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THE DECAY OF ^{124}Sb TO THE LEVELS OF ^{124}Te

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Abstract: The decay of ^{124}Sb → ^{124}Te was studied with curved-crystal and Ge(Li) spectrometers and with γ-γ coincidence techniques. Energy and intensity measurements on 38 γ-rays are reported. A partial decay scheme is proposed which incorporates 34 of the observed γ-rays. Levels at 2483.27 keV, 2701.78 keV and 2710.65 keV are added to the most recently published decay scheme.

E | RADIOACTIVITY ^{124}Sb [from ^{123}Sb(n, γ)]; measured E_γ, I_γ, γ-γ coin. ^{124}Te deduced levels, log *ft*. Natural and enriched targets.

1. Introduction

The decay of ^{124}Sb to the levels of ^{124}Te has been extensively studied [1-11]. The large Q-value, the long half-life and the ease of preparation of ^{124}Sb provide one of the best opportunities to study the properties of a vibrational type nucleus. Since the gamma-ray spectrum of ^{124}Sb is rather complex, it was felt that high-resolution gamma-ray singles and coincidence measurements could provide additional information which would aid in bringing out further features of the decay scheme.

2. Experimental procedure

Sources for the curved-crystal spectrometer (ccs) and Ge(Li) spectrometers were prepared by irradiating samples containing ^{123}Sb in a thermal neutron flux of 2×10^{13} n/sec · cm^2 in the UM reactor. As a check for the possible presence of contaminants, several of the sources for the Ge(Li) spectrometer were chemically purified after irradiation using a modification of an ion-exchange procedure developed by Hicks *et al.* [13]. After purification, no lines were observed which could not be ascribed to ^{124}Sb.

The curved-crystal spectrometer and the methods of measurement are described by Reidy and Wiedenbeck [12]. The spectrometers were calibrated by using the 411.795±0.009 keV transition [14] in the decay ^{198}Au → ^{198}Hg. A Ge(0$\bar{2}$2) crystal bent to a 2 m radius was used with the ccs described by Reidy and Wiedenbeck [12]. Two other crystals, which were bent to a 6 m radius, were used with a more recently constructed ccs. One was a (112) quartz and the other a (422) germanium crystal. The energy resolution of each was $\Delta E = 2.1\times10^{-5}E^2/n$, $\Delta E = 1.4\times10^{-5}E^2/n$ and

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$\Delta E = 1.6 \times 10^{-5} E^2/n$, respectively, where ΔE (in keV) refers to the full width at half maximum (FWHM), E (in keV) to the energy of the γ-ray and n to the order of dif fraction.

Four commercially obtained Ge(Li) detectors ranging in volume from 4 cm^3 to 40 cm^3 were used. The associated electronics are described in ref. [15]).

Both NaI(7.6 cm × 7.6 cm)-Ge(Li) and Ge(Li)-Ge(Li) detector configurations were used in the coincidence work. With all Ge(Li)-Ge(Li) configurations, 180° geometry was used in conjunction with an anti-Compton shield. A fast-slow type circuitry with cross-over timing was employed. The resolving time (2τ) of the system for prompt coincidence work ranged from 50-65 nsec. For delayed coincidence work, a resolving time of 100 nsec and a delay of 200 nsec were used. The coincidence efficiency of the system was greater than 95 % over the energy range of interest. All coincidence spectra were obtained with true-to-chance ratios greater than 15.

3. Results

3.1. ENERGY MEASUREMENTS

The results of the curved-crystal measurements are presented in column 1 of table 1. In general, the high intensity γ-rays were measured in first-, second- and third-order diffraction using the Ge($0\bar{2}2$) crystal and up to second order using the other two crystals. The 603 keV transition was measured several times in order to establish an internal calibration standard of very high reliability.

The γ-ray spectra for three overlapping energy regions are shown in figs. 1a-c. The resolution (FWHM) for these spectra ranges from about 2.7 keV at 603 keV to 5.0 keV at 2091 keV.

The results of the energy measurements obtained from the Ge(Li) work are given in column 2 of table 1. The positions of the peaks were determined after the estimated background under each peak was subtracted. The form of the background distributions was assumed to be a cubic polynomial tangent to straight lines fitted to the data points along the sides of the peak. The lengths and positions of the two intervals used to fit the straight lines were determined by visual inspection. Corrections due to the non-linearity in the electronics were determined using a precision pulser as described by Donnelly *et al.* [16]).

In most of the runs, the median was used as the position defining parameter †, since the median is a less sensitive function of the line shape than the mean and its calculation required less computer time than the Gaussian fit. Where composite peaks were present, a graphical peeling analysis using the line shapes of nearby peaks was performed.

