Decay of 3.5-Min $_{53}I^{122}$†

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Scintillation spectrometer studies of the radiations from I^{122} have shown 564-keV (100), 686-keV (7), 780-keV (5), 1250-keV (1.1), 1420-keV (0.9), 1750-keV (complex, 2), 2180-keV (1), 2540-keV (0.2), 2740-keV, 2920-keV, 3170-keV, and 3450-keV gamma rays with the intensities given in the parenthesis. From the gamma-gamma coincidence, positron-gamma coincidence, and the summing technique, it has been inferred that the 564-, 1250-, 1350±10-, 1950±30-, 2350±50-, 2530±50-, 2750±50-, 2970±50-, 3100±50-, and 3400±50-keV levels in Te^{122} are excited in the decay of I^{122}. From the gamma-gamma angular correlation studies, the 1350-keV level is assigned the spin and parity 0^+. The log*ft* values of the positron decay to the ground, 564-, 1250-, 1340-keV states of Te^{122} have been estimated to be 4.6, 5.1, 6.2, and 6.2, respectively. The log*ft* value of the β^- decay of Sb^{122} to the 1350-keV state of Te^{122} has been estimated to be $\geqslant 9.7$.

I. INTRODUCTION

THE decay of 3.5 min $_{53}I^{122}$ has been studied by a number of workers.[1,2] This isotope is known to decay to the ground state of $_{52}Te^{122}$ with the emission of positrons, having the maximum energy of 3.12 MeV. From the allowed log*ft* value of 4.8 for this decay, it was concluded that the spin and parity of the ground state of I^{122} is 0^+ or 1^+. No gamma rays were observed in the decay of this isotope. The excited states of the decay product $_{52}Te^{122}$ are known from the decay of $_{51}Sb^{122}$,[3] and from the inelastic scattering of the alpha particles.[4] The first and the second excited states of this even-even isotope are at 564 keV (2^+) and 1250 keV (2^+), respectively. The study of this isotope was undertaken in the hope of being able to fix the spin of I^{122} uniquely. The detection of the 564- and the 686-keV gamma rays from the feeding of the 564- and the 1250-keV levels in the positron decay of I^{122} would indicate that the spin of this isotope is 1 and not 0. Whether the spin of this isotope is 0 or 1, the 0^+ member of the second excited triplet, if it exists, should be fed, and it should be possible to detect it.

II. SOURCE PREPARATION

The source of I^{122} was prepared by making its parent Xe^{122}, which has a half-life of 19 h and which decays by electron capture by the emission of only low-energy gamma rays (90, 148, and 240 keV)[2]. It was possible to make Xe^{122} by the bombardment of potassium iodide with about 100-MeV protons in the internal beam of the synchrocyclotron of this institute. The bombarded target was dissolved in water and the xenon gas was frozen in a glass tube at liquid nitrogen temperature. The separation of the xenon gas was performed about 12 h after the bombardment to allow for the decay of 1.8 h Xe^{123} and other short-lived isotopes. The radioactive xenon gas sample consisted of 19 h Xe^{122} in equilibrium with its daughter 3.5 min I^{122}, 18 h Xe^{125}, and 36 day Xe^{127}. The gamma rays from I^{122} have energies greater than 500 keV. Therefore, the presence of the low-energy gamma rays from Xe^{122}, Xe^{125}, and Xe^{127} does not interfere in the understanding of the decay scheme. But Xe^{125} emits gamma rays also in the energy range 450 to 1300 keV[5]. In order to get the spectrum of the gamma rays from a pure source of I^{122}, the following procedure was adopted. The radioactive xenon gas, released from the dissolved KI target, was frozen in the first of a series of glass U-tubes, all immersed in liquid nitrogen. After Xe^{122} and I^{122} had reached equilibrium in the first tube, the liquid-nitrogen bath was removed from this tube and the temperature was raised to the room temperature with the help of an air stream. The vaporized radioactive xenon gas was pumped out to the second tube in the nitrogen bath. The first tube which contained pure I^{122} was quickly sealed, and was used as a source of pure I^{122}. Many tubes of this kind were used to collect the data on the gamma spectrum of I^{122} with

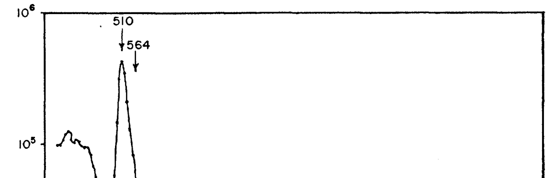

FIG. 1. The gamma-ray spectrum from a source of pure I^{122}.

