Structure of odd-odd ^{132}Sb

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(Received 7 November 1988)

New information is presented on the decay of 40-s ^{132}Sn to levels of odd-odd ^{132}Sb. A second β^--fed 1^+ level was identified in ^{132}Sb; it lies at an energy of 2268 keV and is fed by a relatively strong 0.83% β^--decay branch. Four γ rays were identified that form a weakly populated cascade from a level at 483 keV. Coincidence data demonstrate that the 254-keV level in this cascade is the 102-ns isomer identified previously by Clark *et al.* A 96-keV, isomeric γ ray has been assigned to the decay of the 4.1-min, 8^- isomer in ^{132}Sb. It may also be the 96-keV transition that is associated with the 1.8-μs isomer identified in the $A=132$ chain by Clark *et al.* The splitting of the levels in the proton-neutron multiplets is discussed and compared with the results of several recent shell-model calculations.

I. INTRODUCTION

The nuclide ^{132}Sb has a single proton beyond the closed proton shell at $Z=50$ and a single neutron hole in the closed neutron shell at $N=82$. This simple system makes it one of the most useful nuclides in which to study the multiplet structure in odd-odd nuclides. Multiplets in ^{132}Sb arise from the interaction between the single proton and the single neutron hole. By determining the degree to which these levels break from degeneracy, it is possible to characterize the proton-neutron effective interaction. Figure 1 shows the single proton levels in $Z=51$, ^{133}Sb, and the single hole levels in $N=81$, ^{131}Sn along with the results of our current study. Levels for ^{133}Sb are from the work of Blomqvist *et al.*[1] and those for ^{131}Sn are from the work of Fogelberg and Blomqvist.[2] Proton-neutron multiplets are represented as a single level at an energy of the single proton level plus the energy of the single neutron hole level. Studies by Blomqvist *et al.*[1] on ^{133}Sb and Bjornstad *et al.*[3] on ^{132}Sn showed that the excited core states lie near 4 MeV. With such a large excitation energy, these particle-hole configurations are unlikely to contribute significantly to the structure of the low-lying levels in ^{132}Sb.

The decay of 40-s ^{132}Sn to levels of odd-odd ^{132}Sb has been studied by Kerek *et al.*[4] They observed a single β^--decay branch that populates a 1^+ level at 1325 keV. Additional levels were identified at 1078 keV (2^+), 528 or 549 keV, 425 keV, and 85 keV (3^+). The levels were interpreted by attributing the ground state, 85-, and 425-keV levels to a $\pi g_{7/2}\nu d_{3/2}^{-1}$ configuration and the 1078- and 1325-keV levels to a $\pi d_{5/2}\nu d_{3/2}^{-1}$ configuration. The 529- and 549-keV transitions are in coincidence with each other and have nearly equal singles intensities. These transitions were placed in a cascade from the 1078-keV level in ^{132}Sb but the ordering was uncertain. In their study, Kerek *et al.* measured the conversion electron intensities of several strong transitions in ^{132}Sb. The multipolarity of the 86-keV transition was determined to be $M1$, limiting the ground-state (g.s.) spin to 4^+. Kerek *et al.*[5] also investigated the decay of ^{132}Sb into levels of ^{132}Te and their results are consistent with the 4^+ spin assignment in ^{132}Sb.

Clark *et al.*[6] identified three low-energy, isomeric γ rays in the $A=132$ chain during a recoil fission product study (see Table I). The 91- and 163-keV γ rays were reported to be in coincidence with each other and have similar singles intensities. These data suggest that they form a cascade from a 102-ns isomer. A third γ ray identified by Clark *et al.* was not in coincidence with other γ rays and has a much longer half-life, 1.79 μs. These three transitions were not identified in the other studies on the structure of ^{132}Sb or ^{132}Te.

In this paper, we report the results of a new study on the low-lying structure of ^{132}Sb. The main goals in this study were to identify additional members of the low-energy multiplets in ^{132}Sb, to investigate the isomerism that was identified by Clark *et al.*, and, in particular, to locate the unobserved 5^+ member of the $\pi g_{7/2}\nu d_{3/2}^{-1}$ multiplet.

II. EXPERIMENTAL STUDIES

Experiments on the $A=132$ mass chain were performed using the on-line mass separator TRISTAN, located in the High Flux Beam Reactor at Brookhaven National Laboratory. Details of the operation of the TRISTAN facility are described in Refs. 7 and 8. A high-

TABLE I. Isomeric γ rays identified in a recoil fission product study by Clark *et al.* (Ref. 6).

Energy[a] (keV)	Half-life (ns)	Fission yield[b]
91.1	104(5)	172(6)
96.2	1794(610)	32(10)
163.0	100(4)	176(6)

[a]One-σ uncertainties are shown in parentheses.
[b]The yield is given in fragments per 100 000 fission events.