To determine the energy scale for the energy measurements, the three most intense lines (603, 1691 and 2091 keV) in the decay of ^{124}Sb and the γ-rays of the primary standards listed in table 2 were used. The combined source method was used in ob-

† See ref. [16]) for a comparison and evaluation of peak position defining parameters.

taining the composite spectra of ^{124}Sb and the primary standards. The single- and double-escape peaks were used in the energy determination of the 1691 and 2091 keV lines. Weighted averages were calculated from the curved-crystal and Ge(Li) spectro-

TABLE 1

Energies and relative intensities of the gamma rays associated with the decay of $^{124}Sb \rightarrow {}^{124}Te$

Gamma-ray energy (keV) [a]			Relative intensity [a] Ge(Li)	Stelson [1]	
curved-crystal	Ge(Li)	curved-cryst+Ge(Li)		gamma-ray energy (keV) Ge(Li)	relative intensity Ge(Li)
335.58 ±0.50	335.84 ±0.37	335.75 ±0.30	0.08 ±0.03		
	399.97 ±0.25		0.15 ±0.05		
443.61 ±0.31	444.02 ±0.19	443.91 ±0.18	0.21 ±0.04		
	525.31 ±0.14		0.19 ±0.04		
602.724±0.023	602.674±0.033	602.708±0.023	100.0	602.5±0.3	100
	632.40 ±0.22		0.11 ±0.02		
645.886±0.037	645.825±0.034	645.853±0.030	7.42 ±0.11	645.1±0.3	8.5 ±1
709.77 ±0.30	709.41 ±0.10	709.443±0.099	1.46 ±0.15	709.0±0.5	1.8 ±0.3
714.19 ±0.25	713.798±0.091	713.844±0.13	2.35 ±0.17	713.3±0.5	2.8 ±0.5
723.01 ±0.23	722.769±0.041	722.776±0.042	11.27 ±0.18	722.3±0.3	12.5 ±1
	735.670±0.095		0.11 ±0.03		
790.50 ±0.32	790.742±0.045	790.737±0.045	0.72 ±0.03	790.2±0.5	0.8 ±0.1
	816.59 ±0.29		0.07 ±0.02		
968.26 ±0.25	968.196±0.044	968.199±0.043	1.92 ±0.06	967.8±0.3	2.3 ±0.3
	976.66 ±0.18		0.066±0.007		
1045.33 ±0.40	1045.099±0.044	1045.102±0.044	1.94 ±0.09	1044.8±0.3	2.0 ±0.3
1325.41 ±0.47	1325.594±0.055	1325.592±0.055	1.57 ±0.09	1325.5±0.5	1.6 ±0.3
	1355.267±0.049		0.99 ±0.07	1354 ±1.0	1.2 ±0.2
	1368.210±0.046		2.78 ±0.14	1368 ±1.0	3.0 ±0.4
	1376.248±0.056		0.48 ±0.05		
	1436.600±0.050		1.19 ±0.08	1434 ±1.0	1.4 ±0.2
	1445.308±0.079		0.23 ±0.03	1445 ±1.0	0.3 ±0.1
	1489.061±0.079		0.70 ±0.07	1488 ±1.0	0.8 ±0.2
	1526.352±0.091		0.41 ±0.03	1525 ±1.0	0.5 ±0.1
	(1622.3 ±1.0)		(0.045±0.025)		
1690.86 ±0.26	1691.060±0.035	1691.056±0.035	53.2 ±2.7	1691 ±0.5	50
	1720.162±0.073		0.11 ±0.01	1720 ±1.0	0.15 ±0.04
	1919.06 ±0.13		0.056±0.003	1921 ±2	0.07 ±0.02
	2039.57 ±0.12		0.075±0.008	2040 ±2	0.05 ±0.01
	(2079.3 ±2.0)		(≈ 0.04)		
	2091.001±0.047		6.57 ±0.44	2091.2±0.5	6.0 ±0.5
	2099.09 ±0.28		0.055±0.010		
	2107.94 ±0.23		0.057±0.006	2108 ±1.0	0.03 ±0.01
	2182.476±0.081		0.049±0.004	2183 ±2	0.030±0.007
	2283.41 ±0.93		0.008±0.003		
	2293.71 ±0.11		0.040±0.004	2294 ±2	0.030±0.007
	(2683.2 ±2.0)		(≈ 0.002)	2682 ±2	≈0.002
	(2693.5 ±2.0)		(≈ 0.002)	2694 ±3	≈0.002

[a]) The energies and intensities of those gamma rays whose existence have not been firmly established in the decay of ^{124}Sb are enclosed in parentheses.

meter measurements for these three lines. The resulting energy values 602.708 ± 0.023, 1691.056 ± 0.035 and 2091.001 ± 0.047 keV were then used as the secondary standards.

