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Lifetimes of Excited States of V^{51}, Ni^{61}, Ga^{69}, As^{75}, Br^{79}, Rb^{85}, and Sb^{123}†

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The lifetimes of states at low excitation in several odd-A nuclei have been measured by a pulsed-beam technique. The results (in nsec) of the measurements for the levels at the excitation energies (in keV) listed in parentheses are

$V^{51}(320)$, 0.28 ± 0.05; $Ni^{61}(67)$, 7.3 ± 0.3; $Ga^{69}(320)$, <0.1;
$As^{75}(199)$, 1.30 ± 0.25; $As^{75}(280)$, 0.43 ± 0.08; $Br^{79}(217)$, <0.2;
$Rb^{85}(150)$, 1.01 ± 0.10; $Sb^{123}(160)$, 0.82 ± 0.10.

I. INTRODUCTION

The lifetimes of low-lying excited states in V^{51}, Ni^{61}, Ga^{69}, As^{75}, Br^{79}, Rb^{85}, and Sb^{123} have been measured by using a pulsed-beam technique, which has been described in detail elsewhere.[1] All but one of the states were first excited states, the exception being the third excited state of As^{75}. In all cases, the transition to the ground state occurred by a mixed electric-quadrupole ($E2$) and magnetic-dipole ($M1$) transition. The reduced transition probability $B(E2)$ for electric-quadrupole transitions for each of the states studied was already known[2] from measurements of Coulomb-excitation cross sections. The total lifetime of the state, the reduced transition probability $B(E2)$, and the internal-conversion coefficients are sufficient to determine the partial transition probability for $M1$ radiation.

II. PROCEDURE

The excited states studied were obtained through Coulomb excitation from the ground state by a beam of ~3.5-MeV α particles. The beam was chopped into short pulses of ~1 nsec duration. The time of detection of the deexcitation γ ray was measured relative to the time at which a beam pulse arrived at the target.

The γ rays were detected in a NaI(Tl) scintillator. A detector of thickness $\frac{1}{8}$ or $\frac{1}{4}$ in. was used to minimize the Compton background arising from high-energy γ rays. Only those γ rays producing a pulse in the photopeak of the energy distribution were accepted for time analysis. During alternate short runs, the time distribution of a comparison γ ray known to have a short lifetime ($<10^{-11}$ sec) was separately recorded.

The lifetime of each excited state was determined by measuring the shift in the centroid of the time distribution with respect to that of the comparison γ ray. For states having a lifetime greater than 1 nsec, the lifetime was also extracted from the time distribution by a direct measurement of the exponential decay. The following comments provide specific details about the individual isotopes on which measurements were made.

V^{51}. The target material was a thick foil of natural vanadium. The energy distribution showed a single γ ray at 320 keV, corresponding to the ground-state transition from the first excited state.

Ni^{61}. The target was an enriched nickel foil (83% Ni^{61}). The energy distribution showed a weak γ ray at 240 keV in addition to a line at 67 keV. The latter corresponds to the ground-state transition from the first excited state in Ni^{61}. Approximately 13% of the pulses accepted for time analysis arose from the Compton distribution of the higher-energy γ ray.

The lifetime of the 67-keV level is sufficiently long that the data could be analyzed by a direct measurement of the decay of the excited state. The lifetime of the 240-keV γ ray was found to be short ($\ll 10^{-9}$ sec) so that it did not interfere with the measurement. The errors quoted for the mean lifetime of Ni^{61} represent the rms deviation of individual measurements from the mean of many runs. The error is 5 times that expected on the basis of the statistical uncertainty of the data.

Ga^{69}. The target consisted of evaporated natural Ga on a Ni backing. A single γ-ray photopeak was observed at 320 keV, corresponding to the ground-state transition from the first excited state in Ga^{69}. A smooth background distribution was apparent above the photopeak, and accounted for about 10% of the pulses accepted for time analysis. Because of the low counting rate and the relatively high background, we were able only to establish that the lifetime of the state is less than 0.1×10^{-9} sec.

As^{75}. The lifetimes of both the first excited state (199 keV) and the third excited state (280 keV) were measured by observing the γ rays from the respective ground-state transitions. The second excited state (265 keV) has been detected following β decay, but has not been observed in Coulomb-excitation processes.[3] This would indicate that the 265-keV state is not excited in these measurements. However, the energy

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TABLE I. Summary of lifetime measurements.

