Note on the Decay of Sb^{122m}†

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Recent information has helped remove contradictions in the assigned properties of the isomeric transition in Sb^{122}. The association of a 530-μsec half-life with the second excited state in Sb^{122} is confirmed and yields an $E2$ transition which is delayed by a factor of ~420. A newly reported third transition in Sb^{122m} is confirmed and shown to precede the 530-μsec state. The energy of this transition was measured and found to be 26±1 keV. The decay scheme and the hindered transitions are discussed and compared with theory.

INTRODUCTION

In a recent paper[1] on the decay of Sb^{122m}, contradictions in the properties of an apparent two-step isomeric transition were discussed. Two transitions had been reported[2] associated with this isomer, one of 75-keV energy, the other of 61 keV. By comparing the intensities of the unconverted gamma rays associated with these transitions and the K x rays resulting from the K-shell conversion of the transitions, the character of the 75-keV transition was identified as $E2$ and that of the 61-keV transition as $E1$. Delayed coincidence measurements revealed a state of 1.8-μsec half-life fed by the 75-keV transition and decaying through the 61-keV transition to the ground state (2.8 day). Thus, the 75-keV $E2$ transition appeared to be the decay of the "3.5-min" isomeric state although from lifetime considerations an $L=3$ transition was expected. It was remarked[1] that the contradiction would be resolved if the "3.5-min" lifetime were associated with a third transition preceding the 75-keV transition. A search for such a transition was unsuccessful.

Recently Meyer-Berkhout[3] reported that when Sb is irradiated with 23-MeV bremsstrahlung a 530±40 μsec activity is formed consisting of two gamma rays of 61- and 75-keV energy which appeared in the same intensity ratio as reported for the "3.5-min" isomer. He suggested that this activity was in Sb^{122} resulting from a (γ,n) reaction on Sb^{123}. In a later communication he reported the presence of the "3.5-min" isomer as well, but remarked that the half-life was longer, namely, 4.15±0.2 min. He confirmed the existence of the 1.8-μsec state, seeing it both with the 530-μsec and the 4.2-min activities. Vanhorenbeeck[4] reported a 19.4-keV line in the spectrum of electrons associated with the decay of the Sb^{122m} "3.5-min" isomer which he interpreted to be due to the L conversion of a 24-keV transition preceding the 75-keV transition. Delayed-coincidence studies by this author[4] revealed two half-lives, one of 5×10^{-3} sec, the other of 2 μsec. The 2-μsec half-life is in good agreement with the 1.8-μsec half-life reported previously[1] but the 5×10^{-3} sec half-life is considerably longer than the 530 μsec reported by Meyer-Berkhout.

HALF-LIFE MEASUREMENT

The longer half-life of 4.15±0.2 min for Sb^{122m} was confirmed by following the decay of the unconverted 61- and 75-keV γ rays. A thin source of Sb^{121} was irradiated in the Brookhaven reactor for 1 min and its decay was observed with a NaI(Tl) detector which was $1\frac{1}{2}$ in. in diameter and 1 in. high. The signals were accumulated on a Technical Measurement Corporation Series 400 multichannel analyzer operating as a multiscaler. In this mode of operation, time is converted to pulse height so that each channel of the analyzer represents a certain increment of time. The accumulation time per channel was set at 1 sec per channel. A channel preceding the multichannel analyzer was used to select only that portion of the spectrum to be counted which contained the 61-keV and 75-keV unconverted γ rays. The value obtained for the lifetime of Sb^{122m}, 4.2±0.2 min, is in agreement with that given by Meyer-Berkhout.

CONVERSION ELECTRON SPECTRA

In order to observe the electron line reported by Vanhorenbeeck well enough to identify it as being other than the Auger lines due to the two higher energy (61 keV and 75 keV) transitions, a proportional counter was modified so that very thin (evaporated) sources of several square centimeters area could be mounted within the proportional counter region. The spectrum of conversion electrons associated with the Sb^{122m} 4.2-min activity thus obtained is shown in Fig. 1. A prominent peak is observed at 22±1 keV, which is approximately the energy of the Auger electrons expected from the conversion of the 61- and 75-keV transitions. However, a consideration of the fluorescent yield (82%) indicates that this peak is too intense to be only the Auger electrons and must, therefore, be partly due to conversion electrons of a third transition. The slight peak at about 25.6 keV is interpreted to be a mixture of K x rays and the M conversion electrons of a 26±1 keV transition whose L conversion is re-

