Low-Lying States in ^{122}Sb from the ^{122}Sn(p, n) Reaction*

D. O. Elliott, G. W. Phillips, F. F. Hopkins, and Patrick Richard
Physics Department and Center for Nuclear Studies, University of Texas, Austin, Texas 78712
(Received 7 September 1971)

The low-lying level structure of ^{122}Sb is studied through the observation of coincident γ rays following the ^{122}Sn(p,n) reaction using two Ge(Li) detectors. Thirteen 1024-channel coincidence γ-ray spectra were obtained simultaneously in a PDP-7 computer by means of a two-parameter program. High-resolution singles spectra taken with a small-volume thin-window Ge(Li) detector (full width at half maximum approximately 0.6 keV at 121 keV) were also helpful in determining a level scheme for ^{122}Sb. A (d,p) experiment was also performed in order to gain additional information. The information obtained from the (p,n) reaction was combined with existing ^{121}Sb(d,p) and ^{121}Sb(n,γ) data in constructing a proposed level scheme for ^{122}Sb.

I. INTRODUCTION

The level structure of the even isotopes of antimony remains essentially uncharted. Most work on these nuclei has been done on isotopes 122 and 124, which are accessible through neutron capture and stripping reactions. Hjorth[1] in 1966 performed (d, p) reactions on ^{121}Sb and ^{123}Sb, but not without experimental difficulties. Bhat *et al.*[2] and Ing *et al.*[3] investigated resonant slow-neutron capture in these same isotopes. In addition, Bhat[2] observed γ rays following thermal-neutron capture in ^{121}Sb. As yet no (p, n) studies have been reported. This reaction is a straightforward method of populating the low-lying levels of these nuclei. In this paper we report on a γ-γ coincidence study of the decay properties of the low-lying levels of ^{122}Sb using the reaction ^{122}Sn $(p, n\gamma\gamma)$ ^{122}Sb.

^{122}Sb is an interesting nucleus, as it displays a complex structure of low-energy states, seemingly due to the confluence of the low-lying shell-model configurations for both the odd proton and the odd neutron (see Fig. 1). The ground-state spin and parity of ^{121}Sb is $\frac{5}{2}^+$ and that of ^{123}Sb is $\frac{7}{2}^+$. From β-decay studies[4] the ground-state spin and parity of ^{122}Sb is 2^-. From considerations of angular momentum coupling, this implies that the 71st neutron is $h_{11/2}$, and the 51st proton in ^{122}Sb is $g_{7/2}$. Thus the (d, p) stripping reaction to ^{122}Sb will not populate the ground state, which makes the resulting spectra somewhat ambiguous. The spectra from resonant neutron capture show many low-energy γ rays along with the high-energy lines from decays to the ground state and other low-lying states. The level schemes deduced from these (n, γ) experiments do not account for many of the low-energy γ-ray transitions in the spectra, nor do they relate simply to the states observed in (d, p) stripping.[1]

II. EXPERIMENT

The use of in-beam γ-γ coincidence techniques with two Ge(Li) detectors has permitted us to make a detailed study of the complicated γ-ray spectra from the reaction ^{122}Sn(p, n) ^{122}Sb. The proton beam for this experiment was obtained from the University of Texas Van de Graaff accelerator and was focused by means of a magnetic quadrupole onto the target and subsequently collected in a Faraday cup. The thin target was enriched to 92% of ^{122}Sn. The coincidence spectra were accumulated in runs of about 3 days using a 0.2-μA beam. The target chamber consisted of a 4-in. aluminum cube which was fitted with two thin-walled aluminum wells on either side of the beam line for the placement of the Ge(Li) detectors. In this configuration the detectors could be placed in close geometry, each detector being approximately $\frac{3}{4}$ in. from the target. It was necessary to focus the beam on a quartz viewer prior to inserting the aluminum wells. Figure 2 is a schematic drawing of this target and detector geometry.

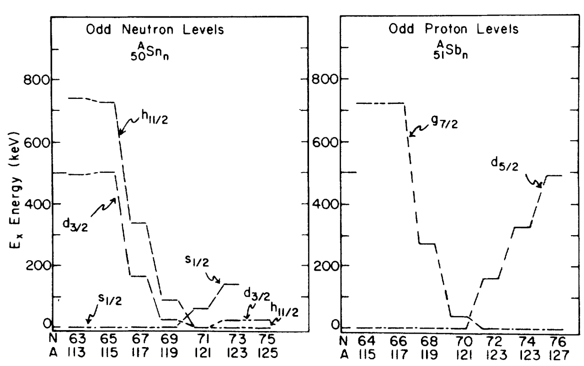


FIG. 1. Systematics of odd-neutron and odd-proton levels in the $^{A}_{50}$Sn and $^{A}_{51}$Sb isotopes.