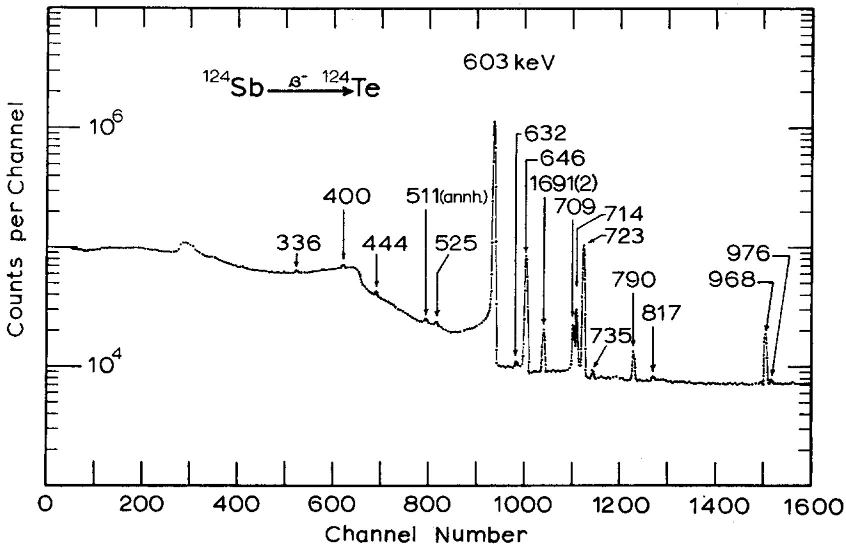

Fig. 1(a). Gamma-ray spectrum following the decay of ^{124}Sb in the energy range 0.01-1.01 MeV obtained with a 40 cm^3 trapezoidal shaped Ge(Li) detector. The gamma rays are identified by their energies in keV. Single- and double-escape peaks are identified by the numbers 1 and 2 enclosed in parentheses following the energy designation of the γ-ray. (b). Gamma-ray spectrum following the decay of ^{124}Sb in the energy range 0.94-1.78 MeV. (c) Gamma-ray spectrum following the decay of ^{124}Sb in the energy range 1.46-2.88 MeV. A 2.6 cm lead absorber was used in front of the detector. Source to detector distance was 65 cm.

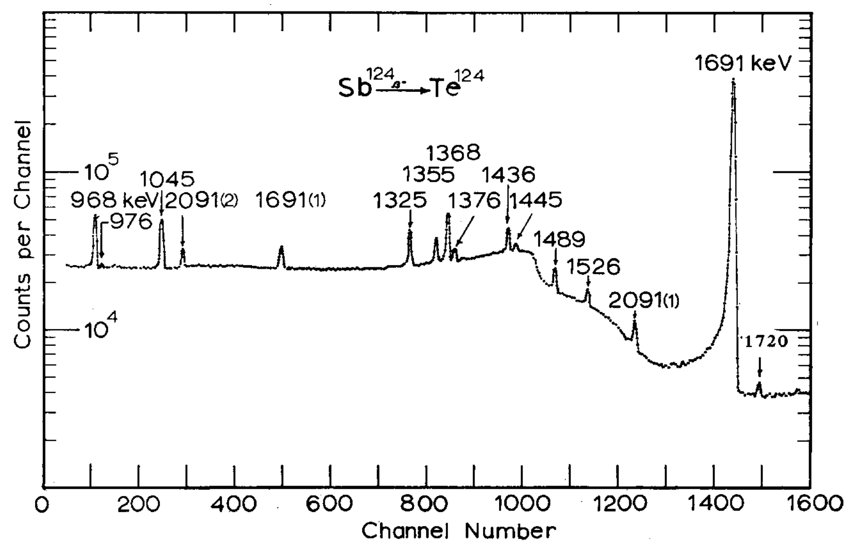

Fig. 1b.

The uncertainties listed in table 1 represent the estimated standard deviations of the measured energies and are given either by the internal or external standard deviations,

