Lifetimes of the 22-keV First Excited States in Eu^{151} and Sm^{149}*

O. C. Kistner, A. C. Li,† and S. Monaro
Brookhaven National Laboratory, Upton, New York

(Received 1 July 1963)

Lifetimes of the first excited states in Eu^{151} and Sm^{149} were measured using the delayed coincidence technique. The half-lives obtained are $(9.3\pm0.7)\times10^{-9}$ and $(7.6\pm0.5)\times10^{-9}$ sec for Eu^{151} and Sm^{149}, respectively, which are in agreement with the lower limits determined previously by Mössbauer experiments. The two transitions, which are predominantly $M1$, are retarded by factors of 127 and 150 relative to Weisskopf estimates. The $E2$ speed of the 22-keV transition in Sm^{149} is also inferred from the known $E2/M1$ ratio and is found to be 83 times the single-particle speed.

INTRODUCTION

THE 22-keV ground-state transition in Eu^{151} and Sm^{149} have been studied previously by the Mössbauer effect.[1–4] A knowledge of the lifetimes of the excited levels would facilitate the interpretation of the Mössbauer spectra. A discrepancy exists between the lifetime of the 22-keV level in Eu^{151} as measured by Berlovich *et al.*,[5] and the lower limit for this lifetime obtained by Shirley *et al.*[3] from the Mössbauer effect. The nuclei in question border on the region of deformed nuclei. Systematics of the variation of radiative transition probabilities as this region is traversed may have an important bearing on nuclear-model considerations. For these reasons in was thought desirable to make an accurate determination of these lifetimes using the delayed coincidence technique.

EXPERIMENTAL PROCEDURE AND RESULTS

I. The 22-keV Transition in Sm^{149}

A source of Eu^{149}, which decays via electron capture to Sm^{149} with a half-life of ≈120 days,[6,7] was prepared by bombardment of samarium oxide (enriched in Sm^{149}) with 10-MeV protons from the 60-in. Brookhaven cyclotron. Separation of the europium activity from all other rare earths was effected by the ion exchange method. The decay scheme of Eu^{149} to Sm^{149} as given by Harmatz *et al.*[6] is shown in Fig. 1. The preceding radiations, which consisted mostly of the 328-keV γ ray were detected with a 2.5×2-cm naton plastic scintillator. The l and m conversion electrons from the delayed 22-keV transition were detected with a film of Pilot-B scintillator 0.025 mm in thickness and approximately 1 cm^2 in area. Both scintillators were mounted on 56 AVP photomultiplier tubes, the electron detector tube being an exceptionally low-noise selected tube. The thin scintillator was practically insensitive to gamma radiation and the low energy electrons emitted by the source were primarily from the conversion of the 22-keV transition. A transistorized time-to-pulse-height converter and fast discriminators which are described in detail elsewhere,[8] were used. Different settings of the γ-ray channel within the range of 250–500

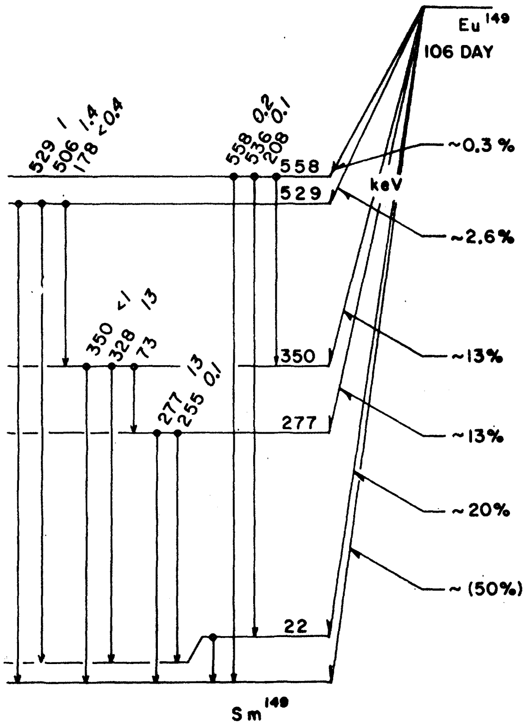

FIG. 1. Decay scheme of Eu^{149} as given by Harmatz *et al.* Gamma-ray energies are given in keV and intensities in percent per disintegration.

---

* Work performed under the auspices of the U. S. Atomic Energy Commission.

