MeV state in O^{18} cannot be distinguished from those from a 6.25-MeV level in N^{17}. The gamma-ray transitions in O^{18} are known for only a few states, but not the states between 4.45 and 6.86 MeV. A transition from the 6.19-MeV state to the 1.98-MeV state could account for those gamma rays observed with the protons associated with the 6.45-MeV state in N^{17}.

Little new information was learned from the B^{11}-$(Li^7,d)N^{16}$, $B^{11}(Li^7,t)N^{15}$, or $B^{11}(Li^7,\alpha)C^{14}$ reactions which were also studied.

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Lifetimes of the First Excited States in Ru^{99} and Xe^{129}†

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Lifetimes of the first excited states in Ru^{99} (90 keV) and Xe^{129} (40 keV) were measured using the delayed coincidence technique. The half-lives obtained are $(20\pm1)\times10^{-9}$ sec for Ru^{99} and $(0.96\pm0.05)\times10^{-9}$ sec for Xe^{129}. These are in agreement with the lower limits previously determined by Mössbauer experiments. The $E2$ part of the 90-keV transition of Ru^{99} is enhanced by a factor of $\sim$50 relative to the Weisskopf estimate, while the $M1$ part is retarded by a factor between 2400 and 7400. The 40-keV $M1$ transition in Xe^{129} is retarded by at least a factor of 31 relative to Weisskopf estimates.

INTRODUCTION

RECENTLY the Mössbauer effect has been observed with the 90- and 40-keV transitions in Ru^{99} and Xe^{129}, respectively. The widths of the resonance lines correspond to half-lives of about 8 nsec [1] for the 90-keV first excited level in Ru^{99} and 0.8 nsec [1,2] for the 40-keV first excited level in Xe^{129}. However, measured widths of resonance lines are often appreciably larger than the natural width, and provide only lower limits for the state lifetimes. Since a knowledge of the natural widths of these levels would facilitate the interpretation of the Mössbauer spectra, we performed an accurate determination of their lifetimes using the delayed-coincidence technique. The Ru^{99} transition has been observed in Coulomb excitation by Temmer and Heydenburg[3] and we compare our results with their $\epsilon B(E2)$ value.

EXPERIMENTAL PROCEDURE AND RESULTS

I. The 90-keV Transition in Ru^{99}

A source of Rh^{99} was prepared by bombardment of ruthenium metal powder, enriched in Ru^{99}, with 10-MeV protons from the Brookhaven cyclotron. The measurements were performed several days after bombardment to allow for decay of the 4.5-h Rh^{88m} activity. No chemical separation was necessary. The partial decay scheme of Rh^{99m} is shown in Fig. 1 where only those levels and transitions pertinent to our measurements are shown. The source of Rh^{99m} was viewed by a gamma-ray counter and an electron counter which were both Naton 136 plastic scintillators having dimension 2.5 cm thick$\times$2 cm diam and 1 mm thick$\times$7 mm diam, respectively. The scintillators were mounted on 56 AVP photomultiplier tubes, the multiplier used for

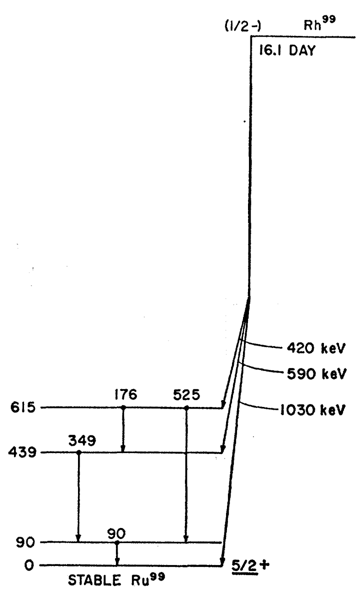

FIG. 1. Partial decay scheme of Rh^{99}. Gamma-ray energies are given in keV.

† Under the auspices of the U. S. Atomic Energy Commission.
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[1] O. C. Kistner, S. Monaro, and R. Segnan, (Ru^{99}) Phys. Letters 5, 299 (1963); Xe^{129} (to be published).
[2] During the course of this work, another measurement of the lifetime of the 40-keV state in Xe^{129} performed by Mössbauer effect was reported by C. L. Chernick, C. E. Johnson, J. G. Malm, G. J. Perlow, and M. R. Perlow, Phys. Letters 5, 103 (1963). Their result was $\tau_{1/2}=(0.58\pm0.07)$ nsec.
[3] *Nuclear Data Sheets*, compiled by K. Way, *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C.), NRC 61-1-49, 50, and 59; G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).