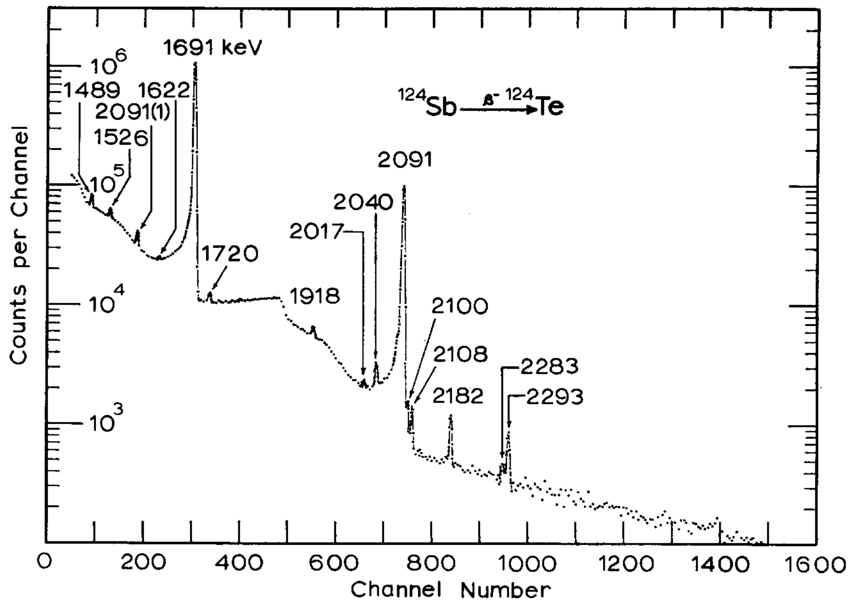

Fig. 1(c).

TABLE 2

Gamma-ray energy standards used in spectrometer calibration

Source	Gamma-ray energy (keV)	Ref.
annihilation	511.006±0.002	[17]
^{228}Th	238.624±0.009	[14]
	583.139±0.023	[14]
	2614.47±0.10	[14]
^{207}Bi	569.62 ±0.06	[18]
	569.71 ±0.1	[19]
	569.664±0.051	weighted average of refs. [18,19]
^{207}Bi	1063.44 ±0.09	[18]
	1063.63 ±0.07	[19]
	1063.558±0.085	weighted average of refs. [18,19]
^{137}Cs	661.635±0.076	[20]
^{60}Co	1173.23 ±0.04	[20]
^{60}Co	1332.49 ±0.04	[20]
^{22}Na	1274.55 ±0.04	[20]

(whichever was greater). The internal and external standard deviations are defined as

$$\sigma_{\text{int}}^2 \equiv [\textstyle\sum_{i=1}^{N}\sigma_i^{-2}]^{-1},$$
$$\sigma_{\text{ext}}^2 \equiv \sigma_{\text{int}}^2[\chi^2/(N-1)],$$

where

$$\chi^2 \equiv \textstyle\sum_{i=1}^{N}[(E_i-\langle E\rangle)^2/\sigma_i^2],$$
$$\langle E\rangle \equiv (\textstyle\sum_{i=1}^{N}\sigma_i^{-2}E_i)/(\textstyle\sum_{i=1}^{N}\sigma_i^{-2}).$$

The standard deviation σ_i^2 is the estimated uncertainty for a single measurement. It includes the uncertainty of the peak position, the uncertainty associated with the straight line fit and the uncertainty in the correction due to the non-linearity in the electronics.

All the γ-rays listed in table 1 have been observed from several different sources. However, some of the γ-rays were of very low intensity or were not adequately resolved from other more intense peaks. Their energies are enclosed in parentheses to indicate that their presence in ^{124}Sb decay could not be firmly established. For comparison, the results from the recent work of Stelson [1]) are included in table 1.

3.2. RELATIVE INTENSITY MEASUREMENTS

The results of the relative intensity measurements are given in column 4 of table 1. The relative intensity measurements from the work of Stelson [1]) are presented in column 6.

The method of calibration of the detectors and the relative intensity measurements are described by Donelly *et al.* [16]).

3.3. GAMMA-GAMMA COINCIDENCE RESULTS

The results of the coincidence work are summarized in table 3. Those γ-rays whose existence in the coincidence spectra could not be firmly established are enclosed in parentheses. Gamma rays appearing at greatly reduced intensities are enclosed in brackets. The chance coincidence contributions were subtracted from all coincidence spectra.

The γ-ray spectrum obtained in coincidence with γ-646 is shown in fig. 2. The duration of the run was 42 h. The contribution due to coincidences with the Compton distribution in the gate has been subtracted.

Fig. 3 shows the γ-ray spectrum obtained with the NaI gate set on the 709-714-723 keV triplet. The inset in fig. 3 shows the region used for gating. The duration of the run was 29 h. This coincidence spectrum gives most of those γ-rays that do not form a direct cascade with the 603 or 646 keV γ-ray. These coincidence spectra were obtained with 135° detector to detector orientation. Of particular interest is the presence of the 444, 632, 735 and 1376 keV peaks.

The coincidence spectra obtained with the 1691 and 2091 keV NaI gates showed a minute but definite presence of the 723 keV γ-ray. The intensity of this line was somewhat greater than could be ascribed to coincidences due to summing or bremsstrahlung radiation present in the gate.

