Coulomb excitation studies in antimony isotopes

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Various low-lying energy levels up to 1.145 MeV in ^{121,123}Sb have been Coulomb excited using 3.0–4.0 MeV proton-beam energies. The reduced transition probabilities of the excited levels have been newly deduced from the measured yields of the deexcitation gamma rays. The values of mixing ratios for a few transitions and the removal of ambiguities in the spin values of some levels have been presented from the angular distribution analysis.

The odd-A transitional nuclei ^{121,123}Sb have been subjected to several theoretical[1,2] and experimental[3,4] investigations. The properties of the levels up to 600-keV excitation energies are well established. However, the information about many levels beyond 600 keV are incomplete. In several cases the experimental $B(E2)$ values reported by various groups[1,3,4] are quite discrepant among themselves and also differ from the theoretical predictions.[1] The assigned spin values for many of the levels are quite ambiguous.[3,4]

Most of the reported Coulomb excitation studies[3–8] on both the antimony isotopes were carried out with heavy ions and alpha particles using relatively coarse resolution and poor efficiency of the detectors. In the present investigations the gamma-ray yields have been measured with high resolution ($\sim$1.9 keV at 1.332 MeV) and better efficiency HPGe detector (57 cm^3). The reduced quadrupole transition probabilities of six levels in ^{121}Sb and four levels in ^{123}Sb up to 1.145 MeV have been extracted from the gamma-ray yields observed at 55° with respect to

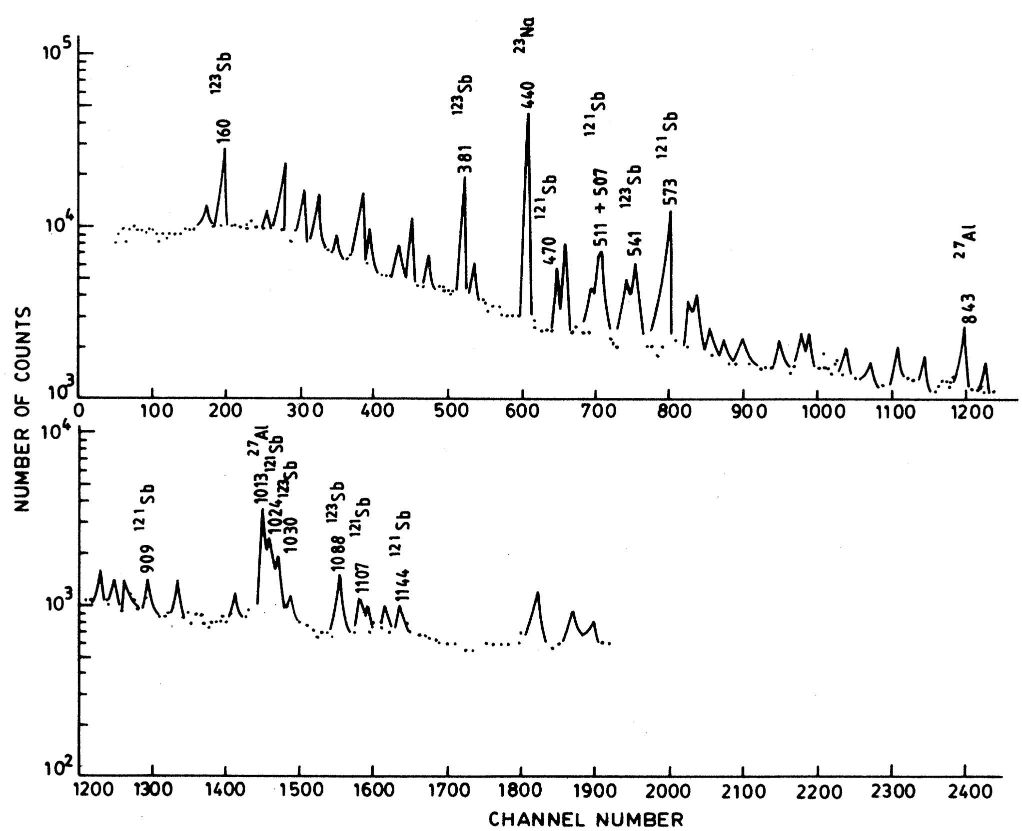

FIG. 1. Gamma-ray spectrum with 4.0-MeV protons incident on a thick natural antimony target. The peaks left unmarked are from $(p,n\gamma)$ reaction and background.

