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Nuclear-Orientation Study of the Decay of ^{125}Sb†

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The decay of ^{125}Sb to levels of ^{125}Te has been investigated using low-temperature nuclear orientation achieved by dilution refrigeration and adiabatic demagnetization. Angular distributions of eight γ rays were observed using Ge(Li) detectors. The values of the $E2/M1$ γ-transition multipole mixing ratios deduced were (energies in keV): $\delta(636) = +0.341^{+0.005}_{-0.006}$; $\delta(428) = -0.542 \pm 0.016$; $-1.7 \leq \delta(177) \leq -0.5$. In addition, mixing amplitudes of angular momentum components in the β-radiation fields were extracted.

I. INTRODUCTION

The decay of ^{125}Sb to levels of ^{125}Te has been the subject of numerous recent investigations.[1-15] The use of high resolution Ge(Li) detectors has allowed many of the previous ambiguities in the level scheme to be eliminated. However, knowledge of the multipole character of the γ rays connecting the states of ^{125}Te, and of the β radiations populating those states, is far from complete. For this reason, we have undertaken a new investigation of this isotope.

It is possible, using low-temperature techniques, to achieve a degree of nuclear orientation sufficient to observe anisotropic γ-ray angular distributions; such distributions yield information regarding the multipolarity of the radiations leading to the final nuclear state, as well as regarding the angular momenta of the sequence of levels populated by the transitions.

The present investigation has consisted of measuring the angular distribution of γ radiation emitted following the decay of oriented ^{125}Sb nuclei.

II. DECAY OF ^{125}Sb

The presently accepted decay scheme of 2.7-yr ^{125}Sb is shown in Fig. 1. The nature of the decay to the levels of ^{125}Te has been established by numerous spectroscopic investigations[1,3-5,15] of the β and γ radiations from the ^{125}Sb parent; measurements of internal-conversion coefficients[5] have yielded data regarding multipolarities of several of the γ transitions. The assignment of the spin and parity of the 443-keV level was determined from Coulomb excitation measurement.[9] Numerous perturbed angular-correlation measurements[6,7,12,16] have been performed and have yielded results for the g factors of the 321-, 443-, and 463-keV levels. Reduced transition probabilities of the ^{125}Te γ rays have been calculated from lifetimes of the ^{125}Te excited states measured by delayed-coincidence techniques.[11] Considerable information regarding the decay of ^{125}Sb has been obtained from previous nuclear-orientation measurements[2,4] and recent γ-γ angular-correlation measurements.[13,14] Results of investigations of the ^{125}Te level scheme through (d, p) reactions[8] are in agreement with the accepted spin assignments.

Attempts at an understanding of the nature of the ^{125}Te level scheme have achieved moderate success. By considering a short-range pairing force and a long-range quadrupole force interacting with a spherical core, Kisslinger and Sorenson[17] (K-S) were able to obtain a spectrum of one quasiparticle and phonon excited states in fair agreement with the observed level scheme. In particular, the spin-parity assignments of the ground state and first excited state were predicted, and a number of additional even-parity excited states were obtained in fair agreement with observed levels. In addition, a state having $I^\pi = \frac{11}{2}^-$ was predicted, although at a somewhat higher energy than the observed level.

A significant failure of the K-S approach was the lack of a predicted $\frac{9}{2}^-$ state which appears in the level scheme at a relatively low excitation energy. A later calculation by Kisslinger[18] showed that three quasiparticles coupled together in the $\frac{11}{2}^-$ level could lead to a $\frac{9}{2}^-$ state of such anomalously low excitation; later measurements of the g factor of the 321-keV level supported this interpretation.[6,12]

Maurelius *et al.*[11] measured the lifetimes of the excited levels of ^{125}Te and deduced the reduced transition probabilities $B(E2)$ and $B(M1)$, which were compared with estimates based on the K-S calculation, as well as with single-particle estimates. Reasonably good agreement was obtained with the K-S predictions, particularly in the case of $E2$ transitions. Based on the three-quasiparticle interpretation of the $\frac{9}{2}^-$ state, Kisslinger[18] predicted that the 177-keV transition ($\frac{9}{2}^- - \frac{11}{2}^-$) would be pure $E2$; a vanishing $M1$ transition probability is to be expected for transitions involving two quasiparticles. The prediction of a reduction in the $M1$ transition probability relative to the single-particle estimate has been confirmed experimentally.[11]