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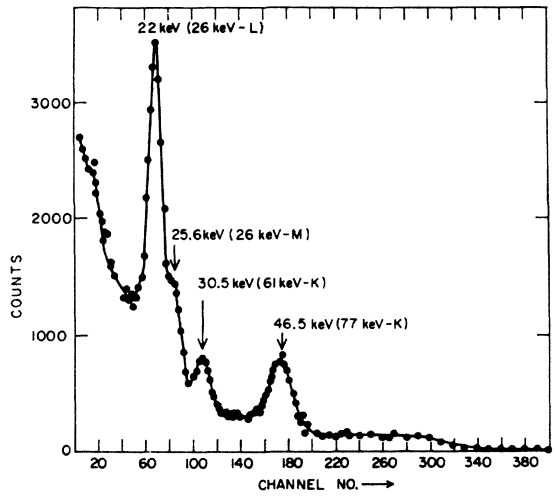

FIG. 1. Spectrum of conversion electrons observed in the decay of Sb^{122m} (4.2 min) with a proportional counter and internal source. The prominent 22-keV electron line is too intense to consist of Auger electrons of the two previously reported higher energy transitions. The ratio of the 61- and 77-keV K conversion electron peaks is compatible with $E1$ and $E2$ assignments, respectively, to these transitions. Our value of the energy of the second transition in Sb^{122m} (77 keV) is slightly higher than the literature value (75 keV).

sponsible for the peak at 22 keV. The ratio of the intensities of these two peaks is consistent with an $L=3$ transition; however, an $M2$ transition is not excluded.

"TIME-OF-FLIGHT" DELAYED COINCIDENCE MEASUREMENTS

In order to prove that this new transition (26 keV) is the missing transition leading to the 530-μsec state, delayed coincidences were studied with a TMC 256-channel analyzer with a time-of-flight plug-in unit. This unit again converts time to pulse height but counts upon receiving an initiating pulse as a trigger. The analyzer was fed pulses from the proportional counter after they had been selected with single-channel analyzers and properly shaped. The 22-keV electron line was selected with one channel and was used to trigger the "time-of-flight" unit. The K conversion lines of the 61- and 75-keV transitions were selected with another channel and applied to the signal input of the unit. The accumulation time per channel was set at 16 μsec. Thus, a pulse from the proportional counter resulting from a 22-keV electron initiated the sweep of the time-of-flight unit and any other pulse from the proportional counter of the chosen energy (61 or 75 keV) was stored in the channel indicative of the time elapse between the initiating pulse and the signal. Figure 2 shows the data obtained in this way. The decay curve with background subtracted yields a half-life of 530±30 μsec. This confirms the existence of a third transition[4] and shows that it precedes a 530±30 μsec state[3] at 136 keV above the ground state. The electron line reported by Vanhorenbeeck is thus seen to be the conversion electron due to the missing transition. The longer lifetime he observed can readily be explained by the extreme difficulty of measuring lifetimes in this region with conventional delayed coincidence techniques. Meyer-Berkhout *et al.*[3] have observed that the γ-ray spectrum associated with the 530±30 μsec half-life is identical with that associated with the 4.2-min lifetime; thus there can not be a measurable cross over from the 161-keV level to the 61-keV level or the ground state. This agrees with our earlier observation[1] that no transitions greater than 75 keV were observed in the 4.2-min decay. A decay scheme is shown in Fig. 3 which is essentially the same as that proposed by Meyer-Berkhout *et al.* except for the addition of the energy of the first transition.

DISCUSSION

The new decay scheme removes the difficulties of the previously proposed scheme. The 61-keV $E1$ transition is retarded by a factor of $\sim 10^6$ compared to the Weisskopf estimate[5] for a single proton transition. The explanation for this delayed transition may be found in the shell model. The ground state and the first excited state (10 keV above the ground state) of Sb^{121} have been assigned spins of 5/2+ and 7/2+ respectively, while in Sb^{123} the ground state has been assigned a spin 7/2+ and the first excited level (160 keV above the ground state) a spin 5/2+. This suggests that $d_{5/2}$ and $g_{7/2}$ may be the available low-lying proton orbitals in Sb^{122}. The observed low-lying states of Sn^{121} and the calculations of Kisslinger and Sorensen[6] suggest that $d_{3/2}$, $s_{1/2}$, and $h_{11/2}$ are the low-lying neutron levels. Both experimental data and Kisslinger and Sorensen's calculations[6] indicate that the 5/2+ and 7/2+ levels

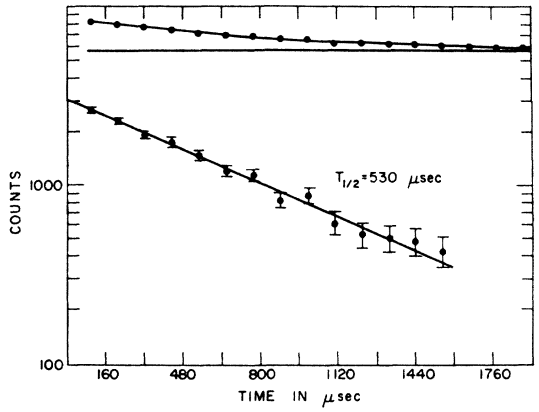

FIG. 2. Lifetime of the second excited level in Sb^{122}. The decay illustrated above is between 22-keV electrons and the conversion electrons of the 61- and 75-keV transitions in Sb^{122m}.

