Half-Lives of the First Excited States in Sn^{117}, Te^{121}, Te^{123}, and Sb^{123}†

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Half-lives of the first excited states of Sn^{117} [161 keV, (0.31±0.03) nsec], Te^{121} [214 keV, (0.062±0.015) nsec], Te^{123} [159 keV, (0.186±0.020) nsec], and Sb^{123} [161 keV, (0.64±0.05) nsec] were measured by the delayed coincidence method. The transitions are predominantly $M1$ and are retarded by a factor of between 30 and 140 relative to the Weisskopf estimate. The $E2$ speeds of these transitions are also inferred from published data and vary from 0.1 to 30 times single-particle speed.

I. INTRODUCTION

THE experiments to be described here constitute an experimental survey of half-lives of first excited states in the odd-A nuclei Sn^{117}, Te^{121}, Te^{123}, and Sb^{123} (see Fig. 1). The lifetimes were determined by the delayed coincidence method.

The transitions studied are mainly of the l-forbidden $M1$ type. Our results agree with the general systematics of these transitions found by earlier investigations.[1–3] The small differences observed in retardation of the transition probabilities are not yet well understood theoretically.

In all the nuclides studied, it is known that the $E2$ admixture is small. Thus, the lifetime measurements essentially determine $\tau(M1)$ directly. Knowledge of the $E2$ speed of these transitions is quite interesting since the simple pairing correlation model predicts[4] that they are retarded.

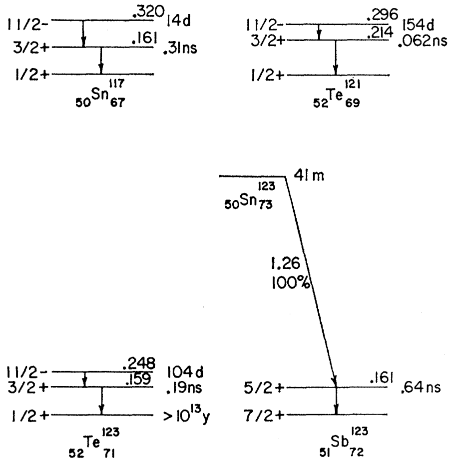

FIG. 1. Decay schemes of nuclei studied.

The $E2$ to $M1$ mixing ratios appear in the literature for several of the transitions. Also, Coulomb excitation of some of these states determines the $E2$ speed directly. These results are discussed.

The results are summarized in Table I.

II. Sn^{117}

The measurement of the lifetime of the first excited state in Sn^{117} was reported beiefly in abstract form.[5] Several milligrams of tin enriched to 94% in Sn^{116} were irradiated in the BNL reactor for 10 days. The 14-day Sn^{117m} was thus produced.

Conversion electron-conversion electron coincidences were observed using thin diphenyl-acetylene scintillators with 56 AVP photomultipliers. A 6BN6 time-to-pulse-height converter of the Green-Bell type[6] was used to determine the lifetime. The "prompt" time distribution of Au^{198} exhibits exponential slopes which decrease by a factor 2 in 1.5×10^{-10} sec. The slopes observed with the Sn^{117m} source yield $T_{1/2}=(3.1\pm0.3)\times10^{-10}$ sec for the first excited state. Since the energies of the conversion electrons from both members of the cascade are almost identical, the coincidences exhibit the lifetime on both sides of the time scale (see Fig. 2). Time spectra observed in electron–γ-ray coincidences resulted in the same lifetime (see Fig. 3). The slope is evident only on the side of the time spectrum corresponding to delay of the γ ray, because the preceding $M4$ transition is practically completely converted. Independently of our work, Metzger,[7] using the thermal resonance fluorescence method, found that the half-life of the first excited state in Sn^{117} is $(3.5_{-1.0}^{+2.0})\times10^{-10}$ sec, which agrees, within the rather large errors, with our result.

Kalebin[8] reports a 1% crossover $E5$ transition in Sn^{117m} of 320 keV. We have searched for this transition both with a NaI detector and a double focusing β spectrometer. No such transition was observed and an upper limit of 1.5×10^{-3} was put on the intensity of this crossover relative to the stopover branch.