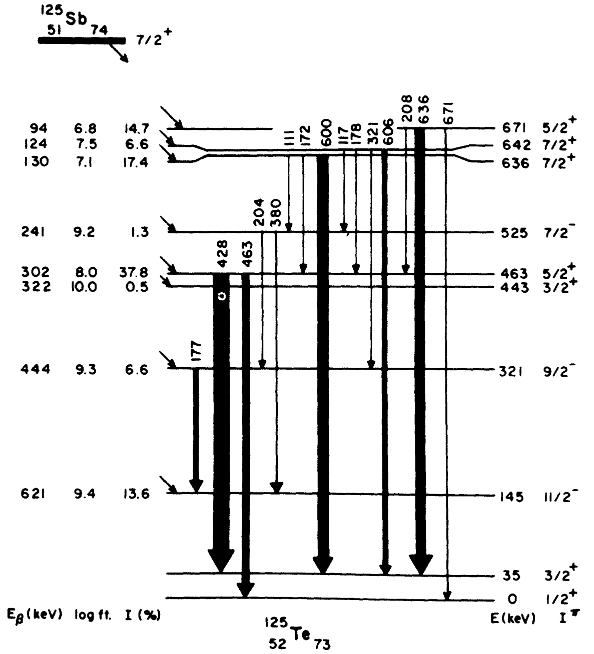

FIG. 1. Decay scheme of ^{125}Sb, taken from Refs. 1–15. Only those transitions relevant to the present investigation are shown.

III. THEORY

The directional angular distribution $W(\theta)$ of γ radiation from an ensemble of oriented nuclei may be written as

$$W(\theta) = \sum_k B_k U_k A_k Q_k P_k(\cos\theta), \qquad (1)$$

where the maximum value of k is determined by the angular momenta of the oriented levels or by the multipolarity of the radiations. For most cases $k_{\text{max}} = 4$, and, assuming parity conservation, only k= even terms are allowed for directional distributions (i.e., no radiation polarizations are observed). The normalization is such that $B_0 = U_0 = A_0 = Q_0 = 1$.

Complete discussions of the derivation and use of Eq. (1) have been given by several authors.[19,20] Our measurement involved employing known orientation parameters B_k (based on the measured nuclear temperature and the hyperfine energy splitting $\mu H/I$) to obtain the reorientation (or depolarization) coefficients U_k of the unobserved radiations and the angular distribution coefficients A_k of the observed radiation; from these latter two parameters, information could be extracted concerning the multipole character of the radiation fields. The A_k are functions of the γ mixing ratio δ, defined in terms of emission matrix elements, and the convention has been chosen so that the sign of the interference term in the expression for A_k is positive [i.e., $+2\delta F_k(LL'II')$].[21] The geometrical correction factors Q_k are employed to correct for the finite angular resolution of the radiation detectors, and have been tabulated for Ge(Li) detectors by Camp and Van Lehn.[22]

A considerable number of independent parameters are involved in a typical measurement. The B_k depend on the angular momentum I of the initial state, the magnetic moment μ and hyperfine field H, and the temperature of the sample. The U_k depend on angular momenta and radiation multipolarities, as well as on branching intensities. The A_k depend on angular momenta and on the multipole character of the observed γ ray. Since a measurement yields only two parameters (the coefficients of P_2 and P_4 in the angular distribution) it is impossible to extract all unknowns. Fortunately, investigations of the ^{125}Sb ground state have resulted in knowledge of its hyperfine energy splitting.[23] A simultaneous measurement of the angular distribution of a γ ray having no uncertainties in branching or multipole content thus allows the extraction of a temperature value, which then uniquely determines the B_k. In addition, the spins of the ^{125}Te excited states and the β and γ branching ratios are reasonably well established; thus the multipole content and mixing amplitudes of the radiation fields are the only parameters to be determined by the experiment.

IV. EXPERIMENTAL DETAILS

A. Sample Preparation

A few droplets of ^{54}MnCl$_2$ and ^{125}SbCl$_3$ in acid solution were dried on the surface of a 1-cm-diam, 0.0075-cm-thick, 99.99% pure iron foil. The foil was heated in a H$_2$-Ar atmosphere at 900°C for $1\frac{1}{2}$ h, and then at 1100°C for $1\frac{1}{2}$ h. (The H$_2$ reduced the chlorides, while the lower initial temperature and the Ar helped prevent evaporation of the volatile Sb metal until it had diffused into the Fe.) After cooling, the outer 10% of the foil was etched away to remove the excess activity along with any surface contamination.