* Supported by the U. S. Air Force Office of Scientific Research.
[1] H. B. Mathur and E. K. Hyde, Phys. Rev. **96**, 126 (1954).
[2] R. B. Moore, Bull. Am. Phys. Soc. **5**, 338 (1960).
[3] B. Farrell, L. Koerts, N. Benczer, R. Van Lieshout, and C. S. Wu, Phys. Rev. **99**, 1440 (1955).
[4] P. H. Stelson and F. R. McGowan, Phys. Rev. **121**, 209 (1961).

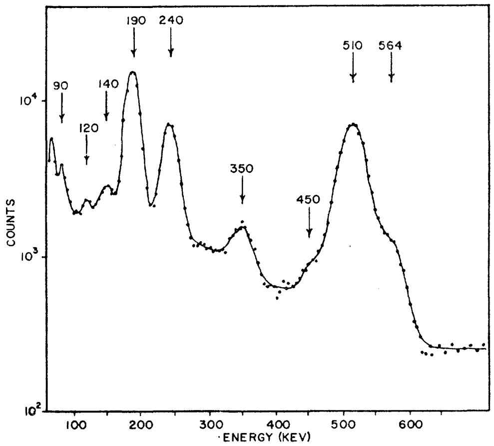

FIG. 2. Low-energy gamma ray spectrum of a mixed source of Xe^{122}, I^{122}, Xe^{125}. The 90 keV, 140 keV and part of the 240 keV peaks are due to Xe^{122}. Xe^{125} gives rise to 120, 190, 240, 350, and 450 keV peaks. The 510 and 564 keV peaks are due to I^{122}.

the help of a multichannel analyzer. Coincidence and other studies were carried out with the sources which contained Xe^{122} and I^{122} in equilibrium, mixed with some Xe^{125} and Xe^{127}.

III. EXPERIMENTAL RESULTS

The spectrum of gamma rays from a pure source of I^{122} was studied in a scintillation spectrometer with 3 in.×3 in. NaI (Tl) crystal and 400-channel RIDL multichannel analyzer. In order to minimize the intensity of the annihilation radiation, the Lucite absorber for the positrons was placed halfway between the source and the detector. The spectrum is reproduced in Fig. 1. In Fig. 2 is reproduced the spectrum of low-energy gamma rays from a mixed source of Xe^{125} and $Xe^{122}-I^{122}$. One can observe the predominant gamma rays of energy 190, 240, and 450 keV from Xe^{125}. The absence of these gamma rays in Fig. 1 indicates that the iodine 122 source was reasonably pure. The spectrum in Fig. 1 has been analyzed to give the energies and intensities of the gamma rays from I^{122} as follows: 564 keV (100), 686 keV (7), 780 keV (5), 1250 keV (1.1), 1420 keV (0.9), 1750 keV (complex 2,) 2180 keV (1), 2540 keV (0.2). With a strong and mixed source of Xe^{125} and $Xe^{122}-I^{122}$, the high-energy part of the gamma rays have been studied. The spectrum is given in Fig. 3. In addition to the abovementioned gamma rays low-intensity gamma rays of energy 2740, 2920, 3170, and 3420 keV were observed. In Fig. 3, the portion of the spectrum before the 1750 keV peak has contributions from Xe^{125}.[5] Due to the continuum background of annihilation of positrons in flight, the intensity values are uncertain by about 20%.

In order to find out what fraction of the positron decay fed the first excited state of Te^{122} at 564 keV and also to find the high-energy levels fed by the electron capture decay of I^{122}, a weak source of $Xe^{122}-I^{122}$, mixed

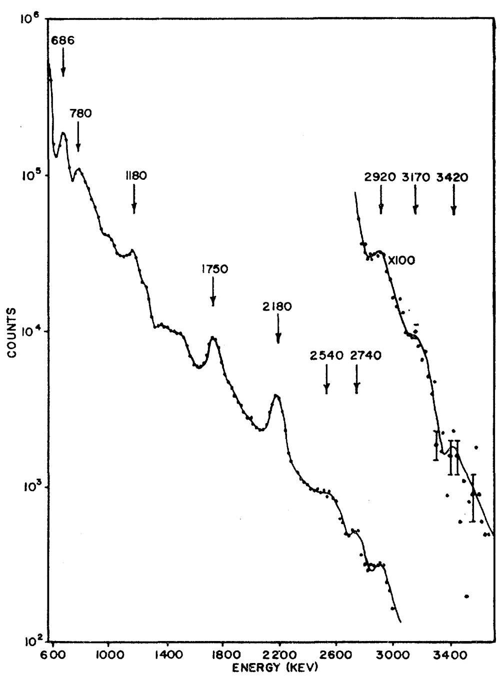

FIG. 3. The gamma-ray spectrum from a mixed source of $Xe^{122}-I^{122}$, Xe^{125}.

