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γ-γ Directional Correlations in the Decay of Sb^{125} †

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γ-γ directional correlations have been measured for two cascades in the decay of 2.7-yr Sb^{125}: 320–177 keV, $A_2 = -0.15(2)$, $A_4 = -0.04(4)$, $\delta(177) = 0.9(+0.9,\ -0.4)$; 203–177 keV, $A_2 = -0.52(5)$, $A_4 = 0.02(5)$, $\delta(203) = 1.0(+1.1,\ -0.4)$ for spin $\frac{11}{2}$ assigned to the 525-keV level in Te^{125}. The present results are inconsistent with spin $\frac{9}{2}$ for this level.

INTRODUCTION

Many features of the low-lying levels in Te^{125} have been established.[1-7] The main features of the level scheme are shown in Fig. 1. This system of levels has been the subject of interesting theoretical studies[8,9] based on a treatment of pairing forces by the quasiparticle concept as developed in the superconductivity problem. The present investigation is aimed at further clarification of a few points which may be studied advantageously by the technique of directional correlation measurements with good energy resolution in one channel through use of a germanium detector. We are concerned here with the spin of the 525-keV level and the multipole mixing parameters of the 203- and 177-keV transitions. The properties of the latter transition have, in fact, been studied[1,6] but in the present work it is essential to have a consistent set of measurements for both transitions. Furthermore, agreement between different investigations in areas where they overlap lends credence to those conclusions which depend upon a combination of the experimental results. A preliminary report of these results has been made.[10]

EXPERIMENTAL PROCEDURE AND RESULTS

The 2.7-yr Sb^{125} was obtained from the Oak Ridge National Laboratory. Except for replacement of a multichannel analyzer by a computer core memory, the general features of the experimental and data reduction procedures are similar to those employed previously in a study of Ir^{192}.[11] The output of the fixed 30-cm^3 lithium-drifted germanium detector was routed to analog-to-digital converters (ADC) interfaced to a Digital Equipment Corporation PDP-8 computer which was operated on-line during the experiment. The movable detector was a 3-in.-diam × 3-in.-high NaI(Tl) crystal. The output went to a single-channel pulse-height analyzer set to the 177-keV γ photopeak which gated the ADC. The region of the coincidence spectrum of interest here is shown in Fig. 2. Data accumulated during a run (usually of 1-h duration) at a particular angle, if consistent with certain accept-

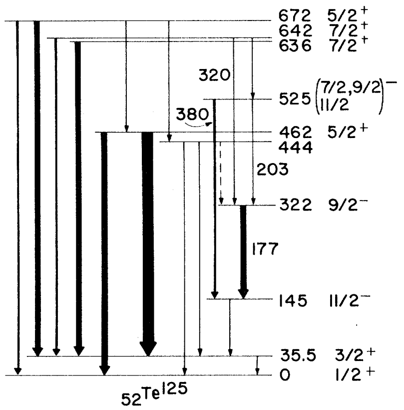

FIG. 1. Main features of the low-lying levels of Te^{125} as populated in the decay of 2.7-yr Sb^{125}. Energies are in keV.

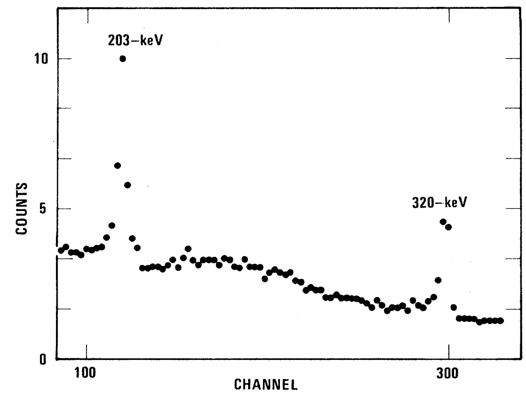

FIG. 2. Schematic representation of the coincidence γ-ray spectrum in the decay of 2.7-yr Sb^{125} as viewed by a 30-cm^3 germanium detector gated by the 177-keV γ ray.

ability criteria and after adjustment for any small shift in the location of a reference peak, were averaged with previous data for the same angle and stored on a magnetic disk memory. The faces of the germanium and NaI crystals were located 7 and 10 cm from the source, respectively.

Analysis of the coincidence spectrum in the vicinity of the 203- and 320-keV peaks permitted correction for coincidence background. Corrections were made either according to a graphical estimate of the background or by fitting of Gaussian distributions plus a linear background, or in many instances both procedures were used with generally consistent results.