Spectroscopic analysis, and analyses for carbon, sulfur, and phosphorus, confirmed the 99.99% purity of the Fe (to within a factor of 3 in total impurities). However, metallography of unannealed Fe foils revealed small islands of undissolved impurities representing about 1% of the foil volume. These were found to be iron oxide inclusions, which were reduced by the high temperature H$_2$ annealing to form spherical "steam pockets" seen in the annealed foils as spherical voids.

In addition, metallographic analysis of indium-soldered Fe foils (see Sec. IV B) showed no evidence of formation of indium-iron alloys. These investigations lead us to believe the source represents a dilute solution of ^{54}Mn and ^{125}Sb in pure Fe.

The total activity of the source consisted of 0.1 μCi of ^{54}Mn and 0.6 μCi of ^{125}Sb.

B. Apparatus

A complete description of the apparatus has been given in previous publications.[24,25] The low temperatures necessary to orient the nuclei were achieved using a He^3-He^4 dilution refrigerator, capable of continuous operation at 15 mK, coupled to an adiabatic demagnetization stage, consisting of a solid cylinder of pressed copper and cerium magnesium nitrate (CMN) powder. Lead heat switches provided the thermal connection between the dilution refrigerator mixing chamber and the demagnetization stage. The source foils were indium soldered to the base of a split copper tube, which was thermally connected to the Cu-CMN cylinder by copper wires. A superconducting solenoid provided the field of 2 kG for the demagnetization, and a superconducting Helmholz pair provided a polarization field in the range 1.4-2.1 kG.

The γ rays were observed using two 40-cc coaxial Ge(Li) detectors, placed at 0 and 90° relative to the direction of the polarizing field, and 5.3-cm distant from the source. The preamplifier output of each detector was fed to a shaping amplifier and then to a 400-channel analyzer.

C. Procedure

Immediately following the demagnetization, temperatures in the range of 4-5 mK were achieved at the source. Due to the residual heat leak, primarily from the β decay, the source would warm to 10-20 mK in 1-2 h. During this time simultaneous measurements were made at 0 and 90° for periods of 4-20 min, with the shorter periods used at the beginning of the measurement when the rate of change of anisotropy was greatest. The anisotropy of the ^{54}Mn γ ray was used for temperature monitoring during the course of the measurement.

After about 2 h of "cold" data were taken, the sample was heated electrically to approximately 200 mK and "warm" data were taken, to be used for normalization. Following the warm measurements the demagnetization cycle was repeated.

D. Data Analysis

The raw data from the measurement consisted of a set of spectra of the ^{125}Te γ rays and the ^{54}Mn γ ray taken at 0 and 90° with respect to the polarization axis. Figure 2 shows the spectrum from a typical 20-min "cold" run superimposed on that of a "warm" run of equal duration. The counting rates for each peak in the spectra were obtained by numerically integrating the peak areas; corrections were made for an assumed linear background under each peak. The data were normalized by the "warm" counting rates so that $W(\theta)$ would go to unity in the high-temperature limit, where $B_k = 0$ for $k > 0$.