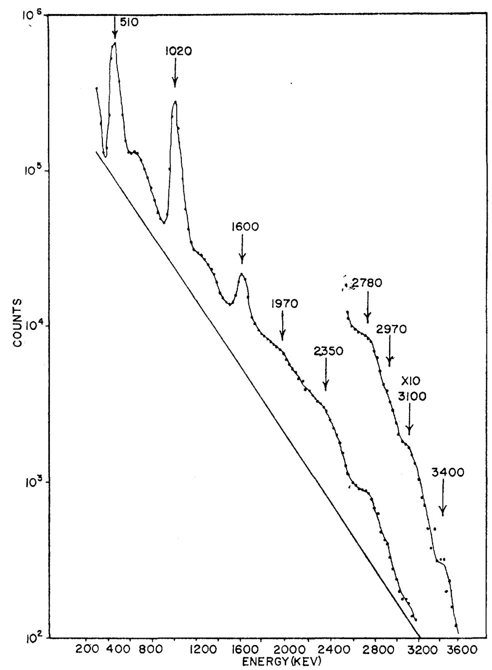

FIG. 4. The gamma-ray spectrum of a mixed source of $Xe^{122}-I^{122}$, Xe^{125} and Xe^{127} with the source inside the well of a 3 in. ×3 in. NaI(Tl) crystal. The solid line is the estimated intensity of the bremmsstrahlung due to positron annihilation.

[5] S. Jha (to be published).

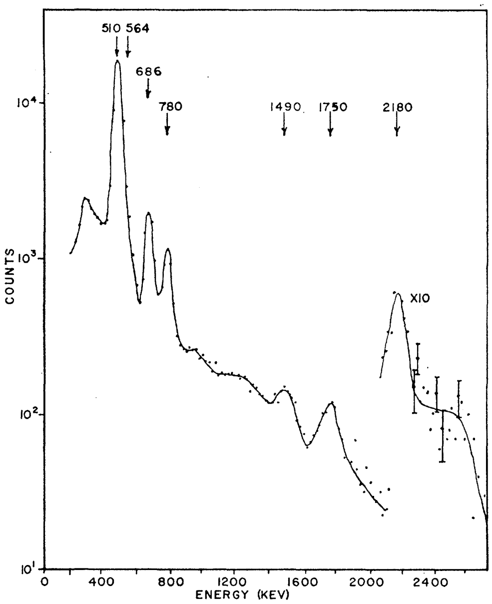

FIG. 5. The spectrum of gamma rays in coincidence with the 564-keV gamma ray.

with a little of Xe^{125} sealed in a small glass tube, was encased in a copper tube with the wall thickness of about 2 mm and was introduced in the well of a 3 in.×3 in. NaI (Tl) crystal. The spectrum of the gamma rays with the source inside the well of the crystal is reproduced in Fig. 4. The continuous spectrum of the annihilation of the positrons in flight almost swamps the gamma-ray spectrum but the appearance of humps at the end of the spectrum at 2780±50, 2970±50, 3100±50, and

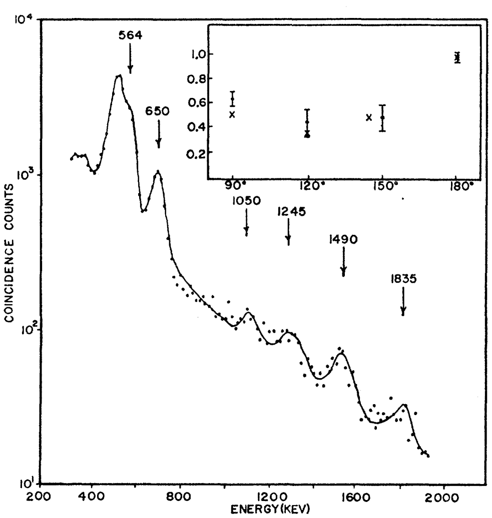

FIG. 6. The spectrum of gamma rays in coincidence with the 686-keV gamma ray. In the inset is given the result of angular correlation studies of the 564-keV and 780-keV cascade. The dots with the vertical lines indicating statistical error are the experimental points. The crosses are the calculated values for a 0—2—0 cascade.

