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Energy levels below 2 MeV in ^{121}Sb and ^{123}Sb

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Energy levels below 2 MeV in ^{121}Sb and ^{123}Sb have been studied using the ^{121,123}Sb$(n,n'\gamma)$ and ^{120}Sn(p,γ) reactions. γ-ray angular distributions have been measured and spins and γ-ray multipole mixing ratios deduced. Spin assignments have been made for the 1025 (7/2), 1036 (9/2), and 1145 (9/2) keV levels in ^{121}Sb, and an assignment of 9/2 is suggested for the 1030 keV level in ^{123}Sb. Present and previous results are discussed in the framework of an intermediate coupling model.

[NUCLEAR REACTIONS ^{121,123}Sb$(n,n'\gamma)$, $E=1.5$–2.7 MeV; measured E_γ, $\sigma(E_\gamma, \theta_\gamma)$, branching ratios; ^{121,123}Sb deduced levels, J, δ; natural targets. ^{120}Sn(p, γ), $E=3.4$ MeV; measured E_γ; enriched target. Intermediate coupling model calculations.]

I. INTRODUCTION

The two naturally occurring $Z=51$ isotopes, ^{121}Sb and ^{123}Sb, can be described to first order in terms of a single proton coupled to a vibrating core.[1-4] A knowledge of the structure of these isotopes can provide information on the coupling of single-particle and collective states. A number of experimental studies[5-13] have been made of these two nuclei. The properties of the first four levels in both nuclei are well known but information on levels above 1 MeV is still incomplete; spins have not been measured for most levels above 1 MeV, and the excitation energies of states above 1.4 MeV are in some doubt.

In this work angular distributions of a number of γ rays emitted in the ^{121,123}Sb$(n, n'\gamma)$ reactions, as well as excitation energies and γ-ray branching ratios, have been obtained using a natural Sb target. The ^{120}Sn(p, γ) reaction was also studied using an enriched target. This latter study was necessary to eliminate ambiguities in the assignment of γ rays observed from the $(n, n'\gamma)$ reaction.

The results of these experiments are discussed in terms of an intermediate coupling model in which either single-particle or two-particle–one-hole states are coupled to quadrupole and octupole vibrations of a $Z=50$ core.

II. EXPERIMENT

A. The $(n,n'\gamma)$ experiment

γ-ray angular distributions were determined using the small-sample technique of Davidson *et al.*[14] The neutron scatterer consisted of a cylinder of natural Sb powder (57.2% ^{121}Sb, 42.8% ^{123}Sb) of height 1.59 cm, radius 0.87 cm, and mass 13.5 g, and was contained in a thin-walled nylon tube. The scatterer was aligned axially with the beam at a distance of 0.8 cm from the neutron production target.

Neutrons were produced in a ^{3}H$(p, n)^3$He reaction using a proton beam pulsed every 500 ns with a width of 10 ns. The average beam current was 0.7 μA, with typical runs requiring an accumulated charge of 10 mC per angle. The target consisted of tritium absorbed at about a 1 : 1 atomic ratio in a 3.27 mg/cm^2 layer of metallic erbium deposited on a tantalum backing.

γ-ray excitation curves were measured in order to select the appropriate neutron bombarding energies for the angular distribution measurements. The energies were chosen so that there was no appreciable feeding from higher excited states. Maximum neutron energies ranged from 1.5 to 2.7 MeV. The energy spread of the neutron beam due to the target thickness was typically 150 keV.

γ rays were detected in two Ge(Li) detectors placed about 50 cm from the scatterer. A NE213 liquid scintillator neutron detector was used to monitor total neutron flux. A ^{137}Cs source was placed close to the Ge(Li) detectors in order to monitor dead time and stability of the system. The energy spectrum was calibrated using ^{133}Ba, ^{137}Cs, and ^{60}Co γ-ray sources. A typical γ-ray spectrum is shown in Fig. 1(a).

B. The (p,γ) experiment

The target consisted of SnO_2 enriched in ^{120}Sn (>98% ^{120}Sn) of thickness 3.5 mg/cm^2 on a Ta backing. A 3.4 MeV dc proton beam was used. This energy is just below the threshold for the ^{120}Sn$(p, n)^{120}$Sb reaction. The beam current was typically 3 μA.

