where K=normalizing constant, n_j=yield from fission of the jth Z value, G=Gaussian resolution function for the NaI(Tl), Y=fluorescent yield, and C=internal-conversion coefficients.

The n_j were obtained by equal charge displacement (ECD), sometimes referred to as "Glendenin's rule," from the mass distributions in Weinberg and Wigner[21] using an average chain length of 3 for U^{235} and 2.5 for Pu^{239}. Values for C were taken from Rose.[22]

The calculated spectra are presented as the solid lines in Figs. 8 and 9. It was found that agreement was best when the U^{235} data were fitted by assuming a mixture of 50% $M1$ and 50% $E2$ transitions at an average energy of 100 keV. Agreement was best when the Pu^{239} data were fitted with the same mixture but at an average energy of 50 keV. To illustrate the sensitivity of the calculated spectrum to the type and energy of transitions used in the calculation, the curves in Figs. 10 and 11 are shown.

[21] A. M. Weinberg and E. P. Wigner, *The Physical Theory of Neutron Chain Reactors* (University of Chicago Press, Chicago, 1958).

[22] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

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Lifetime of the 462-keV Level in Te^{125}†

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Resonance scattering from Te^{125} has been investigated with Sb^{125} as the source of the exciting gamma radiation. The centrifuge technique was used for the compensation of the recoil energy losses. Appreciable resonance scattering was observed only from the 462-keV $\frac{5}{2}^+$ level. With a branching ratio $\Gamma_0/\Gamma=0.24$, the observed scattering corresponds to a partial width $\Gamma_0=(8.5\pm0.9)\times10^{-6}$ eV for the 462-keV $E2$ ground-state transition. The mean life of the 462-keV level is thus $(1.9\pm0.3)\times10^{-11}$ sec. The absence of resonance scattering from Te^{125} levels reported at 633-, 640-, 652-, and 668-keV excitation energy is consistent with the assignment of spin values $\geq\frac{7}{2}$ to the first two of these states, an upper limit of 0.03% per Sb^{125} decay for the intensity of the 652-keV transition, and a lower limit of 10^{-11} sec for the mean life of the 668-keV ground-state transition.

I. INTRODUCTION

In the course of a program aimed at the measurement of gamma-ray transition probabilities in odd-mass nuclei and at their comparison with the predictions of the pairing-plus-quadrupole-force model,[1] it was decided to study transitions in Te^{125}. The decay scheme of 2.7-year Sb^{125}, which populates at least eight excited states of Te^{125}, appeared to be well established.[2] It indicated ground-state transitions from states at 462-, 633-, and 668-keV excitation energy, thus making it feasible to perform resonance-fluorescence experiments. In addition to the study of the 462-keV level, which is most prominently populated in the decay of Sb^{125}, the investigation of the 633-keV excited state appeared to be of special interest because of difficulties encountered in the interpretation[2] of early Coulomb-excitation results[3] and the suggestion of a spin assignment of $\frac{3}{2}^+$ made on the basis of γ-γ angular-correlation data.[4]

After completion of our experiments, which succeeded only in exciting the 462-keV level, the results of a study utilizing oriented Sb^{125} nuclei and high-resolution Li-drifted Ge detectors became available.[5] The modifications in the decay scheme suggested by that study readily explain our failure to observe resonance scattering from the 633-, 652-, and 668-keV levels.

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[1] L. S. Kisslinger and R. A. Sorenson, Rev. Mod. Phys. **35**, 854 (1963).

[2] K. C. Mann, F. A. Payne, and R. P. Chaturvedi [Can. J. Phys. 42, 1700 (1964)], where references to earlier work on the decay scheme of Sb^{125} are given.

[3] L. W. Fagg, E. A. Wolicki, R. O. Bondelid, K. L. Dunning, and S. Snyder, Phys. Rev. **100**, 1299 (1955).

[4] T. Inamura, T. Iwashita, Y. Ikemoto, and S. Kageyama, J. Phys. Soc. Japan **19**, 239 (1964).

[5] N. J. Stone, R. B. Frankel, J. J. Huntziker, and D. A. Shirley, Lawrence Radiation Laboratory Report UCRL-11828, 59, 1965 (unpublished).