3400±50 keV indicates the existence of a level at these energies in Te^{122}, populated by the electron capture decay of I^{122}. In this figure, the peak at 510 keV is due to the annihilation radiation. The peak at 1020 keV is due to the simultaneous detection of two annihilation gamma rays inside the well of the crystal. The small hump in between the 510-keV peak and the 1020-keV peak has been observed before by Girgis[6] and attributed by him to the summation of one annihilation radiation and the back-scattered part of the other annihilation

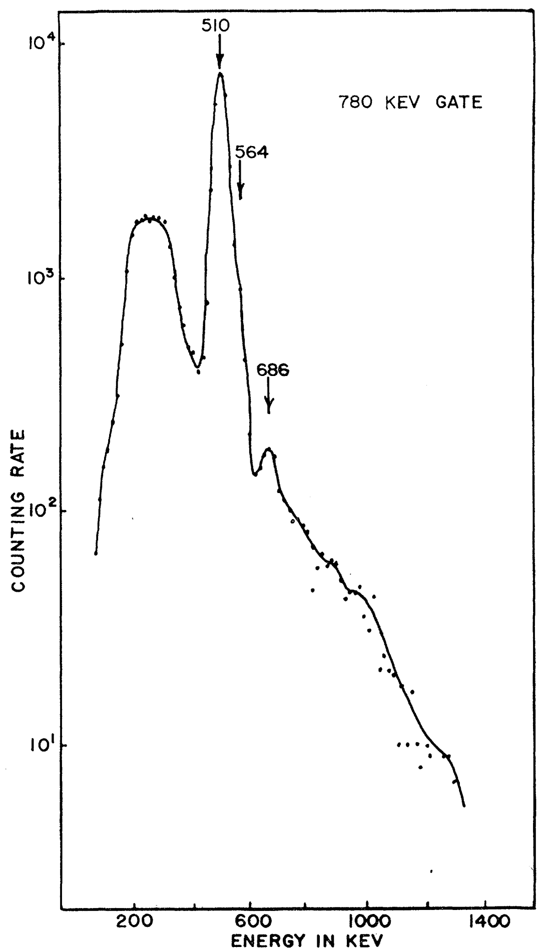

FIG. 7. The spectrum of gamma rays in coincidence with the 780-keV gamma ray.

quantum. Finally, the peak at 1600 keV is due to the simultaneous detection of the two annihilation quanta and the 564 keV gamma ray. From the relative areas of the 510-, 1020-, and the 1584-keV peak, the positron branching to the 564-keV state can be calculated. If we neglect the positron branching to the second excited state and assume that a fraction α of total positron decay n leads to the 564-keV state, and if the detection

[6] R. K. Girgis, Thesis, University of Amsterdam, 1959 (unpublished).

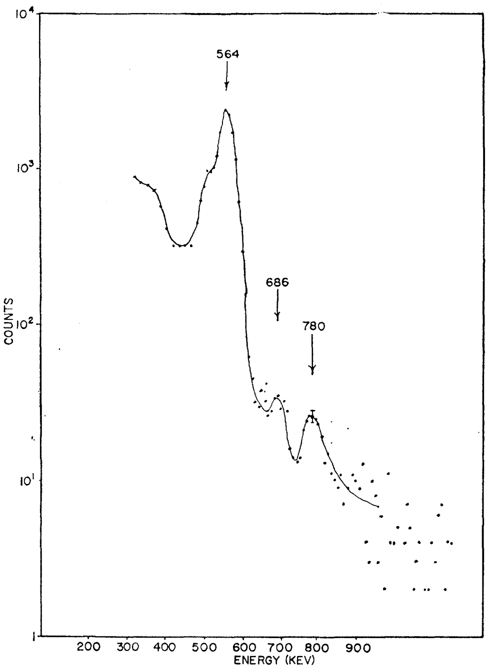

FIG. 8. The spectrum of gamma rays in coincidence with the positrons of energy between 1200 and 2000 keV.

