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Decay of ^{126}Sn and of the 19-min and 12.4-day Isomers of ^{126}Sb†

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The γ radiations of $\approx 10^5$-yr ^{126}Sn and of the ^{126}Sb isomers have been studied with NaI(Tl) scintillation spectrometers and Ge(Li) detectors. β-ray spectra were measured with a *trans*-stilbene scintillation unit, and conversion electrons were examined with Si(Li) detectors. The decay of ^{126}Sn involves a 0.25 ± 0.03-MeV β transition followed by 21.6-, 23.4-, 42.7-, 64.4-, and 87.7-keV γ transitions in ^{126}Sb. The 23.4- and 87.7-keV transitions are in prompt coincidence with the β rays; the 64.4-keV and either the 21.6- or 42.7-keV transitions deexcite an intermediate delayed level with $t_{1/2} = 0.5 \pm 0.1$ μsec. Both the 19-min and the 12.4-day isomers of ^{126}Sb have essentially the same 1.90 ± 0.15-MeV maximum β-ray endpoint energy; however, the β spectrum of the latter is more complex (intense inner groups). The 19-min isomer decays by β emission (86%) to excited levels in ^{126}Te and by ≲31-keV isomeric transition (14%) to the 12.4-day ground state. The ^{126}Te excited levels involved in the decay of both ^{126}Sb isomers are at 665(2^+), 1359(4^+), 1774(6^+), 2215, 2395, 2494, 2514, 2702, 2761, 2834, 3086, 3187, and 3413 keV. Spin and parity assignments of 5^+ and 8^- are proposed for the 19-min and 12.4-day isomers, respectively. The total β-disintegration energy of the ^{126}Sb ground state is 3.67 ± 0.15 MeV.

I. INTRODUCTION

The discovery of long-lived ($\approx 10^5$ yr) ^{126}Sn was reported[1] in 1958, along with the observation that a 19-min[2,3] and a longer-lived[3,4] (12.4-day) ^{126}Sb daughter grew into secular equilibrium with the decaying tin parent. In succeeding years stronger sources of ^{126}Sn became available from various large fission-product samples. In 1962, in a summary paper[5] on some fission-product tin and antimony isotopes, the results of a preliminary scintillation-spectrometer study of the ^{126}Sb isomers were reported. In the case of ^{126}Sn, only its approximate half-life and three γ rays measured with NaI(Tl) were reported.[1,5] The following year a more detailed presentation of the ^{126}Sb data, including our proposed decay schemes, was given.[6]

During this period Horen *et al.*[7] and Lange[8] were investigating the decay of the ^{126}Sb isomers produced by the (n,p) reaction on enriched ^{126}Te or by fission of ^{235}U. These studies, employing β- and γ-scintillation spectrometry, gave results in good general agreement with our work with regard to half-lives, β endpoints, and principal γ-ray energies. Some disagreement existed, however, regarding the antimony and tellurium level placements and assignments as proposed by Horen *et al.*[7]

Gujrathi *et al.*[9] have also investigated the decay of 19-min ^{126}Sb produced by bombardment of enriched ^{126}Te with 14.5-MeV neutrons. They report some γ rays which we do not observe. These γ rays are apparently due to both sum peaks and contamination.

The excited levels of ^{126}Te have been studied in work[10-12] on the decay of ^{126}I, in Coulomb excitation[13,14] and inelastic particle scattering experiments[15-17] with ^{126}Te, and by the ^{124}Sn$(\alpha, 2n\gamma)$ reaction.[18-20]

The present study represents an effort to add to and improve upon our earlier measurements of the radiations of ^{126}Sn and ^{126}Sb by making use of high-resolution Ge(Li) and Si(Li) detectors. Also, by means of an isotopically separated ^{126}Sn source, it was possible to study the mass-126 radioactivities without interference from the intense radiations from $\approx$50-yr ^{121m}Sn present in all fission-product tin samples. This source was essentially mass free, thus permitting high-resolution electron studies.

The present data confirm and extend our earlier reported level scheme but remain in disagreement with the ^{126}Sb level assignments proposed by Horen *et al.*[7]

II. EXPERIMENTAL: ^{126}Sn

A. Source Preparation

Our first ^{126}Sn sources were prepared by radiochemically separating the tin fraction from some 12-yr-old "water boiler" reactor fuel which was in the form of concentrated uranyl nitrate solu-

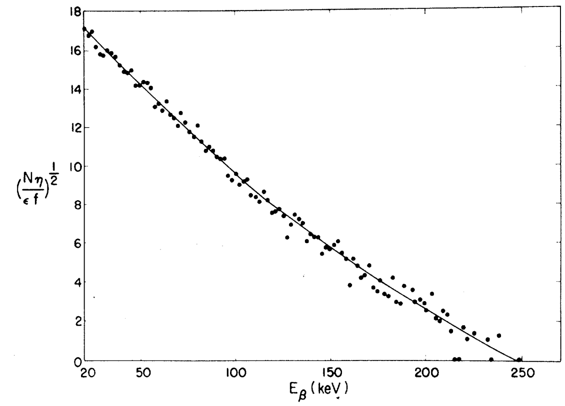

FIG. 1. Fermi-Kurie plot of the ^{126}Sn β-ray spectrum measured with a $\frac{5}{8}$-in.-thick by $1\frac{1}{2}$-in.-diam *trans*-stilbene scintillation spectrometer gated by 87.7-keV γ-ray events. The end-point energy is 0.25 ± 0.03 MeV.

tion that had undergone 10^{17} fissions/ml. From this solution, with tin carrier added, the tin was separated as the sulfide, decontaminated from antimony by many strong acid Sb_2S_3 scavenging steps and finally distilled as $SnBr_4$. The distillate, which contained a radiochemically pure mixture of ^{121m}Sn and ^{126}Sn activities, was generally used for preparing pure samples of the ^{126}Sb isomers.