II. EXPERIMENTS AND RESULTS

The experiments reported here were carried out in a typical one-rotor geometry.[6] Since the results of preliminary runs,[7] which had been carried out with a 3-mCi source of Sb^{125}, showed rather large statistical uncertainties, a 10-mCi source was used for the final measurements.

The expected velocity dependence of the resonance scattering cross section[6] for the levels at 462-, 633-, and 668-keV excitation energy is shown in Fig. 1. In calculating these curves it was assumed that the lifetimes of the levels are longer than $\approx 10^{-12}$ sec, i.e., that the emitted lines are not affected by the recoils from the preceding beta decays.

For an actual geometry, the maximum scattering occurs at a source velocity which is slightly higher than the one deduced from Fig. 1 because gamma rays emitted at angles of up to $\pm 35°$ with respect to the tangent to the source path are permitted to strike the scatterer. As indicated in Fig. 1, the velocity of 1.23×10^5 cm/sec, which was used for the experiments reported here, is thus close to the optimum for the 462-keV level, but provides only a small overlap of the emission and absorption lines for the 600-keV group of levels.

In Fig. 2, the pulse-height distribution of the resonantly scattered radiation, obtained as the difference of the counting rates measured with Te and Sb scatterers, is compared with the pulse-height distribution observed for the incident radiation. The two distributions were normalized to the same number of counts in the (427+462)-keV "line." There is no indication of resonance scattering from the 600-keV group of levels.

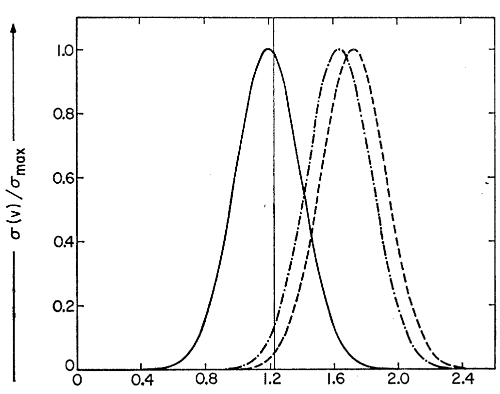

FIG. 1. Expected velocity dependence of the resonance scattering from the 462-keV (solid line), 633-keV (dot-dash line), and 668-keV (dashed line) levels of Te^{125} when the gamma radiation from a solid Sb^{125} source is used. The sum of the effective temperatures (Ref. 6) of source and scatterer was assumed to be $T_1+T_2=630°K$.

[6] See, e.g., F. R. Metzger and H. Langhoff, Phys. Rev. **132**, 1753 (1963).

[7] F. R. Metzger and R. S. Raghavan, Bull. Am. Phys. Soc. **10**, 426 (1965).

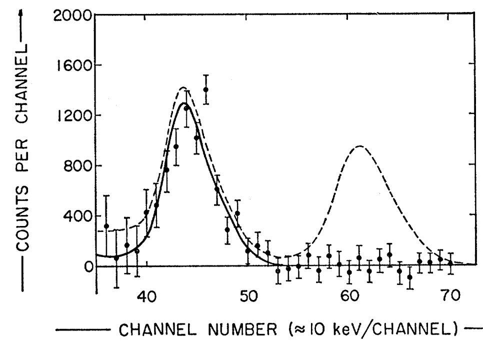

FIG. 2. Comparison of the pulse-height distribution of the resonance radiation (solid line) with that of the incident radiation (dashed line). The two distributions were normalized to the same number of counts in the (427+462)-keV "line."

Short runs at a source speed of 1.3×10^5 cm/sec also failed to give any indication of resonance scattering from these levels.