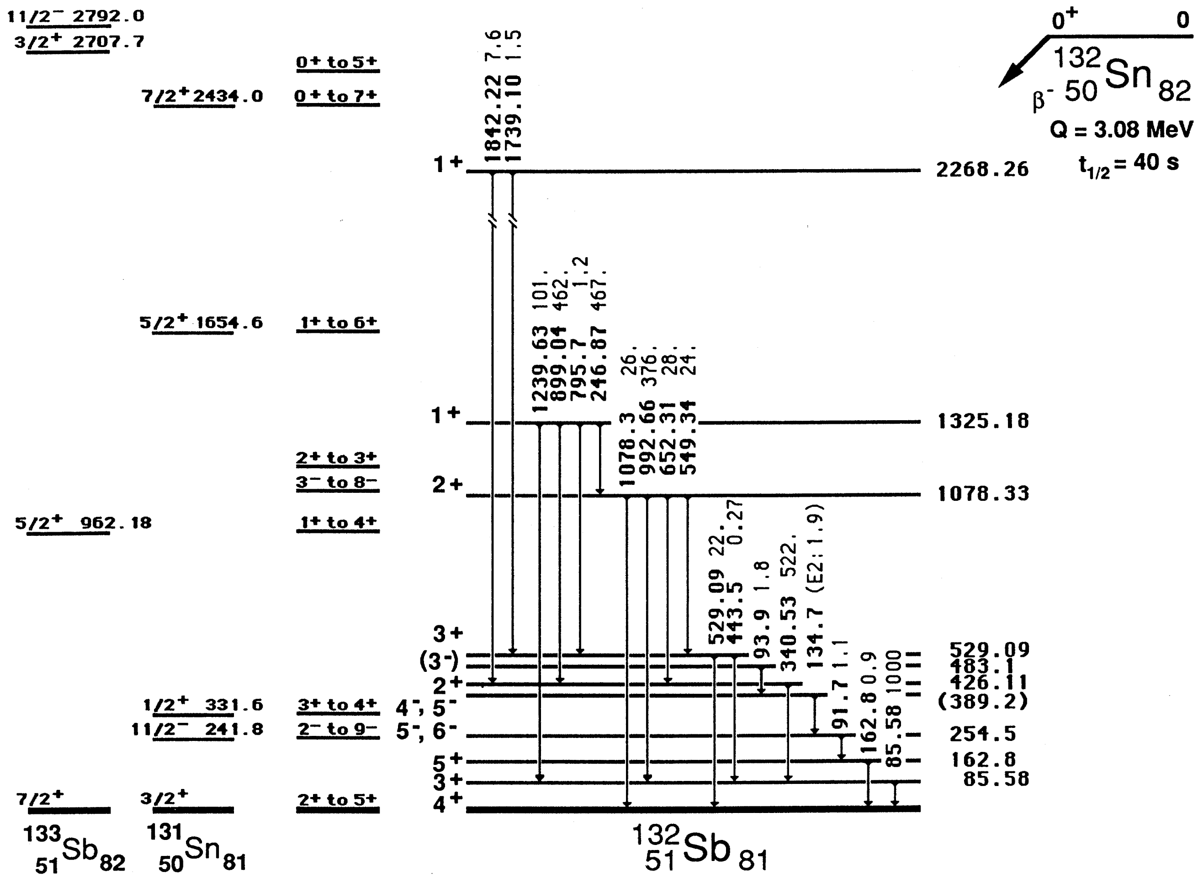

FIG. 1. Multiplets in ^{132}Sb and the proposed level scheme for the decay of 40-s ^{132}Sn into levels of ^{132}Sb. The energy of a degenerate multiplet is taken as a sum of the energy of the single proton level in ^{133}Sb and the single neutron level in ^{131}Sn. Total transition intensities in the level scheme are shown relative to 1000 for the 86-keV transition which is assumed to have an $M1$ multipolarity. Transition multipolarities used are shown in Table II.

temperature plasma ion source[9] was used to produce the ionized fission products and it is efficient for the extraction of Sn and Sb ions. The mass separated $A=132$ ion beam was deflected to the "parent/daughter" port where experiments on the decay of ^{132}Sn were performed.

Samples were created by depositing the ion beam on an aluminized Mylar tape. This point of deposition is known as the parent port and it is designed such that detectors can be placed around it for data collection during beam deposition. These samples can also be moved to a remote counting station, known as the daughter port, using a tape sequencer. The deposition time, a deflection time where the ion beam is deflected from the parent port, and the length that the tape can be moved are adjustable to optimize the activity for a particular range of half-lives.

Growth and decay of the $A=132$ activity were observed using four detectors placed around the parent port at a distance of 7.5 cm. One of the detectors was a 90-cm^3 Ge(Li) detector with a full width at half-maximum (FWHM) of 2.2 keV at 1332 keV. Two coaxial n-type Ge detectors, with sizes of 77 and 79 cm^3 were used and each had a FWHM of 2.0 keV at 1332 keV. The fourth detector was a 2-cm^3 planar Ge detector and it was used to collect data on the low-energy γ rays; it had a FWHM of 0.55 keV at 122 keV. The ion beam was deposited on the tape for 64 s and then deflected for 192 s. Sixteen time-sequential spectra with a time bin of 16 s were collected using one of the n-type Ge detectors. After 256 s, the tape was moved and the cycle restarted.

In a second experiment, coincidence data were acquired using the two n-type Ge detectors and the planar Ge detector, each placed 2.5 cm from the daughter port, which is located 60 cm from the deposition point. Samples of activity were deposited for 40 s on the Mylar tape and then transported to the daughter port using a tape sequencer. Approximately 75 million coincidence events were recorded over a period of three days.