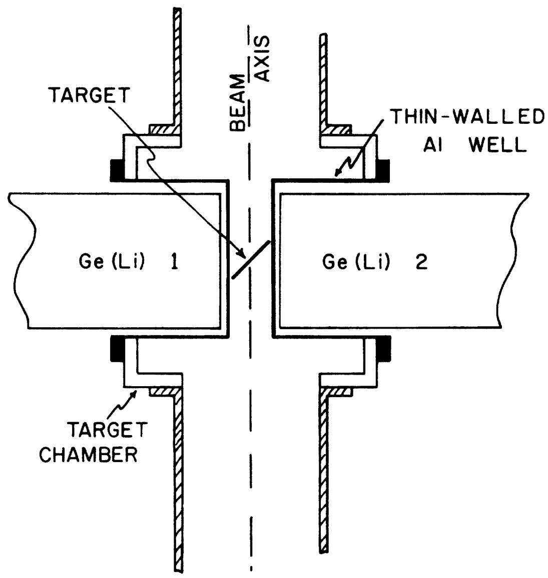


FIG. 2. Schematic diagram of the experimental arrangement for doing in-beam γ-γ coincidence with two Ge(Li) detectors.

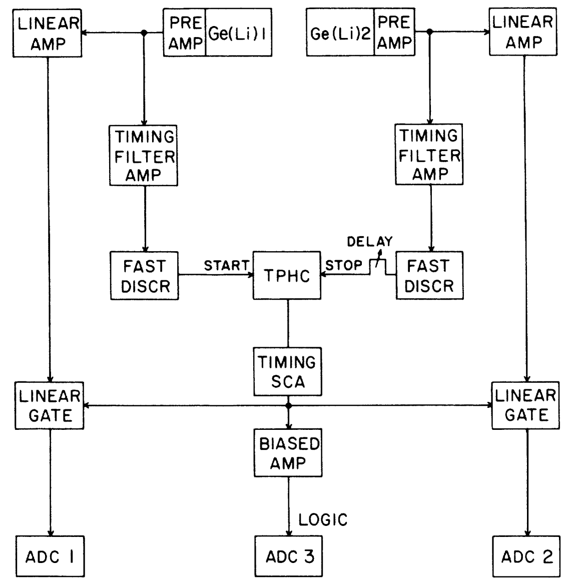


FIG. 3. Schematic of the fast-slow coincidence electronics used in the $(p,n\gamma\gamma)$ experiment.

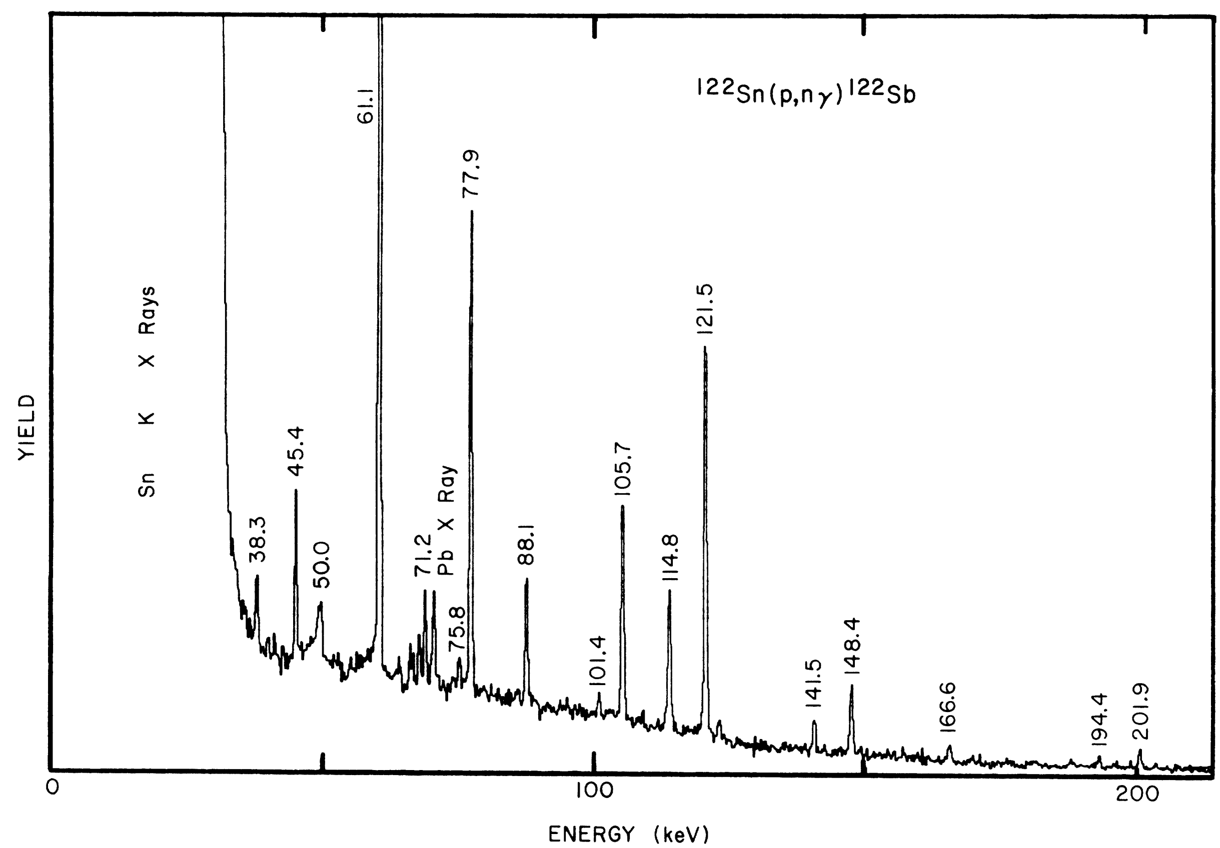


FIG. 4. Low-energy γ-ray spectrum taken with the 0.14-cm^3 Ge(Li) detector. These data were taken with an incident proton energy of 6.5 MeV. Resolution FWHM is 0.625 keV at 121 keV.