The multipolarities of the ^{54}Mn β and γ radiations are well known; thus the counting rate of the 835-keV ^{54}Mn γ ray should provide a measure of the sample temperature, since the value of the hyperfine energy splitting for ^{54}Mn in Fe is well established.[26] However, due to the spin-lattice relaxation times, the "true" lattice temperature will not be equal to the measured spin temperature until equilibrium has been reached. The characteristic spin-lattice relaxation times (in min) are $2/T$ (T in mK) for ^{54}Mn in Fe[26] and $37/T$ for ^{125}Sb in Fe.[24] Thus for the first few runs following the demagnetization the Mn temperature will be different from the Sb temperature. In order to remove this possible source of systematic error, it would be desirable to have a direct measure of the Sb temperature. There are several transitions in the ^{125}Sb-^{125}Te decay which, due to known multipolarities of the β and γ radiations, would serve as acceptable thermometers. One line of this type is the 463-keV ($\frac{5}{2}^+$-$\frac{1}{2}^+$)γ transition, which is expected to be pure electric quadrupole ($E2$). The 463-keV level is populated by a $\frac{7}{2}^+$-$\frac{5}{2}^+$ β transition, which would be expected to be a pure allowed Gamow-Teller (GT) transition, with the β-radiation field carrying away one unit of total angular momentum. However, the 463-keV level is also populated by γ feeding from higher levels; since the multipolarities of the γ rays are unknown, a small uncertainty in the temperature would result from using the 463-keV line as a thermometer. The 600-keV ($\frac{7}{2}^+$-$\frac{3}{2}^+$) pure $E2$ γ transition could likewise serve as a thermometer, since the preceding β decay is believed to be pure GT. This line would not be completely resolved from the 606-keV transition; however, since the 600- and 606-keV transitions have the same spin sequences, they have the same angular distribution. The principal drawback in using these lines as a thermometer is that the presence of a small amount of Fermi (F) component in the β decay, permitted by angular-momentum-coupling rules, would cause a systematic error. An estimate of the order of magnitude of this error can be obtained by computing the U_2 and U_4 of the 130-keV β radiation preceding the 600-keV γ transition, using the temperature computed on the basis of the 463-keV transition (after allowing for possible effects of the preceding γ transitions). The results of this analysis were

$$U_2(130\text{-keV }\beta)=0.790\pm0.019\,,$$

$$U_4(130\text{-keV }\beta)=0.419\pm0.142\,.$$

The theoretical values of these coefficients are

$$U_2(\tfrac{7}{2}^+-\tfrac{7}{2}^+)=0.810+0.191\,|\alpha_0|^2\,,$$

$$U_4(\tfrac{7}{2}^+-\tfrac{7}{2}^+)=0.365+0.635\,|\alpha_0|^2\,,$$

where $|\alpha_L|^2$ is the relative contribution of the component of the lepton field with total angular momentum L, normalized such that

$$\sum_L |\alpha_L|^2=1\,.$$

The measured values of U_2 and U_4 indicate that the $L=0$ component could be neglected for the 130-keV β transition.

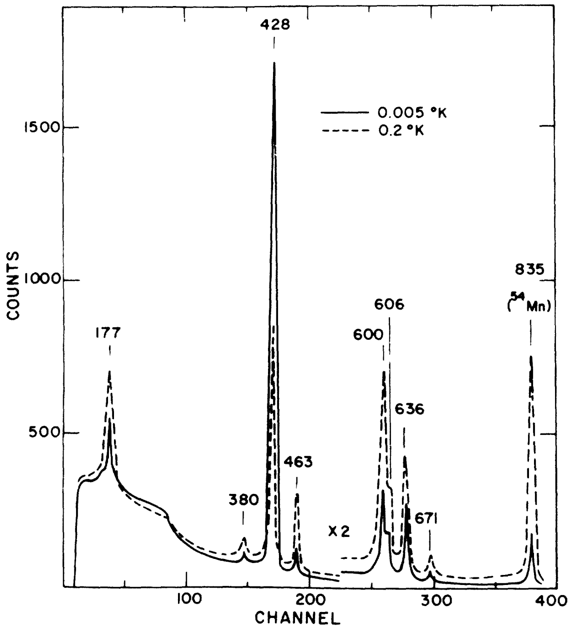

FIG. 2. γ-ray spectra from the decay of ^{125}Sb taken with a 40-cc Ge(Li) detector, placed at 0° relative to the axis of nuclear orientation. The solid curve represents "cold" data, taken at 0.005°K; the dashed curve represents "warm" data, taken at 0.2°K. (The resolution has been exaggerated somewhat to improve legibility.)

In consideration of the above results, the Sb temperature was computed using a weighted average of the results from the 463- and 600-keV transitions as thermometers, with the γ feeding of the 463-keV level taken into account as an uncertainty in the computed U_k, and with the 130-keV β transition assumed to be pure GT. Knowledge of the temperatures enabled B_k to be computed for each counting period, and thus the U_kA_k could be computed. The method used for the extraction of the U_kA_k was a least-squares fit over the course of each run. A weighted average of the results of the various runs was then computed to arrive at a final value.