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[1] R. L. Graham and R. E. Bell, Can. J. Phys. 31, 377 (1953).

[2] L. V. Groshev and A. M. Demidov, Atomnaya Energ. 7, 321 (1959).

[3] J. deWaard and T. Gerholm, Nucl. Phys. 1, 281 (1956).

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

[5] A. Li, M. Schmorak, and A. Schwarzschild, Bull. Am. Phys. Soc. 6, 229 (1961).

[6] R. E. Green and R. E. Bell, Nucl. Instr. Methods 3, 127 (1958).

[7] F. Metzger, J. Franklin Inst. 270, 138 (1960).

[8] S. M. Kalebin, Soviet Phys.—JETP 3, 799 (1956).

TABLE I. Results of lifetime measurements and reduced transition probabilities.

Isotope	transition	β_{tot}	$T_{1/2}$ (10^{-10} sec)	$\tau_\gamma(M1)E_\gamma^3$ (10^{-12} sec MeV^3)	$\tau_{\text{exp}}/\tau_{\text{s.p.}}$ $M1$ retardation	$E2/M1$[a]	$B(E2)$ ($e^2\times10^{-48}$ cm^4)	$\tau(E2)_{\text{s.p.}}/\tau(E2)_{\text{exp}}$ $E2$ enhancement from $E2/M1$ and $T_{1/2}$	from $B(E2)$
${}_{50}\text{Sn}_{67}{}^{117}$	$d_{3/2}\rightarrow s_{1/2}$	0.15	3.1 ± 0.3	2.1 ± 0.2	65	$0.0015_{-0.0010}^{+0.0015}$[b]	0.00074[c]	0.6	0.1
${}_{50}\text{Sn}_{69}{}^{119}$	$d_{3/2}\rightarrow s_{1/2}$	···	···	2.6[d]	78	$<10^{-5}$[e]	···	<1	···
${}_{52}\text{Te}_{69}{}^{121}$	$d_{3/2}\rightarrow s_{1/2}$	0.08	0.62 ± 0.15	1.00 ± 0.25	31	0.06[f]	···	30	···
${}_{52}\text{Te}_{71}{}^{123}$	$d_{3/2}\rightarrow s_{1/2}$	0.19	1.86 ± 0.20	1.32 ± 0.15	41	0.013 ± 0.001[f]	0.018[g]	8.9	2.5
${}_{52}\text{Te}_{73}{}^{125}$	$d_{3/2}\rightarrow s_{1/2}$	···	···	1.9[h]	60	···	···	···	···
${}_{51}\text{Sb}_{72}{}^{123}$	$d_{5/2}\rightarrow g_{7/2}$	0.17	6.4 ± 0.5	4.5 ± 0.4	140	···	0.0039[i]	···	1.4

[a] For γ intensities only.
[b] R. K. Golden and S. Frankel, Phys. Rev. **102**, 1053 (1956).
[c] D. S. Andreev, V. D. Vasilev, G. M. Gusinskii, K. I. Erokhina, I. Kh. Lemberg, Izvest. Akad. Nauk. SSSR Ser. Fiz. **25**, 832 (1961).
[d] J. L. Olsen, L. G. Mann, M. Linder, Phys. Rev. **106**, 985 (1957).
[e] From L subshell ratios, J. W. Mihelich, Phys. Rev. **87**, 646 (1952).
[f] N. Goldberg and S. Frankel, Phys. Rev. **100**, 1350 (1955).
[g] L. W. Fagg, Phys. Rev. **100**, 1299 (1955).
[h] Taken from compilation in reference 2.
[i] L. W. Fagg, Phys. Rev. **109**, 100 (1958).

III. Te^{121}

Te^{121m} was produced by the Sb$^{121}(d,2n)$Te^{121m} reaction with a 20-MeV deuteron beam from the BNL cyclotron. The enriched Sb^{121} target was dissolved in aqua regia. Te was precipitated (with Se carrier) by bubbling SO$_2$ through the solution in $3N$ HCl. The Sb remained in solution.

Conversion electrons of the 82-keV $M4$ transition in coincidence with conversion electrons of 214 keV were detected by Naton plastic scintillators. A transistorized time-to-pulse-height converter and fast discriminators[9] were used for these measurements.