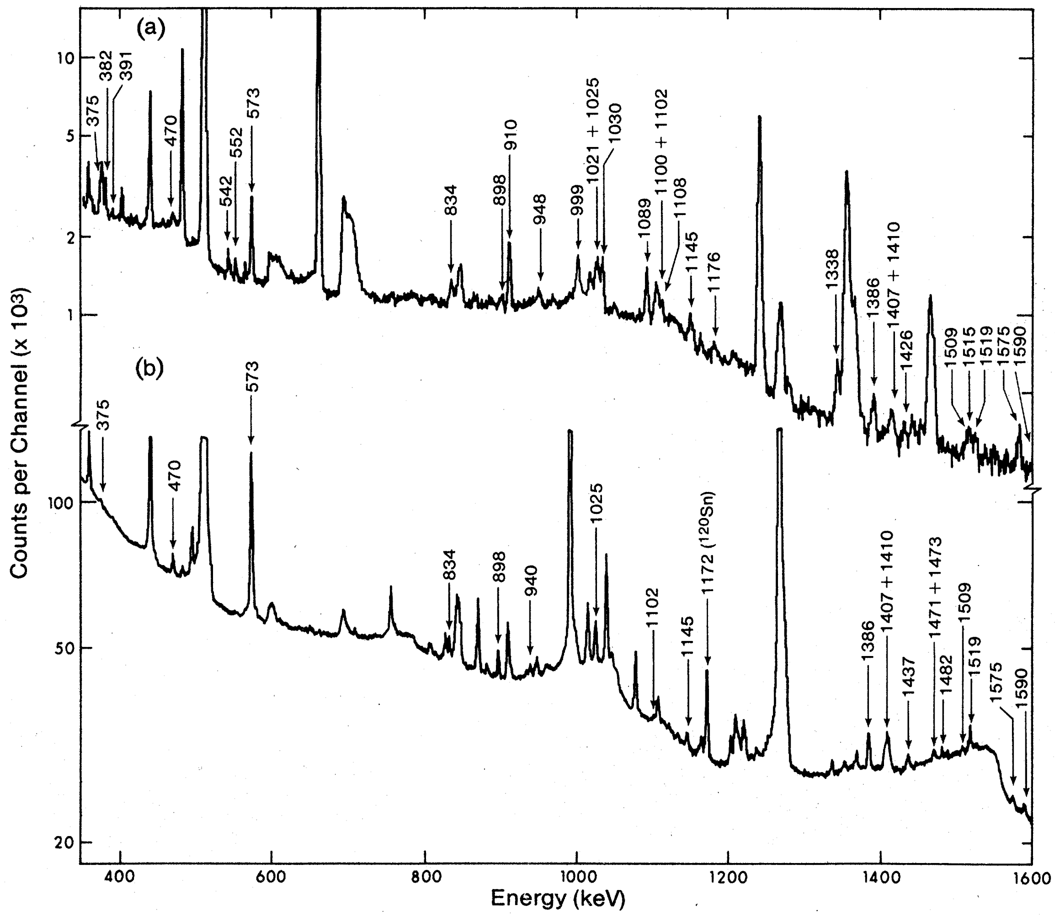

FIG. 1. γ-ray spectra from (a) the $(n,n'\gamma)$ and (b) the (p,γ) experiments. Sb peaks have been indicated. All unlabeled peaks have been identified as background. For both spectra the Ge(Li) detector was aligned at an angle of 50° to the incident proton beam direction.

γ rays were detected in a Ge(Li) detector placed 1 cm from the target at an angle of 50° to the beam direction. Spectra were accumulated for about four hours. A typical γ-ray spectrum is shown in Fig. 1(b).

III. RESULTS

Decay schemes, measured branching ratios and deduced spins are shown in Figs. 2 and 3. The results of the γ-ray angular distribution measurements are given in Table I.

The alignment of the initial state in a γ decay was calculated using the compound nuclear statistical model[15] and the optical model parameters of Wilmore and Hodgson.[16] A computer code[17] was used to average the distributions over the target geometry. Plots of χ^2 per degree of freedom (χ^2/df) for various initial state spins J_i and γ-ray multipole mixing ratios δ were generated. J_i was limited to the values $J_f - 3$ to $J_f + 3$. These limits were reasonable because the time-of-flight gating of signals from the γ-ray detectors, which was used to reduce background, also set an upper limit of approximately 20 ns on the lifetimes of all Sb states observed. Combinations of J_i and δ for which the minima in $\chi^2/\mathrm{df}(J_i, \delta)$ fell above a 0.1% confidence limit were rejected.[18] Values of J_i and δ which were not rejected, and which have not been ruled out by previous work, are listed in Table I. The errors reported in the mixing ratios are calculated according to a $\chi^2_{\min} + 1$ criterion.[19] The phase convention of Rose and Brink[20] was used.

IV. CALCULATIONS

Calculations for ^{121}Sb and ^{123}Sb were performed using an intermediate coupling model, following closely the work of Vanden Berghe and Degrieck.[4] The odd-mass Sb nuclei were described in terms of either single-particle or two-particle–one-hole (2p1h) states coupled to the vibrational states of the appropriate even-mass Sn core. The two pro-

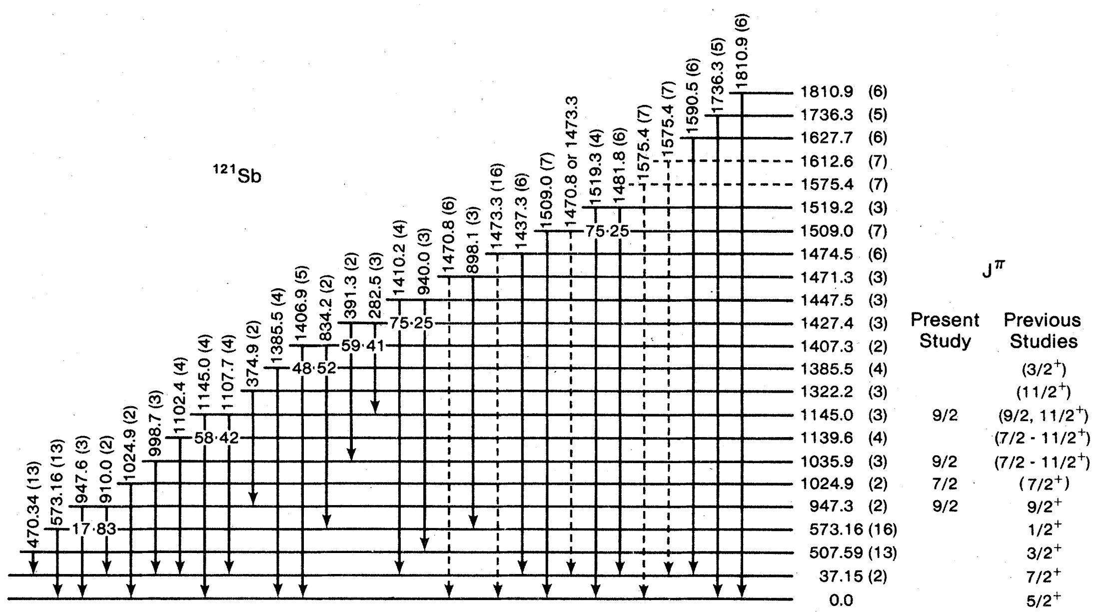

FIG. 2. The level and decay scheme for ^{121}Sb is shown. Uncertainties in γ-ray and level energies are indicated in brackets following the energy values. Uncertainties in branching ratios are about 4%. Levels and transitions represented by dashed lines are tentative. Previous spin assignments are taken from Refs. 5, 6, 8, 9, 11, and 13.