An estimate of the statistical reliability of the final results was obtained by computing the χ^2 value for the average $\bar{X}$:

$$\chi^2=\frac{1}{N-1}\sum_{i=1}^{N}\frac{(X_i-\bar{X})^2}{\sigma_i^{\,2}}\,, \tag{2}$$

where σ_i is the statistical uncertainty associated with the value X_i. Three-fourths of the calculated values of χ^2 were between 0.5 and 2.0, indicating

TABLE I. Angular distributions of γ transitions from the decay of ^{125}Sb.

γ transition (keV)	Present work U_2A_2	Present work U_4A_4	Ref. 4 U_2A_2	Ref. 2 U_2A_2
177	-0.398 ± 0.007	-0.073 ± 0.051	-0.43 ± 0.03	-0.445 ± 0.018
380	-0.211 ± 0.029	-0.10 ± 0.22	-0.47 ± 0.20	-0.31 ± 0.05
428	$+0.907 \pm 0.006$	$+0.092 \pm 0.024$	$+0.91 \pm 0.01$	$+0.899 \pm 0.012$
463	-0.461 ± 0.014	-0.456 ± 0.068	-0.47 ± 0.03	-0.468
600	-0.370 ± 0.009	-0.15 ± 0.05	-0.42 ± 0.02	-0.373 ± 0.004
606	-0.335 ± 0.021	-0.32 ± 0.14	-0.36 ± 0.04	
636	-0.231 ± 0.008	-0.08 ± 0.06	-0.24 ± 0.02	-0.218 ± 0.006
671	-0.474 ± 0.028	-0.39 ± 0.16	-0.51 ± 0.09	-0.460 ± 0.015

that the deviations among the individual runs did not greatly exceed the statistical uncertainty.

V. RESULTS

The results of the present measurement for the U_kA_k for each of the γ transitions investigated are presented in Table I, along with the U_2A_2 results of two previous nuclear-orientation measurements of ^{125}Sb, which did not achieve low enough temperatures to measure the P_4 term. The U_k values of Table I for the present investigation represent contributions from possible γ feeding of the appropriate level, as well as from direct β feeding. In all, six individual demagnetizations were performed in the present work, and for the last three, an effort was made to resolve the 600- and 606-keV transitions. Figure 2 shows the moderate success achieved; it was believed that the separation was sufficient to obtain results for the 606-keV transition.

In general good agreement is obtained between the results of the present investigation and those of previous investigations. We have achieved, for most of the lines, a smaller limit of error than previous work; in addition we have succeeded in obtaining values for the coefficient of the P_4 term.

Using the theoretical relations for the U_k and A_k coefficients, it is possible to obtain the β and γ mixing amplitudes for the transitions studied. Results will be presented individually below and are summarized in Table II.

671 keV. This transition is pure $E2$ ($\frac{5}{2}^+ - \frac{1}{2}^+$), and the 94-keV β is expected to be pure GT. Thus all parameters for this line are determined. (The use of this line as a thermometer is unreliable because of its low intensity.) Based on the above assignments the theoretical values would be

$$U_2A_2 = -0.468\,,$$

$$U_4A_4 = -0.358\,,$$

in excellent agreement with the values of Table I.

636 keV. This transition proceeds from the same level as the 671-keV transition discussed above, and thus the U_k(94 keV β) can be assumed to be those for a pure GT transition. The results may then be expressed as:

$$A_2(636 \text{ keV } \gamma) = -0.264 \pm 0.009\,,$$

$$A_4(636 \text{ keV } \gamma) = -0.14 \pm 0.11\,.$$

TABLE II. Angular-momentum multipolarities of radiations emitted in the decay of ^{125}Sb to ^{125}Te.

^{125}Te level (keV)	Angular-momentum components of lepton field populating level	$E2/M1$ mixing ratio of γ ray deexciting level
671	$\lvert\alpha_1\rvert^2 = 1.0$ [a]	$\delta(671) = \infty$ $\delta(636) = +0.341^{+0.005}_{-0.006}$
642	$\lvert\alpha_0\rvert^2 = 0.0$; $\lvert\alpha_1\rvert^2 = 1.0$	$\delta(606) = \infty$
636	$\lvert\alpha_0\rvert^2 = 0.0$; $\lvert\alpha_1\rvert^2 = 1.0$	$\delta(600) = \infty$
525	$\lvert\alpha_2\rvert^2 < 0.2$	$\delta(380) = \infty$
463	$\lvert\alpha_1\rvert^2 = 1.0$ [a]	$\delta(463) = \infty$ $\delta(428) = 0.542 \pm 0.016$
321	$\lvert\alpha_1\rvert^2 = 0.59 \pm 0.17$; $\lvert\alpha_2\rvert^2 = 0.41 \pm 0.17$	$-1.7 \leq \delta(177) \leq -0.5$

[a] β transition must be pure GT since $\Delta I = 1$.