The coincidence-electronics configuration is depicted in Fig. 3. The fast electronics consisted of two timing-filter amplifiers followed by fast leading-edge discriminators, the outputs of which were fed to a time-to-pulse-height converter (TPHC). The time resolution [full width half maximum (FWHM)] of 40 nsec was obtained over the wide range of γ-ray energies studied. A window was set with a single-channel analyzer (SCA) to accept practically all of the timing peak. The SCA output signal was used to gate the linear signal from each Ge(Li) detector and was also fed into an analog-to-digital converter (ADC) through a biased amplifier in order to reduce the pulse height and shorten the conversion time in the ADC. This signal was used to initiate a program in a PDP-7 computer which would accept the two linear pulses in ADC 1 and ADC 2. The memory of a PDP-15/20 computer was also used as additional storage space in order to increase the number of coincidence spectra which could be taken simultaneously.

TABLE I. A comparison of ^{122}Sb γ-ray energies from (n, γ) and $(p, n\gamma)$. All energies are in keV.

Bhat *et al.* [a] (n, γ)	0.14-cm^3 Ge(Li) [b]	30-cm^3 Ge(Li) [c]	Label [d]
	38.3		
	45.4	45.4	
	50.0		
61.6	61.1	61.1	1
	71.1	71.2	2
	75.8		
78.1	77.9	77.9	3
	88.1	88.1	4
	101.4		
105.5	105.7	105.7	5
114.5	114.8	114.8	6
121.2	121.5	121.5	7
	141.5	141.5	8
147.8	148.4	148.4	9
	166.6	166.6	10
		184.0	11
	194.4	194.4	12
	201.9	201.9	13
231.2		231.0	14
		233.0	
		253.0	15
		273.0	16
280.9		283.0	17
		287.0	
330.5		331.0	18
		384.0	
		398.0	
		423.0	

[a] See Ref. 2.

[b] The error in the energies determined with this detector is ~0.3 keV.

[c] The error in the energies determined with this detector alone (e.g. 184.0 keV) is ~2.0 keV.

[d] Labels refer to numbered peaks in Figs. 7–9.

The resulting total coincidence spectra were stored in 1024-channel blocks. Windows were set on the desired peaks in the spectrum of detector 1. The program would sort coincident pulses from detector 2 into 1024-channel blocks according to these windows. In this arrangement 12 sorted coincidence spectra were accumulated simultaneously.

Since there were many low-energy γ rays seen in the data presented here, a small (0.14-cm^3) Ge(Li) detector was used to obtain their energies accurately; however, the efficiency of this detector was too low to allow its use in coincidence. For the coincidence experiment, detectors of nominal volumes of 55, 33, 30, and 20 cm^3 were used as described in Sec. III. The (d, p) experiment is described in Sec. IV.

III. EXPERIMENTAL RESULTS

Figure 4 shows the low-energy γ rays from ^{122}Sn$(p, n\gamma)$ at a proton energy of 6.5 MeV taken with the 0.14-cm^3 Ge(Li) detector with a resolution of 625 eV at 121 keV. 17 lines which can be identified as due to transitions in ^{122}Sb are observed. The position of each line was determined to less than one-half channel or approximately 0.1 keV, and from the calibration with a ^{133}Ba source the absolute energies were determined to ±0.3 keV. Every γ ray observed here was also seen in the low-energy spectrum of Shera[5] from resonant slow-neutron capture on ^{121}Sb which further identifies these transitions as occurring in ^{122}Sb. Table I gives a listing of all the γ rays seen with this detector.

A singles spectrum taken with a 30-cm^3 Ge(Li) detector is shown in Fig. 5 and a list of these transition energies is given in Table I. The resolution of this detector was ~3.0 keV at 121 keV and energies of the transitions determined from this data alone were determined to the nearest keV with an estimated absolute error of ±2.0 keV. The data of Bhat *et al.*[2] is given in Table I where it can be seen that the transition energies are in good agreement with the present results. Many more lines are observed in the present experiment in both the low-energy and high-energy range of the observed γ-ray transitions.

The total coincidence spectra from each detector presented at ADC 1 and ADC 2 (see Fig. 3) were accumulated in separate blocks and, after several minutes of running, windows could be set on the peaks of interest. Figure 6 shows a portion of such a total coincidence spectrum taken with a