† Present address: Yale University, New Haven, Connecticut.

[1] The results presented here have previously been published in abstract form in A. C. Li, O. Kistner, and S. Monaro, Bull. Am. Phys. Soc. **8**, 332 (1963).

[2] R. L. Mössbauer, Z. Physik **151**, 124 (1958); Naturwiss. **45**, 538 (1958); and Z. Naturforsch. **14a**, 211 (1958).

[3] D. A. Shirley, M. Kaplan, R. W. Grant, and D. A. Keller, Phys. Rev. **127**, 2097 (1962).

[4] S. Jha, R. Segnan, and G. Lang, Phys. Letters **2**, 117 (1962).

[5] E. YE. Berlovich, Yu. K. Gusev, V. V. Ilyin, V. V. Nikitin and M. K. Nikitin, Nucl. Phys. **37**, 469 (1962).

[6] B. Harmatz, T. H. Handley, and J. W. Mihelich, Phys. Rev. **123**, 1758 (1961).

[7] Otto K. Harling, Phys. Rev. **124**, 1907 (1961).

[8] A. Schwarzschild, in *Electromagnetic Lifetimes and Properties of Nuclear States* (Nuclear Science Council Report No. 37) (National Academy of Sciences, National Research Council Publication 974, Washington 25, D. C., 1962). Also published in Nucl. Instr. Methods **21**, 30 (1963). See also R. Sugarman, F. C. Merrit, and W. A. Higinbotham, Brookhaven National Laboratory Report, BNL 711 (T-248), 1962 (unpublished).

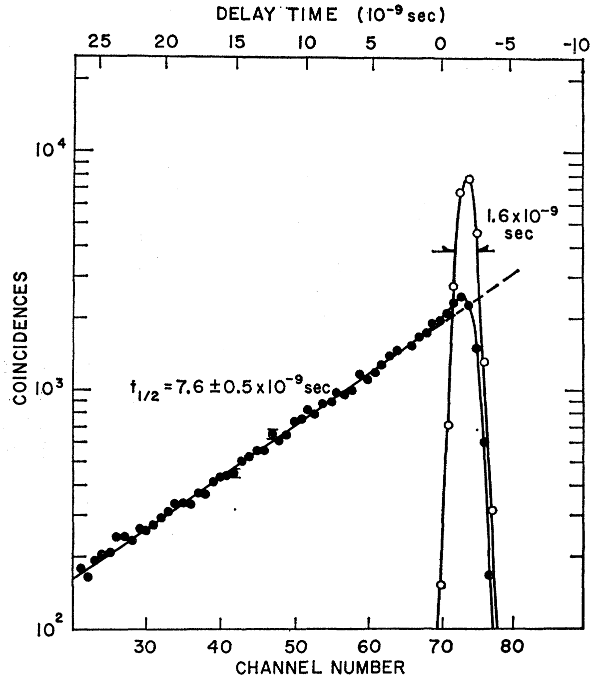

FIG. 2. Time spectrum of coincidences between the 22- and 328-keV transitions, giving the half-life of the 22-keV state in Sm^{149}.

keV gave the same value for the half-life. The observed time spectrum is given in Fig. 2. The prompt curve was obtained by measuring the coincidences between the β rays and the 1.17- or 1.33-MeV γ rays of Co^{60} with both channel settings remaining unchanged. The half-life of the first excited state in Sm^{149} as determined from the slope of the time spectrum is $(7.6\pm0.5)\times10^{-9}$ sec. This result is consistent with the limit of $\geq 2.8\times10^{-9}$ sec obtained from the Mössbauer work of Jha, Segnan, and Lang.[4]