Energy calibrations were made with ^{56,60}Co and ^{133}Ba standard sources. The energy values were taken from the high-precision γ-ray energies of Greenwood *et al.*[10] for ^{56,60}Co and from Helmer *et al.*[11] for ^{133}Ba. Borner *et al.*[12] have provided a set of high-precision energies for several intense γ rays identified in mass-separated fission products. Their γ rays for the $A=129$, 130, 131, and 132 mass chains were also included in these calibrations. Detector efficiencies were determined using the mixed radionuclide Standard Reference Material SRM 4275 from the National Institute of Standards and Technology. This source contains ^{125}Sb, ^{125}Te^{m}, and ^{154,155}Eu, and is provided with certified values for the γ-ray activities. Additional details on these experiments can be found in Ref. 13.

III. EXPERIMENTAL RESULTS: ANALYSIS AND DISCUSSION

The proposed level scheme for the decay of 40-s ^{132}Sn is shown in Fig. 1. Eight new transitions have been assigned to this decay, establishing five new levels at 163, 254, (389), 483, and 2268 keV. Intensities shown in Fig. 1 are relative transition intensities that include contributions from conversion electron emission. Transition intensities are listed relative to 1000 for the 86-keV transition using an $M1$ multipolarity. Theoretical conversion coefficients were calculated using the tables of Rosel *et al.*[14] The coefficients provided for $Z=51$ were fit using a cubic spline fit routine and values were then calculated for each of the γ-ray energies. The half-life for the 86-keV level is from the work of Kerek *et al.*[4] and the half-life of the 254-keV level is from the work of Clark *et al.*[6] A summary of γ-ray energies and intensities is given in Table II. Logft values were calculated using a half-life of 40 ± 1 s for the decay of ^{132}Sn, as reported by Fowler *et al.*,[15] and a Q_β value of 3.08 ± 0.04 MeV from the work of Aleklett *et al.*[16] Properties of the levels are summarized in Table III, and the observed coincidences are tabulated in Table IV.

The 2268-keV level is fed by a strong β^--decay branch with a logft of 4.8. This level depopulates by two γ rays, a 1739-keV γ ray to the 529-keV level, and an 1842-keV γ ray to the 426-keV level. Gates on the 1739-keV γ ray and on the 529-keV γ ray are consistent with a level at 2268 keV. Gating on the 1842- and 341-keV peaks also confirm the placement of this level. It is unlikely that this level is fed by unobserved transitions from higher-lying levels because it is at such a high energy. This suggests the spin of the level is 1^+.

The highest level which can be expected to be populated in β^- decay is the 1^+ member of the $(\pi g_{7/2}\nu d_{5/2}^{-1})_{1^+,2^+,3^+,4^+,5^+,6^+}$ multiplet, whose unsplit position is shown at 1655 keV in Fig. 1. As this is a particle-hole multiplet, the low- and high-spin levels will lie at the highest energies. No other levels were identified near 2 MeV. Transitions to the 426- and 529-keV levels would be expected to have a smaller intensity than those to the levels within the $\pi g_{7/2}\nu d_{5/2}$ multiplet. But, given the larger energy of transitions to lower-lying levels than to levels within the $\pi g_{7/2}\nu d_{5/2}$ multiplet, the E^3 and E^5 dependence of transition energy enables transitions to the lower levels to dominate.

The remainder of the β^- decay intensity in ^{132}Sb feeds the 1^+ level at 1325 keV whose configuration is $\pi d_{5/2}\nu d_{3/2}^{-1}$. The 2^+ level at 1078 keV is likely to be the 2^+ member of the $\pi d_{5/2}\nu d_{3/2}$ multiplet, although there could be some admixture of the somewhat higher-lying 2^+ member of the $\pi d_{5/2}\nu s_{1/2}$ doublet. The 1^+ level is about 480 keV above the expected position of the degenerate multiplet. This is a much smaller splitting than observed in the $\pi g_{7/2}\nu d_{5/2}$ multiplet, which lies 614 keV

TABLE II. Properties of transitions observed in the decay of ^{132}Sn to levels of ^{132}Sb.

Energy[a] (keV)	γ ray intensity (no conversion)	Transition intensity[b] (with conversion)		Decays from	Decays to
85.58(8)	980(20)	1000	$M1$	85.58	0
91.7(2)	1.7(3)	1.1(2)	$E1$	254.5	162.8
93.9(2)	2.0(2)	1.8(2)		(483.1)[c]	(389.2)
134.7(2)	2.4(3)	1.9(2)	if $E2$	(389.2)[c]	(254.5)
162.8(2)	1.5(7)	0.9(4)		162.8	0
246.87(5)	861(43)	467(23)		1325.18	1078.33
340.53(5)	1000	522(26)		426.11	85.58
443.5(2)	4.6(4)	2.4(2)		529.09	85.58
529.09(6)	43(4)	22(2)		529.09	0
549.23(7)	47(4)	24(2)		1078.33	529.09
652.31(6)	55(4)	28(2)		1078.33	426.11
795.7(2)	6.3(4)	3.2(2)	$E2$	1325.18	529.09
899.04(5)	906(45)	462(23)		1325.18	426.11
992.66(8)	753(38)	376(18)		1078.33	85.58
1078.3(1)	51(3)	26(2)	$E2$	1078.33	0
1239.63(5)	198(10)	101(5)	$E2$	1325.18	85.58
1739.10(25)	2.9(6)	1.5(3)	$E2$	2268.26	529.09
1842.22(25)	15(1)	7.6(5)		2268.26	426.11

[a]One-σ uncertainties are shown in parentheses.
[b]An $M1$ multipolarity is assumed except where noted.
[c]The parentheses reflect the uncertain order of these two transitions.