Co^{60} was used as the "prompt" source. The slope of the prompt curve decreased a factor of 2 in 8×10^{-11} sec, while the slope with the Te^{121m} source was only slightly less steep on the side corresponding to the delay of the 214-keV conversion electrons. The small difference between the two slopes made an accurate slope measurement difficult. Therefore, the lifetime was determined by measurement of the centroid shift of the time distributions. The centroids of the time distributions of Te^{121m} and of Co^{60} were measured alternately numerous times in order to average out the effect of drifts in the electronics. The difference in counting rate between the two sources did not have a noticeable effect on the centroid position. The effect on the centroid position of the difference in the energy spectra of the two sources within the common energy selection windows was minimized by using a pulse-height compensating circuit.[9] The centroid shift obtained corresponds to a half-life of $(6.2\pm1.5)\times10^{-11}$ sec for the first excited state in Te^{121}. The relatively large error reflects an estimate of possible systematic shifts inherent in the centroid method.

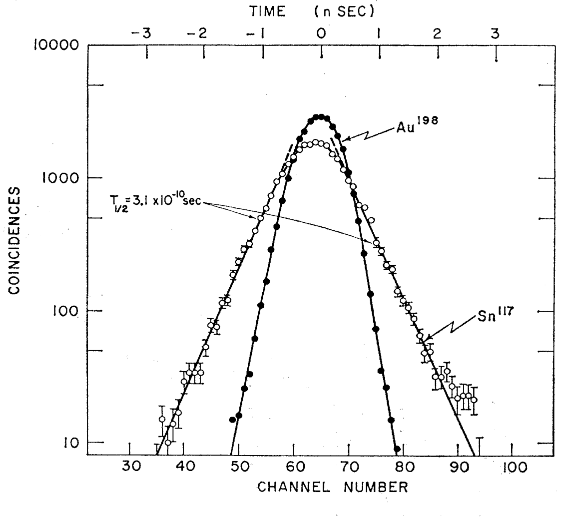

FIG. 2. Time spectra of e-e coincidences in the decay of Sn^{117m}. A "prompt" time distribution from β-γ coincidences in Au^{198} decay is shown.

The γ transitions in the decay of the ground state of Te^{121} did not interfere with our measurements. This decay scheme was subject to a careful study which will be reported elsewhere.

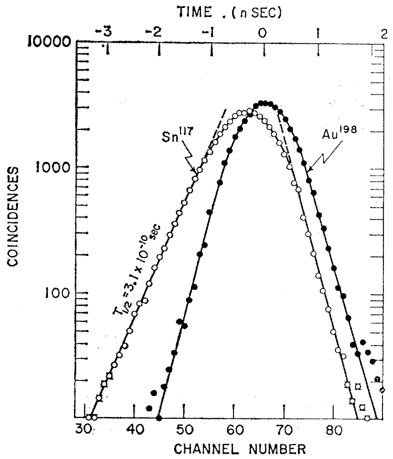

FIG. 3. Time spectrum of e-γ coincidences in decay of Sn^{117m}.

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[9] A. Schwarzschild, Nuclear Science Series Report Number 37 (National Academy of Sciences–National Research Council, Washington, D. C., 1962) NRC Publication 974; also, Nucl. Instr. Methods **21**, 1 (1963). R. Sugarman, F. C. Merritt, and W. A. Higinbotham, Brookhaven National Laboratory Report BNL 711 (T-248), 1962 (unpublished).

IV. Te^{123}

The half-life of the first excited state of Te^{123} was measured by the centroid shift method in 1953.[1] In view of the improvement in techniques since that time, it was possible to remeasure this lifetime more accurately by observing the exponential slope of the coincidence time spectrum.

The source of Te^{123m} was produced by irradiating enriched Te^{122} in the BNL reactor.

The instrumentation used was identical with that used for the Te^{121} experiment. Conversion electron-conversion electron coincidences were detected. The observed time spectrum is given in Fig. 4. The slope of the "prompt" Co^{60} source decreased by a factor of 2 in 10^{-10} sec. The slope with the Te^{123m} source indicated that the 160-keV transition is delayed and has a half-life of $(1.86\pm0.2)\times10^{-10}$ sec, in agreement with the result of Graham and Bell[1] who obtained $T_{1/2}=1.9\times10^{-10}$ sec.