II. The 22-keV Transition in Eu^{151}

The Gd^{151} source, which decays by electron capture to Eu^{151}, was produced by proton bombardment of europium oxide enriched in Eu^{151}. Although the decay scheme of Gd^{151} is not known in detail, the work of Shirley and Rasmussen[9] gives the levels and transitions pertinent to our measurements as shown in Fig. 3. The results were confirmed by our own coincidence studies. The experimental arrangement was identical to that used for Eu^{151} with the exception that a NaI(Tl) scintillator was used to detect the preceding γ radiation. Curve A in Fig. 4 shows the singles gamma-ray spectrum in the NaI(Tl) detector. Curve B in the same figure shows the gamma-ray spectrum in coincidence with the conversion electrons from the 22-keV transition detected by the electron counter (resolving time $\sim$0.4 μsec). It is clear from curve B that only the 175-keV transition is strongly in coincidence with the 22-keV transition. The gamma channel was accordingly set on the 175-keV photopeak. The time spectrum, shown in Fig. 5, gives a half-life of $(9.3\pm0.7)\times10^{-9}$ sec. This value is consistent with the one obtained from the interpretation of the Mössbauer spectrum in Eu^{151}, which yielded a lower limit of 6.4×10^{-9} sec.[3] It is, however, in serious disagreement with the previous electronic measurement performed by Berlovich *et al.*[5] which yielded a value of $(3.3\pm0.2)\times10^{-9}$ sec.[10] The "prompt" spectrum in Fig. 5 was obtained with Sn^{117m}, in which a highly converted transition of 159 keV is in coincidence with a 161-keV transition through a level of 3.1×10^{-10} sec half-life.[11]

CONCLUSION

The radiative transitions from the 22-keV states in both Sm^{149} and Eu^{151} are of a predominantly $M1$ nature.[6,12] In the case of Eu^{151} the transition can be interpreted, most probably, as a $g_{7/2}\rightarrow d_{5/2}$ proton transition, being, thus, l forbidden ($\Delta l=2$). To find

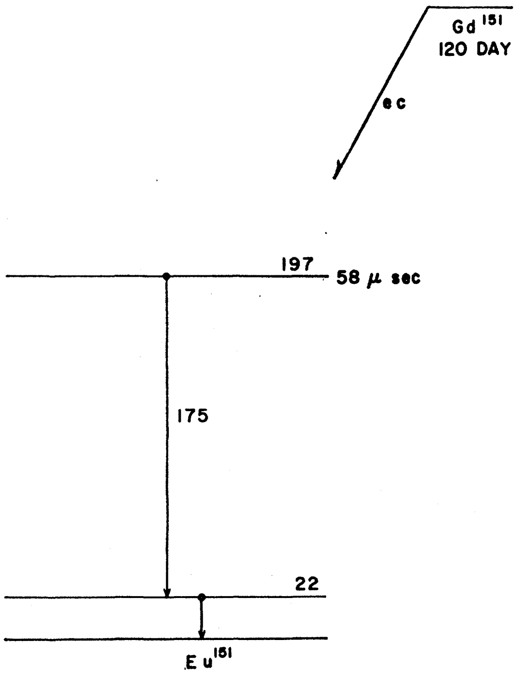

FIG. 3. Partial decay scheme of Gd^{151} as given by Shirley and Rasmussen (see Ref. 9). Gamma-ray energies are given in keV.

---

[9] V. S. Shirley and J. O. Rasmussen, Phys. Rev. **109**, 2092 (1958).

[10] During the course of this work, another measurement of the lifetime of the 22-keV state in Eu^{151} was reported by D. J. Horen, H. H. Bolotin, and W. H. Kelly in Bull. Am. Phys. Soc. **8**, 127 (1963). Our result agrees well with their value of $(9.5\pm0.5)\times10^{-9}$ sec.

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

[12] W. T. Achor, W. E. Phillips, J. I. Hopkins, and S. K. Haynes, Phys. Rev. **114**, 137 (1959).

the retardation factor, we used the Weisskopf estimate for the radiation width of $M1$ transitions which is given by Wilkinson[13] as

$$\Gamma_\gamma = 2.1 \times 10^{-2} E_\gamma^3,$$

where E_γ is measured in MeV, and Γ_γ in eV. To this is compared the actual radiation width for gamma decay,

$$\Gamma_{(\mathrm{exp})} = \hbar/\tau_\gamma = \hbar/1.44 \times (1+\alpha_{\mathrm{tot}}) \times \tau_{\mathrm{exp}},$$

where τ_γ is the mean life for gamma decay alone, τ_{exp} is the experimental observed half-life and α is the internal conversion coefficient. To calculate the radiative half-life for the 22-keV transition in Eu^{151}, use was made of the total conversion coefficient as measured by Achor *et al.*[12] For the 22-keV transition in Sm^{149}, the total conversion coefficient was taken to be $\alpha_{\mathrm{tot}} = 1.3 \sum \alpha_L$, where α_L was obtained by extrapolation from the L-shell conversion coefficients of Sliv and Band.[14] From the known $E2/M1$ admixture in this transition,[6] a correction was made according to the formula

$$\tau_\gamma = 1.44(1+\alpha_{\mathrm{tot}})(1+E2/M1)\tau_{\mathrm{exp}}.$$

The $E2$ transition probability was also calculated and compared with the single particle estimates.[13] This comparison shows that the partial electric quadrupole transition for the 22-keV γ ray in Sm^{149} is enhanced by a factor of 83.