The pulse-height distribution of the radiation emitted by the resonantly excited 462-keV level, shown in Fig. 2, represents the sum of measurements carried out at scattering angles of 107°, 126°, and 141°. The accuracy of the individual measurements was not sufficient to reveal variations in the shape of the pulse-height distributions due to the different angular distributions of the 427- and the 462-keV gamma rays. All one could hope for was to obtain a crude idea of the angular distribution of the combined (427+462)-keV line. This information is compared in Fig. 3 with the angular distributions expected on the basis of $E2/M1$ mixing amplitudes reported[4,5] for the 427-keV transition. The agreement with the distributions expected for the mixing amplitudes $\delta=-0.5$ and $\delta=1.1$, which were suggested by recent alignment experiments,[5] is very good. On the other hand, it is difficult to reconcile the measured points with the distribution expected for $\delta=+1.43$, the value reported on the basis of γ-γ

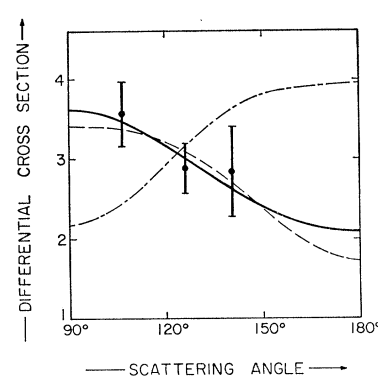

FIG. 3. Angular distribution of the resonant radiation from the 462-keV level. The experimental values of the differential cross section (in arbitrary units) are compared with the distributions expected for the following values of the $E2/M1$ mixing amplitude: $\delta=-0.5$ (solid line), $\delta=-1.1$ (dashed line), and $\delta=1.43$ (dot-dash line). A value of 3.13 was used for the ratio of the contributions of the 427- and 462-keV lines.

angular-correlation experiments.[4] It should be mentioned that these γ-γ correlation experiments were analyzed assuming spin $\frac{3}{2}$ for the 668-keV state because they were not considered to be compatible with the assignment of spin $\frac{5}{2}$. Clearly, further experiments involving the 668- and 462-keV levels are desirable.

Fortunately, the total resonance scattering cross section obtained for the 462-keV level from the three measured differential cross sections is very insensitive to the value assumed for δ. For the three values of δ used in Fig. 3, the variation in the total cross section is only 3%. In what follows, $\delta = -0.5$ will be assumed.

For the 462-keV level in Te^{125}, which decays by the emission of either 427- or 462-keV gamma rays, the number of resonantly scattered gamma rays $N_{sc}(427+462)$ may be written in the form

$$N_{sc}(427+462) = N_0(427+462) \times G \times (\Gamma_0^2/\Gamma)_{462},$$

where N_0 is the total number of 427- and 462-keV gamma rays emitted by the source in the time interval used for the measurement of N_{sc}, and where G is a factor describing the geometry. G includes the averaging over the source path and the detector volume. The symbols N_0 and N_{sc}, instead of referring to the actual numbers of gamma rays, may equally well stand for the counting rates in a given pulse-height interval as long as the same interval is used for both, and contributions from other gamma rays to this interval are subtracted.

From our data with the second Sb^{125} source, a value $(\Gamma_0^2/\Gamma) = (2.24 \pm 0.17) \times 10^{-6}$ eV was obtained if channels 40 to 49 (Fig. 3) were taken as being representative of the (427+462)-keV "line." From the intensities given in the literature[2,8] one calculates a ratio $\Gamma_0/\Gamma = 0.243 \pm 0.017$ for the 462-keV level. Combined with the experimental value for Γ_0^2/Γ, this then leads to a partial width $\Gamma_0(462) = (9.2 \pm 1.0) \times 10^{-6}$ eV for the 462-keV ground-state transition in Te^{125}. The adjusted result of the preliminary run[7]—an absorption correction had to be applied—was $\Gamma_0 = (6.0 \pm 1.8) \times 10^{-6}$ eV. Combining the two sets, one then finds

$$\Gamma_0(462) = (8.5 \pm 0.9) \times 10^{-6} \text{ eV},$$

and for the total width Γ of the 462-keV level

$$\Gamma(462) = (3.5 \pm 0.5) \times 10^{-5} \text{ eV}.$$

This corresponds to a mean life $\Gamma_{level} = (1.9 \pm 0.3) \times 10^{-11}$ sec. For the 427-keV transition to the 35-keV $\frac{3}{2}^+$ state, the partial width becomes

$$\Gamma_1(427) = (2.6 \pm 0.4) \times 10^{-5} \text{ eV},$$

corresponding to a mean life of 2.5×10^{-11} sec.