TABLE 3

Results of gamma-gamma coincidence measurements

Gate (keV)		Gamma rays in coincidence (keV) [a, b]
NaI	575-610	336, 400, 444, (525), [603], (632), 646, 709, 714, 723, 735, 790, (817), 968, (976), 1355, 1368, 1376, 1436, (1445), 1489, 1526, (1622), 1691, (1720), 1918, 2091, (2100), (2108), {($\approx$697), ($\approx$ 1387), ($\approx$ 1459), ($\approx$ 1801)} [c]
Ge(Li)	646	603, 709, 790, 1045, 1445, 1526
Ge(Li)	709	603, 646
Ge(Li)	714	(444), (525), 603, 723, (735), 1325
Ge(Li)	723	603, 714, (723), 968, 1368, (1376)
NaI	720-750	(336), 400, 444, 603, 632, [646], 714, [723], 735, [790], (817), 968, [1325], 1368, 1376
Ge(Li)	1325	714, 968, 1368, 1376
Ge(Li)	1368	603, 723
Ge(Li)	1376	603, 723
NaI	1691	(400), (444), 603, (646), [723]
NaI	2091	(400), (444), 603, [723]

[a]) Annihilation radiation is excluded.

[b]) Those γ-rays whose existence in the coincidence spectra could not be firmly established are enclosed in parentheses. Gamma rays appearing at greatly reduced intensities are enclosed in brackets.

[c]) No substantial evidence was found in the present work to associate these γ-rays with the decay of ^{124}Sb.

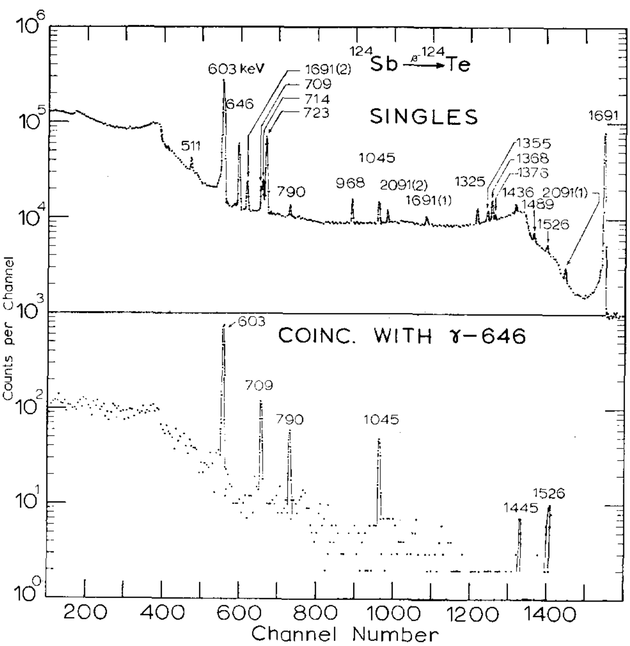

Fig. 2. The gamma-ray spectrum in the energy range 0.18 to 1.75 MeV in coincidence with the 646 keV gamma ray. A 17 cm^3 coaxial Ge(Li) detector was used on the display side and a 4 cm^2 $\times$ 0.5 cm planar detector on the gate side.