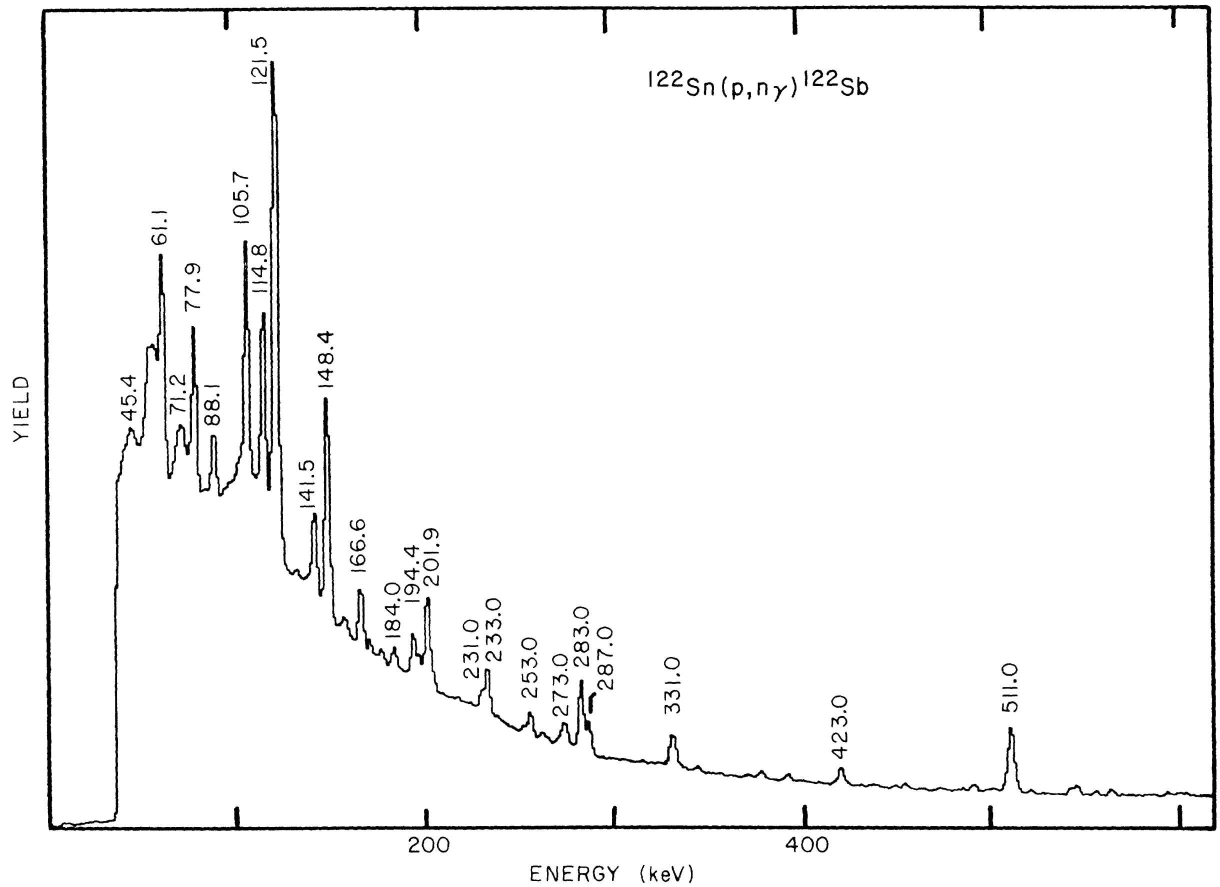


FIG. 5. Singles spectrum taken with a 30-cm^3 Ge(Li) detector. These data were taken with an incident proton energy of 6.5 MeV. Resolution is approximately 3.0 keV at 300 keV.

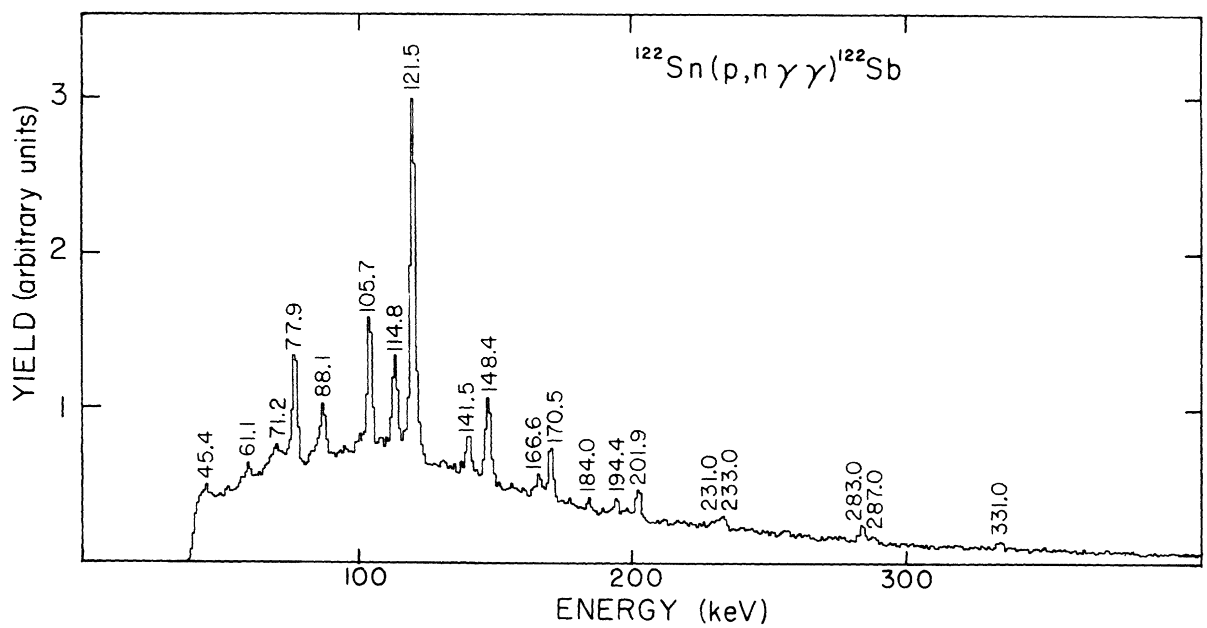


FIG. 6. Total coincidence spectrum taken with a 20-cm^3 Ge(Li) detector. The 170.5-keV line in this spectrum is spurious and unaccounted for.