TABLE III. Properties of levels placed in the ^{132}Sb level scheme.

Energy[a] (keV)	Spin	Half-life	β^- (absolute)	β^- (in %)	log(ft)
0	4^+	3.07 min			
85.58(8)	3^+	14.8 ns			
162.8(2)	5^+				
254.5(6)	$(5^-,6^-)$	102 ns			
(348.4)[b](7)	$(4^-,5^-)$				
426.11(9)	2^+				
483.1(7)	$(3^-,2^-)$		< 1.5(2)	< 0.14(2)	> 8.82[c]
529.09(6)	3^+				
1078.33(7)	2^+				
1325.18(5)	1^+		1033(63)	99.0(59)	4.01
2268.26(7)	1^+		9.1(6)	0.87(5)	4.81

[a]One-σ uncertainties are shown in parenthesis.
[b]This assignment is dependent on the ordering of the 94- and 135-keV transitions.
[c]This value is for log($f_1 t$).

above the 1654-keV position of the $d_{5/2}$ neutron hole in ^{131}Sn. Paar[17] showed that level splitting within odd-odd multiplets has a $J(J+1)$ dependence and that the centroid of particle-hole multiplets moves down in energy while the centroid of particle-particle and hole-hole multiplets moves up in energy. As all of the multiplets in ^{132}Sb are particle-hole multiplets, all of the centroids can be expected to be shifted to lower energies, though by slightly different amounts. In a multiplet with a wider range of angular momentum, the levels cover a broader energy range. The level splitting in the $\pi d_{5/2}\nu d_{3/2}$ multiplet, then, will lie closer to the energy of the degenerate multiplet than those in the $\pi g_{7/2}d_{5/2}$ multiplet. A possible small peak at 870-keV peak was identified in one of the 246-keV gated spectra suggesting that the 3^+ member of this multiplet lies at either 870 or 955 keV. This peak was too weak to be found in the singles spectra and did not appear in other gated spectra to firmly establish its existence. If it is a transition from the 3^+ level in the $\pi d_{5/2}\nu d_{3/2}$ multiplet, the 955-keV energy is consistent with the expected multiplet structure. In addition, no evidence could be found for a populating transition, particularly from the 1078-keV, 2^+ level. Consequently, it has not been placed in the level scheme.

Kerek *et al.* could not determine the ordering of the 549- and 529-keV transitions. The transitions identified in this work at 444 and 796 keV establish the 529-keV transition as the ground-state transition. There is no evidence for β^- feeding to the level, indicating the spin of the 529-keV level is > 1. The spin of this level is restricted to 2^+ or 3^+ as it is populated by 1^+ and 2^+ levels and depopulates to 3^+ and 4^+ levels. The relatively weak branch from the 1^+ level at 1325 keV suggests $E2$ multipolarity and a 3^+ spin and parity.

A 3^+ level at 529 keV is most likely to be part of the $\pi g_{7/2}\nu s_{1/2}$ multiplet. The energy difference between this level and the 2^+ member of the $\pi d_{5/2}\nu d_{3/2}$ multiplet is too large for it to belong to the latter multiplet although

TABLE IV. Coincidences observed in the decay of ^{132}Sn to levels of ^{132}Sb.

Gate	Observed γ rays[a]															
85	247	340	443	549	652	898	992	1238	1842							
91	93	135	163													
93	91	135	163													
135	91	93	163													
163	91	93	135													
247	84	91	93	135	163	340	443	528	549	652	(710)	(816)	(870)	992	1078	
340	85	246	652	898	1842											
443	85	246	549	1737												
529	246	549	795	1737												
549	85	246	443	528												
652	85	246	340													
899	85	340														
992	85	246														
1078	246															
1239	85															

[a]Gamma rays enclosed in parentheses were observed in only one of two gates.

some configuration mixing is possible. γ-ray singles and coincidence data show no unplaced γ rays in the 400- to 600-keV energy range that would establish another level near 529 keV which could be the 4^+ member of this multiplet. Shell-model calculations[18] suggest that the 3^+-4^+ splitting is not larger than ca. 100 keV and the levels are expected to lie near 550 keV. The Siemens and quadrupole-quadrupole (QQ) interaction[18] predict the 4^+ level to lie significantly below the 3^+ level. If this were true, the 4^+ level would be fed by a transition from the 3^+ level and then decay to the 3^+ level at 86 keV. There is no evidence for such transitions.

The gate in one direction on the 246-keV, 1^+ to 2^+ transition does, however, show a possible weak peak at 712 keV. If this is the 4^+ to ground-state transition, it would place the 4^+ level at a position that is somewhat higher than expected by the calculations and give a 3^+ to 4^+ splitting of 183 keV. Such a splitting would not be inconsistent with the 148- and 166-keV splitting of the $\pi g_{7/2}\nu s_{1/2}$ multiplet observed in transfer reactions in ^{122}Sb and ^{116}Sb, respectively.[19,20] In both of those nuclides, the 4^+ level lies above the 3^+ level. This level is not shown in the level scheme as it was too weak to appear in the singles spectra and did not appear in the gate on the 246-keV γ ray in the other detector.