Nuclide	E_0 (keV) [a]	Mean lifetime Present expt (nsec)	Mean lifetime Other expt (nsec)	Observer
V^{51}	320	0.28±0.05	0.15±0.03 [b]	Schopper[c]
			0.31±0.08	Delyagin and Preisa[d]
			0.28±0.03	Sunyar[e]
			0.27±0.05	Frauenfelder[f]
			0.40±0.06	Nainan[g]
			0.36±0.08	Samueli and Sarazin[h]
			0.25±0.06	Weaver and Barton[i]
Ni^{61}	67	7.3±0.3	7.6±0.7	Schwarzchild[j]
Ga^{69}	320	<0.1		
As^{75}	199	1.30±0.25		
As^{75}	280	0.4±0.2	0.78±0.08 [b]	Varma and Eswaran[k]
As^{75}	280	0.44±0.10	(Our coincidence measurement)	
Br^{79}	217	<0.2		
Rb^{85}	150	1.01±0.10	1.14±0.12	Burgov *et al.*[l]
			0.8±0.4	Spighel[m]
Sb^{123}	160	0.82±0.10	0.92±0.08	Schmorak *et al.*[n]
			0.89±0.30	Schubnyi *et al.*[o]

[a] Energy of the excited state as given by C. M. Lederer, J. M. Hollander, and I. Perlman, in *Table of Isotopes* (Wiley-Interscience, Inc., New York, 1967), 6th ed.

[b] This value was not included in the averages given in Table II.

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resolution of the γ-ray detector is such that an admixture of 10% or less of the 265-keV γ ray would be undetected in the 280-keV photopeak. The quoted error in the lifetime of the third excited state includes allowance for the possible presence of such an undetected process.

No 80-keV γ rays, corresponding to the transition from the third to the first excited state, were observed. The presence of such a transition would have affected the observed centroid shift of the 199-keV state because the third excited state has an appreciable lifetime. The data for the 199-keV state were analyzed both by direct measurement of the exponential decay and by determination of the centroid shift. There was good agreement between the two methods of analysis.

TABLE II. Weighted averages of lifetime measurements.

Nuclide	E_0 (keV)	Mean lifetime τ (nsec)
V^{51}	320	0.29±0.02
Ni^{61}	67	7.3±0.3
Ga^{69}	320	<0.1
As^{75}	199	1.3±0.3
	280	0.43±0.08
Br^{79}	217	<0.2
Rb^{85}	150	1.05±0.08
Sb^{123}	160	0.88±0.07

TABLE III. Transition probabilities derived from $B(E2)$ data and the measured lifetimes indicated in Table II. The partial lifetimes $\tau(E2)$ and $\tau(M1)$ for γ-ray decay were obtained from τ and $\epsilon B(E2)$ by using calculated conversion coefficients, as described in the text.

Nuclide	E_0 (keV)	Mean lifetime τ (nsec)	$\epsilon B(E2)$ [a] ($e^2\times10^{-48}$ cm^4)	$\tau(E2)$ [b] (nsec)	$\tau(M1)$ [b] (nsec)
V^{51}	320	0.29	0.0055	3.30	0.32
Ni^{61}	67	7.3	0.00038	2.11×10^5	8.23
Ga^{69}	320	<0.1	0.0079	1.53	<0.11
As^{75}	199	1.30	0.025	5.08	1.81
	280	0.43	0.071	0.99	0.78
Br^{79}	217	<0.2	0.023	10.8	<0.21
Rb^{85}	150	1.05	0.0032	212	1.11
Sb^{123}	160	0.88	0.0039	129	1.03

[a] The factor ϵ is defined by the relation $\epsilon=1/(1+\alpha_T)$, where α_T is the total internal-conversion coefficient. These data were obtained from *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington, D.C., 1959).

[b] Partial mean lifetime for $E2$ or $M1$ transitions.

Our value for the mean lifetime (0.4±0.2 nsec) of the third excited state differs considerably from a measurement of the same state by Varma and Eswaran[4] (0.78±0.08 nsec), who measured the delay of the γ rays relative to the preceding conversion electrons. The value 0.22 nsec has been calculated from the mixing parameter δ and the Coulomb-excitation cross section.[5] Because of this disagreement between the measurements of Varma and Eswaran and ours, we used a Se^{75} source to remeasure the lifetime of the 280-keV level. This source decays by K capture to the 401-keV level of As^{75}. This state feeds the 280-keV level through the emission of a 121-keV γ ray. Organic scintillators were used to observe coincidences between Compton events arising from the 121- and 280-keV γ rays. The slope of the decay curve for these events gave a mean life of 0.44±0.10 nsec. For prompt events of the same pulse height, the slope of the same portion of the decay curve corresponded to a mean life of 0.11 nsec. From the description of Varma and Eswaran's experiment, it seems likely that their value reflects primarily their time resolution and is not a measurement of the lifetime of the state. For this reason we have used only our two measurements in arriving at the average value given in Table II.