From the theoretical expression for the A_2 coefficient, we obtain two possible solutions for the mixing ratio of the 636-keV γ transition

$$\delta_1 = +0.341^{+0.005}_{-0.006},$$

$$\delta_2 = +25.7^{+3.6}_{-2.9}.$$

The value δ_1 would necessitate an A_4 coefficient of 0.073, while δ_2 would give $A_4 = 0.704$. On the basis of the measured value of A_4 given above, the smaller value δ_1 is strongly favored.

The present results are consistent with the values of Stone, Frankel, and Shirley[4] ($\delta = 0.36^{+0.2}_{-0.3}$ or $\delta = 14 \pm 2$) and Andrews *et al.*[2] ($\delta = 0.327 \pm 0.004$ or $\delta = 32.4^{+4.5}_{-3.5}$). In addition, recent directional correlation work[14] on the 636-35.5-keV cascade has reported $A_2(636) = -0.13 \pm 0.06$. From our measured δ values we compute, for the case in which the 636-keV transition is the first member of a cascade, $A_2(\delta_1) = -0.23$ and $A_2(\delta_2) = +0.31$; thus the directional correlation data also favors the choice of δ_1.

606 keV. Assuming this transition to be pure $E2$ $(\frac{7}{2}^+ - \frac{3}{2}^+)$ we obtain

$$U_2(124\text{-keV } \beta) = 0.716 \pm 0.045,$$

$$U_4(124\text{-keV } \beta) = 0.91 \pm 0.38.$$

The theoretical expression for the reorientation coefficient for an allowed $\frac{7}{2}^+ - \frac{7}{2}^+$ β transition is

$$U_2 = |\alpha_0|^2 + 0.810\ |\alpha_1|^2.$$

Thus our results would support the assignment $|\alpha_1|^2 = 1.0$, $|\alpha_0|^2 = 0.0$, i.e., a pure GT transition. For such a transition, $U_4 = 0.365$; thus the U_2 and U_4 coefficients measured differ from their theoretical values by 2 and $1\frac{1}{2}$ standard deviations, respectively. This should not be surprising, due to the low intensity of this transition and to its lack of resolution from the 600-keV transition. For the purpose of analysis, the operational definition of the 606-keV peak was taken to be two channels on the high-energy side of the 600-keV peak. Thus small amplifier or multichannel-analyzer gain shifts would produce large effects on the measured 606-keV peak intensity, which may account for the observed deviations from the theoretical values.

600 keV. This transition was used for thermometry, so no parameters were extracted. A discussion of the distribution coefficients measured using the 463-keV transition as a thermometer has been given in Sec. IV D.

463 keV. This transition was likewise used for thermometry, but a check on the assumptions regarding this transition can be obtained by analyzing this line using the temperature calculated from the 600-keV transition. Taking into account the feeding from the 172- and 178-keV γ transitions [each with multipolarities (50 ± 50)% $E2$, and with intensities I_{172} 0.02 ± 0.02 and I_{178} 0.1 ± 0.1 per 100 ^{125}Sb decays] as well as the direct 302-keV β feeding, and assuming the 463-keV transition to be pure $E2$ $(\frac{5}{2}^+ - \frac{1}{2}^+)$ we obtain

$$U_2(302\text{-keV } \beta) = 0.866 \pm 0.015,$$

$$U_4(302\text{-keV } \beta) = 0.634 \pm 0.063.$$

These values are in good agreement with the expected values for a pure GT $(\frac{7}{2}^+ - \frac{5}{2}^+)$ transition of $U_2 = 0.875$ and $U_4 = 0.580$.