An $A=132$ singles spectrum is shown in Fig. 2 for the energy range 75–175 keV. The overlay represents an expansion of the vertical axis by a factor of 10. In this figure, it can be seen that all three of the isomeric γ rays identified by Clark *et al.*[6] are present. Although these γ rays are of low intensity, there were enough data to identify them in coincidence with their x rays. The 96-keV γ ray was identified in this manner as a transition in ^{132}Te. It was also in coincidence with 974-, 697-, and 103-keV γ rays, which are strong transitions within the ^{132}Te level scheme. A 150-keV γ ray was identified in the coincidence spectrum, but it may not be the same transition as the strong 150-keV transition[5] that deexcites the 9 μs, 1925-keV, 7^- isomer in the ^{132}Te level scheme.

Clark *et al.* attributed the 92- and 163-keV γ rays to the decay of ^{132}Sn. We found they are in coincidence with each other, as was reported by Clark *et al.* and they are also in coincidence with 94- and 135-keV γ rays. The 94- and 135-keV γ rays can be seen as weak peaks in Fig. 2. Gates placed on the four γ rays show that each of the γ rays is in coincidence with the other three, suggesting they form a cascade from a level at 483 keV. These gated spectra also show coincident Sb x rays.

Coincidence data also show the 92- and 163-keV γ rays to be in prompt coincidence, as are the 94- and 135-keV γ rays. Figure 3(a) is a sum of gates on the 92- and 163-keV peaks and the 94- and 135-keV peaks, resulting in a well-defined prompt peak. When one gate is placed on the 92- or 163-keV γ rays with the other gate on the 94- or 135-keV γ rays, respectively, the time distribution exhibited in Fig. 3(b) shows a half-life in the range of 150 ± 70 ns. This half-life agrees with the 102 ± 4-ns value published by Clark *et al.* The fact that Clark *et al.* did not observe the 94- and 135-keV γ rays indicates that these γ rays lie above the 102-ns isomer, placing the iso-

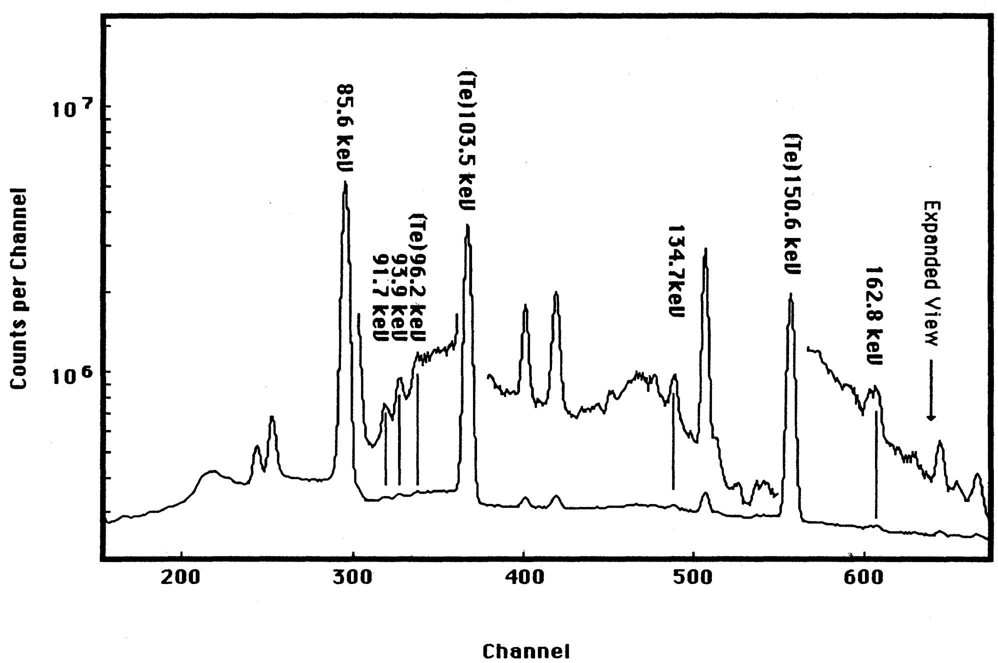

FIG. 2. A portion of the $A=132$ singles spectrum near 100 keV. The overlaid spectrum represents a ten-fold vertical expansion. Unlabelled peaks arise from the Pb x rays and the decay of Sb isomers.

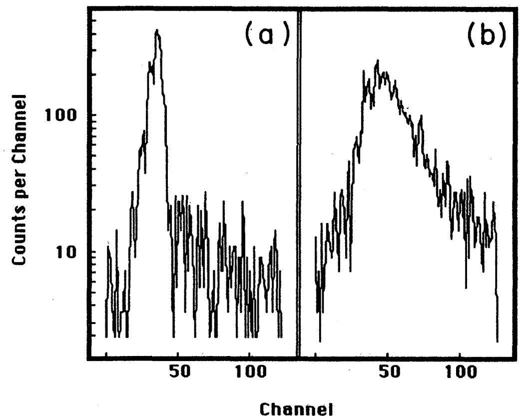

FIG. 3. Time spectrum showing the isomerism of the 254-keV level. (a) is a sum of the gates on the 135- and 94-keV peaks and the 92- and 163-keV peaks. (b) is a sum of several gates in which one gate is set on a peak above the 254-keV level and one gate on a peak below the 254-keV level.

mer at an energy of 254 keV.