Another much larger tin source was prepared, in the above manner, from a 2-yr-old solution of the relatively volatile fission products from 10^{21} fissions. In order to permit the study of low-energy radiations of ^{126}Sn free from the interfering radiations due to ^{121m}Sn and ^{123}Sn (since this was a relatively young source), this sample was put

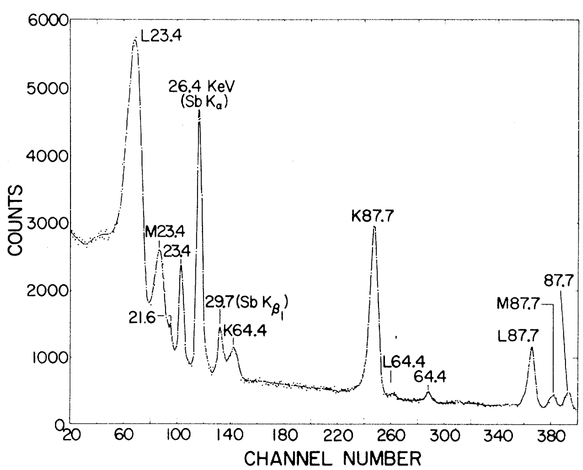

FIG. 2. Conversion-electron spectrum of ^{126}Sn measured with a 3-mm-thick by 80-mm^2 cooled Si(Li) detector. The conversion electrons are labeled with their associated transition energy and electron shell vacancy. Sb rays and γ rays are also detected and labeled with their energies.

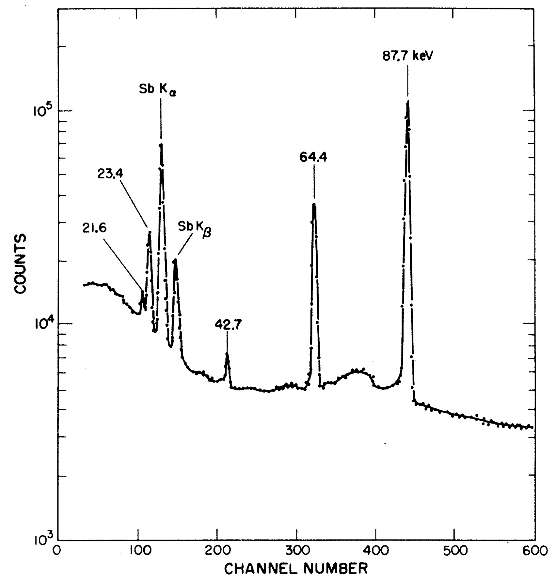

FIG. 3. γ-ray spectrum of ^{126}Sn measured with a 5-mm-thick by 1-cm-diam Ge(Li) detector with a 0.010-in. Be window.

through the Aldermaston electromagnetic isotope separator.[21] The ion-source-charge material consisted of 5.9 mg of SnS, and was volatilized over the temperature range 560–610°C. The overall transmission was measured to be 12%. The deposit of 50-keV ^{126}Sn ions on 0.002-in. Al foil formed a good source for subsequent measurements of the low-energy radiations of this isotope. No detectable amount of ^{123}Sn or ^{121m}Sn was found in the ^{126}Sn sample.

B. β-Ray and Conversion-Electron Spectra

The β-ray spectrum of the mass-separated ^{126}Sn source is shown in Fig. 1. This spectrum was measured with a $\frac{5}{8}$-in.-thick $\times 1\frac{1}{2}$-in.-diam *trans*-stilbene scintillation spectrometer gated with 87.7-keV γ rays that were detected at 180° in a $\frac{1}{2}$-in. $\times 1\frac{1}{2}$-in. NaI(Tl) detector. An almost identical spectrum was also found in coincidence with the K x-ray region. Although the ungated and gated β-ray spectra gave essentially the same endpoint energy, the error in the energy value from the former is larger because of the underlying high-energy β rays from the ^{126}Sb daughters. The ^{126}Sn β-ray spectrum has an endpoint energy of 0.25 ± 0.03 MeV and is composed of a single group as indicated by the ungated and coincidence data.

The internal-conversion electron spectrum, examined with a 3-mm $\times$ 80-mm^2 Si(Li) detector, is shown in Fig. 2. The electron peaks are labeled with the appropriate transition energy (keV) and electron shell vacancy.

C. γ-Ray Spectra

The γ-ray spectrum of ^{126}Sn, shown in Fig. 3, was measured with a 5-mm-thick by 1-cm-diam Ge(Li) detector having a 0.010-in. beryllium window. Although the ^{126}Sb daughters were in equilibrium, they contribute only a continuous Compton distribution under the lower-energy ^{126}Sn γ-ray spectrum, because the lowest-energy ^{126}Sb γ ray is at 224 keV.

γ-ray data for ^{126}Sn are presented in Table I. Multipolarities are suggested on the basis of a comparison between conversion-electron intensities (Fig. 2) and γ-ray intensities (Fig. 3). Theoretical conversion coefficients were interpolated from the tables of Rose.[22]

D. Coincidence Measurements

Both β-γ and γ-γ coincidence measurements were performed with the mass-separated ^{126}Sn source. In one set of experiments the γ-ray spectrum detected in a thin-window Ge(Li) detector was gated by both prompt and delayed (0.5-μsec) β-ray events in the energy range 100 to 240 keV in a *trans*-stilbene "gate" detector. The 23.4- and 87.7-keV γ rays were found to be in prompt coincidence with β rays, while the 21.6-, 42.7-, and 64.4-keV γ rays were found to be delayed.

In a series of γ-γ coincidence measurements using the thin-window Ge(Li) unit as the "analyzer" detector and a beryllium-window NaI(Tl) scintillator unit as the gate detector, no γ or x rays were observed in coincidence with the 87.7-keV γ transition. Delayed coincidences were observed between the 23.4-keV γ ray and the 21.6-, 42.7-, and 64.4-keV γ rays, indicating that the 23.4-keV γ transition excites a delayed level in ^{126}Sb.