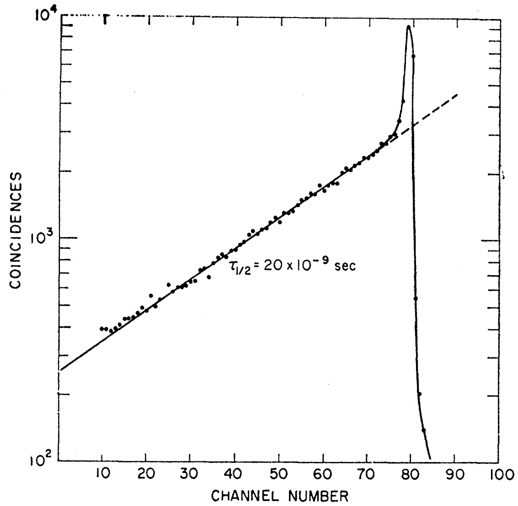

FIG. 2. Time spectrum of coincidences between the 90- and 349-keV transitions of Ru^{99} showing the half-life of the 90-keV state.

electron detection being an exceptionally low noise selected one. A transistorized time-to-pulse-height converter and fast discriminators, which are described in detail elsewhere,[4] were used. Appropriate pulse-height selection was performed to select conversion electrons from the 90-keV transition in the electron counter, and the 349-keV and other higher energy preceding radiations in the γ counter. The half-life of the 90-keV first excited state in Ru^{99} as determined from the slope of the time spectrum given in Fig. 2 is $(20\pm1)\times10^{-9}$ sec. This result is consistent with the limit of $\geq 8\times10^{-9}$ sec obtained from the Mössbauer work of Kistner, Monaro, and Segnan.[1]

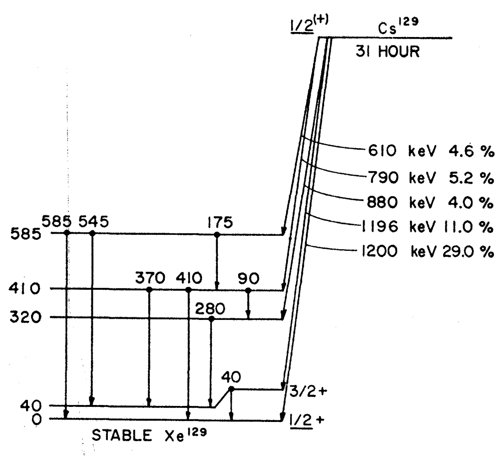

FIG. 3. Partial decay scheme of Cs^{129}.

[4] A. Schwarzschild, Nucl. Instr. Methods **21**, 1 (1963); R. Sugarman, F. C. Merritt, and W. A. Higinbotham, Nanosecond Counter Circuit Manual, Brookhaven National Laboratory Report BNL 711(T-248), 1962 (unpublished).

II. The 40-keV Transition in Xe^{129}

A source of Cs^{129} was produced by bombardment of potassium iodide with 40-MeV alpha particles from the Brookhaven 60-in. cyclotron. After several days the short-lived activities (Cs^{129}, Cs^{130}, Sc^{43}) produced in the bombardment decayed relative to the Cs^{129} so that no chemical separation was necessary. The partial decay scheme[5] of Cs^{129} is shown in Fig. 3 where, again, only those levels and transitions pertinent to our measurements are shown. The experimental arrangement was identical to that used for the Ru^{99} measurements with the exception that the Naton 136 plastic scintillator used for detecting electrons was replaced by a film of Pilot-B scintillator 0.0025 mm thick and approximately 1 cm^2 in area. The L and M conversion electrons from the 40-keV delayed transition were detected with the Pilot-B scintillator film while the preceding γ radiations, which consisted mostly of 370- and 545-keV γ rays, were detected by the thicker

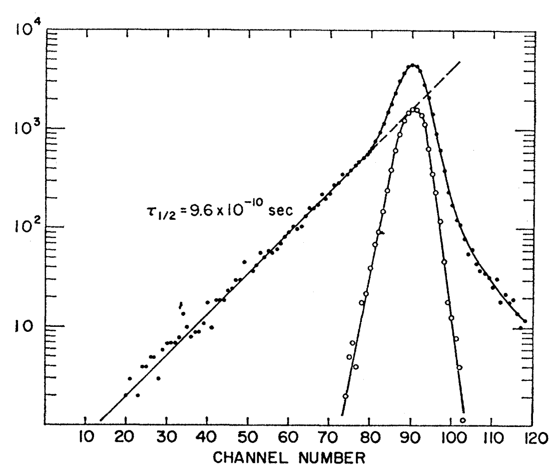

FIG. 4. Time spectrum of coincidences between the 40- and 370-keV transitions of Xe^{129} giving the half-life of the 40-keV state. The opened circled points represent the "prompt" spectrum obtained with a Co^{60} source using identical pulse-height selection as for the Cs^{129} source.