Because of the low energy of these transitions, multipolarity assignments are quite important in establishing their total transition intensities and in balancing the intensities of this cascade. The intensity values for different multipolarities are shown in Table V. Two different balances must be considered, those that populate the isomer, and those that depopulate the isomer. For the two depopulating transitions (the 92- and 163-keV transitions) balance can only be achieved if the 92-keV transition is an $E1$ transition, regardless of the $M1/E2$ admixture of the 162-keV transition.

The data thus establish a 102-ns isomer at 254 keV that decays by an $E1$ transition to a level at 162 keV that in turn decays to the 3.1-min 4^+ isomer or to the 4.1-min 8^- isomer and another level at 483 keV that cascades by 94- and 134-keV transitions to the 102-ns isomer. The intensity imbalance between the γ-ray cascade that populates the 102-ns isomer at 254 keV and the cascade that depopulates this isomer suggests the possibility of a highly converted low-energy transition to the other isomer. Owing to the near equality of the intensities of the 94- and 134-keV transitions, it is not possible to establish the position of the intermediate level that lies between 483 and 254 keV.

It is not possible to establish which of the two isomers this cascade populates, and consequently not possible to determine with complete firmness the spin and parity assignments for the four new low-energy levels that we have identified in ^{132}Sb. We favor the sequence shown in Fig. 1 for a variety of reasons discussed below, but cannot rule out a number of other sequences shown in Fig. 4. Whatever sequence is chosen, it is clear that negative parity levels are involved. The presence of the 91-keV $E1$ transition requires a parity change. There are only two positive parity levels below 750 keV that have not been identified, the 5^+ member of the ground state $g_{7/2}d_{3/2}$ multiplet and the 4^+ member of the $g_{7/2}s_{1/2}$ doublet that should lie in the vicinity of the 3^+ member of that doublet near 529 keV. The depopulation sequence shown in Fig. 1 in which the isomer is a 6^- level has the advantage that it permits the 254-keV isomer to populate the 4.1-min 8^- isomer with a low-energy $E2$ transition. Because of the absence of any $E3$ internal transition between the 8^- isomer and 5^+ member of the gd multiplet or $M4$ transition between the 8^- and 4^+ isomers the two isomers must not be separated by more than 300 keV. As we do not observe any transition between these two levels, the transition energy would have to be below 100

TABLE V. Total transition intensities for transitions in the cascade from the 483-keV level.

Energy (keV)	Multipolarity $M1$	$E1$	$E2$
91.7	1.6(3)	1.1(2)	2.9(5)
93.9	1.8(2)	1.3(1)	3.2(3)
134.7	1.5(2)	1.3(2)	1.9(2)
162.8	0.9(4)	0.8(4)	1.0(5)

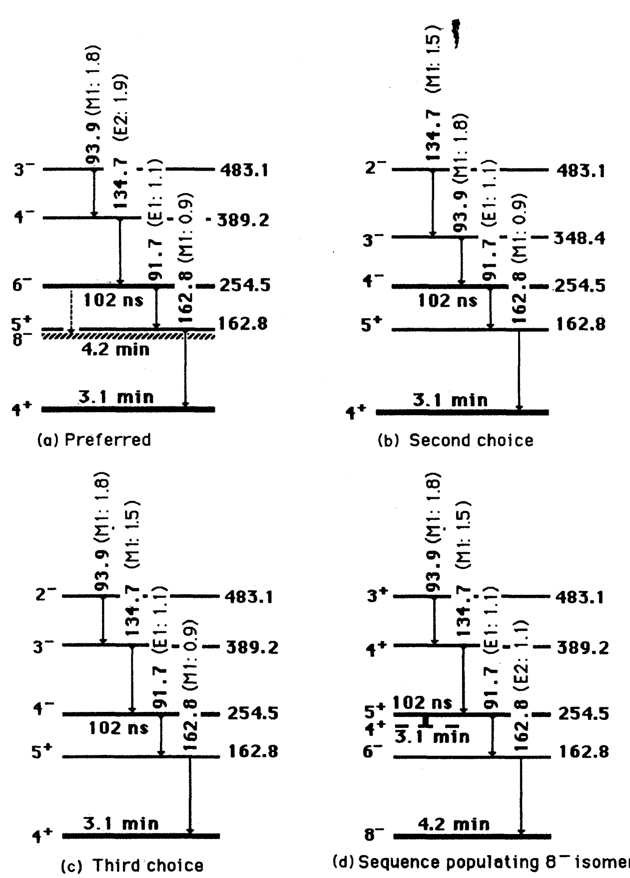

FIG. 4. (a) shows the preferred placement of the 92-, 94-, 135-, and 163-keV γ rays along with proposed spin-parity assignments for the levels. (b) and (c) show two alternate possibilities. In (d), a less likely possibility is shown where the 8^- isomer is below the 4^+ isomer.

keV, placing the 8^- isomer between 150 and 250 keV above the 4^+ ground state.

The choice of 6^- for the spin and parity of the 254-keV isomer reflects the positions of the low-lying levels in the adjacent odd-odd nuclide ^{130}Sb that has negative parity levels populated in the beta decay of the 7^- isomer in ^{130}Sn. In that nuclide, the 8^- isomer is thought to be the ground state with a 6^- level lying at 60 keV and a 7^- level lying at 145 keV.[13] This staggering of levels with adjacent spins and parities in large multiplets that lie near double closed shells has been well characterized by several previous reviews.[21–24] This staggering can be readily accounted for in calculations using a simple δ-function interaction as illustrated in Fig. 5 from the work of Sau,[25] Sau and Heyde,[26] and also found in the work of Lane.[27] The staggering can also be accounted for in the Paar model[17] and in other multipole expansion models by the addition of a cubic term.[26] As can be noted by examining the results of that calculation, it would be unlikely that a 5^- level would be isomeric with both 4^- and 6^- nonparity changing transitions available for its decay, and a 4^- isomer would be expected to decay directly to the much lower-energy 4^+ ground state rather than to the 5^+ level.