E. Half-Life of Delayed Level in ^{126}Sb

The coincidence measurements described in Sec. II D indicated that the 21.6-, 42.7-, and 64.4-keV transitions are in delayed coincidence with both ^{126}Sn β rays and 23.4-keV γ rays. The half-life of the delayed state was measured with a time-to-pulse-height converter (TPHC). The converter was started with pulses due to 23.4-keV photon pulses which were unresolved from antimony *K* x rays. The *K* x rays are due to internal conversion of the 64- and 87-keV transitions and did not interfere with the measurement using the 23-keV γ ray. Data were stored in 100 channels of a 400-channel analyzer. A typical decay curve in which the TPHC was started by 23.4-keV γ rays is shown in Fig. 4. Time calibration was confirmed by the use of a ^{85}Sr source whose decay curve is shown in Fig. 4. In this case the TPHC was started with Rb *K* x rays. The half-life of the 514-keV delayed state in ^{85}Rb has previously been measured[23] to be 0.98 ± 0.02 μsec.

The half-life of the ^{126}Sb delayed level that de-excites by the 64.4-keV transition was found to be 0.5 ± 0.1 μsec. The same 0.5-μsec half-life was measured when the TPHC was started with pulses due to ^{126}Sn β-ray events in a *trans*-stilbene scintillation unit.

TABLE I. γ transition data for ^{126}Sn decay.

E_γ (keV)	Photon intensity/ 100 β rays	Suggested multipolarity	Transition intensity/ β ray
21.6	1.6	(*E*1)	0.04
23.4	7.0	(*E*1)	0.18
42.7	0.5	(*M*1)	0.04
64.4	9.3	(*E*1)	0.14
87.7	47.5	(*M*1)	0.82

F. ^{126}Sn Half-Life

The ^{126}Sn half-life, which we have previously reported[1] to be ≈10^5 yr, was determined from the amount of ^{126}Sn found in tin samples radiochemically separated from the "water boiler" reactor fuel solution described in Sec. II A. The following relation was used:

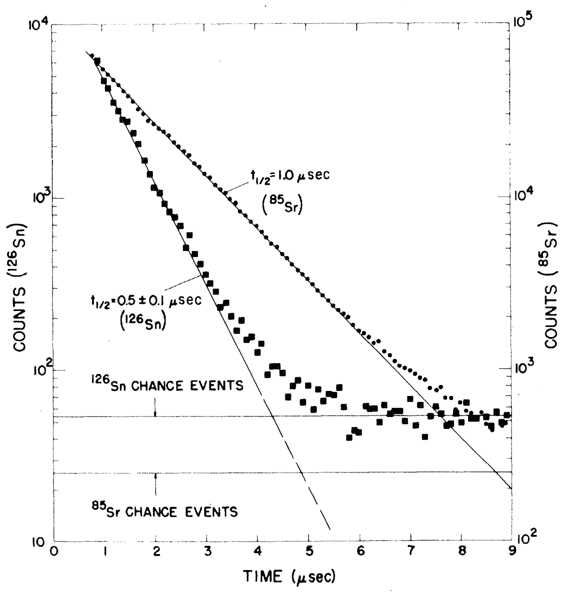

FIG. 4. Decay curve for the ^{126}Sb delayed state that de-excites by the 64.4-keV transition. The decay curve for the 514-keV delayed state (1.0 μsec) in ^{85}Rb is shown for comparison. Decay data were obtained with a time-to-pulse-height converter that was started with Sb or Rb *K* x-ray events and stopped with either 64-keV γ ray (^{126}Sn decay) or with 514-keV γ-ray (^{85}Sr decay) events.

$$t_{1/2}=0.693\ N_f\ Y_f\ /A_0\ ,$$

where N_f is the number of fissions in the samples as determined by ^{90}Sr analysis, Y_f is an interpolated value of the thermal-neutron ^{235}U fission yield for ^{126}Sn (0.05%), and A_0 is the disintegration rate of ^{126}Sn in the sample measured by radiochemical determination of the activities of the ^{126}Sb isomers in secular equilibrium.

III. EXPERIMENTAL: ^{126}Sb ISOMERS

A. Source Preparation

^{126}Sb sources were prepared for β- and γ-ray studies by chemically separating the antimony fraction from a solution containing the ^{126}Sn parent and ^{121}Sn, plus tin carrier. Antimony carrier was added to the solution which was then made 5*M* in HCl. Sb_2S_3 was precipitated with H_2S gas and was then centrifuged away fron the tin, which stays in solution under these conditions. The Sb_2S_3 was dissolved in concentrated HCl and reprecipitated in the presence of added tin "holdback" carrier. In general the antimony samples were reduced to the metal with $CrCl_2$ and mounted on cardboard plates.

When pure 12.4-day ^{126}Sb sources were desired, about 5 h were allowed for the decay of the 19-min isomer before counting. Essentially pure 19-min sources were prepared by separating the total antimony fraction from the ^{126}Sn parent solution,

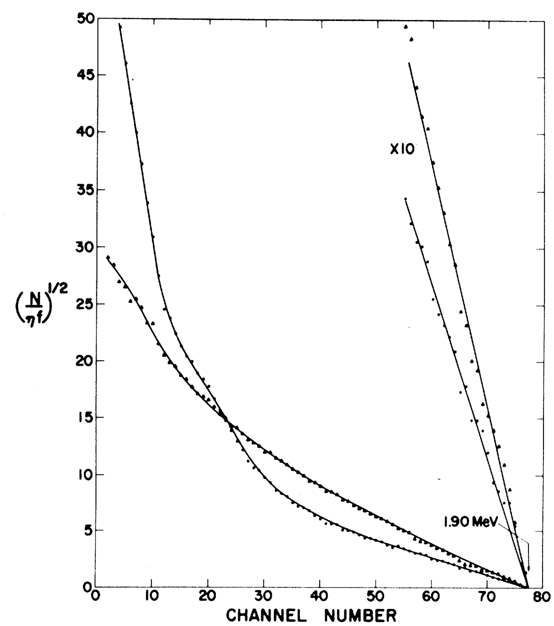

FIG. 5. Fermi-Kurie plots of the ^{126}Sb β-ray spectra measured with a $\frac{5}{8}$-in.-thick by $1\frac{1}{2}$-in.-diam *trans*-stilbene scintillator unit. Solid circles: 12.4-day ^{126}Sb. Solid triangles: 19-min ^{126}Sb.