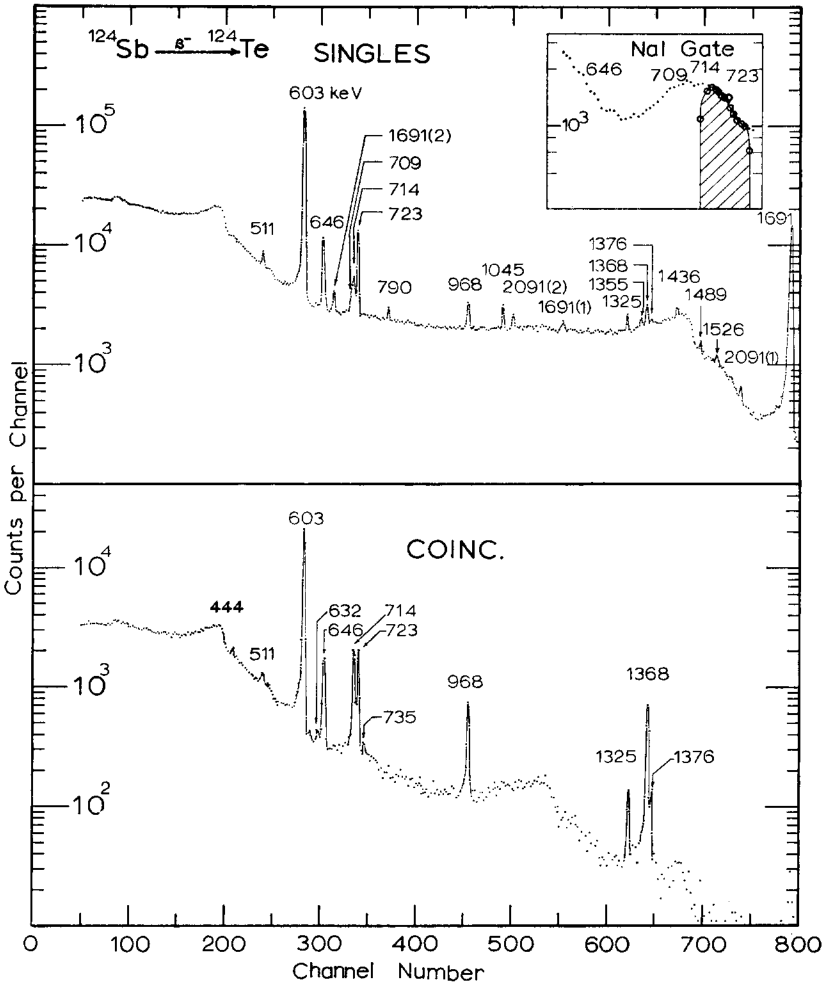

Fig. 3. The gamma-ray spectrum in the energy range 0.11 to 1.71 MeV in coincidence with gamma-rays in the gate shown in the inset. A 17 cm^3 coaxial Ge(Li) detector was used on the display side and a 7.6 cm × 7.6 cm NaI detector on the gate side.

4. Discussion and interpretation of the results

4.1. CONSTRUCTION OF THE DECAY SCHEME

A decay scheme for ^{124}Sb which incorporates 33 of the 34 well-established γ-rays is shown in fig. 4. The decay scheme is basically in agreement with that proposed by Stelson [1]) and supports many of the levels of ^{124}Te proposed by Ragaini et al. [10]). The β-feedings were calculated from the γ-ray intensity balance, and the corresponding $\log ft$ values were calculated with the aid of Moszkowski's nomogram [21]) with Q_β = 2916 [ref. [22])]. The numbers enclosed in parentheses next to the γ-ray energies represent the number of γ-ray transitions per 100 decays.

To aid in establishing the possible energy levels, a search was conducted using the energy sum relation. The search was performed through the use of a computer code

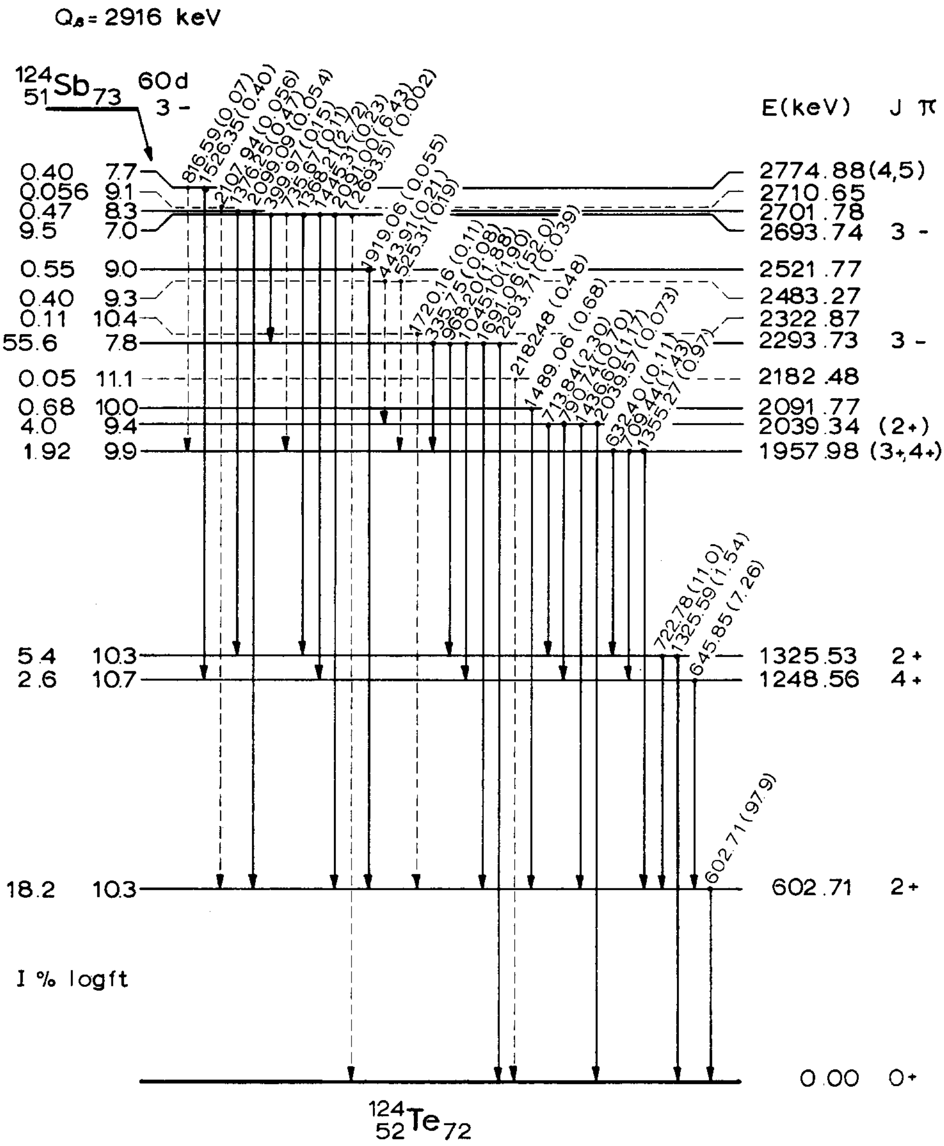

Fig. 4. Proposed decay scheme of ^{124}Sb → ^{124}Te.

developed by Bäcklin [23]). Generally, the energy levels satisfying energy sum relations were included in the decay scheme only when supported by coincidence data.