V. Sb^{123}

41-min Sn^{123} was produced by irradiating a sample of tin enriched in Sn^{122} in the BNL reactor.

The instrumentation was similar to the one used for Sn^{117m}. The conversion electrons of the 160-keV transition in Sb^{123} were measured in coincidence with the 1.26-MeV β^- branch of Sn^{123}. The total number of coincidences decayed with a 42-min half-life. The slope on the time spectrum shown in Fig. 5 determined the half-life of the first excited state of Sb^{123} as $T_{1/2}=(6.4\pm0.5)\times10^{-10}$ sec.

The half-life of the first excited state of Sb^{123} was measured independently by Holland *et al.*[10] using a pulsed-beam method. They obtained $T_{1/2}=(5.7\pm0.7)\times10^{-10}$ sec.

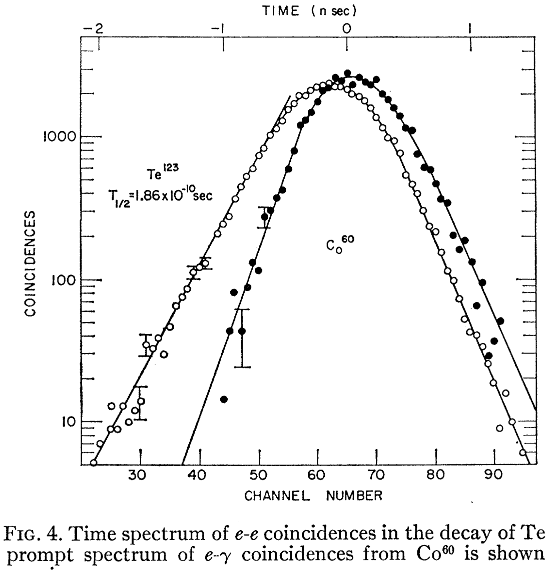

FIG. 4. Time spectrum of *e-e* coincidences in the decay of Te^{123m}. A prompt spectrum of *e-γ* coincidences from Co^{60} is shown for comparison.

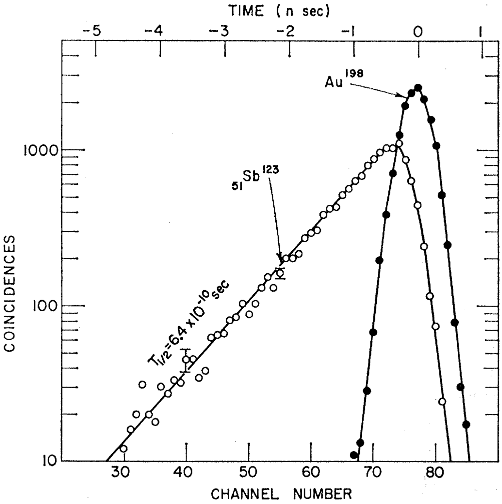

FIG. 5. Time spectrum of *β-e* coincidences in the decay of Sn^{123} to Sb^{123}.

VI. DISCUSSION

A. *M*1 Transitions

The *E*2 admixtures from angular correlation and Coulomb excitation experiments are reported in the literature. All four transitions whose lifetimes were measured are predominantly *M*1.

Table I summarizes the results. Sn^{119} and Te^{125} were included for comparison purposes, though they were not measured by us. The transitions in Sn and Te are interpreted as neutron transitions $d_{3/2}\rightarrow s_{1/2}$; thus, the *M*1 transitions are *l* forbidden ($\Delta l=2$). In Sb^{123} we have a proton transition, most probably $d_{5/2}\rightarrow g_{7/2}$, the *M*1 transition is again *l* forbidden. The measured half-lives, $T_{1/2}$, were corrected for internal conversion and the small *E*2 admixture to give the mean *M*1 γ lifetime $\tau_\gamma(M1)$ according to the formula $\tau_\gamma(M1)=1.44(1+\alpha_{\text{tot}})\times(1+E2/M1)T_{1/2}$. $\tau_\gamma E_\gamma^3$ is the reduced lifetime for *M*1 transitions. The single-particle Weisskopf estimate (taking the statistical factor equal to 1) is $\tau_\gamma E_\gamma^3=3.2\times10^{-14}$ sec. Thus, the odd neutron transitions are retarded by factors of 30–80 while the odd proton transition is retarded by a factor of ~140. This is in agreement with the general trend (see, for example, Groshev and Demidov[2]).