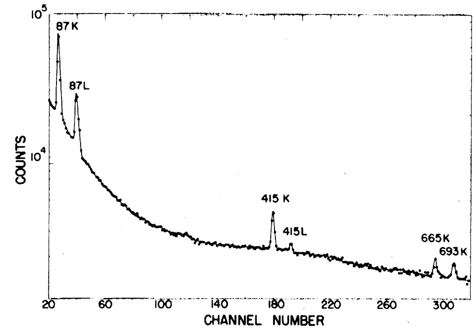

FIG. 6. Electron spectrum of the mass-separated ^{126}Sn source in equilibrium with the ^{126}Sb isomers, measured with a 2-mm × 1-cm^2 Si(Au) detector. The 87-keV transition lines are associated with ^{126}Sn decay and the higher-energy lines are associated with the decay of the ^{126}Sb isomers.

allowing 1 h of growth time (3 half-lives) and then separating the antimony fraction again. This second fraction contained only 0.2% of the 12.4-day ^{126}Sb isomer. All ^{126}Sb conversion-electron studies were performed with the mass-separated ^{126}Sn source.

B. Half-Life Measurements

Half-lives of the ^{126}Sb isomers were measured by following their β decay with a proportional counter. Essentially pure samples of each isomer were prepared as described in Sec. III A and were followed over a period of 8 to 10 half-lives. Least-squares analyses gave half-life values of 19.0 ± 0.3 min and 12.4 ± 0.1 day for the two ^{126}Sb isomers.

C. β-Ray and Conversion-Electron Spectra

Fermi plots of the β-ray spectra of the ^{126}Sb isomers are shown in Fig. 5. The samples were mounted as antimony metal (5 mg cm^{-2}) on cardboard plates and covered with 0.001-in. Mylar film. The spectra were measured with a $\frac{5}{8}$-in.-thick × $1\frac{1}{2}$-in.-diam *trans*-stilbene scintillation spectrometer. It will be noted that: (1) both isomers exhibit the same maximum endpoint energy (1.90 ± 0.15 MeV), and (2) the 12.4-day ^{126}Sb β-ray spectrum is more complex than that of the 19-min isomer, i.e., it contains inner groups. The γ-ray contribution has been subtracted from these spectra.

An electron spectrum of the mass-separated ^{126}Sn source in equilibrium with the ^{126}Sb isomers is shown in Fig. 6. The spectrum was measured with a cooled 3-mm × 80-mm^2 Si(Li) detector. Internal-conversion electron lines are labeled with their associated transition energy and electron shell vacancy. The 87-keV *K* and *L* lines

TABLE II. γ transition data for 19-min ^{126}Sb decay.

E_γ (keV)	Transition intensity/ 100 β rays	α_K [a]	Assigned multipolarity	Observed in coincidence with
415	96.8	1.5×10^{-2}	$M1$, $E2$	621, 680 (complex), 928
621	2.1			
665	100	3.4×10^{-3}	$E2$	415, 680 (complex)
694	100	3.0×10^{-3}	$E2$	
928	1.8			415
1036	2.6			680 (complex)
1060	0.9			
1475	0.7			680 (complex)

[a] α_K values for the 415- and 694-keV transitions are based upon their K conversion-electron intensity relative to the 665-keV K electron line. The 665-keV transition is assumed to be pure $E2$, and therefore its α_K is assigned the theoretical value of 3.4×10^{-3}.

are due to the transition in ^{126}Sb, while the 415, 665, and 693 lines are due to internal conversion of transitions in ^{126}Te. No other electron lines were discernible above the β-ray continuum. Tables II and III contain the conversion-electron data for the decay of the ^{126}Sb isomers.

D. γ-Ray Spectra

The γ-ray spectra of radiochemically purified 19-min and 12.4-day ^{126}Sb sources are shown in Fig. 7. They were measured with a 3-in.×3-in. NaI(Tl) scintillator and with the samples placed 15 cm above the crystal axis to minimize summing. Comparison of the two spectra shows that the 12.4-day ^{126}Sb spectrum is more complex than that of the 19-min isomer, although they both contain an intense 415-keV photopeak and a complex peak at 0.68 MeV. High-resolution Ge(Li) detectors resolved the complexities observed in these NaI(Tl) spectra. γ-ray spectra measured with Ge(Li) detectors are shown in Figs. 8 and 9. The spectrum of 19-min ^{126}Sb, shown in Fig. 8, was measured with a tin source that was freshly separated from its antimony activities so that essentially only the low-energy ^{126}Sn γ rays (below channel 50) and newly grown-in 19-min ^{126}Sb γ rays were present. A small amount of ^{123}Sn was also present, contributing the 1090-keV γ-ray peak.

The 0.29- and 0.58-MeV photopeaks in the 12.4-

TABLE III. γ transition data for 12.4-day ^{126}Sb decay.

E_γ (keV)	Transition intensity/ 100 β rays	Observed α_K [a]	Assigned multipolarity	Observed in coincidence with
224	2			
279	1.7			415, 680 (complex), 856
298	5.5			
415	83	1.5×10^{-2}	$M1$, $E2$	680 (complex), 987
555	2			
573	6.4			415, 680 (complex), 856
592	7.7			
604	2			
621	2			
639	1			
656	3			
665	100	3.4×10^{-3}	$E2$	415, 680 (complex), 856, 987
673	3			
694	132	3.0×10^{-3}	$E2$	415, 680 (complex), 856, 987
720	58			280 (complex)
856	17			415, 680 (complex), 580 (complex)
989	5.7			680 (complex)

[a] K values for the 415- and 694-keV transitions are based upon their electron intensity relative to the 665-keV K electron line. The 665-keV transition is assumed to be pure $E2$, and therefore its α_K is assigned the theoretical value of 3.4×10^{-3}.