This work is especially prone to erroneous results because of scattering of the higher-energy γ rays between counters; coincident events are then produced in the two detectors which simulate the desired events. Our previous experience with a β-γ correlation in this decay had also emphasized the serious nature of this problem.[12] Accordingly, several variations of the experimental and data reduction precedures were made to test for spurious effects: (a) Runs were made with a conical lead shield in front of only the germanium detector and in front of both detectors, (b) data were taken at only three independent angles (90, 135, 180°, and corresponding angles in the next quadrant) and later at five independent angles (the 112.5 and 157.5° positions were added),[13] and (c) for data taken at five angles, coefficients were determined with and without inclusion of the 180° data, the position at which scattering between counters is most serious. The experimental results were relatively independent of these variations. In particular, the large A_2 coefficient which we find for the 203–177-keV cascade was observed under any reasonable set of experimental or data reduction procedures.

The experimental results used in the interpretation are summarized in Table I. Although, as noted, significantly different results were not found for variations in the procedures used, it was deemed proper to base the interpretation on those measurements performed under the most favorable conditions rather than attempt some averaging procedure which would then include data taken under inferior conditions. However, the errors indicated in the table include some allowance for possible systematic errors based on the results obtained using varied procedures. Geometrical correction factors[14] of 0.92 and 0.75 have been applied to the A_2 and A_4 coefficients, respectively.

INTERPRETATION

The second-order, partial directional correlation coefficient appropriate to the mixed $M1+E2$ 177-keV transition is determined from the result for the 320–177-keV cascade under the assumption that the spin and multipolarity sequence is $\frac{7}{2}(1)\frac{9}{2}(1,2)\frac{11}{2}$. This partial coefficient is then used in the subsequent interpretation of the 203–177-keV cascade. The spin-parity assignment to the 525-keV level has been limited to $(\frac{7}{2},\frac{9}{2},\frac{11}{2})^-$ as no other assignment seems likely, in view of existing information concerning the β and γ transitions in the Sb^{125} decay. The quantity $f=\delta/(1+\delta^2)^{1/2}$ will be used as a measure of multipole mixing, where δ

TABLE I. Experimental directional correlation coefficients. Under "Cascade" are listed the energies, in keV, of the radiations detected by the germanium and NaI counters, respectively.

Cascade	A_2	A_4
320–177	-0.15 ± 0.02	-0.04 ± 0.04
203–177	-0.52 ± 0.05	0.02 ± 0.05

is the usual ratio of reduced matrix elements with the phase convention defined according to Rose and Brink.[15]

From the observed A_2 coefficient for the 320-177-keV cascade and the partial coefficient for a pure $E1$ transition, one finds the partial coefficient for the mixed 177-keV transition to be $A_2(177) = -0.49 \pm 0.07$. The mixing parameters for the 177-keV transition may be read from Fig. 3 as $f(177) = 0.66 \pm 0.21$; $\delta = 0.9(+0.9, -0.4)$.[16] The A_4 coefficient should be zero because of the dipole nature of the 320-keV transition.

The present experimental results for the 320-177-keV correlation are consistent with those found by Inamura[6] who used two NaI detectors. Stone, Frankel, and Shirley (SFS)[1] have made a study of Sb^{125} using the nuclear-orientation technique and give $\delta(177) = -1.28$ or -0.67 ($f = -0.79$ or -0.56). Comparison of their experimental results with the Rose and Brink tabulations[15] indicate that the sign convention for δ employed by SFS is opposite to that used here, hence, the present result is consistent with their work. The magnitude of $f(177)$ is consistent with measurements of the K-shell conversion coefficient[3,4] and the L/K ratio[3,4,7]; however, these quantities are not very sensitive to mixing in this case. The magnitude of f is also consistent with the L-subshell measurements of Mazets and Sergeenkov.[17]

The interpretation of the 203-177-keV cascade is most conveniently discussed in terms of the partial coefficient for the 203-keV transition. From the experimental values of A_2 for this cascade and $A_2(177)$ one has $A_2(203) = 1.06 \pm 0.18$. The error now represents the cumulative effect of errors in both correlation experiments, so it has, unfortunately, become rather large. If the spin of the 525-keV level is $\frac{9}{2}$ the largest positive value that $A_2(203)$ may have for a mixed $M1+E2$ transition is 0.4, which is in disagreement with the experiment.

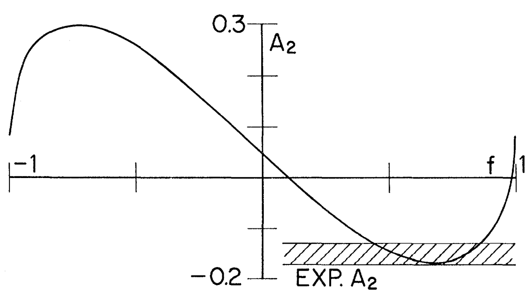

FIG. 3. Plot of A_2 versus the mixing parameter $f = \delta/(1+\delta^2)^{1/2}$ for the sequence $\frac{7}{2}(1)\frac{9}{2}(1,2)\frac{11}{2}$. The experimental range of A_2 for the 320–177 keV cascade is indicated by the shaded region.