428 keV. This transition proceeds from the same level as the 463-keV transition; thus comments made in the preceding section concerning the γ feeding of this level are relevant here as well. With those assumptions, we derive

$$A_2(428\text{-keV } \gamma) = 1.041 \pm 0.007,$$

$$A_4(428\text{-keV } \gamma) = 0.160 \pm 0.024.$$

The A_2 coefficient can be analyzed in terms of the $E2/M1$ mixing ratio of the 428-keV transition to yield

$$\delta_1 = -0.998 \pm 0.025,$$

$$\delta_2 = -0.542 \pm 0.016.$$

The values of A_4 calculated from these possible mixing ratios are $A_4 = 0.352$ and $A_4 = 0.160$, respectively. Thus our data indicate a strong preference for δ_2.

Previous measurements of the mixing ratio of this transition have yielded ambiguous results. Stone, Frankel, and Shirley[4] report $\delta = -0.95 \pm 0.02$ or $\delta = -0.55 \pm 0.02$, and Andrews *et al.*[2] report $\delta = -1.05 \pm 0.05$ or $\delta = -0.512 \pm 0.025$; these values are in good agreement with the present values of δ, but the lack of a measured P_4 term did not indicate a preference between the measured values. Directional correlation results[14] for the 428-35.5-keV cascade have been reported as $A_2(428) = +0.46 \pm 0.08$. From our measured values for δ we compute for the 428-keV transition as the first member of the cascade, $A_2(\delta_1) = 0.82$ and $A_2(\delta_2) = 0.64$. The directional correlation results thus favor the choice of δ_2. Results of conversion-electron measurements[5] indicate that the 428-keV transition is 50 ± 10% $M1$, based on $L_{\text{I}}/L_{\text{II}}/L_{\text{III}}$ subshell ratios; this implies $|\delta| = 1.0 \pm 0.2$, which would favor our δ_1 value. At the present time, however, we prefer the choice of δ_2, based on our A_4 measurement and the angular-correlation results.

380 keV. This transition is of very low intensity, and thus we have relatively poor statistics for the results for this line. Assuming the transition to be pure $E2$ ($\frac{7}{2}^- - \frac{11}{2}^-$), and taking into account the feeding from the 111- and 117-keV γ transitions (assumed to be pure $E1$), we obtain

$$U_2(241\text{-keV } \beta) = 1.04 \pm 0.17\,,$$

$$U_4(241\text{-keV } \beta) = 5 \pm 11\,.$$

For a first-forbidden $\frac{7}{2}^+ - \frac{7}{2}^-$ β transition, we expect $U_2 = |\alpha_0|^2 + 0.810\ |\alpha_1|^2 + 0.467\ |\alpha_2|^2$ and $U_4 = |\alpha_0|^2 + 0.365\ |\alpha_1|^2 - 0.333\ |\alpha_2|^2$. Thus there are two independent parameters to be derived (since $\sum_L |\alpha_L|^2 = 1$), but the poor statistics of U_4 make it impossible to draw any definite conclusions from that result. Based on U_2, we can state that the 241-keV β transition is predominantly $L=0$, with possibly some $L=1$, but with little or no $L=2$ component. Upper limits can be set on $|\alpha_2|^2$ for three cases: (a) for $|\alpha_1|^2 \sim 0$, $|\alpha_2|^2 < 0.2$; (b) for $|\alpha_0|^2 < 0.4$, $|\alpha_2|^2 = 0$; (c) for $|\alpha_1|^2 \approx |\alpha_0|^2$, $|\alpha_2|^2 < 0.01$.

There has been some uncertainty regarding the spin assignment of the 525-keV level. Previous nuclear-orientation experiments[2,4] have favored $\frac{9}{2}^-$ or $\frac{11}{2}^-$ assignments, while observation of a transition[1,5] between the 525-keV level and the 443-keV level (currently assigned[9,16] $\frac{3}{2}^+$) would favor the $\frac{7}{2}^-$ assignment. Our data, with the appropriate choice of $\delta(380)$, are consistent with all three possible assignments.

177 keV. The derivation of the U_2A_2 and U_4A_4 for this transition was based on the inclusion in the 177-keV peak of contributions from the 172- and 178-keV transitions, assumed to have a combined intensity of 5 ± 1% of the intensity of the 177-keV transition. Since the 444-keV β decay has only $L=1$ and $L=2$ components, there are only two parameters to be derived – one for the β mixing and one for the $E2/M1$ γ mixing – which could in principle be derived from the two measured parameters U_2A_2 and U_4A_4. However, the existence of a negative value of U_4A_4 as large as that measured in this work is not possible, and hence we can derive no direct information from that parameter. For a $\frac{7}{2}^+ - \frac{9}{2}^-$ β transition, $0.637 \leqslant U_2 \leqslant 0.925$, and thus our measured U_2A_2 implies $-0.625 \leqslant A_2(177\text{-keV } \gamma) \leqslant -0.430$; the range of possible values of A_2 restricts $\delta(177)$ to $-1.7 \leqslant \delta \leqslant -0.5$.