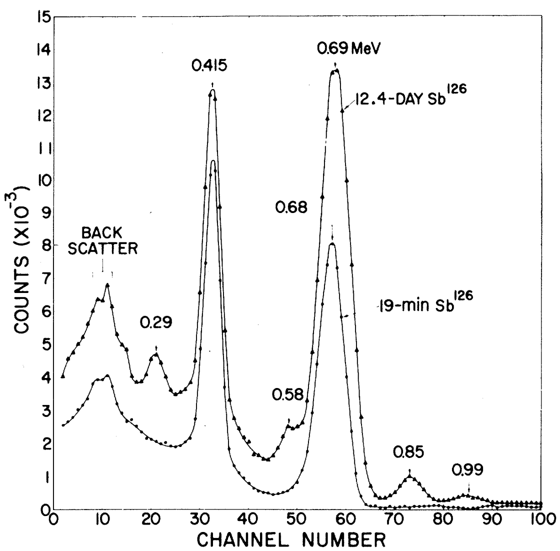

FIG. 7. ^{126}Sb γ-ray spectra measured with a 3-in. × 3-in. NaI(Tl) scintillation spectrometer at a source distance of 15 cm.

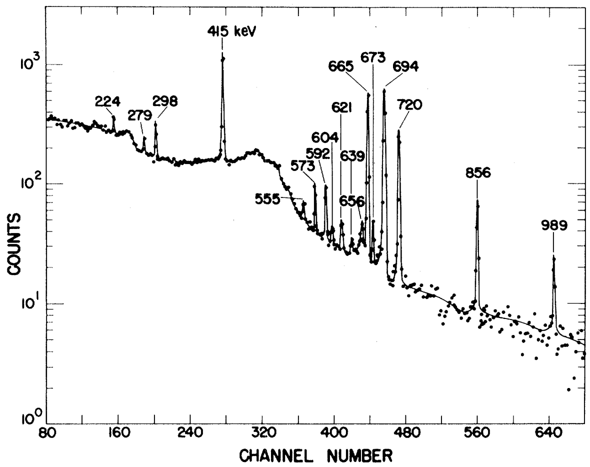

FIG. 9. γ-ray spectrum of 12.4-day ^{126}Sb measured with a 7-mm × 4-cm^2 Ge(Li) detector.

day ^{126}Sb spectrum shown in Fig. 7 are seen to be multiplets according to the spectrum in Fig. 9. The relative intensities of the 665- and 694-keV γ peaks in Figs. 8 and 9 are particularly noteworthy. From Fig. 8 the 665- and 694-keV γ rays are of equal intensity (when corrected for detector efficiency), while from Fig. 9 (12.4-day ^{126}Sb) the 694-keV γ ray is 1.3 times as intense as the 665-keV γ ray. These two γ rays deexcite the 1359-keV 4^+ ^{126}Te collective state (a 694-keV transition to the 2^+ first excited state followed by the 665-keV transition to the 0^+ ground state). The fact that the 694-keV γ ray is stronger than the 665-keV γ ray in the 12.4-day isomer decay indicates that the former peak is due to a γ-ray doublet.

An 11-in. × 11-in. NaI(Tl) crystal with an axial well proved useful in establishing β-populated levels in ^{126}Te. Sum spectra measured with this instrument are shown in Fig. 10. Spectrum a is due to the 12.4-day ^{126}Sb and b is due to the 19-min isomer. Clearly, the 19-min ^{126}Sb strongly populates a ^{126}Te level at 1.78 MeV and only weakly populates levels at ≈2.3 and 2.8 MeV. In marked contrast, 12.4-day ^{126}Sb populates ^{126}Te levels at 1.78, 2.5, and 3.2 MeV to roughly the same extent. This fact is in accord with the com-

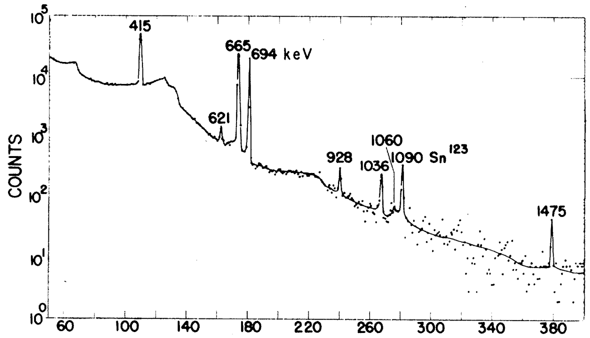

FIG. 8. γ-ray spectrum of 19-min ^{126}Sb measured with a 7-mm × 4-cm^2 Ge(Li) detector.

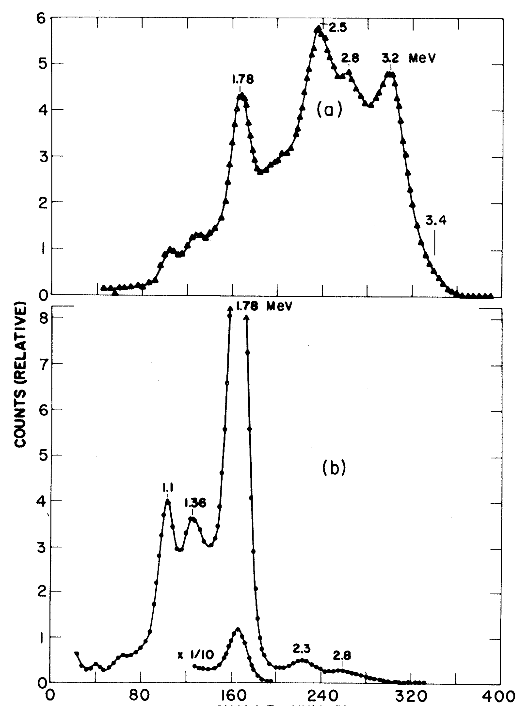

FIG. 10. Sum γ-ray spectra of 12.4-day ^{126}Sb (a) and 19-min ^{126}Sb (b) measured in the center of an 11-in. × 11-in. NaI(Tl) well crystal.

plexity of the β-ray spectrum of 12.4-day ^{126}Sb.

Extensive γ-γ coincidence measurements were made on the ^{126}Sb isomers. In general, a 3-in. $\times$3-in. NaI(Tl) scintillator was used in conjunction with a 2-in.$\times$2-in. NaI(Tl) unit. When intensities permitted, the 3-in.$\times$3-in. crystal was used as the "gate" detector and a 7-mm$\times$4-cm^2 Ge(Li) unit was used as the "analyzer" detector. The γ-γ coincidence data are not shown graphically but are presented in Tables II and III along with single-crystal γ-ray energy and intensity data.