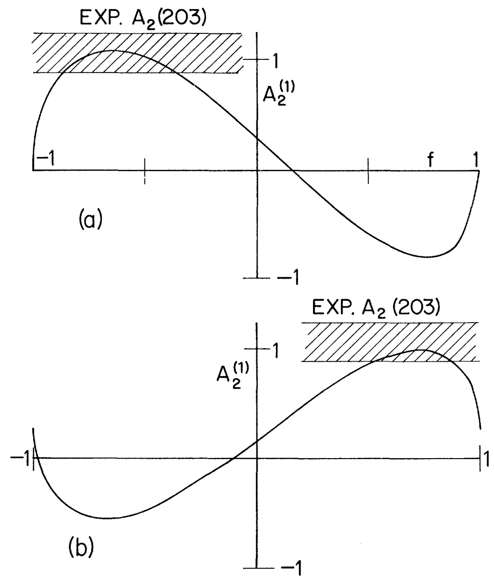

FIG. 4. Plots of the partial, second-order directional correlation coefficients for the first transition in the sequences (a) $\frac{7}{2}(1,2)\,\frac{9}{2}(\;)J_3$ and (b) $\frac{11}{2}(1,2)\,\frac{9}{2}(\;)J_3$ versus the mixing parameter $f = \delta/(1+\delta^2)^{1/2}$. The experimental range of $A_2(203)$ is indicated by the shaded regions.

The partial, second-order coefficients appropriate to the 203-keV transition are plotted in Figs. 4(a) and 4(b) for spins of $\frac{7}{2}$ and $\frac{11}{2}$, respectively, as signed to the 525-keV level. The experimental results may be fit in either case: (a) If the 525-keV level has spin $\frac{7}{2}$ then $f(203) = -0.6 \pm 0.3$, $\delta = -0.75(+0.45, -1.3)$; (b) if the 525-keV level has spin $\frac{11}{2}$ then $f(203) = 0.7 \pm 0.2$, $\delta = 1.0(+1.1, -0.4)$.

Consideration of the fourth-order coefficients does not further contribute to the interpretation. For $f(177) = 0.66 \pm 0.21$, one has $A_4(177) \leq 0.16$. For the $f(203)$ values assigned with spins of $\frac{7}{2}$ and $\frac{11}{2}$ for the 525-keV level, one has $A_4(203) \leq 0.5$ and $A_4(203) \leq 0.17$, respectively. Thus, in any event, A_4 for the 203–177-keV cascade should be ≤ 0.08.

The magnitude of the A_2 coefficient found by Inamura[6] ($A_2 = -0.364 \pm 0.048$) for the 203–177-keV correlation was somewhat smaller than found here. From their orientation experiments, SFS[1] ruled out spin $\frac{7}{2}$ for the 525-keV level, but found $\frac{9}{2}$ or $\frac{11}{2}$ acceptable. Thus, only spin $\frac{11}{2}$ is consistent with their results and the present work.

The complex nature of the wave functions calculated by Kumar and Baranger[18] for nuclei near a region of spherical equilibrium shapes perhaps emphasizes that one should not take very seriously models in which the wave function space available for the wave functions has been severely truncated. However, one may hope that such models are useful in delineating some of the salient features which will persist in the more exact treatment.

The work by Kisslinger and Sorenson[8] and Kisslinger[9] suggests that the negative-parity levels in odd-neutron nuclei near Te^{125} may show features characteristic of: (a) a one-quasiparticle $h_{11/2}$ state, (b) collective states in which an $h_{11/2}$ quasiparticle couples to one phonon, and (c) a three-quasiparticle $\frac{9}{2}$ state which is substantially depressed in energy relative to the other three quasiparticle states arising from the configuration $(h_{11/2})^3$.

The spins of the 145-, 322-, and 525-keV levels are consistent with such states. The presence of comparable $M1$ and $E2$ amplitudes in the 177- and 203-keV transitions implies, of course, that mechanisms other than simple single-neutron transitions are operable. In a realistic treatment of the odd-parity levels one may expect to find enhanced $E2$ transitions due to collective motion and inhibition of the $M1$ transitions. Inamura[6] is able to calculate absolute transition probabilities for the components of the 177-keV transition on the basis of his measurement of the lifetime of the 322-keV level as about 0.9 nsec. Then, for about equal mixture of $M1$ and $E2$ radiation, one has an $E2$ transition probability which is roughly that expected for a single-*proton* transition while the $M1$ transition probability is about two orders of magnitude less than a single-particle transition.[19]

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