20-cm^3 detector. All of the strong γ-ray transitions seen in the singles spectrum (Fig. 5) are also seen in the total coincidence spectrum (Fig. 6) with the exception of an additional line at 170.5 keV in the coincidence spectrum. This line is spurious and unaccounted for in this spectrum and is not contained in the gated coincidence spectra presented in Figs. 7–9. The 61.1-keV transition from the decay of the isomer at that energy is very weak in the coincidence spectrum as would be expected because of its 1.8-μsec half-life. Transitions from the decay of the other isomeric states at 136 and 162 keV with half-lives of 0.53 msec and 4.2 m, respectively, are not seen in either coincidence or singles spectra.

In Sec. V we discuss each level. Figures 7–9 contain the total and 12 gated coincidence spectra for gates on the following γ rays: 77.9, 88.1, 105.7, 114.8, 121.5, 141.5, 148.4, 166.6, 194.4, 201.9, 231.0, and 331.0 keV. The data given in Figs. 7–9 were taken with a 54-cm^3 Ge(Li) detector which had worse resolution than either the 20- or 30-cm^3 Ge(Li) detector but was more efficient. These data complemented the higher-resolution data shown in Figs. 4–6 to allow for an accurate determination of the coincidence matrix.

IV. (*d, p*) EXPERIMENT

A ^{121}Sb(*d, p*) experiment was performed to locate some levels in ^{122}Sb in order to provide a starting place for the γ-γ coincidence analysis. The deuteron beam from the accelerator was focused as

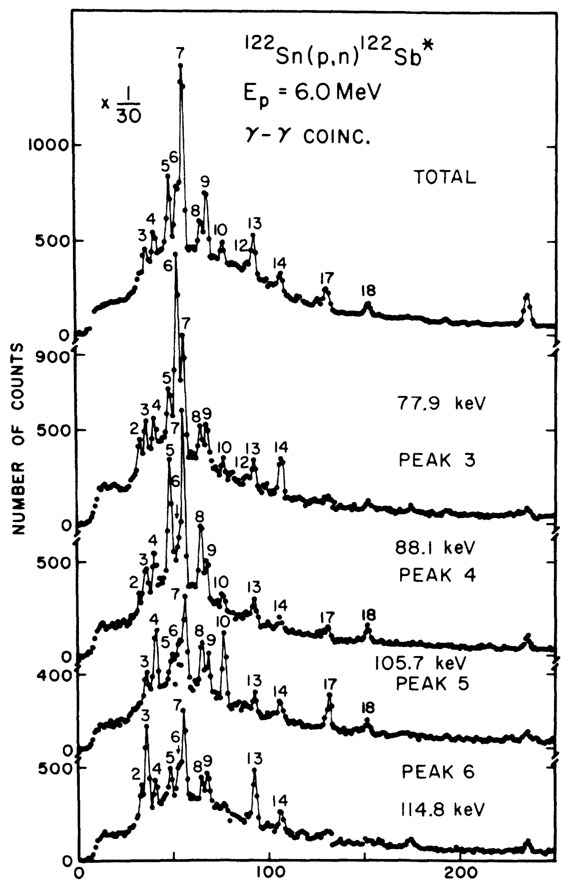


FIG. 7. The gated coincidence spectra taken with the experimental arrangement of Fig. 2 and the electronics of Fig. 3. The detector 1 [33-cm^3 Ge(Li)] was used for setting the coincidence gates and detector 2 [54-cm^3 Ge(Li)] was used for accumulating the coincidence spectra. The individual spectra are labeled with the energy of the γ ray on which the window was set.