Several measurements of the $E2/M1$ mixing ratio of the 177-keV γ transition have been reported. Based on internal-conversion measurements, Mazets and Sergeenkov[5] have obtained $|\delta| = 0.624 \pm 0.034$. Angular-correlation measurements[6] of the 321-177-keV cascade have yielded $A_{22} = -0.165 \pm 0.004$, and have derived a mixing ratio of $\delta = -0.82 \pm 0.03$ or $\delta = -1.05 \pm 0.03$, assuming the 321-keV transition to be pure $E1$. The latter results would seem to be in disagreement with the conversion-electron measurement, but the two can be brought into agreement by considering a small $M2$ admixture in the 321-keV transition. Assuming $|\delta(177)|$ from the conversion-coefficient measurement and assuming its sign to be negative, we calculate

$$\delta(321) = 0.016 \pm 0.008\,.$$

Such $M2$ admixtures would not be unreasonable, and thus we have chosen to accept the value $\delta(177) = -0.624 \pm 0.034$ as consistent with both internal conversion coefficients and γ-γ measurements. With this assumption, and taking into account the γ feeding of the 321-keV level, we calculate for the 444-keV β transition

$$U_2(444\text{-keV } \beta) = 0.806 \pm 0.048\,,$$

$$U_4(444\text{-keV } \beta) = -1.5 \pm 1.0\,.$$

From U_2 we calculate

$$|\alpha_1|^2 = 0.59 \pm 0.17\,.$$

The U_4 calculated from this value is $U_4 = 0.48$, which is within 2 standard deviations of the measured value.

VI. CONCLUSIONS

The desirability of achieving temperatures in the 4–5-mK range has been demonstrated by the resolving, based on our observed P_4 coefficients, of ambiguities in previously measured γ-mixing ratios. Information has been obtained regarding the multipole character of the β- and γ-radiation fields emitted in the decay of ^{125}Sb to levels in ^{125}Te. In particular, the allowed β radiations were determined to be of Gamow-Teller type, and the first-forbidden β radiations were observed to favor the $L=0$ or $L=1$ components over the $L=2$ component. The $E2/M1$ γ mixing ratios deduced indicate substantial competition between the dipole and quadrupole components, implying the presence of both collective and single-particle effects.

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Fission of Heavy Nuclei at Higher Excitation Energies in a Dynamic Model*

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The dynamic model of asymmetric fission used in calculating the mass and kinetic energy distributions of the fragments from thermal-neutron-induced fission of ^{235}U is employed here to calculate these distributions for fission at higher excitation energies and for other heavy nuclei at low excitation energies. The model itself is investigated with respect to the semiphenomenological shell correction. It is found that the mass distribution of the fragments in the reaction ${}^{235}\mathrm{U}(n,f)$, which for thermal neutrons is strongly peaked at the heavy-fragment mass 132, goes over into a symmetric mass distribution at a compound-nuclear temperature of about 6 MeV.

1. INTRODUCTION

The experimental data associated with symmetric fission of medium-heavy nuclei (lighter than about radium) can be explained rather well in the framework of a dynamic liquid-drop model[1]: The classical Hamiltonian here consists of the potential energies of an incompressible liquid drop, i.e., surface and Coulomb energies, and of the kinetic energy of the irrotational flow of an ideal nonviscous liquid.

After having prescribed some arbitrary family of shapes which is passed through by the nucleus en route to fission, the potential energy is first made stationary to find the saddle point. The deformation coordinates are then transformed at the saddle point into a normal coordinate system in order to determine the probability of the system having some initial condition. The equations of motion are then solved for a limited number of initial conditions close to the saddle point up to the scission point. Usually one takes only $2n+1$ sets of different initial conditions, with n being the number of deformation or normal coordinates taken into account: one set with all normal coordinates and momenta vanishing, i.e., on top of the saddle; and $2n$ sets with only one of the normal coordinates or momenta having a small nonzero value.

The smooth dependence of the Hamiltonian on