Most *M*1 proton transitions which are not *l* forbidden are retarded by factors of 3–30. There is little reliable information on odd neutron allowed *M*1 transitions.

There is no convincing argument at present to explain these regularities. The calculations of Arima *et al.*,[11] based on configuration mixing, give the right order of

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[10] R. E. Holland, F. J. Lynch, and E. N. Shipley, Bull. Am. Phys. Soc. **5**, 424 (1960).

[11] A. Arima, H. Horie, and M. Sano, Progr. Theoret. Phys. (Kyoto) **17**, 567 (1957).

magnitude for the retardation of l-forbidden $M1$ transitions. To explain the variations in the retardation, a more refined calculation would be necessary. It is not clear whether there is a contribution to the transition probability from extraordinary moments[12] such as spin-orbit coupling or exchange moments.

B. $E2$ Transitions

The determination of the $E2$ transition probabilities is less accurate than the $M1$ results, due to the additional error in the small $E2/M1$ ratios.

For Sn^{117}, Te^{121}, and Te^{123}, the $E2$ to $M1$ mixing ratio has been determined by angular correlation (conversion electron–γ-ray) measurements. In these cases the value of $\tau(E2)$ can be calculated from our measured lifetimes and the results are given in Table I. For Te^{123}, Sb^{123}, and Sn^{117}, the $B(E2)$ has been directly measured by Coulomb excitation. It should be noted that for Te^{123}, where both methods yield values for $\tau(E2)$, the agreement is poor.

The reported angular correlation measurements on Te^{123} yield a value of the coefficient of $P_2(\cos\theta)$ which is smaller than that which is predicted by the ratio of $\tau(E2)$ from Coulomb excitation and our $T_{1/2}$ for the state. Thus, some mechanism which causes attenuation of the correlation might explain the discrepancy. In any case, remeasurement of both the Coulomb excitation data and the correlations would seem valuable.

Odd-neutron $E2$ transitions near closed shells should be highly retarded according to a simple one-particle picture; the fact that they are not is explained[13] as a consequence of the polarization of the core by the odd particle. In fact, the odd neutron $E2$ transition probability in Pb^{207}, for example, is of the order of the single-particle estimate for protons. In a partially filled shell, the pairing correlation model predicts[4] the occurrence of retarded $E2$ transitions. Such retarded $E2$'s were reported by several authors[14] in Sn^{118}, Sn^{120}, and Sb^{122}. High retardations are expected near the middle of shells where the factor $(U_1U_2-V_1V_2)$ is near zero (U and V are the quasi-particle occupancy parameters). In the tin region the retardation (of the order of 100) is expected to peak sharply near neutron number 69. It is clear from Table I that this expected trend is not observed. It may be that contributions to the wave function of these states corresponding to core excitation[15] are responsible for the enhancements of the $E2$ transition probabilities.

ACKNOWLEDGMENTS

The authors wish to thank Dr. Joseph Weneser for useful discussions on the theoretical aspects of this problem. We also thank Dr. G. Scharff-Goldhaber for her constant interest in this work.

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[12] R. Sachs and M. Ross, Phys. Rev. **84**, 379 (1951).

[13] K. Alder, A. Bohr, T. Huus, B. Mottelson, and A. Winther, Rev. Mod. Phys. **28**, 432 (1956).

[14] H. H. Bolotin, A. C. Li, and A. Schwarzschild, Phys. Rev. **124**, 213 (1961); E. der Mateosian and M. L. Sehgal, *ibid.* **129**, 2195 (1963); H. Ikegami, *ibid.* **124**, 1518 (1961).

[15] R. A. Sorensen, Nucl. Phys. **25**, 674 (1961); A. de-Shalit, Phys. Rev. **122**, 1530 (1961).