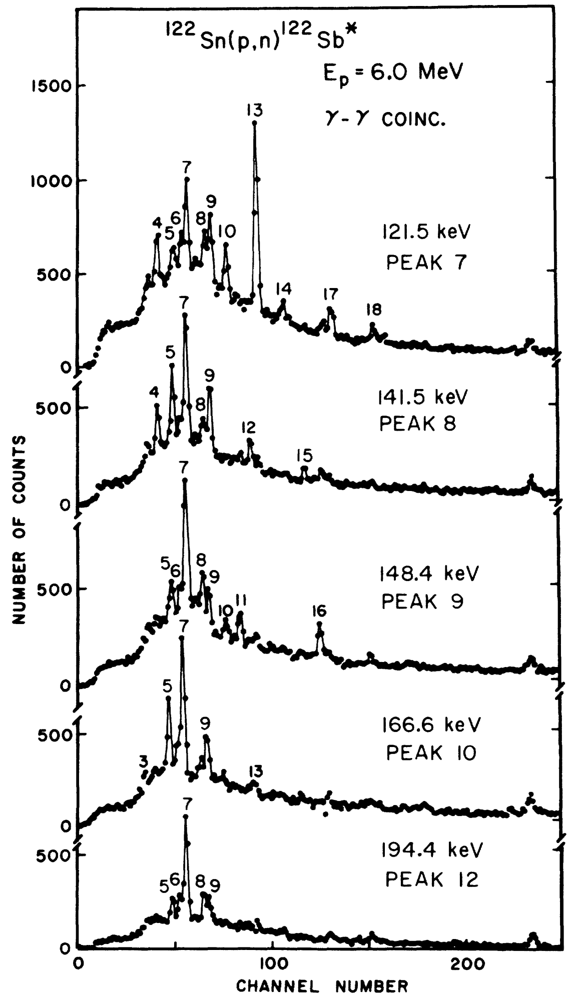


FIG. 8. The gated coincidence spectra taken with the experimental arrangement of Fig. 2 and the electronics of Fig. 3. The detector 1 [33-cm^3 Ge(Li)] was used for setting the coincidence gates and detector 2 [54-cm^3 Ge(Li)] was used for accumulating the coincidence spectra. The individual spectra are labeled with the energy of the γ ray on which the window was set.

described earlier. The outgoing particles were detected with Si(Li) detectors cooled to dry-ice temperature. With a 13-MeV deuteron beam, typical energy resolution was 25 keV on the 18-MeV proton groups.

The target consisted of ^{121}Sb metal evaporated onto thin carbon foils. Typical target thicknesses were about 200 μg/cm^2 and isotopic purity was 98%. The spectrum at 70° is shown in Fig. 10.

The configuration problem which inhibits population of the ground state by this reaction has been discussed earlier. This hampers the identification of peaks. For this reason and because some of the levels are overlapping, the level energies are given to ±10 keV. The energy calibration was obtained from the carbon and oxygen contaminant peaks and by comparison with the spectrum from ^{14}N(d, p) using a melamine target. The levels observed are 71, 128, 173, 266, 292, 401, 426, and 492 keV. A comparison of these levels with those observed in the other experiments is shown in Figs. 11 and 12. If we assume a systematic shift of 10 keV in the (d, p) data, the levels match up extremely well with the ($p, n\gamma$) data. Noteworthy also is the correspondence of the present (d, p) data with that of Hjorth,[1] and the almost complete disparity with the published (n, γ) data.

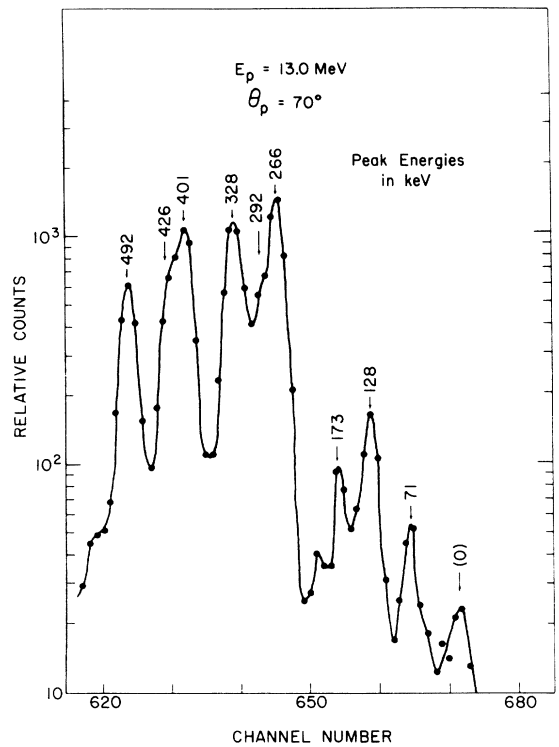


FIG. 10. Portion of ^{121}Sb(d,p)^{122}Sb spectrum taken at 70° and at 13-MeV incident energy, showing proton groups leading to low-lying states in ^{122}Sb.

V. DISCUSSION OF THE LEVEL SCHEME

The following discussion refers to the coincidence data of Figs. 7–9 and the decay scheme

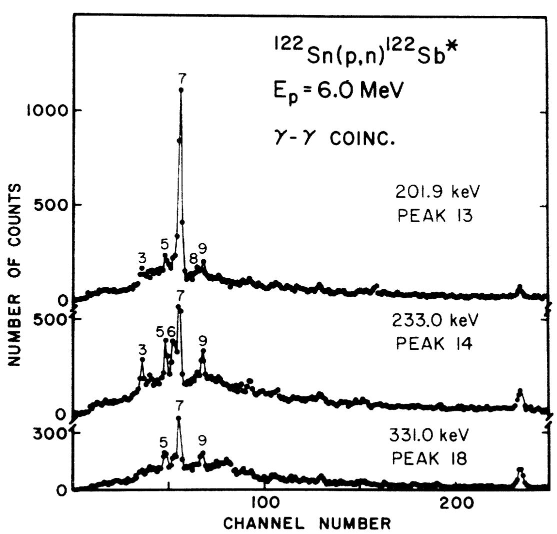


FIG. 9. The gated coincidence spectra taken with the experimental arrangement of Fig. 2 and the electronics of Fig. 3. The detector 1 [33-cm^3 Ge(Li)] was used for setting the coincidence gates and detector 2 [54-cm^3 Ge(Li)] was used for accumulating the coincidence spectra. The individual spectra are labeled with the energy of the γ ray on which the window was set.