The energies of the seven levels which are fed or depopulated by four or more γ-ray transitions are listed in column 1 of table 4. We observed† 22 of the 28 possible γ-rays, which could depopulate these seven proposed energy levels, in both the singles and coincidence spectra. The energy differences between the levels listed in column 2 of table 4 are consistent with the measured γ-ray energies listed in column 3 to within the listed uncertainties of either column 2 or 3.

TABLE 4

Seven energy levels of ^{124}Te with their associated energy differences and γ-transitions

Proposed energy level (keV)	Energy difference between levels (keV)	Observed γ-ray energy (keV)
602.708±0.023	602.708±0.023	602.708±0.023
1248.561±0.038	1248.561±0.038	[a]
	645.853±0.038	645.853±0.030
1325.531±0.036	1325.531±0.036	1325.592±0.055
	722.853±0.043	722.776±0.042
	76.970±0.057	[a]
1957.979±0.047	1957.979±0.047	[a]
	1355.271±0.053	1355.267±0.049
	709.418±0.061	709.443±0.099
	632.448±0.059	632.40 ±0.22
2039.339±0.041	2039.339±0.041	2039.57 ±0.12
	1436.631±0.047	1436.600±0.050
	790.778±0.056	790.737±0.045
	713.808±0.055	713.844±0.13
	81.360±0.063	[a]
2293.726±0.029	2293.726±0.029	2293.71 ±0.11
	1691.018±0.037	1691.056±0.035
	1045.165±0.048	1045.102±0.044
	968.195±0.046	968.199±0.043
	335.747±0.055	335.75 ±0.30
	254.387±0.050	[a]
2693.738±0.031	2693.738±0.031	(2694 ±1) [b]
	2091.030±0.039	2091.001±0.047
	1445.177±0.049	1445.308±0.079
	1368.207±0.050	1368.210±0.046
	735.759±0.057	735.670±0.095
	654.399±0.052	[a]
	400.012±0.043	399.97 ±0.25

[a] No γ-ray was observed with this energy.

[b] Observed but not definitely established as belonging to this decay.

Two additional levels at 2701.8 and 2774.9 keV found by the computer code were strongly supported by coincidence data. In addition, the coincidence results give strong evidence (see table 3) for the existence of levels at 2091.77 and 2521.77 keV and weak evidence for the levels at 2182.48, 2322.87 and 2710.65 keV. The level proposed at 2483.27 keV is based on energy sum relations alone. This is the only proposed level, which is not supported by the coincidence work, but it is included since the γ-rays associated with this level could not be placed elsewhere in the decay scheme.

† The position of one of the γ-rays (735.6) in the decay scheme was not uniquely determined, since it could have been placed between the 2774.88 keV and 2039.34 keV levels, which are not listed in table 4.

In addition, two possible levels of ^{124}Te at 2225.3 keV and at 2683 keV were not included in the proposed decay scheme. The search program suggested the presence of a level at 2225.3 keV energy on the basis of the combination of the 1248.67 keV level and the 976.66 keV γ-ray and the combination of the 602.7 keV level and the not well-established 1622.3 keV γ-ray. A very low intensity (0.002 %) γ-ray at 2683 keV appeared in some high-energy γ-ray spectra. This in conjunction with the 2682 ± 3 keV γ-ray reported by Stelson [1]) gives some evidence for the existence of a level at this energy.

Refs. [24-32]) indicate the presence of at least one level at 1.66 MeV and at least two levels in the energy interval from 1.73 MeV to 1.75 MeV. The above reported levels were populated by modes of decay or excitations other than by the decay of the 60 d ^{124}Sb. No supporting evidence was found for these levels in the present study.

The present decay scheme differs from that of Stelson [1]) by the addition of levels at 2483.27, 2701.78 and 2710.65 keV and the absence of a level at 2108 keV. Whereas the 2108 keV transition was designated a ground state transition in the work of Stelson, the coincidence results of the present work indicate this transition to be in coincidence with the 603 keV transition. With the exception of the 2091.77 keV, all levels shown in fig. 4 are also proposed by Ragaini *et al.* [10]); no supporting evidence for the additional levels proposed by Ragaini *et al.* was found in the present work.