E. Equilibrium Activity of the ^{126}Sb Isomers

In order to determine the ratio of the 19-min to the 12.4-day isomer at equilibrium with ^{126}Sn, a chemical separation of antimony from the tin parent was performed after secular equilibrium was reached ($\approx$3 months of growth time). The gross ^{126}Sb β decay was followed with a proportional counter for two months. The zero-time β activities of the two isomers, corrected for counting efficiencies, were calculated with a least-squares program, and the results show that

$$\frac{A_0\ (19\ \text{min})}{A_0\ (19\ \text{min}) + A_0\ (12.4\ \text{day})} = 0.86 \pm 0.04,$$

where the A_0 are the disintegration rates of 19-min ^{126}Sb and 12.4-day ^{126}Sb at the time of separation from ^{126}Sn. The 19-min ^{126}Sb isomer, which grows directly into equilibrium with ^{126}Sn, is assigned as the upper state. If we made the reasonable assumption that all of the 12.4-day ^{126}Sb ground state is formed by isomeric transition

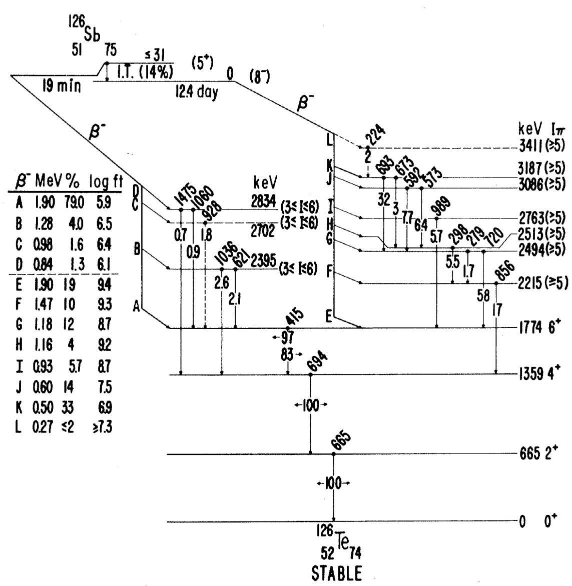

FIG. 11. Decay scheme for the ^{126}Sb isomers.

(IT) of the 19-min upper state, then we can conclude from the data that the 19-min isomer decays 14% by IT and 86% by β decay to ^{126}Te.

IV. DISCUSSION

A. Decay of the ^{126}Sb Isomers

Decay schemes for the ^{126}Sb isomers, consistent with the measurements described above, are shown in Fig. 11. The first excited state of ^{126}Te at 665 keV has been previously assigned as 2^+ from Coulomb-excitation studies.[13,14] A second 2^+ state at 1410 keV, reported[10-12] in the decay of ^{126}I ($I_{g.s.} = 2^-$), is not observed in the decay of either of the ^{126}Sb isomers. A level is observed at 1359 keV, however, that is not excited by ^{126}I decay. This level deexcites by either $E2$ or $M1$ transition to the 2^+ state at 665 keV, and has been assigned $I^\pi = 4^+$ in the ^{124}Sn(α, $2n\gamma$) studies.[19,20]

The next ^{126}Te level, at 1774 keV, is directly populated by the β decay of both ^{126}Sb isomers, as demonstrated by β-γ coincidence experiments. γ-ray spectra gated by β-ray events $\geq$1500 keV contained only the 415-, 665-, and 694-keV γ rays, all in equal intensity. These coincidence measurements confirmed the indications in the β-ray spectra (Fig. 5) that $\leq$5% of the β decays of either isomer proceed directly to any of the lower-energy states ($\leq$1359 keV) in ^{126}Te. Thus, the total β-disintegration energy of the ^{126}Sb isomers is then the sum of the 1.90-MeV β end-point energy and the 1.774-MeV of γ-transition energy, or 3.67 $\pm$ 0.15 MeV. Based upon the absence of K x rays, the IT energy of the 19-min isomer is $\leq$31 keV; this energy difference was not detectable in the β-ray spectra (Fig. 5).

The 1774-keV state deexcites by a single 415-keV transition whose conversion coefficient is consistent with either $M1$ or $E2$ multipolarity. Although this measurement does not establish the spin of the state it does provide a positive-parity assignment. The spin must be 5 or 6; if it were $\leq$4, a 1110-keV crossover transition to the 665-keV level (2^+) should have been observed. The recent ^{124}Sn(α, $2n\gamma$) results[19,20] indicate $I^\pi = 6^+$ for the 1774-keV state on the basis of angular-correlation data and systematics.

Above the 1774-keV level of ^{126}Te the ^{126}Sb isomers populate no levels in common. Consideration will now be given to those higher-energy ^{126}Te levels populated by the 19-min isomer. The levels at 2395, 2702, and 2834 keV are assigned on the basis of accurate energy and intensity measurements for the 621-, 928-, 1036-, 1060-, and 1475-keV γ transitions. The 621- and 928-keV γ rays were also observed in the Ge(Li) γ-ray spectrum gated by pulses produced by 415-keV γ-ray events in a 3-in.×3-in. NaI(Tl) scintillator unit. The 1060-keV γ ray was apparently too weak for detection in this coincidence experiment. Pramila *et al.*[16] have excited a ^{126}Te level at 2395 employing the (p,p') reaction which they assign $I^{\pi}=3^{-}$. On the other hand, the 2395-keV state that we observe is more likely $4\leqslant I\leqslant 6$, since it deexcites to the 4^+ state at 1359 keV and to the 6^+ state at 1774 keV and not to the 2^+ state at 665 keV, although transition to the latter state is highly energy favored.

The 12.4-day isomer populates a completely different set of levels above 1774 keV, beginning with one at 2215 keV that is established by the coincidence relationship of the relatively strong 856-keV γ ray with the 1359-keV sum peak. In addition, the 856-keV γ ray is not in coincidence with the 415-keV transition which deexcites the 1774-keV level.