The sequence of transitions proposed in Fig. 1 that populates the 254-keV isomer also reflects possible staggering. Only the 134-keV transition can be $E2$ to maintain an intensity balance with the 94-keV transition whose minimum intensity is associated with $M1$ multipolarity and which then results in a 3^- spin and parity assignment for the 483-keV level. For both transitions to be $M1$ would place the spin of the 483-keV level at 4^-, allow for no staggering irrespective of the order of the transitions, and raise some concern as to how a level with that high spin could be populated without any of the populating γ rays being identified. A lower spin such as 4^- for the 254-keV isomer would permit the 483-keV level to be 2^-. However, such an assignment would not be consistent with the observations shown by Schiffer[21] that the lowest and highest spins of particle-hole multiplets near double magic nuclides tend to have rather high energies and be somewhat split away from the other members of the multiplet. Typical calculations such as that shown in Fig. 5 tend to underestimate the positions of the lowest and highest spin members. For the 2^- level to be at 483 keV and the 8^- level to be at approximately 200 keV would imply an almost degenerate multiplet, again contrary to the behavior of the particle hole multiplets near ^{40,48}Ca, ^{56}Ni, ^{90,96}Zr, and ^{208}Pb.

But, a 3^- assignment implies a multiplet splitting consistent with other odd-odd nuclides and one whose population can be understood. Inasmuch as there is some evidence for these four γ rays in the 247-keV gate, it is likely that the 483-keV level is populated by several paths, which results in intensities for the individual populating γ rays that are below our detection limits owing to the declining detector efficiencies at higher energies. It must be noted that the detector efficiency is at a peak in the region below 150 keV and would be only about $\frac{1}{3}$ as high for rays in the 500-keV energy range. These possible paths are shown in Fig. 6. Included are possible transitions populating and depopulating a number of levels that

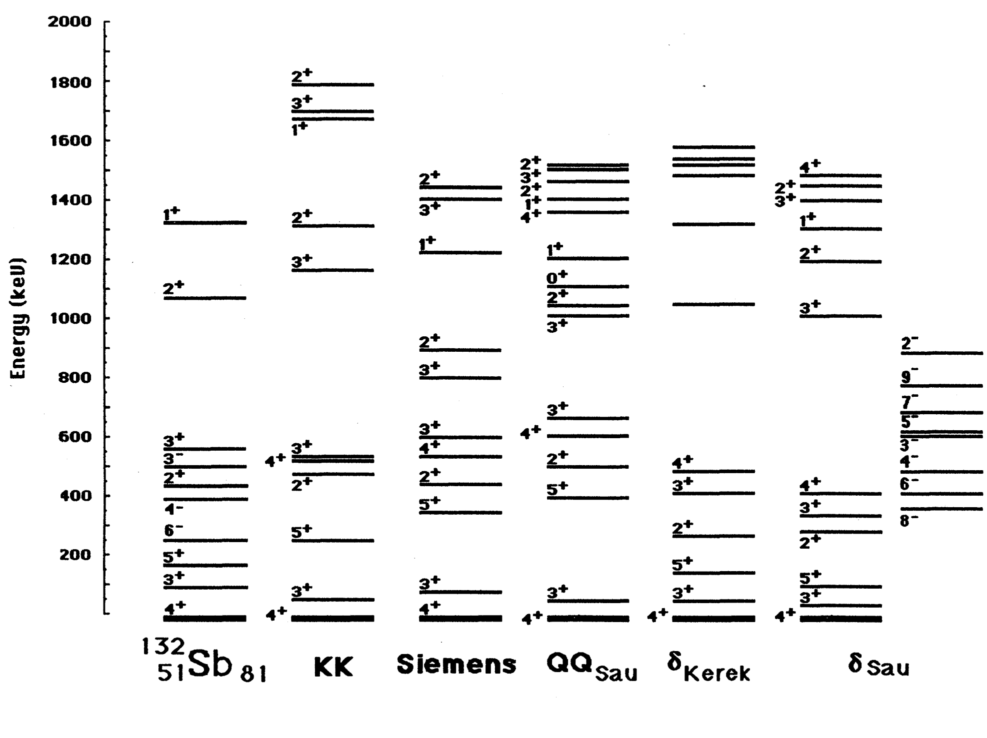

FIG. 5. Results from several shell-model calculations on the structure of ^{132}Sb.