4.2. SPIN AND PARITY ASSIGNMENTS

The spin and parity of the $^{124}_{51}$Sb$_{73}$, $^{124}_{52}$Te$_{72}$ and $^{124}_{53}$I$_{71}$ ground states are 3^-, 0^+ and 2^-, respectively. The spin assignments for the ground states of ^{124}Sb and ^{124}I were determined by atomic-beam measurements [34, 35]).

The spin and parity assignments 2^+, 2^+, 3^- and 3^-, for the levels at 602.71, 1325.53, 2293.73 and 2693.74 keV have been firmly established by earlier work [6, 36-42]).

A discussion of some of the levels follows.

The 1248.53 keV *level.* The results of γ-γ NaI-Ge(Li) correlation measurements [1]) and the absence of electron capture or β^+ feeding to this state in the decay [27]) of ^{124}I strongly support a spin-parity value of 4^+ for this state.

The 1957.98 keV *level.* The spin-parity assignment 3^+ or 4^+ is preferred for this state. This would be consistent with both the log *ft* value of 9.9 and with the branching ratios of γ-rays depopulating this state.

The 2039.34 keV *level.* The γ-ray transitions depopulate this state to the 0^+ ground state, the 4^+ second excited state and the first and second 2^+ excited states. This strongly indicates a spin value of 2 for this level. A positive parity is strongly suggested by the log *ft* value of 9.4. This spin-parity assignment 2^+ is also adopted by Lagrange *et al.* [11]) and Chaturvedi *et al.* [24]).

The 2774.88 keV *level.* The spin of this state is probably restricted to 4 or 5 due to the predominant γ-transition connecting this state with the 4^+ second excited state and to the log *ft* value of 7.7.

The possible three-phonon character of the 1956.87 keV and 2039.34 keV states has been pointed out by Stelson [1]; the branching ratios found in the present work support this conclusion. In addition, if the proposed 2483.27 keV state decays only via transitions to the 1957.98 keV and 2039.34 keV levels, then it may be a state of four-phonon character.

Stelson [1] has pointed out the unusual presence of both the E3 ground state transition and the E1 transitions from the 2293.73 keV 3^- state to the first and second 2^+ states and the first 4^+ state. The present data on branching ratios and γ-ray energies permit the calculation of the enhancement of the E3 over the E1 transition rates. These are

$$\frac{B(\mathrm{E3};\,3^- \to 0^+)}{B(\mathrm{E3};\,3^- \to 0^+)_{\mathrm{sp}}} \approx 5.2\times 10^{+4}\,\frac{B(\mathrm{E1};\,3^- \to 2^+)}{B(\mathrm{E1};\,3^- \to 2^+)_{\mathrm{s.p.}}}$$

$$\approx 3.4\times 10^{+5}\,\frac{B(\mathrm{E1};\,3^- \to 2'^+)}{B(\mathrm{E1};\,3^- \to 2'^+)_{\mathrm{s.p.}}}$$

$$\approx 2.7\times 10^{+5}\,\frac{B(\mathrm{E1};\,3^- \to 4^+)}{B(\mathrm{E1};\,3^- \to 4^+)_{\mathrm{s.p.}}}$$

In the above relations, $2'^+$ refers to the second 2^+ state and s.p. to the single-particle estimate [43]) with S set equal to one. The large coefficients in these relations indicate the overwhelming preference for the E3 over the E1 decays of the 2293 keV level.

There is no precise measurement for $B(\mathrm{E3};\,3^- \to 0^+)$ of the above state. The work of Hansen and Nathan [44]) provides an upper limit ≈ 70 for the E3 enhancement. Stelson [1]) estimates a $B(\mathrm{E3};\,3^- \to 0^+) = 2\times 10^{-74}e^2\mathrm{cm}^6$ (which correspond to an enhancement ≈ 20) from the results [44]) of inelastic scattering of protons on ${}^{126}_{52}\mathrm{Te}_{74}$.

A similar situation may arise in the case of the 2693.71 keV 3^- state. The existence of the ground state transition from the 2693.71 keV level could not firmly be established. If this transition is present with an intensity value as shown in table 1, then the values of the enhancement of this E3 transition compared to the E1 transitions to the 2^+, $2'^+$ and 4^+ states are $\approx 1.3\times 10^4$, $\approx 8.5\times 10^3$ and $\approx 1.2\times 10^5$, respectively. The $B(\mathrm{E3};\,3'^- \to 0^+)$ value for the 2693.71 keV state has not been determined, but it is likely to be substantially smaller than the $B(\mathrm{E3};\,3^- \to 0^+)$ value for the 2293.74 keV state judging from the relative cross sections of these states found in inelastic scattering studies [31,33]). It is likely therefore that the E1 transitions depopulating the 2693.71 keV level are at least as retarded as the E1 transitions depopulating the 2293.74 keV level.

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