efficiency of the crystal for the 510- and 564-keV radiation is assumed to be ϵ, the number of the 510-keV gamma rays detected in this geometry is given by $2n\epsilon$, the number of simultaneous detection of the two 510-keV gamma rays is given by $n\epsilon^2$, and lastly the number of the simultaneous detection of the two annihilation radiation and the 564-keV gamma ray is given by $\alpha n\epsilon^3$. $\alpha n\epsilon^3$ is proportional to area under the 1584-keV peak, $n\epsilon^2$ is proportional to the sum of the areas under the 1584- and 1020-keV peaks, and $2n\epsilon$ is proportional to the sum of the area under the 510 keV, and twice the areas under 1020-keV and 1584-keV peaks. From these numbers, the value of α, the branching ratio of the positron decay to the 564-keV state is estimated to be $10\pm3\%$.[6a] The largest uncertainty is introduced by the uncertainty in the contribution of the continuum of annihilation in flight.

The gamma-ray coincidence studies have been carried out with two $1\frac{3}{4}$ in.$\times$2 in. NaI (Tl) crystals, a slow-fast coincidence circuit with a resolving time of 6×10^{-8} secs, a 400 channel pulse height analyzer. The spectra of the gamma rays in coincidence with the 564-, 686- and the 780-keV gamma ray are reproduced in Figs. 5, 6, and 7, respectively. In coincidence with the 564-keV gamma ray, 686-, 780-, 1490-, 1750-, and 2180-keV gamma rays have been observed, and 1050-, 1250- and 2400-keV gamma rays are suspected. In coincidence with the 686-keV gamma rays, we have observed the following gamma rays: 564, 650, 1050, 1245, 1490, and 1835 keV. With the 780-keV gamma ray in the gate, 564-keV gamma ray was observed. The presence of a small 686-keV peak could be due to the inclusion, in 780-keV gate, of the Compton pulses of higher energy gamma rays which are in coincidence with the 686-keV gamma ray.

With the help of these coincidence data and the data from the sum spectrum, one can draw the inference that in Te^{122} there are levels at 564, 1250, 1350 keV and presumably also at 1950 ± 30, 2350 ± 50, 2530 ± 50, 2750 ± 50, 2970 ± 50, 3100 ± 50 and 3400 ± 60 keV.

In order to test some of these conclusions, the positron spectrum I^{122} from a composite source of $Xe^{122}-I^{122}$ and Xe^{125} was studied in a plastic scintillator. In Fig. 8 is reproduced the spectrum of the gamma rays in coincidence with the positrons of energy between 1200 keV and 2 MeV. It was gratifying to observe that 560-, 680-, and 780-keV gamma rays appeared. In Fig. 9 is reproduced the total positron spectrum having an end point at about 3.1 MeV, and also the positron spectra in coincidence with the 560-keV gamma ray, 680-keV, and 780-keV gamma ray. The end point of these positron spectra appeared, as expected, at about 2600 keV in coincidence with the 560-keV gamma ray but at about 1800 keV in coincidence with the 680-keV gamma ray and 780-keV gamma ray.

From the sum spectrum of the annihilation radiation and the 564-keV gamma ray, it was mentioned before, the positron branching to the 564-keV first excited state has been estimated to be $10\pm3\%$. The relative positron branching to the 564-keV, first excited state and the 1250- and 1350-keV second excited states has been estimated as follows: a small source containing Xe^{122}

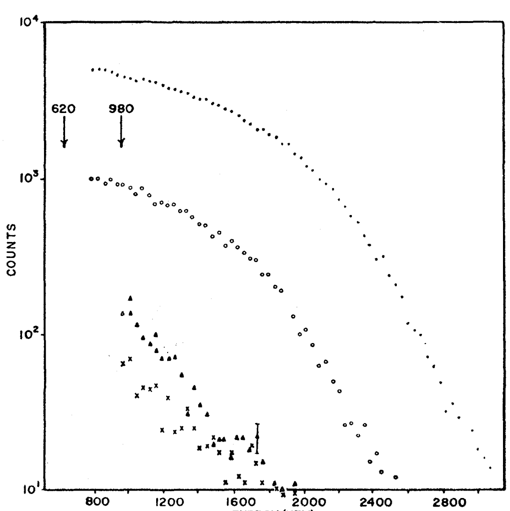

FIG. 9. The positron spectrum in an anthracine crystal. The dots represent the single spectrum. The circles, triangles and crosses represent the positron spectrum in coincidence with the 564-, 686-, and 780-keV gamma rays, respectively.