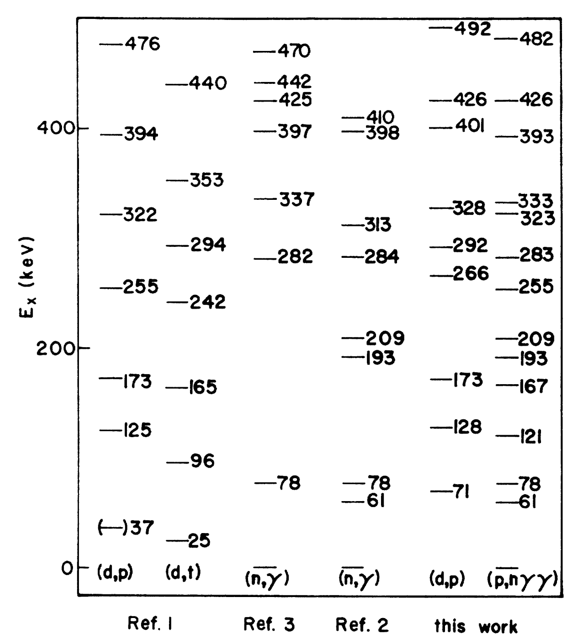


FIG. 11. Summary of level schemes from earlier work, Refs. 1, 2, 3, and this work.

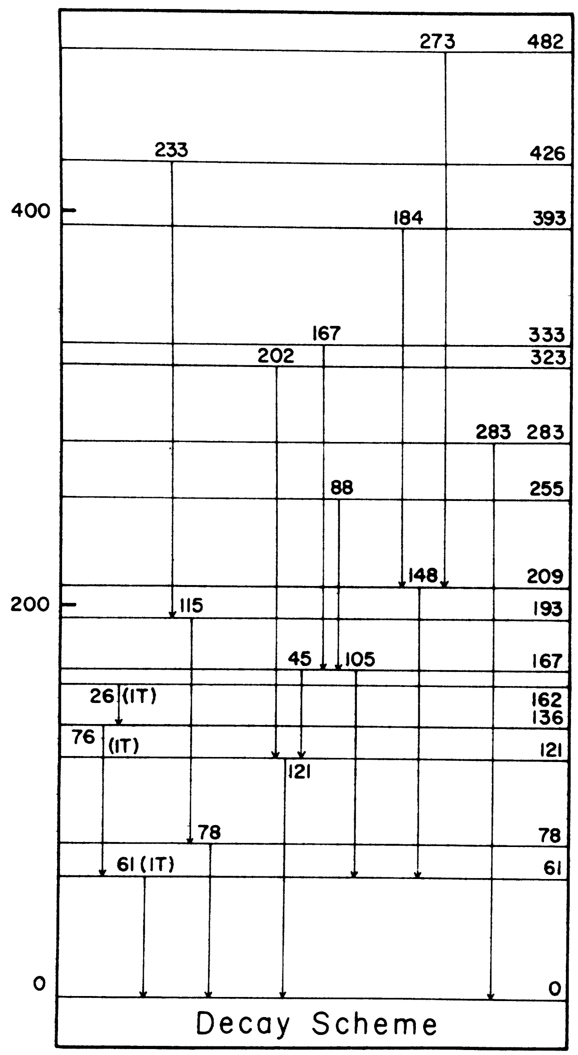
shown in Fig. 12.

Level at 61 keV. This level is well established from the (n, γ) data as well as the isomeric transition work. The measured half-life of 1.8 μsec for this state is much too long for any decay from this level to be observed in the time window of 100 nsec unless this state is populated strongly by decays to it from higher levels. Since this γ ray is visible in the coincidence spectra, the conclusion follows that this level is a terminus for several decay cascades.

Level at 78 keV. This state is also well established from the (n, γ) work. The transition from this level to the ground state is visible in the spectra as the 77.9-keV γ ray.

Level at 121 keV. This level was not observed by the (n, γ) work, but was suggested by the (d, p) data. The strong coincidence between the 121- and 202-keV lines suggests that they are in a direct cascade, and the other coincidence data can be satisfied if there are two decays from a level at 167 keV; a 45-keV transition to a level at 121, and a 105-keV transition to the 61-keV isomer. The 121- and 105-keV lines are observed to be not in coincidence, although other lines show coincidence with both of them.

Level at 136 and 162 keV. These isomers are well established. The lower level is given as 5^+ and the higher level is probably 8^- (see Lederer, Hollander, and Perlman[6]). These levels are not shown in Fig. 12 because they do not appear to be populated by the observed transitions.