tons in the 2p1h states were assumed to lie in the same orbital and were coupled to spin zero. The particle orbitals used for Sb were the $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$, and $1h_{11/2}$ states; the hole orbitals were the $1g_{9/2}$, $2p_{1/2}$, and $2p_{3/2}$ states. The vibrational states were composed of up to three quadrupole phonons, up to two octupole phonons, or up to two quadrupole phonons coupled to one octupole phonon.

Input parameters included the quadrupole and octupole phonon energies ($\hbar\omega_2$ and $\hbar\omega_3$), the coupling-strength parameters (ξ_2 and ξ_3), the particle and hole orbital energies, the pairing energy, and a maximum energy cutoff which excluded from the calculations any basis states whose unperturbed energies were above a certain level. An energy cutoff of 5 MeV was used for most of the calculations, since only states below 2 MeV were being considered. The pairing energy was chosen to be $27/A$ MeV,[21] and $\hbar\omega_2$ and $\hbar\omega_3$ were assumed to be equal to the energies of the lowest 2^+ and 3^- states respectively in the appropriate even-mass Sn nucleus. Single-particle energies and coupling-strength parameters were deduced by comparison with experimentally measured energies and spectroscopic factors[22,23] for the lowest $\frac{7}{2}^+$, $\frac{5}{2}^+$, $\frac{3}{2}^+$, $\frac{1}{2}^+$, and $\frac{11}{2}^-$ levels in ^{121}Sb and ^{123}Sb. Since a low-lying $\frac{9}{2}^+$ 2p1h state has been identified[9] in both ^{121}Sb and ^{123}Sb, the energy separation of the $1g_{9/2}$ orbital from the lowest single-particle state could also be determined. Calculations were carried out for ^{119}In and ^{121}In in order to deduce the relative separations of the $1g_{9/2}$, $2p_{1/2}$, and $2p_{3/2}$ hole orbitals.

Input parameters for the calculations are listed in Table II. Calculated levels are compared with experiment in Figs. 4 and 5. Table III lists the main components of the wave functions for some of these levels.

Magnetic dipole and electric quadrupole moments, γ-ray branching and multipole mixing ratios for $E2$ and/or $M1$ transitions, and $B(E2)$ values were calculated in a method similar to that of Heyde and Brussaard.[24] Input parameters included the radial parameter $k = 40$ MeV, and the magnetic g factors $g_l = 1.0$, $g_s = 2.62$, and $g_R = Z/A$, while values for the quadrupole phonon energy $\hbar\omega_2$ and coupling strength parameter ξ_2 were fixed by the fit to the energy levels. Experimental and

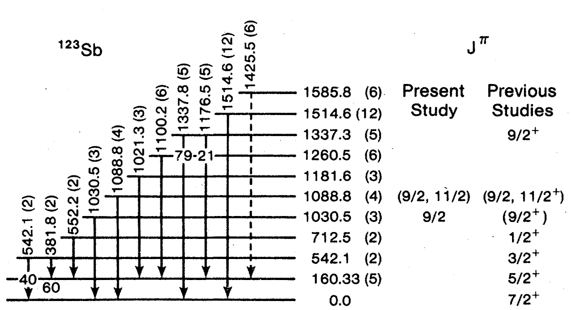

FIG. 3. The level and decay scheme for ^{123}Sb is shown. Previous spin assignments are taken from Refs. 7, 9, and 11.

TABLE I. Experimental spin values and mixing ratios.

Nucleus	Level energy (keV)	γ-ray energy (keV)	$J_i \to J_f^\pi$	arctanδ [a] (deg)
^{121}Sb	947	947	$\frac{9}{2} \to \frac{5}{2}^+$	All δ
		910	$\frac{9}{2} \to \frac{7}{2}^+$	13(6) 67(6)
	1025	1025	$\frac{7}{2} \to \frac{5}{2}^+$	4 → 75
	1036	999	$\frac{9}{2} \to \frac{7}{2}^+$	19(11) 61(11)
	1145	1145	$\frac{9}{2} \to \frac{5}{2}^+$	−90 → −56 −33 → 31 60 → 90
		1108	$\frac{9}{2} \to \frac{7}{2}^+$	6 → 74
	1386	1386	$\frac{1}{2} \to \frac{5}{2}^+$	All δ
			$\frac{3}{2} \to \frac{5}{2}^+$	All δ
			$\frac{5}{2} \to \frac{5}{2}^+$	All δ
			$\frac{7}{2} \to \frac{5}{2}^+$	All δ
			$\frac{9}{2} \to \frac{5}{2}^+$	−90 → −85 −4 → 90
^{123}Sb	1030	1030	$\frac{9}{2} \to \frac{7}{2}^+$	9 → 72
	1089	1089	$\frac{9}{2} \to \frac{7}{2}^+$	−81 → −18
			$\frac{11}{2} \to \frac{7}{2}^+$	−89(12) 3(12)
	1182	1021	$\frac{1}{2} \to \frac{5}{2}^+$	All δ
			$\frac{3}{2} \to \frac{5}{2}^+$	All δ
			$\frac{5}{2} \to \frac{5}{2}^+$	−90 → −56 −2 → 90
			$\frac{7}{2} \to \frac{5}{2}^+$	All δ
			$\frac{9}{2} \to \frac{5}{2}^+$	All δ
	1337	1337	$\frac{9}{2} \to \frac{7}{2}^+$	−90 → −88 −10 → 90