III. DISCUSSION

On the basis of the decay scheme given in Ref. 2, the absence of appreciable resonance scattering from

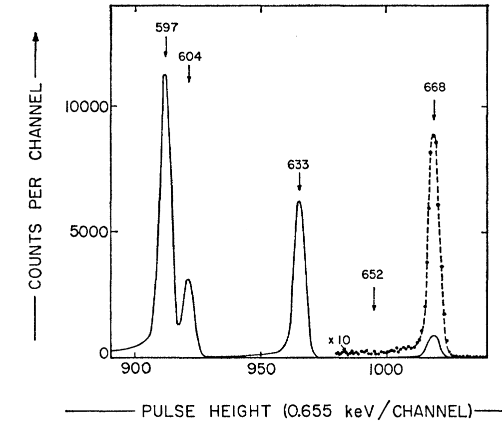

FIG. 4. Pulse-height distribution due to the 600-keV group of gamma rays from Sb^{125}, observed with a 1.1-cm^2×0.4-cm Li-drifted germanium detector. The experimental points are shown only for the expanded portion of the spectrum.

the 600-keV group of levels is surprising: one is forced to conclude that the mean lifetime of the 633-keV level is rather long ($> 10^{-10}$ sec), a fact which is incompatible with the observation[3] of a large $B(E2)$. With the new information[5] that (95±5)% of the 633-keV gamma rays originate from the 668-keV level and thus are not expected to be capable of exciting the 633-keV state, the absence of resonance scattering from this excited state of Te^{125} is easily explained. The assignment[5] of spin $\frac{7}{2}^+$ to the 633-keV level does not contradict the information available[2] on the internal conversion of the 597-keV transition and on the ft value of the beta decay feeding the level, and takes care of the absence of a ground-state transition. A ground-state transition has never been observed for the 640-keV level, and the spin of $\frac{7}{2}^+$ appears to be uncontested. As far as the 652-keV level is concerned, the absence of resonance scattering is most simply explained by the absence of 652-keV gamma rays in the incident beam, or by their presence with an intensity which is many times smaller than had been reported.[2] To put this statement on a more quantitative basis, the gamma radiation from an Sb^{125} source was studied with a 1.1 cm^2×0.4 cm Li-drifted germanium detector which was connected to a Tennelec Model 100 C preamplifier followed by a model TC 200 amplifier. The 600-keV region of the pulse-height spectrum obtained in $2\frac{1}{2}$ h of counting is shown in Fig. 4. It is concluded that the 652-keV line, if at all present, is at least 100 times weaker than the 668-keV line, which is involved in less than 3% of the Sb^{125} decays. Thus less than 0.03% of the Sb^{125} decays are followed by a 652-keV gamma transition. This is at least 20 times smaller than the intensity reported in Ref. 2.

For the 668-keV level, the absence of resonant scattering is consistent with a lower limit of 10^{-11} sec for the mean life of the 668-keV ground-state transition, or a lower limit of 1.5×10^{-12} sec for the mean life of the level. The fact that the intensity of the 633-keV transi-

[8] R. S. Narcisi, Lyman Laboratory, Harvard University, Cambridge, Massachusetts, quoted by Ref. 2.

tion to the $\frac{3}{2}^+$ level is six times larger than the intensity of the 668-keV transition to the $\frac{1}{2}^+$ ground state may be taken as favoring the assignment of spin $\frac{5}{2}$ to the 668-keV level, although spin $\frac{3}{2}$ cannot be ruled out on these grounds.

The results for the transitions originating from the 462-keV level are summarized in Table I. In calculating the $E2$ transition probabilities,[9] using the wave functions given by Kisslinger and Sorensen,[1] a value $B(E2)_{0^+\rightarrow 2^+}=46\times 10^{-50}e^2$ cm^4 was assumed for the average of the $B(E2)$ values of the neighboring even-even nuclei. For the $\frac{1}{2}^+$ and $\frac{3}{2}^+$ states, the wave functions were taken from Ref. 1, for the $\frac{5}{2}^+$ state, the following no-phonon and one-phonon amplitudes were used[10];

$$C_{\frac{5}{2}00}{}^{\frac{5}{2}}=0.461,\quad C_{\frac{7}{2}12}{}^{\frac{5}{2}}=0.117,\quad C_{\frac{5}{2}12}{}^{\frac{5}{2}}=0.308,$$
$$C_{\frac{3}{2}12}{}^{\frac{5}{2}}=0.226,\quad C_{\frac{1}{2}12}{}^{\frac{5}{2}}=0.653.$$