The 2494-keV level is assigned on the basis of the intense 720-keV γ rays found in coincidence with the 1774-keV triple sum-peak pulses. In addition, a complex 290-keV γ ray found in NaI(Tl) spectra was also observed in a spectrum gated by 856-keV γ-ray pulses. The Ge(Li) spectrum (Fig. 9) shows that the 0.29-MeV peak is actually a doublet produced by 279- and 298-keV γ rays. The 279-keV transition fits the energy difference between the 2494- and 2215-keV levels.

A level at 2513 keV is suggested by the (856-γ–298-γ) coincidence relationship. The postulate of levels at 2494 and 2513 is supported by the observation of two other pairs of γ transitions, at 573 and 592 keV and at 673 and 693 keV. The members of both of these pairs differ in energy by $\approx$19 keV, the energy difference between the 2513- and 2494-keV levels. The 573-592 pair was observed in coincidence with the 856-keV γ-ray pulses, but the 673-693 pair was obscured in the coincidence spectrum by the intense 665- and 694-keV γ rays that comprise the 856-, 694-, and 665-keV γ-ray cascade to the ground state from the 2214-keV level. The (p,p') reaction studies[16] showed a proton group corresponding to a single level at 2505 keV. It is not clear which of the two nearby states inferred from this present work is to be identified with this level.

The 2763-keV state is assigned on the basis of the coincidence relationship observed between the 989- and 415-keV γ rays. The 2.8-MeV sum peak indicated in the spectrum taken with the 11-in.×11-in. NaI(Tl) well crystal [Fig. 10(a)] is consistent with this assignment. Warner and Draper[20] have recently observed this state in their ^{124}Sn$(\alpha, 2n\gamma)$ studies and assign it $I^{\pi}=8^{+}$.

The 3086-keV level is indicated on the basis of the 572- and 592-keV γ rays found in coincidence with the 856-keV γ rays. The 279- and 298-keV γ rays are presumed, as stated before, to complete these coincidence cascades.

A strongly populated level at $\approx$3200 keV is indicated by the sum spectrum [Fig. 10(a)] measured with the 11-in.×11-in. NaI(Tl) well crystal. The high intensity of the 694-keV photopeak requires two 694-keV γ transitions to account for its 1.32:1.00 ratio to the 665-keV γ ray (Fig. 9 and Table III) because the 665-keV γ ray has a γ/β ratio of 1. The two 694-keV transitions were unresolved with the Ge(Li) detector whose resolution at this energy was 2.4 keV. Based upon energy and intensity considerations this second 694-keV γ transition is shown in Fig. 11 to deexcite a level at 3187 keV. The weak 673-keV γ ray shown in Fig. 9 is presumed to be due to the transition to the 2513-keV level.

A possible weakly populated level at 3411 keV is suggested from a comparison of sum spectra taken with both the 11-in.×11-in. NaI(Tl) well crystal and with a higher-resolution 5-in.×5-in. NaI(Tl) well crystal (spectrum not shown). In the latter detector the $\approx$3400-keV sum peak stands out quite clearly because of better resolution. If the previously unassigned 224-keV γ ray shown in Fig. 9 proceeds to the 3187-keV level, then the state that it deexcites is at 3411 keV.

The percentage of β feeding of the ^{126}Te levels by each ^{126}Sb isomer was determined from the relative intensities of the observed γ rays assuming that no β transitions proceeded directly to ^{126}Te levels below the 1774-keV state. The $\log ft$ values were determined by using Moszkowski's[24] nomographs.

A spin and parity assignment of 5^+, 6^+, or 7^+ is proposed for 19-min ^{126}Sb on the basis of the allowed β transition ($\log ft=5.9$) to the 1774-keV ^{126}Te level with $I^{\pi}=6^{+}$. Based upon model considerations, 19-min ^{126}Sb can only be assigned $I^{\pi}=5^{+}$, because 5 is the highest spin possible with positive parity; in ^{126}Sb the low-lying neutron states are $h_{11/2}$, $d_{3/2}$, and $s_{1/2}$, while the low-energy proton states are $g_{7/2}$ and $d_{5/2}$.

The fact that the 19-min isomer with $I^{\pi}=5^{+}$ β decays to the 4^+ level (1359 keV) in ^{126}Te with $\log ft \geqslant 7.5$ is similar to the situation found in the β decay of ^{130}I and ^{132}I. β decay of ^{130}I ($I^{\pi}=5^{+}$) to the 4^+ level (1207 keV) in ^{130}Xe is hindered ($\log ft \approx 9.5$).[25] β decay of ^{132}I ($I^{\pi}=4^{+}$) proceeds to the 4^+ level (1441 keV) in ^{132}Xe but with a relatively large $\log ft=7.5$.[26,27] Although we do not detect β feeding of the 4^+ ^{126}Te level (1359 keV) by the 19-min isomer, we cannot preclude $\leqslant$3% branching, corresponding to $\log ft \geqslant 7.5$.

The 19-min isomer grows directly into secular equilibrium with its ^{126}Sn parent and is presumed to be the upper isomer decaying 14% of the time by isomeric transition to the 12.4-day ^{126}Sb ground state.

On the basis of the IT partial half-life of 135 min, the ^{126}Sb ground-state spin (I) is expected to differ by ≥ 3 units from that of the isomeric state. In addition, the spin of the 12.4-day ground state must be larger than that of the 19-min isomer, since the former does not directly β populate the 1359-keV ^{126}Te level of $I^{\pi} = 4^+$, but does feed the 1774-keV state ($I^{\pi} = 6^+$) and other higher-energy states not common to those fed by the 19-min isomer. The $\log ft$ (9.4) of the β branch from the ^{126}Sb ground state to the 1774-keV ^{126}Te level is consistent with a unique first-forbidden classification ($\Delta I, \Delta\pi = 2$, yes). The indicated 8^- assignment for 12.4-day ^{126}Sb results from the coupling of an $h_{11/2}$ neutron with $d_{5/2}$ and $g_{7/2}$ protons ($I^{\pi} \leq 9^-$).

This combination of ^{126}Sb assignments is contradicted by the conclusions of Sastry.[28] By measuring β-γ angular correlations he concludes that I^{π} for 12.4-day ^{126}Sb is 7^-. If the 1774-keV state in ^{126}Te is indeed 6^+ the ^{126}Sb isomers must be as we assigned them (5^+ and 8^-).