[a] arctanδ is given in degrees. The numbers in parentheses give the uncertainties in degrees. In cases where no values of δ could be rejected the term "All δ" appears. The phase convention of Rose and Brink (Ref. 20) has been used.

calculated electromagnetic properties are compared in Tables IV and V.

V. DISCUSSION

A. Excited states of ^{121}Sb

1. Levels between 900 and 1400 keV

The angular distribution results for the 947 → 37 keV transition confirm a previous spin assignment[9] of $\frac{9}{2}$. The 947 keV level has been strongly excited in the ^{122}Te(t, α) reaction[9] with an l transfer of 4. The calculations are consistent with a large 2p1h component (two protons in the $1g_{7/2}$ orbital and a single hole in the $1g_{9/2}$ orbital).

TABLE II. Input parameters for the intermediate coupling model calculations.

Input parameters [a]	^{121}Sb	^{123}Sb
ξ_2	1.8	1.8
ξ_3	1.3	1.3
$\hbar\omega_2$	1.171	1.140
$\hbar\omega_3$	2.400	2.492
$1g_{7/2}$	0.0	0.0
$2d_{5/2}$	0.20	0.40
$2d_{3/2}$	1.40	1.50
$3s_{1/2}$	1.45	1.55
$1h_{11/2}$	1.65	1.95
$1g_{9/2}$	2.70	3.05
$2d_{1/2}$	3.30	3.65
$2d_{3/2}$	3.85	4.20

[a] All energy parameters are measured in MeV.

The 947 keV level has been suggested[13] as the band head for a $\Delta J = 1$ rotational band, the second level in the band occurring 375 keV above the band head. Similar rotational bands have been observed in other odd-mass Sb nuclei.[25] A 374.9 ± 0.2 keV γ ray observed in both the $(n, n'\gamma)$ and (p, γ) spectra would appear to be a transition between these two states. This indicates a level at 1322.2 ± 0.3 keV.

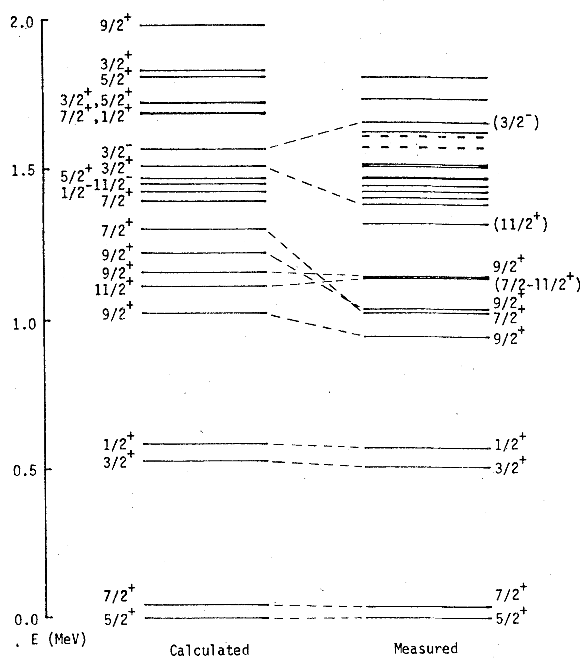

FIG. 4. A comparison of calculated and measured energy levels in ^{121}Sb. Experimental results are from the present study and Ref. 9.

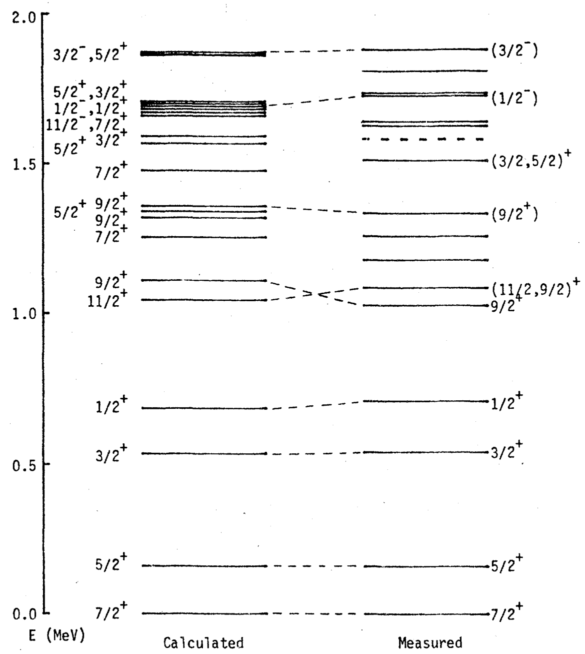

FIG. 5. A comparison of calculated and measured energy levels in ^{123}Sb. Experimental results are from the present study and Refs. 7 and 9.

The spin-parity for this level should be $\frac{11}{2}^+$. Accurate angular distribution measurements to test this spin proposal could not be made, however, because of the existence of a background γ ray at 377.5 keV.