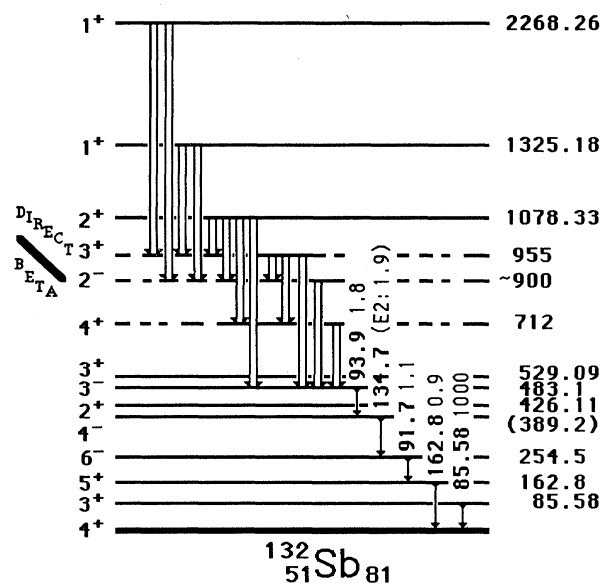

FIG. 6. Possible paths by which the 3^- level at 483 keV can be populated that would likely be below our detection limits.

have not been established in this nuclide, but that are surely present as part of multiplets where some of the levels have been observed.

IV. COMPARISON TO SHELL-MODEL RESULTS

Several calculations have been performed to predict the structure of ^{132}Sb; some of the levels from these calculations are shown in Fig. 5. Two realistic effective interactions have been used in calculations by Stone *et al.*[13,18] The first interaction used was the Kallio-Koltveit (KK) effective interaction,[28] an interaction containing only even components. For the second interaction the Siemens *g*-matrix interaction[29] at a Fermi momentum of 1.4 fm^{-1} was used. This interaction contains both even and odd components. Sau and Heyde[26] used a quadrupole plus quadrupole interaction (QQ) for one set of calculations, and a δ interaction (δ_{Sau}) in another. A δ interaction was also used in calculations by Kerek *et al.*[4] (δ_{Kerek}).

Two points should be noted when comparing results from these calculations. For the calculations by Stone *et al.*[13,18] using the KK and Siemens potentials, single-particle energies were fixed by simultaneously fitting the single proton levels in ^{133}Sb and the single neutron hole levels in ^{131}Sn. No other parameters were adjusted. Calculations by Sau and Heyde[26] and by Kerek *et al.*[4] were performed by adjusting parameters to fit the ^{132}Sb levels. Since the level structure of ^{132}Sb was not well defined at the time of the calculations, their results may not accurately reflect the performance of the interactions.

The Siemens interaction and the δ_{Sau} interaction appears to give the best representation of the $\pi d_{5/2} \nu d_{3/2}$ multiplet. Both calculations predict the 1^+ level (which provides most of the β^- decay population) to lie close in energy to the experimental energy. The Siemens interaction predicts a larger level splitting than is observed experimentally, while the δ_{Sau} interaction underestimates this splitting. Although the 3^+ level may not have been observed, the 2^+-3^+ level splitting with the Siemens interaction is closer to what is expected in a particle-hole multiplet than that by the δ_{Sau} interaction.

The $\pi g_{7/2} \nu d_{3/2}$ multiplet is reasonably well determined in the shell-model calculations. Both δ-interaction calculations appear to give a multiplet which is compressed although the energy of the 5^+ level is close to the experimental energy. The fit to the levels is improved with the KK, Siemens, and QQ interactions except that the 5^+ level energy is overestimated in each calculation. Of the five calculations, the KK interaction probably gives the best overall fit to the experimental levels.

The level splitting for the negative-parity levels was calculated by Sau and Heyde.[26] As can be seen, the absolute position of the negative parity levels is somewhat higher than observed experimentally and the splittings are somewhat smaller than determined experimentally. The calculated splitting for the 3^- and 4^- levels and 4^- and 6^- levels is about 60 and 80 keV, respectively, whereas transition energies of 94 and 134 keV are observed. These larger experimental splittings suggest that the strength of the interaction used by Sau and Heyde has been underestimated.

V. CONCLUSIONS

Results from these studies provide new information on the structure of ^{132}Sb. Much of the low-lying structure of the positive-parity system has now been determined. The energy of all four levels in the $\pi g_{7/2} \nu d_{3/2}$ multiplet are known and only the 4^+ level in the $\pi g_{7/2} \nu S_{1/2}$ multiplet remains unobserved. Three levels from the $\pi g_{7/2} \nu h_{11/2}$ multiplet were identified, and limits can be made on the energy range of the 8^- isomer relative to the 4^+ ground state. These results can be used to further test and develop effective interactions for use near ^{132}Sn. While there are many aspects of the structure of ^{132}Sb that remain unknown, these experiments were done with reasonably intense beams for an extended period. Thus, it is unlikely that further studies of the radioactive decay of ^{132}Sn to levels of ^{132}Sb will reveal additional levels without an extensive commitment of time. As it is the high-spin levels for which data are lacking, studies of the deexcitation of fission products comparable to those carried out by Phillips *et al.*[30] would provide an excellent path to exactly those kinds of data that are lacking. Measurement of the magnetic moments 4^+ and 8^- isomers and the 3^+ 14-ns 85-keV level would also reveal additional information about the degree of configuration mixing among the levels that to lie below 1500 keV.

ACKNOWLEDGMENTS

The authors appreciate the assistance of Dr. R. L. Gill and Dr. A. Piotrowski and the TRISTAN technical staff during the performance of these experiments and the subsequent reduction of the data, as well as the hospitality of Dr. R. F. Casten and the entire Neutron Nuclear Physics Group at Brookhaven National Laboratory. This work was supported by the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-FG05-8ER40418 with the University of Maryland and through Brookhaven National Laboratory under Contract DE-AC02-76CH00016.

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