For the pure $E2$ 462-keV ground-state transition, which is enhanced by a factor of 13 over the single-particle value, the Kisslinger and Sorensen wave functions reproduce the experimental value to within a factor of 2. With respect to the 427-keV transition one is handicapped by the uncertainty concerning the multipole mixing. It appears, however, that in this case the quasiparticle-plus-phonon wave functions[1] underestimate the $E2$ transition probability considerably: Even with the smallest value of δ^2 suggested by experiment,[5] $\delta^2=0.25$, the experimental transition probability exceeds the predicted value by a factor of 7. In this connection it might be pointed out that the transition probability for the 35-keV $M1$ transition involving the same $\frac{3}{2}^+$ first excited state is also rather poorly accounted for[11] by the Kisslinger and Sorensen wave functions.

Any further discussion of the 427-keV transition as, e.g., the retardation of the $M1$ part, is best left to those[5] in better position to judge the uncertainties in the mixing amplitudes. It is our understanding that such a discussion is forthcoming.[12]

Table I. Comparison of the experimental $E2$ transition probabilities (column 3) with theoretical estimates. In column 4 the transition probabilities calculated with the quasiparticle-plus-phonon wave functions of Kisslinger and Sorensen[a] are given; olumn 5 lists the Weisskopf[b] estimates.

E_γ (keV)	Spin sequence	$T(E2)_{\text{expt}}$ (sec^{-1})	$T(E2)_{\text{K+S}}$ (sec^{-1})	$T(E2)_{\text{W}}$ (sec^{-1})
427	$\frac{5}{2}^+ \rightarrow \frac{3}{2}^+$	$[\delta^2/(1+\delta^2)]40\times 10^9$	1.1×10^9	0.7×10^9
462	$\frac{5}{2}^+ \rightarrow \frac{1}{2}^+$	13×10^9	7.0×10^9	1.0×10^9

[a] See Ref. 1.
[b] See, e.g., J. M. Blatt, and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, Inc., New York, 1952), Chap. 12.

[9] See, e.g., R. A. Sorensen, Phys. Rev. **133**, B281 (1964), Eq. (6).
[10] We are indebted to Professor Sorensen for providing us with these amplitudes.
[11] R. A. Sorensen, Phys. Rev. **132**, 2270 (1963).
[12] N. J. Stone (private communication).

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Isobaric Analogue States in Heavy Nuclei. III. Tin Isotopes*

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Isobaric analogue resonances have been identified in (p,p) and (p,n) excitation functions on the target isotopes Sn^{112}, Sn^{114}, Sn^{116}, Sn^{117}, Sn^{118}, Sn^{119}, Sn^{120}, Sn^{122}, and Sn^{124}. All the resonances observed on the even isotopes have been analyzed using a Coulomb-plus-single-level formula. Level separations, l-value determinations, spreading widths, spectroscopic factors, and Coulomb displacement energies are discussed. The spectroscopic information from (d,p) on the same targets are compared to the analogue results.

1. INTRODUCTION

The recent study of isobaric analogue resonances by Moore, Richard, Watson, Robson, and Fox[1] on the isotopes of Mo demonstrates the use of this type of resonance as a spectroscopic tool in heavy nuclei. It is seen that neutron capture states formed in (d,p) stripping compare very well with the resonances formed by proton-induced reactions on the same target. The two types of reaction lead to states with all quantum numbers the same including isobaric spin but differing in T_z by one and differing in energy by the Coulomb displacement energy for a single proton. The purpose of this paper is to extend these studies to the Sn isotopes where the recent (d,p) data of Schneid, Prakash, and Cohen[2] is available for making comparisons between isobaric analogue states.

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[1] C. F. Moore, P. Richard, C. E. Watson, D. Robson, and J. D. Fox, Phys. Rev. **141**, 1166 (1966).
[2] E. J. Schneid, A. Prakash, and B. L. Cohen (to be published).