Levels at 1025, 1036, and 1145 keV are assigned spins of $\frac{7}{2}$, $\frac{9}{2}$, and $\frac{9}{2}$, respectively, on the basis of the angular distributions of their γ-ray decays. Sample angular distributions and plots of χ^2/df for the 1025 → 0 keV, 1036 → 37 keV, and 1145 → 37 keV transitions are shown in Fig. 6.

A level at 1140 keV was observed to decay to the first excited state with the emission of an 1102 keV γ ray. The presence of an 1100 keV γ ray from the 1260 → 160 keV transition in ^{123}Sb, however, prevented an accurate measurement of the angular distribution.

Previous experimental results suggest that the levels at 1025, 1036, 1140, and 1145 keV are collective in nature. Both the 1025 and 1145 keV levels are strongly excited by the (d, d'),[26,27] Coulomb excitation,[5,11] and (γ, γ') (Ref. 8) reactions, while the 1036 and 1140 keV levels are excited in the ^{123}Sb(p, t) reaction[28] but only weakly in the other reactions. The present calculations predict

TABLE III. Calculated wave function components.

Nucleus	Energy[a] level (keV)	Spin	Wave function component (%)[b] Single particle $\frac{7}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	2p1h $\frac{1}{2}$	$\frac{7}{2}$	$\frac{5}{2}$	One quad. phonon $\frac{7}{2}$	$\frac{5}{2}$	$\frac{3}{2}$	$\frac{1}{2}$
^{121}Sb	0	$\frac{5}{2}$		77					2	9		3
	37	$\frac{7}{2}$	77						13	1	4	
	508	$\frac{3}{2}$			31				40	5	4	4
	573	$\frac{1}{2}$				31				42	10	
	947	$\frac{9}{2}$					77		6			
	1025	$\frac{7}{2}$	4						36	34		
	1036	$\frac{9}{2}$					4	2	58	12		
	(1140)	$\frac{11}{2}$							74			
	1145	$\frac{9}{2}$					1	6	11	58		
	(1386)	$\frac{3}{2}$							10	69	1	1
^{123}Sb	0	$\frac{7}{2}$	79						13	1	4	
	160	$\frac{5}{2}$		76					3	10	1	3
	542	$\frac{3}{2}$			29				45	4	4	3
	712	$\frac{1}{2}$				32				38	12	
	1030	$\frac{9}{2}$					3		72	1		
	(1089)	$\frac{11}{2}$							75			
	1337	$\frac{9}{2}$					76		3	3		

[a] Experimental energies are listed. Correlations between bracketed levels and calculated levels are not definite.
[b] For single particle and one quadrupole phonon states, the orbitals listed contain a single proton. The 2p1h states have two protons coupled to spin zero in the designated orbital, and a single hole in the $1g_{9/2}$ orbital.

TABLE IV. Model predicted and experimentally observed electromagnetic properties of ^{121}Sb.

Electromagnetic observable	Level or transition (keV)	Experimental values [a]	Calculated values
Magnetic dipole	0	3.359	3.21
moment (μ_N)	37	2.51	2.75
Electric quad.	0	−0.29	−0.33
moment (*e*b)	*Q*(37)/*Q*(0)	1.34 ± 0.01	1.32
Branching ratios	507 → 0	94%	96%
	→ 37	6%	4%
	947 → 0	17%	2%
	→ 37	83%	98%
	1025 → 0	100%	75%
	→ 37	0%	25%
	1036 → 0	0%	10%
	→ 37	100%	90%
	1145 → 0	58%	68%
	→ 37	42%	32%
	1386 → 0	100%	98%
	→ 37	0%	2%
Mixing ratios [b]	507 → 0	16° ± 5° [c]	−4°
arctanδ	947 → 37	13° ± 6°	49°
		or 67° ± 6°	
	1025 → 0	4° → 75°	40°
	1036 → 37	19° ± 9°	42°
		or 61° ± 9°	
	1145 → 37	6° → 74°	−35°
$B(E2\uparrow)$	37	<0.018	0.0054
(e^2b^2)	507	0.010 ± 0.003	0.0061
		0.011 ± 0.002 [d]	
	573	0.024 ± 0.003	0.023
		0.028 ± 0.002 [d]	
	947	0.0007 ± 0.0002 [d]	0.0001
	1025	0.100 ± 0.016	0.022
		0.070 ± 0.005 [d]	
	1036	0.004 ± 0.001	0.011
		0.0029 ± 0.0003 [d]	
	1145	0.081 ± 0.005 [d]	0.064
	1386	0.020 ± 0.005	0.011
		0.007 ± 0.002 [d]	

[a] Experimental mixing ratios and branching ratios are taken from the present work, with the exception of the 507 keV level for which results are from Ref. 5. Except where indicated, other experimental values are from Ref. 5.

[b] The signs of both the experimental and model deduced mixing ratios are consistent with the phase convention of Rose and Brink (Ref. 20).

[c] The sign of this mixing ratio has not been determined experimentally.

[d] Reference 11.

that the 1036 and 1140 keV levels have a large one quadrupole phonon term coupled to a single proton in the $1g_{7/2}$ orbital, and that the 1145 keV level has a large one quadrupole phonon term coupled to a proton in the $2d_{5/2}$ orbital. However, the calculations for the 1025 keV level predict too large a component for one phonon coupled to a proton in the $1g_{7/2}$ orbital, and too small a component for one phonon coupled to a proton in the $2d_{5/2}$ orbital.