[5] A. H. Wapstra, G. J. Nijgh, and R. van Lieshout, in *Nuclear Spectroscopy Tables* (North-Holland Publishing Company, Amsterdam, 1959).

[6] L. S. Kisslinger and R. A. Sorensen, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 32, No. 9 (1960).

which are present in this shell are about 1 MeV above the three low-lying levels. The ground-state spin has been measured[7] and is 2−. The negative parity of this state implies that although configuration mixing may be present in these levels, a major contribution to the ground state must be made by the $h_{11/2}$ neutron orbital. The dominant configuration in the ground state may thus be $(g_{7/2},h_{11/2})_{2-}$. The first excited (3+) state may have large contributions from $(g_{7/2},s_{1/2})_{3+}$ and $(g_{7/2},d_{3/2})_{3+}$ configurations. The important point is that there is no configuration readily available in the shell model that allows an unhindered $E1$ transition to take place between these two levels. It is thus not surprising that this transition is hindered by a large factor since it may have to go on the strength of small admixtures of configurations far removed from the available ones.

The 138-keV level may be receiving significant contributions from a $(g_{7/2},d_{3/2})_{5+}$ configuration so that the $E2$ transition to the 3+ level may go by a $d_{3/2} \rightarrow s_{1/2}$ neutron transition. The 77-keV $E2$ transition between the 138- and 61-keV levels is slower than the Weisskopf estimate by a factor of ~420. Of course, the comparison of neutron transitions to the Weisskopf estimate for a single proton jump assumes an effective charge of 1, which has been found to be appropriate as an approximate rule for an $E2$ transition.[6,8] Several effects may be contributing to the slowness of this transition as compared to a single proton jump. A large hindrance factor (10 or more) is predicted by the Kisslinger and Sorensen[6] calculations, though it is hard to obtain an exact number since it is not clear what values to choose for several parameters upon which the hindrance factor depends critically. Another hindrance factor of ~1.5 is obtained by virtue of the coupling of the odd neutron to the odd proton. A further reduction might result from configuration mixing.

The lifetime of the 26-keV transition from the 164-keV level to the 138-keV level suggests that it may be an $E3$ transition. This is consistent with the approximate measure of the L to M conversion ratio one obtains from Fig. 2 (ratio of 22-keV peak to 25.6-keV peak). A spin of 8 is suggested for the 164-keV level and the shell model requires either a $(d_{5/2},h_{11/2})_{8-}$ or $(g_{7/2},h_{11/2})_{8-}$ configuration to supply this high spin. Thus the parity of the state would be negative, consistent with an $E3$ transition. The transition is delayed by a factor of 46

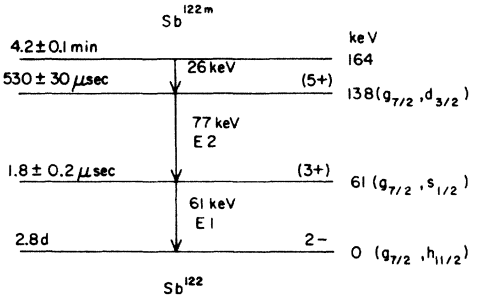

FIG. 3. Decay scheme of Sb^{122m} (4.2 min). The configurations shown at the right are those which obey coupling rules and are expected to make significant contributions to these levels.

over the Weisskopf estimate. Again the Kisslinger and Sorenson calculations predict a reduction in rate by a factor of about 10. The configurations suggested in the decay scheme (Fig. 3) as being predominant are those which agree with empirical coupling rules.[9,10] However, the configuration assignments proposed above for the 164-keV level are not too satisfactory because this assignment effectively forbids the $E3$ transition.

Slow $E1$ and $E2$ transitions have been reported in the Sn region by several investigators.[11–13] Several authors[12,13] report delayed $E2$ transitions between 7− and 5− states both in Sn^{118} and Sn^{120}. They suggest that the predominant configurations in these levels are $(h_{11/2},d_{3/2})_{7-}$ and $(h_{11/2},s_{1/2})_{5-}$ so that these transitions also may be predominantly neutron transitions between a $d_{3/2}$ and an $s_{1/2}$ state as in Sb^{122}. The retardations they observed[13] were 16 in Sn^{118} and 250 in Sn^{120}. It is interesting to compare this with Sb^{122} and to note that the retardation differs by large factors from isotope to isotope and may assume large values.

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