[6a] *Note added in proof*. The above consideration is correct only if the gamma rays are detected entirely by the photoelectric absorption. The positron branching to the first excited state has been re-estimated. The value given above has been confirmed.

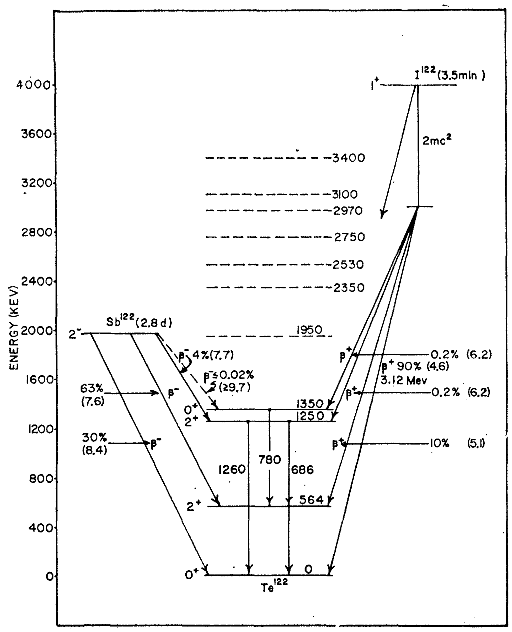

FIG. 10. Partial decay scheme of I^{122}.

$-I^{122}$ and Xe^{125} was sandwiched between two Lucite disks about 2-cm thick. With the help of a triple coincidence circuit, the spectra of gamma rays in simultaneous coincidence with two annihilation quanta was measured. From the relative intensity of the 564-keV gamma ray and the 686-keV and 780-keV gamma rays (100 : 2 : 2.5) the positron branching to the ground state, 560-, 1250-, and 1350-keV state have been estimated to be 90 : 10 : 0.2 : 0.2, respectively. From this the logft to the four states have been calculated to be 4.6, 5.1, 6.2 and 6.2, respectively.

The partial decay scheme of I^{122}, for which some confirmation was available, has been given in Fig. 10.

IV. DISCUSSION

It can be concluded, from the observation that the positron decay of I^{122} leads to the ground state (0^+) and the 564-keV state (2^+) of Te^{122} both with the allowed log ft values, that I^{122}, like the light odd-odd isotopes of $_{55}Cs$, has the spin and parity 1^+.

From the gamma-gamma and positron-gamma coincidence studies, it has been concluded that in the region of the second excited state in Te^{122}, there are two levels; one at 1250 keV is well-known from the study of Sb^{122} to have the spin are parity 2^+, and the other at 1350 keV is a new one. Since this level is fed from positron decay of I^{122} (1^+), its spin is unlikely to be different from 0, 1, or 2. A rough angular correlation study of the 564- and 780-keV cascade has been made. The result is given in the inset of Fig. 6. It is tentatively concluded that the 1350-keV level is 0^+. In order to lend additional support to this conclusion, attempts were made to observe this level in the decay of 2.8 day $_{51}Sb^{122}$ (2^-), where the 1250-keV level of Te^{122} is fed by β decay having an end-point energy of 0.75 MeV with an intensity of 4%. The β transition from Sb^{122} to the possible 1350-keV level (0^+) will be of the unique first-forbidden type, having perhaps the same logft as for the ground-to-ground transition. This would imply a partial lifetime for this decay of about 2 yr and an intensity of about 0.4%, i.e., about one tenth of the intensity of the transition to the 1250-keV level. The gamma rays in coincidence with the 564-keV gamma ray from an extremely pure sample of Sb^{122} were studied in a coincidence scintillation spectrometer. The intensity of the possible 780-keV gamma ray was not more than about 0.5% of the intensity of the 686-keV gamma ray, i.e., about one twentieth of the expected intensity. It is concluded that the logft of the possible beta transition from Sb^{122} to the 1350-keV level is $\geqslant 9.7$. This logft value, although not inconsistent with the unique first-forbidden type beta decay, is higher than the logft value for the same type of beta decay in the ground-to-ground transition. In this connection, attention may be drawn to the estimate of the logft values for the allowed positron decay of I^{122} to the ground state, 564-keV first excited state, and the 1250- and 1350-keV second excited states. The unusually large logft for the allowed transition to the two latter states could be attributed to the hindrance associated with the simultaneous creation of two phonons along with β decay.

Our data about the higher excited states are so meager that we cannot say anything about their properties.

ACKNOWLEDGMENTS

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