The angular distribution for the 1386 → 0 keV transition was isotropic, and a definite spin assignment could not be made. A spin-parity of $\frac{3}{2}^+$ has previously been proposed for this level,[8] and only for a spin of $\frac{3}{2}$ did the calculations reproduce the large branching ratio of this level to the ground state. The $B(E2\uparrow)$ value for this level is also correctly predicted assuming this spin.

2. *Levels above 1400 keV*

The existence of a level[6] at 1407 keV was confirmed on the basis of the 1407 and 834 keV γ rays

TABLE V. Model predicted and experimentally observed electromagnetic properties of ^{123}Sb.

Electromagnetic observable	Level or transition (keV)	Experimental values [a]	Calculated values
Magnetic dipole	0	2.547	2.76
moment (μ_N)	160		3.20
Electric quad.	0	−0.37	−0.43
moment (*e*b)	160		−0.33
Branching ratios	542 → 0	40%	21%
	→ 160	60%	79%
	1030 → 0	100%	99%
	→ 160	0%	1%
	1337 → 0	79%	90%
	→ 160	21%	10%
Mixing ratios [b]	1030 → 0	9° → 72°	51°
arctanδ	1337 → 0	−90° → −88°	−11°
		−10° → 90°	
$B(E2\uparrow)$	160	0.0035 ± 0.0007	0.0040
(e^2b^2)	542	0.028 ± 0.004	0.031
		0.040 ± 0.003 [c]	
	1030	0.08 ± 0.01	0.044
		0.073 ± 0.009 [c]	
	1089	0.055 ± 0.014	0.065 ($\frac{11}{2}$)
		0.076 ± 0.008 [c]	0.002 ($\frac{9}{2}$)
	1337		0.0011

[a] Experimental mixing ratios and branching ratios are taken from the present work. Except where indicated, other experimental values are from Ref. 7.
[b] Same as in Table IV.
[c] Reference 11.

observed in the $(n, n'\gamma)$ and (p, γ) experiments.

A level at 1427 keV was observed to decay to the 1036 and 1145 keV levels via 391 and 282 keV γ rays. Previous experiments[6,11] have noted a weak γ-ray decay of this level to the ground state. A 1426 keV γ ray was observed in the present study, but neither its energy nor its threshold were consistent with a decay of the 1427 keV level.

On the basis of energy sums a level at 1448 keV is proposed. This level is assumed to decay to the first excited state with the emission of a 1410 keV γ ray, and to the second excited state with the emission of a 940 keV γ ray. These two γ rays were observed in both the $(n, n'\gamma)$ and (p, γ) experiments. A level at 1446 ± 5 keV had been observed previously.[5]

Levels at 1471 and 1474 keV were observed with energies assigned on the basis of the decay of the 1471 keV level to the 573 keV level, and the decay of the 1474 keV level to the first excited state. These levels are in agreement with those seen by Barnard *et al.*[6] Possible ground state decays were observed in the (p, γ) experiment, although either one of these γ rays could have originated from the 1509 keV level. A possible 1471 → 1036 keV transition[6] was obscured by background.

Barnard *et al.* have assigned a level at 1514 ± 2 keV to ^{121}Sb and a level at 1511 ± 2 keV to ^{123}Sb. Since a 1509 keV γ ray was observed in both the $(n, n'\gamma)$ and (p, γ) experiments, but a 1515 keV γ ray was seen only in the $(n, n'\gamma)$ experiment, the 1515 keV level has been assigned in this study to ^{123}Sb, while a level at 1509 keV is proposed for ^{121}Sb. This level may decay to the first excited state in ^{121}Sb through the emission of either the 1471 keV or 1473 keV γ ray.

Other excited states were observed at energies of 1519 keV and 1628 keV. The 1628 → 0 keV transition observed by Barnard *et al.* was obscured by background.

A 1575 keV γ ray was observed in both the $(n, n'\gamma)$ and (p, γ) experiments. Based on the neutron threshold energy for its observation, it may originate from either a level at 1575 keV decaying to the ground state, or a level at 1617 keV decaying to the first excited state. Levels at either of these energies have not been observed in previous experiments.

Levels at 1736 keV and 1811 keV were assigned on the basis of the 1736 and 1811 keV γ rays present in both the $(n, n'\gamma)$ and (p, γ) spectra. Energies of 1736 ± 1 keV and 1810 ± 1 keV had previ-