Naton plastic scintillator. The observed time spectrum is shown in Fig. 4. The prompt curve shown was obtained by measuring the coincidences between 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 Xe^{129} as determined from the slope of the time spectrum is $(9.6\pm0.5)\times10^{-10}$ sec. This result is consistent with the limit of ≥ 0.8 nsec[1] and ≥ 0.58 nsec[2] obtained from the Mössbauer work and with a previous electronic measurement performed by T. Alväger *et al.*[6] which yielded a value of $7\pm3\times10^{-10}$ sec.

[5] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C.), NRC 61-1-96 and 103.

[6] T. Alväger, B. Johansson, and W. Zuk, Arkiv Fysik **14**, 373 (1959).

CONCLUSIONS

The ground-state spin of Ru^{99} has been measured by Griffith and Owen as $\frac{5}{2}$.[7] The spin of the 90-keV level has been determined to be $\frac{3}{2}$, and the mixing ratio is $\delta^2 = E2/M1 = 2.4 \pm 0.9$.[8] Combining these results with the theoretical conversion coefficients and the measured lifetime, the partial γ-ray transition rates can be determined. The results of these calculations are that $\tau_\gamma(E2) = (1.04_{+0.10}^{-0.05}) \times 10^{-7}$ sec and $\tau_\gamma(M1) = (2.4_{-1.4}^{+1.0}) \times 10^{-7}$ sec. Comparison of these rates to the Weisskopf single-particle estimates[9] indicates that the $E2$ transition is enhanced by a factor of 50, and that the $M1$ is retarded by a factor of between 2400 and 7400. Thus the $E2$ appears to be of a collective nature and the $M1$ is one of the most highly retarded $M1$ transitions known. A more complete discussion of the nature of these levels of Ru^{99} will be presented at a later date. It should be noted that the $E2$ speed determined from this experiment is in some disagreement with early Coulomb excitation results.[3] Combination of the new mixing ratio and spin results with the $\epsilon B(E2)$ determined by Heydenburg and Temmer yields a state lifetime of 1.3×10^{-8} sec as compared with our value of 2.0×10^{-8} sec.

The 40-keV transition in Xe^{129} takes place from the $\frac{3}{2}^+$ first excited state to the $\frac{1}{2}^+$ state.[5] Level systematics in this region indicates that the 40-kev state has a $d_{3/2}$ character while the ground state in Xe^{129} is expected to be an $s_{1/2}$ single-particle state. The 40-keV transition is therefore an l-forbidden $M1$ neutron transition with most probably very little $E2$ admixture. The total $M1$ conversion coefficient as derived from the tables of Sliv and Band[10] is $\alpha_{\mathrm{Tot}} = 10$. Combination of this value with the measured lifetime leads to a γ lifetime $\tau_\gamma = 10.5 \times 10^{-9}$ sec. By comparing this value with the single-particle Weisskopf estimate,[9] a retardation factor of at least 31 is found for the 40-keV $M1$ neutron transition in Xe^{129}. The magnitude of this retardation factor is in agreement with a general trend of values found in previous publications.[11–13]

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[7] J. H. E. Griffith and J. Owen, Proc. Phys. Soc. (London) **A65**, 951 (1956).

[8] The determination of the spin of the 90-keV level and the mixing ratio for the transition was performed by O. C. Kistner and R. Segnan using the Mössbauer effect. A short report of this work was presented in an abstract at the Washington APS meeting, Bull. Am. Phys. Soc. **9**, 396 (1964) and will be published in detail in *The Physical Review*. The mixing ratio for the transition was also determined from measurements of internal conversion-coefficient studies of P. I. Connors and A. Schwarzschild (to be published).

[9] Calculated from the formulas given in *Nuclear Spectroscopy Tables*, edited by A. H. Wapstra, G. T. Nijgh, and R. Van Lieshout (North-Holland Publishing Company, Amsterdam, 1959).

[10] L. Sliv and I. Band, Leningrad Physics Technical Institute Report, 1956, [(English transl.: Physics Department, University of Illinois, Translation Report 57 ICC K1) (unpublished)].

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

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

[13] O. C. Kistner, A. C. Li, and S. Monaro, Phys. Rev. **132**, 1733 (1963).