A possible explanation of the small $\log ft$ (5.9) for the β branch to the 1774-keV ^{126}Te level from the 19-min isomer is that the 1774-keV level contains a strong $\pi g_{7/2} \pi d_{5/2}$ component; β decay from a $\pi g_{7/2} \nu d_{3/2}$ state should then be allowed.

We have made some measurements[5] on the decay of the shorter-lived isomers of ^{128}Sb and ^{130}Sb, and in addition there has been reported information on the decay of the 90-sec ^{124}Sb isomer.[29] All four (including ^{126}Sb) of these isomers exhibit a very similar decay mode, i.e., predominant β decay to a single tellurium level followed by a triple γ-transition cascade. We have plotted, in Fig. 12, the energies of the 2^+ and 4^+ collective states and this undescribed third excited state, which is labeled 6^+, against the mass number of the tellurium isotope involved. The slope of the line connecting the points is steeper in the case of the collective states than for the 6^+ state. Our interpretation of this observation is that the 6^+ state is predominantly two particle in nature as opposed to the relatively collective 2^+ and 4^+ states. The level assignments above mass 130 are estimated from systematics for this region.

The low-intensity 604-, 621-, 639-, and 656-keV γ rays listed in Table III are not placed in the ^{126}Te level scheme because of the meager information about them. It appears that several other ^{126}Te states are weakly fed by the decay of 12.4-day ^{126}Sb.

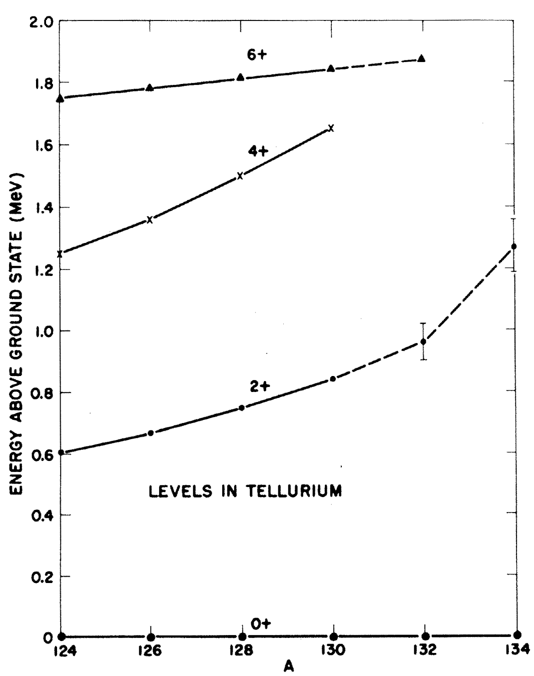

FIG. 12. Levels in the even-mass tellurium isotopes. The 0^+ ground states are plotted on the abscissa. Levels for tellurium isotopes above mass 130 are estimated from systematics.

B. ^{126}Sn Decay

Although several important questions concerning the decay of ^{126}Sn remain unanswered, the present interpretation of our data is shown in the ^{126}Sn decay scheme in Fig. 13. ^{126}Sn with a half-life of $\approx 10^5$ yr decays by essentially a single 0.25-MeV β transition from its presumed 0^+ ground state. The resulting $\log ft$ value (≈ 12) is most

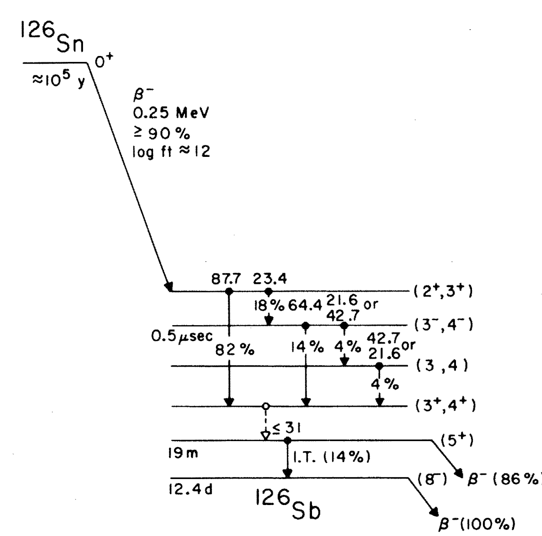

FIG. 13. Decay scheme for ^{126}Sn. An undetected but possible γ transition in ^{126}Sb is shown as a dashed arrow.

consistent with a (2, no) or (3, no) ($\Delta I, \Delta\pi$) classification for the β transition although a highly hindered 2, yes classification cannot be entirely ruled out. If the (2, no) or (3, no) assignment is correct, the terminal state in ^{126}Sb can then be assigned $I^{\pi} = 2^+$ or 3^+. Deexcitation of this initial state is by a 23.4-keV $E1$ transition and by a 87.7-keV $M1$ transition. The former proceeds to a delayed level with a 0.5-μsec half-life. The delayed state deexcites by a 64.4- and either a 21.6- or 42.7-keV transition. The lack of data for the 21.6-42.7-keV γ cascade precludes a sequence assignment for these two γ transitions.

At this point we are at a level 87.7 keV below the initially β populated ^{126}Sb state. This lower level should have a spin of 3 or 4 with the former the more plausible if the angular momentum is correctly accounted for. This leaves the ^{126}Sb with possibly one or two units of angular momentum less than that required by the 19-min isomeric state ($I^{\pi} = 5^+$) leading us to hypothesize a possible undetected (low-energy) transition shown as a dashed arrow in the decay scheme.

The 12.4-day ^{126}Sb ground state is given a 8^- assignment as described in the previous section. The IT energy of the 19-min isomer is shown ≤ 31 keV because we detected no antimony K x rays associated with the decay of the 19-min isomer.

It is not too surprising that the 64.4-keV γ transition has a half-life of 0.5 μsec. In ^{122}Sb, for example, a 61-keV $E1$ transition has a 1.8-μsec half-life, and a 75-keV $E2$ transition is delayed with a 530-μsec half period.[30]

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