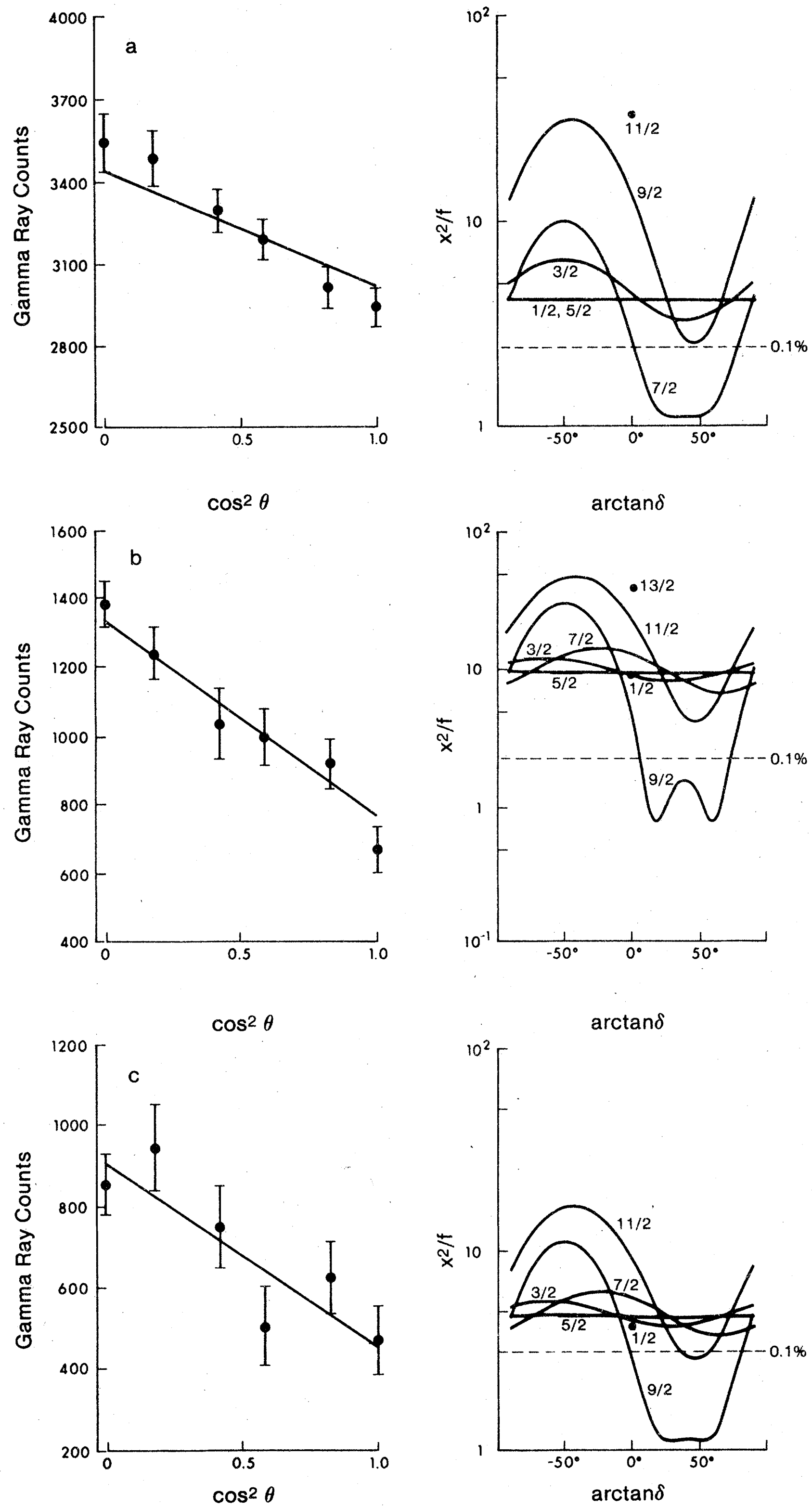

FIG. 6. Sample angular distributions and plots of χ^2/df for the (a) 1025→0 keV, (b) 1036→37 keV, and (c) 1145→37 keV transitions in ^{121}Sb. A possible spin assignment of $\frac{11}{2}$ for the 1145 keV level was rejected on the basis of angular distribution measurements of the 1145→0 keV transition.

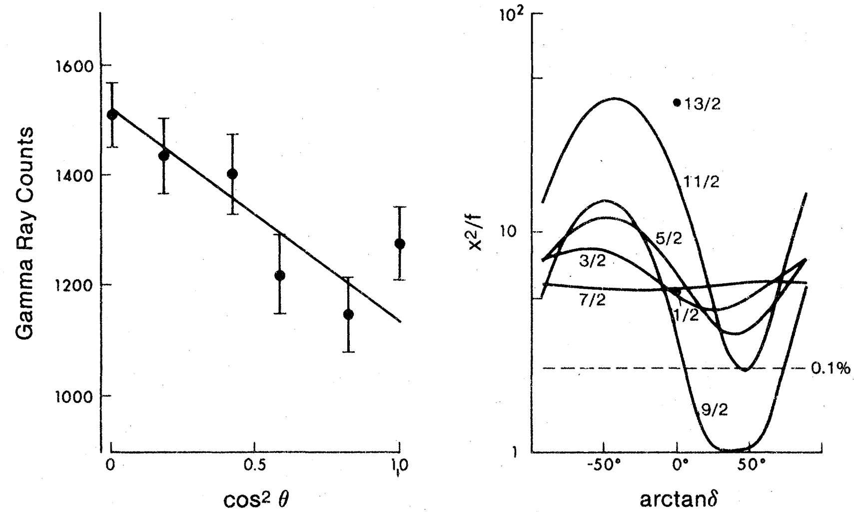

FIG. 7. A sample angular distribution and a plot of χ^2/df for the 1030 → 0 keV transition in ^{123}Sb.

ously been reported[8] for these levels.

There is contradictory evidence concerning the excited state at 1736 keV. A level with an energy of 1735 ± 10 keV was originally observed to be moderately excited in a (^{3}He, d) experiment,[26] but no l transfer was measured. A later (^{3}He, d) experiment[22] noted a level with an energy of 1770 ± 20 keV and having a measured spectroscopic factor of 0.16 ± 0.03 for an l transfer of 0. On the basis of these measurements, the level at 1736 keV was assigned[5] a spin-parity of $\frac{1}{2}^+$. This assignment was challenged following a (γ, γ') scattering experiment,[8] on the grounds that the $E2$ strength required to populate this level, assuming a spin-parity of $\frac{1}{2}^+$, was too large. The measured $B(E2\uparrow)$ for this level assuming this spin-parity was 0.09 ± 0.02 e^2b^2. The present calculation tends to support this conclusion. A $\frac{1}{2}^+$ level is predicted in this energy region, but the calculated $B(E2\uparrow)$ of 0.0006 e^2b^2 for this level is at least 2 orders of magnitude lower than the experimental value quoted above. Furthermore, the spectroscopic factor calculated for the predicted state is less than 0.01, in clear disagreement with the measured value. On the basis of the $B(E2\uparrow)$ measurements, it would appear that the 1736 keV level is not the $\frac{1}{2}^+$ level seen in the (^{3}He, d) study.