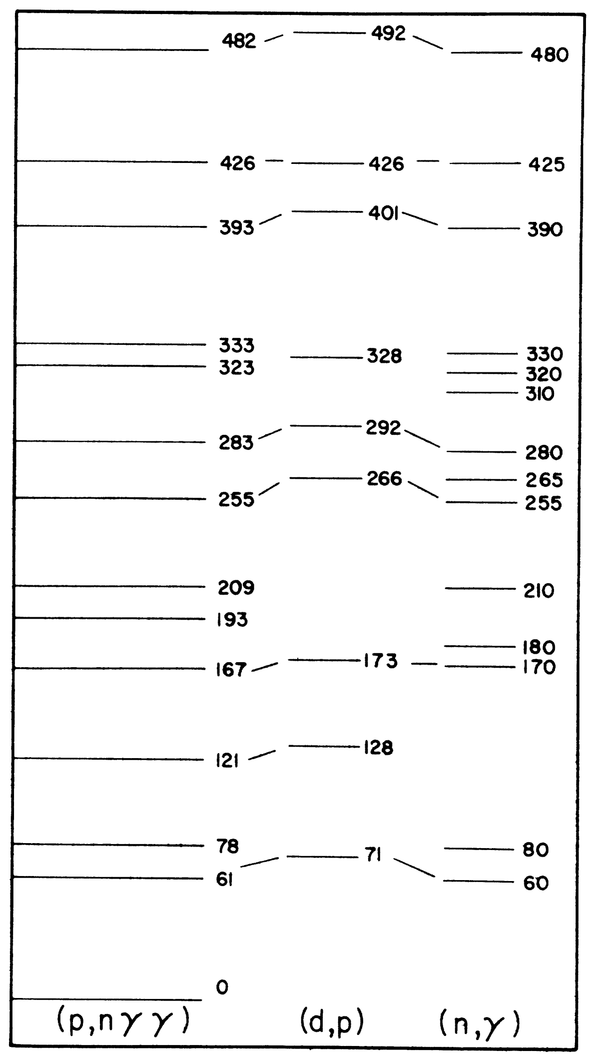


FIG. 12. On the left is the ^{122}Sb decay scheme from the data reported here. A comparison of the ^{122}Sb levels obtained in $(p,n\gamma\gamma)$, (d,p), and (n,γ) studies are shown on the right. The (n,γ) levels were taken from a high-energy γ spectrum of Shera (Ref. 5).

Level at 167 keV. This level was discussed earlier in connection with the 121-keV level. This level is also suggested by the (d, p) data as a level at 173 keV. The γ ray at 166.6 keV is not a transition from this level to the ground state, since the coincidence data show the 121-, 105-, and 167-keV γ rays to be coincident.

Level at 194 keV. This level was seen weakly in the (n, γ) work but not in the (d, p); however, the strong coincidence of the 116- and 78-keV lines clearly indicates such a level.

Level at 209 keV. This level is present in the (n, γ) data of Bhat *et al.*[2] and Shera.[5] Such a level does provide a place for the 148-keV transition, from this level to the 61-keV isomer. The other γ rays in coincidence with the 148-keV line imply levels at 393 and 482 keV, which compare well with the (d, p) levels at 401 and 492 keV.

Level at 255 keV. The (d, p) level at 266 keV and the strong coincidence of the 88-keV γ ray with both the 121- and 105-keV lines suggest this level at 255 keV.

Level at 323 keV. The (d, p) data show a level at about 328 keV. This level is also suggested by the strong coincident between the 121- and 202-keV coincidence γ rays and by the (n, γ) work of Shera.

Level at 333 keV. This level is suggested in the (n, γ) work of Ing *et al.* It provides a place for the 167-keV γ ray and satisfies the coincidence data for the 167-keV line.

Level at 393 keV. This level probably corresponds to the 398-keV level of the (n, γ) work, and the 401-keV level from the (d, p) experiment. The strong coincidence of the 184- and 273-keV transitions with the 148-keV transition indicates the presence of levels at 393 and 482 keV.

Level at 426 keV. This level was present in both (d, p) experiments, and the coincidence of the 233-keV line with the 88- and 105-keV lines supports this placement.

Level at 482 keV. As noted before, the 273-148 coincidence places a level at 482 keV which is consistent with the 492-keV state observed in the (d, p) data.

VI. SUMMARY

There are some specific problems that should be summarized here, since they were not pointed out in the discussion of the level scheme: (1) The 141-keV γ-ray transition is not placed in the decay scheme even though it is known to be in coincidence with the 88-, 105-, and 148-keV lines and not in coincidence with the 184-keV transition. (2) The 283-keV transition is assigned as a ground-state transition only on the basis of its energy, which is within experimental error of the 280-keV level assigned from the (n, γ) experiment. (3) There may be more than one 148-keV transition, since the coincidence data show other coincidences that should be satisfied.

A level scheme of ^{122}Sb is obtained which is consistent with the ^{122}Sn$(p, n, \gamma\gamma)$ coincidence data and which shows some correlation with both ^{121}Sb(d, p) and ^{121}Sb(n, γ) studies. The level scheme obtained from the γ-γ coincidence data is, however, not unique. A $(d, p\gamma)$ coincidence experiment should clear up the few uncertainties associated with the γ-γ coincidence work.

---

*Work supported in part by the U. S. Atomic Energy Commission.

[1]S. A. Hjorth, Arkiv Fysik 33, No. 12 (1966).

[2]M. R. Bhat, R. E. Chrien, D. I. Garber, and O. A. Wasson, Phys. Rev. C 2, 1115 (1970).

[3]H. Ing, A. Kukoc, J. D. King, and H. W. Taylor, Nucl. Phys. A137, 561 (1969).

[4]B. Farrelly, L. Koerts, N. Benczer, R. van Lieshout, and C. S. Wu, Phys. Rev. 99, 1440 (1955).

[5]E. B. Shera, private communication.

[6]C. M. Lederer, J. M. Hollander, and I. Perlman, *Table of Isotopes* (Wiley, New York, 1967).