Br^{79}. A pressed pellet of KBr was used as a target. γ rays were observed at 217 keV (corresponding to the ground-state transition from the first excited state of Br^{79}) and at 270 keV (probably corresponding to the first excited state in Br^{81}). The second excited state in Br^{79} (261 keV) is apparently not excited through Coulomb excitation.[6] Because of the relatively high background level from higher-energy γ rays, it was possible only to establish an upper limit (0.2×10^{-9} sec) for the lifetime of the first excited state in Br^{79}.

Rb^{85}. The target was a pressed pellet of RbCl. Special Li-free RbCl was obtained[7] to eliminate an otherwise large background arising from excitation of the first excited state of Li^7. With the Li-free target, a single photopeak was observed at 150 keV, corresponding to the ground-state transition from the first excited state in Rb^{85}.

Sb^{123}. The target was natural antimony metal. A single γ-ray photopeak was observed at 160 keV, arising from the ground-state transition from the first excited state of Sb^{123}. However, approximately 25% of the pulses accepted for time analysis were background counts arising principally from the accelerator rather than from reactions in the target. Because of the low relative counting rate obtained from Sb^{123}, higher-than-usual beam currents were used in the Sb^{123} measurements.

III. RESULTS

The results of the measurements reported here are summarized in Table I. In addition, results of other investigations are included for comparison. All of the values given in Table I represent mean lifetimes.

The weighted averages of the lifetime measurements reported here and in the literature are given in Table II.

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All of the data included in Table I have been included in the average, except for one result on V^{51} that differed from the accepted average by five standard deviations and one result on As^{75} (280-keV state) that was not used for the reasons given above. Each measurement included in Table II was weighted in proportion to the inverse square of the standard deviation quoted by the respective experimenters. The uncertainties listed in Table II represent the root mean square of the (weighted) deviations between the average and the individual measurements.

The partial mean lifetime $\tau(E2)$ for electric-quadrupole γ-ray emission and the partial mean lifetime $\tau(M1)$ for magnetic dipole γ-ray emission are given in Table III. These were obtained by simultaneous solution of the equation relating $\tau(E2)$ to $\epsilon B(E2)$ as given by Alder *et al.*[2] and the equation

$$1/\tau=[(1+\alpha_2)/\tau(E2)]+[(1+\beta_1)/\tau(M1)],$$

where τ is the mean lifetime of the state, and α_2 and β_1 are the internal-conversion coefficients for $E2$ and $M1$ radiation, respectively. The values used for α_2 and β_1 were obtained by extrapolation or interpolation of Rose's table[8] for V^{51} and Ni^{61} and by interpolation in Hager and Seltzer's table[9] for the remainder of the nuclei.

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Levels in ^{35}Cl Populated by ^{34}S(d, n)^{35}Cl†

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The low-lying levels in ^{35}Cl were populated by the reaction ^{34}S$(d,n)^{35}$Cl at 4.95 MeV. The neutron spectrum was measured using the time-of-flight technique. Interpretation of the angular distribution of the neutrons, together with results of previous experiments, confirmed or determined the following spin-parity assignments: $J^\pi=\frac{3}{2}^+, \frac{1}{2}^+, \frac{5}{2}^+, \frac{5}{2}^-$, and $\frac{7}{2}^-$ for the levels at 0.0, 1.220, 1.762, 3.006, and 3.163 MeV, respectively.

1. INTRODUCTION

RECENT experimental studies[1–4] of the ^{35}Cl energy levels up to 4.2 MeV have left several spins and parities still in doubt. Most of the assignments are based on the angular distribution of γ rays emitted in (p,γ), $(p,\gamma\gamma)$, (p,p',γ), and $(n,n'\gamma)$ reactions. As is well known, it is difficult to obtain parities in this way, although spins can often be determined.

Deuteron stripping reactions may frequently be used to determine the angular momentum transferred (l_p) to the residual nucleus. When the target nucleus has spin zero, the parity of a level populated by such a direct interaction is given by $(-1)^{l_p}$, and the spin is restricted to be $J=l_p\pm\frac{1}{2}$. A study of the ^{34}S$(d,n)^{35}$Cl reaction was, therefore, undertaken to clarify some of the remaining problems concerning the low-lying states of ^{35}Cl.

The angular distribution of γ rays from the decay of the 1.220-MeV level is found to be isotropic,[3,4] which is consistent with a spin of $\frac{1}{2}$, $\frac{3}{2}$, or $\frac{5}{2}$ for the 1.220-MeV level.[5] Hauser-Feshbach calculations carried out in a study of the ^{35}Cl$(n,n'\gamma)^{35}$Cl reaction by Nichols[3] favor a spin of $\frac{1}{2}$, but no parity assignment could be made. The only direct evidence for positive parity is the observation of a $\log ft$ value of 4.7 for the β^+ decay of ^{35}Ar to this level.[6] Such a value indicates an allowed transition which requires the 1.22-MeV level to have the same parity (even) as the ^{35}Ar ground state. An

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