B. Excited states of ^{123}Sb

1. Levels between 1000 and 1400 keV

A sample angular distribution and a plot of χ^2/df for the 1030 → 0 keV transition is shown in Fig. 7. A spin of $\frac{9}{2}$ or $\frac{11}{2}$ is possible for this level, but the $\frac{9}{2}$ assignement is favored since the $\frac{11}{2}$ assignment is acceptable only at the 0.13% confidence level. A spin assignment of ($\frac{9}{2}$, $\frac{11}{2}$) has been made for the 1089 keV level. These results confirm earlier experiments.[11]

Angular distribution measurements for the 1182 → 160 keV transition are consistent with a number of different spin assignments. Angular distribution measurements for the 1260 → 160 keV transition could not be made because of the presence of an 1102 keV γ ray from the 1140 → 37 keV transition in ^{121}Sb.

The 1030 and 1089 keV levels are strongly excited in (d, d'),[26,27] Coulomb excitation,[7,11] and (γ, γ')[8] reactions. These levels can be correlated with calculated levels having large one quadrupole phonon terms coupled to a proton in the $1g_{7/2}$ orbital. In Table V, measured $B(E2\uparrow)$ values[7,11] for the 1089 keV level are compared with calculated values for levels in this energy region with spins of $\frac{9}{2}$ and $\frac{11}{2}$. The comparison favors an $\frac{11}{2}^+$ assignment for the 1089 keV level.

The levels at 1182 and 1260 keV were not strongly excited in either the reactions mentioned above or in the (^{3}He, d) reaction.[23,26] Since their spin-parities are unknown, no correlation can be made between these levels and calculated levels.

The results of the present angular distribution measurements are consistent with a previous spin assignment[9] of $\frac{9}{2}$ for the 1337 keV level. This level is strongly excited by the ^{124}Te(t, α) reaction[9] with an l transfer of 4, and ought to have a structure similar to the 947 keV level in ^{121}Sb.

2. Levels above 1400 keV

Since a 1515 keV γ ray was observed in the (n, $n'\gamma$) experiment but not in the (p, γ) experiment, a level at 1515 keV is proposed for ^{123}Sb. This level is probably the level observed in a (^{3}He, d)

experiment[26] at 1502 ± 10 keV, in a (d, d') experiment[26] at 1510 ± 5 keV, and in a (γ, γ') experiment[8] at 1512 ± 2 keV. This level may also correspond to a level with an energy of 1500 ± 30 keV and an l transfer of 2 observed in a second $(^3He, d)$ experiment,[23] and to a level at 1526 ± 15 keV seen in a second (d, d') experiment.[27]

A 1577 ± 2 keV γ ray was previously[6] assumed to originate from a 1577 keV level in ^{123}Sb. In the present work this γ ray (1575.4 ± 0.7 keV) was observed in both the (p, γ) and $(n, n'\gamma)$ experiments and hence was assigned to ^{121}Sb. The earlier assignment of a 1577 keV level to ^{123}Sb was based on an observation of a level at 1574 ± 10 keV in a $(^3He, d)$ experiment.[26] A level at 1586 keV is proposed because of the presence of a 1426 keV γ ray. The threshold for this γ ray indicates that it originates from a level between 1500 and 1700 keV. Only a level at 1586 keV decaying to the first excited state of ^{123}Sb would be consistent with this threshold requirement. This level may also correspond to a level at 1601 ± 15 keV observed in a (d, d') experiment,[27] and to one of at least two levels at 1630 ± 30 keV observed in a $(^3He, d)$ study.[23]

VI. CONCLUSIONS

Level spins have been deduced for a number of levels in ^{121}Sb and ^{123}Sb by measuring γ-ray angular distributions produced from the ^{121,123}Sb$(n, n'\gamma)$ reaction. Some information was also obtained on mixing ratios, although the errors were large as a result of low counting rates. Angular distributions could not be measured for levels above 1.4 MeV since these levels were only weakly excited by the $(n, n'\gamma)$ reaction. At this energy the level density in ^{121}Sb and ^{123}Sb increases considerably. Many more exit channels exist, therefore, for the compound nucleus to decay through, and the yield to any one channel decreases.

Intermediate coupling model calculations are in reasasonable agreement with the experimental results. The model correctly predicts the large one quadrupole phonon components in the lowest $\frac{1}{2}^+$ and $\frac{3}{2}^+$ states in the Sb nuclei, and also explains many of the features of the predominantly one quadrupole phonon levels grouped in the 1.0 to 1.2 MeV region. There are insufficient experimental data available to extend the comparison to higher levels, where two quadrupole phonon states would start to become important. In this region a comparison between experimental results and model calculations can be expected to break down because the experimentally observed two quadrupole phonon states in the Sn nuclei are split in energy, whereas the model two phonon states are degenerate.

The 2p1h terms included in the model calculations appear to couple only weakly to the single-particle terms. Most of the eigenstates predicted by the model below 2 MeV do not have both large single-particle and large 2p1h components, but instead have either single-particle terms or 2p1h terms coupled to vibrational components.

A comparison of the calculations with both present and previous experimental results leads to a consistent picture of the structure of the low lying levels in the Sb isotopes. As excitation energy increases, however, the structure can no longer be interpreted in terms of such a simple model.

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