The resulting retardation factors, F, for the two $M1$ transitions are 127 and 150 for Eu^{151} and Sm^{149}, respectively. The value for the l-forbidden odd proton transition of Eu^{151} is in good agreement with a general trend of values found in previous publications.[15,16] This result, however, shows that in the approach to the region of deformation, the retardation factors for the l-forbidden $M1$ transitions to the ground states in Eu^{147}, Eu^{149}, and Eu^{151} do not decrease monotonically, as it has been previously suggested.[5]

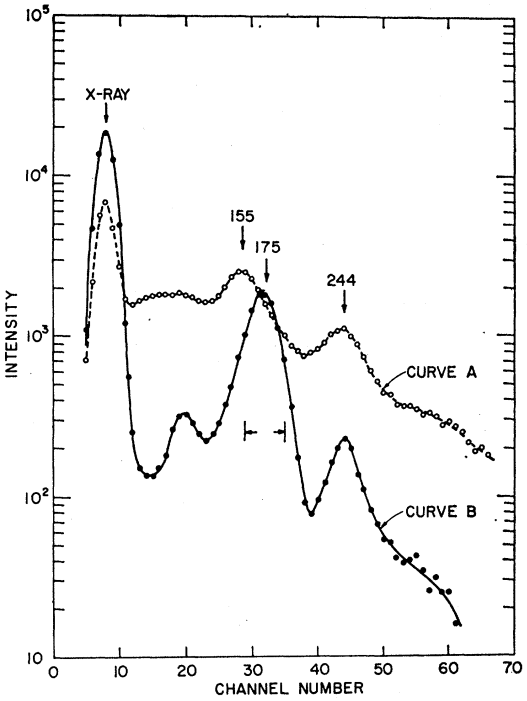

FIG. 4. The γ-ray spectrum for Eu^{149}. Curve A—the singles spectrum. Curve B—the spectrum in coincidence with the conversion electrons from the 22-keV transition. The energies are designated in keV and the channel used for the life-time measurement is indicated.

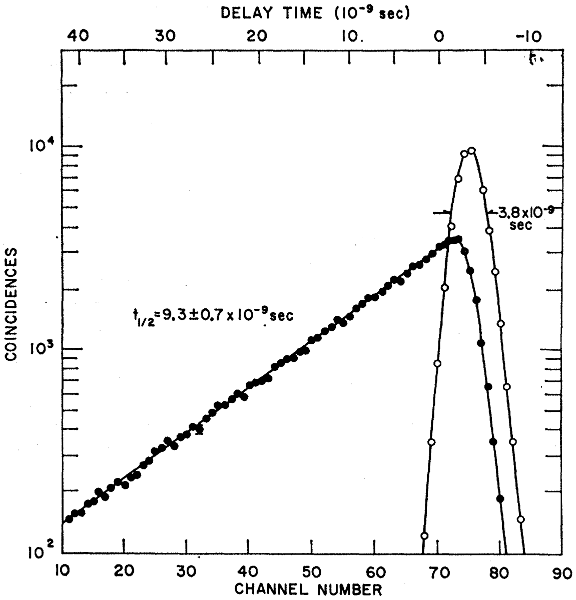

FIG. 5. Time spectrum of coincidences between the 22- and 175-keV transitions, giving the half-life of the 22-keV state in Eu^{151}.

---

[13] D. H. Wilkinson, in *Nuclear Spectroscopy*, edited by F. Ajzenberg-Selove (Academic Press Inc., New York, 1960).

[14] L. Sliv and I. Band, Leningrad Physica-Technical Institute Report, 1956. (Translation Report 57 ICC K1, issued by Physics Department, University of Illinois, Urbana) (unpublished).

[15] L. V. Groshev and A. M. Davidov, At. Energ. USSR **7**, 321 (1959).

[16] M. Schmorak, A. C. Li, and A. Schwarzschild, Phys. Rev. **130**, 727 (1963).