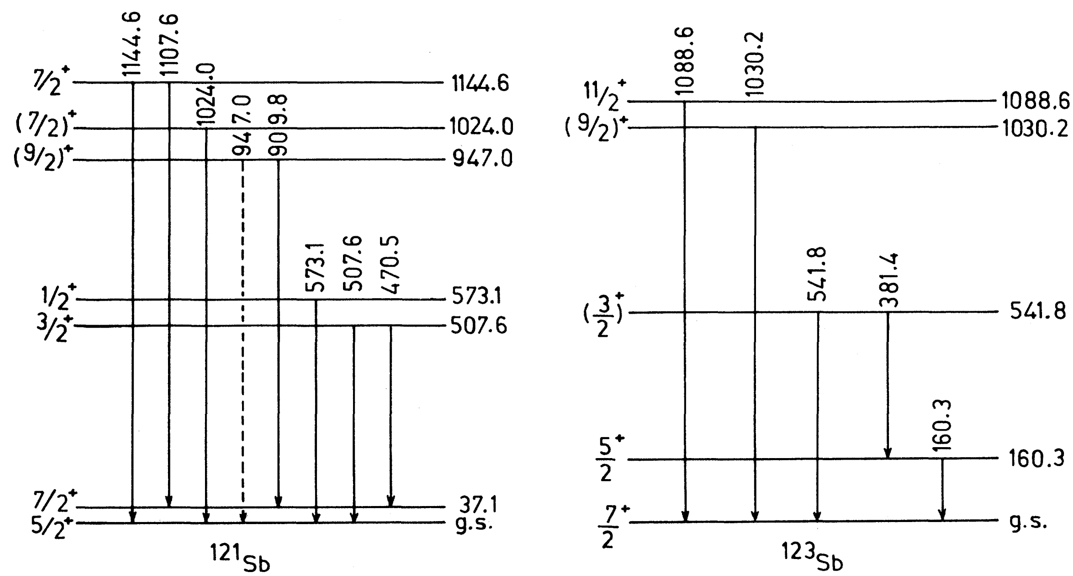

FIG. 2. Level schemes proposed for the Coulomb excited levels in ^{121}Sb and ^{123}Sb.

beam direction. The results have been discussed in the light of earlier experimental data[5–8] and the predictions of the intermediate coupling model.[2]

The low-lying levels in ^{121,123}Sb were excited with 3.0–4.0-MeV proton beams using a thick target of spectroscopically pure antimony. The details of the experiments are described elsewhere.[9] A typical spectrum at 90° with a 4.0-MeV proton beam is shown in Fig. 1. The angular distributions were measured at 0°, 30°, 45°, 75°, and 90° for spin assignments. The photopeaks corresponding to the gamma ray from energy levels at 507.6, 573.1, 947.0, 1024.0, and 1144.6 keV in ^{121}Sb and from energy levels at 150.3, 541.8, 1030.2, and 1088.6 keV in ^{123}Sb are clearly resolved in the spectrum. The unmarked peaks in the spectrum belong to $(p,n\gamma)$ reactions from these two nuclei. The compound contribution to the total $(p,p'\gamma)$ cross sections at this proton energy were calculated with the computer code CINDY (Ref. 10) and found to be less than 5% of the Coulomb contribution. The proposed level schemes for the Coulomb excited levels in ^{121}Sb and ^{123}Sb are shown in Fig. 2.

The present experimental $B(E2)$ values and the

TABLE I. Present branching ratios and $B(E2)$ values along with the earlier data on Coulomb excited levels in ^{121,123}Sb. $B(E2)$ ($e^2\,\mathrm{cm}^4\times10^{-50}$).

Energy level (keV)	E_γ (keV)	Present branching ratio (%)	Present	Barnes *et al.* (Ref. 5)	Galperin *et al.* (Ref. 6)	Andreev *et al.* (Ref. 7)	Kulkarni and Patrawale (Ref. 8)	Hooper *et al.*[a] (Ref. 2)
				^{121}Sb				
507.59	507.59	80	1.32±0.41	0.7±0.2	1.3±0.4	1.1±0.2	b	0.61
	470.47	20						
573.14	573.14	100	2.70±0.40	2.7±0.3	2.0±0.4	2.8±0.2		2.30
946.98	909.84	100	0.06±0.02			0.07±0.02		0.01
1024.00	1024.00	100	1.80±0.35	10.0±1.6		7.0±0.5		2.20
1144.65	1144.65	74	2.24±0.33		3.0±0.1	8.1±0.5		6.40
	1107.60	26						
				^{123}Sb				
160.3	160.33	100	0.23±0.04	0.43±0.07	0.23±0.08		0.46±0.04	0.40
541.8	541.8	26	3.00±0.30	2.8±0.6	2.8±0.6	4.0±0.3		3.10
	381.4	74						
1030.23	1030.23	100	1.96±0.30	8.0±1.0	9.0±2.0	9.0±2.0	7.0±4.5	4.40
1088.64	1088.64	100	2.06±0.3	7.0±1.0	4.2±0.9	7.6±0.8	3.0±0.28	6.5,0.2[c]

