbitals from which to couple to the core.

| $J^\pi$ | Number | $J^\pi$ | Number |
|---|---|---|---|
| $\frac{1}{2}^+$ | 6 | $\frac{1}{2}^-$ | 3 |
| $\frac{3}{2}^+$ | 13 | $\frac{3}{2}^-$ | 6 |
| $\frac{5}{2}^+$ | 18 | $\frac{5}{2}^-$ | 10 |
| $\frac{7}{2}^+$ | 19 | $\frac{7}{2}^-$ | 13 |
| $\frac{9}{2}^+$ a | 16 | $\frac{9}{2}^-$ b | 14 |
| $\frac{11}{2}^+$ a | 12 | $\frac{11}{2}^-$ b | 14 |
| $\frac{13}{2}^+$ a | 9 | $\frac{13}{2}^-$ b | 13 |
| $\frac{15}{2}^+$ | 8 | $\frac{15}{2}^-$ | 11 |
| $\frac{17}{2}^+$ | 6 | $\frac{17}{2}^-$ | 8 |
| $\frac{19}{2}^+$ | 5 | $\frac{19}{2}^-$ | 4 |
| $\frac{21}{2}^+$ | 4 | $\frac{21}{2}^-$ | 1 |
| $\frac{23}{2}^+$ | 3 | | |
| $\frac{25}{2}^+$ | 2 | | |
| $\frac{27}{2}^+$ | 1 | | |

[a] States that could conceivably be fed by first-forbidden nonunique $\beta$ decay from $\frac{11}{2}^-$ $^{127}$Sn$^g$.

[b] States that could conceivably be fed by allowed $\beta$ decay from $\frac{11}{2}^-$ $^{127}$Sn$^g$.

Our results offer a challenge to the theorists to account for both the positions and $\gamma$ branchings of the levels observed in $^{127}$Sb. Presumably, in order to obtain a reasonably good fit to the experimental results below 2 MeV, it will be necessary to employ a model at least as complex as the unified model used by Vanden Berghe and Heyde.[30] To fit the positions and branchings of the levels above 2 MeV a wider basis set of states would undoubtedly be necessary.

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