[a]Results from intermediate coupling model.
[b]$B(E2)$ values by Kulkarni *et al.* (Ref. 8) for ^{121}Sb contain large systematic errors.
[c]The 6.5 and 0.2 $e^2\,\mathrm{cm}^4\times10^{-50}$ values have been calculated for $J^\pi=\frac{11}{2}^+$ and $\frac{9}{2}^+$, respectively.

TABLE II. Present $B(E2)$ values compared with the single-particle estimates.

Isotope	Energy level	Spin $J^{\pi a}$	$B(E2)\downarrow$ ($e^2\,\mathrm{cm}^4 \times 10^{-50}$)	$B(E2)\downarrow / B(E2)_{\mathrm{s.p.}}$ [b]
^{121}Sb	507.6	$\frac{3}{2}^+$	1.98±0.62	4.73±1.5
	573.1	$\frac{1}{2}^+$	8.10±1.20	19.4±2.7
	947.0	$(\frac{9}{2})^+$	0.036±0.012	0.09±0.03
	1024.0	$(\frac{7}{2})^+$	1.35±0.26	3.2±0.6
	1144.6	$\frac{7}{2}^{+a}$	1.68±0.25	4.0±0.6
^{123}Sb	160.3	$\frac{5}{2}^+$	0.31±0.05	0.72±0.12
	541.8	$(\frac{3}{2})^+$	6.0±0.6	14.0±1.4
	1030.2	$(\frac{9}{2})^+$	1.57±0.24	3.7±0.6
	1088.6	$\frac{11}{2}^{+a}$	1.37±0.20	3.2±0.5

[a] J^π values for 1144.6 and 1088.6 keV were assigned in the present work, other values were taken from literature. Those enclosed in the parentheses are tentative assignments.

[b] The single-particle estimates $B(E2)_{\mathrm{s.p.}}$ have been obtained from $e^2/4\pi|\frac{3}{5}R_0^2|^2$, with $R_0 = 1.25 \times 10^{-13}$ $A^{1/3}$ cm.

branching ratios along with the $B(E2)$ values from the earlier measurements[5–8] are summarized in Table I. Our values in ^{121}Sb for the 507.6-, 573.1-, and 947.0-keV levels agree with the earlier data.[3,4] However, for the levels at 1024 keV, our results are lower by a factor of ~4 compared to others. This may be partly due to the fact that the earlier authors, due to poor resolution, could not resolve this state from the adjacent peaks due to ^{27}Al and ^{123}Sb. In the case of ^{123}Sb, our results for 160.3 and 541.8 keV agree with earlier data, except at 1030.2-keV levels for which our $B(E2)$ value is ~4 times smaller than others. This is also due to the same reason of poor resolution and interference of adjacent peaks due to ^{27}Al and ^{121}Sb in the earlier data.

Table II compares the experimental $B(E2)$ values with single-particle estimates. Our data confirm that the 947-keV level in ^{121}Sb and 160.3-keV level in ^{123}Sb are essentially of single-particle character, while the 573.1- and 541.9-keV levels have collective structures. The other levels at 507.6, 1024.0, and 1144.6 keV in ^{121}Sb and 1030.2 and 1088.6 keV in ^{123}Sb seem to have mixed nature intermediate between these two extremes. These observations are consistent with the predictions of Conjeaud *et al.*[11] based on ^{120}Sn(^{3}He,d) and ^{122}Te(t,α) reactions.

The angular distribution for the 1088.6-keV level in ^{123}Sb predicts the A_2 value equal to 0.175±0.021, which suggests the spin of this level as $\frac{11}{2}$ rather than $\frac{9}{2}$. Similarly, for the 1144.6-keV level in ^{121}Sb our experimental value of $A_2 = -0.048 \pm 0.007$ suggests the spin of this level as $\frac{7}{2}$ and mixing ratio (δ) as -0.162 for the 1144.6-keV transition from this state.

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