

Radiative lifetimes of Am I atomic levels

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The lifetimes of several atomic levels of Am I that are connected by electric dipole transitions to the ground state have been measured. The Am atoms were excited by light pulses from a cw single-mode dye laser with the aid of an optoacoustic modulator. The decay curve of the delayed emitted photons was measured by counting single photons in the beam-off periods. The lifetimes of 14 levels in the wavelength region between 6405 and 4265 Å were measured using Am-metal vapor. The metallic Am was obtained by reducing AmO₂ with La at 1500°C in a high-vacuum system and collecting Am on a catcher foil. The Am vapor was then produced by controlled reevaporation from the foil at a temperature of about 800°C. These lifetime measurements, in combination with the line intensities from a hollow-cathode discharge, allow the identification of the Am transitions homologous to the strong Eu I transitions from the $y \text{ } ^8P_{5/2,7/2,9/2}$ terms to the ground state.

I. INTRODUCTION

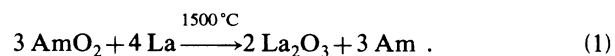
In this work we measure lifetimes of a number of Am atomic states that are of interest to optical pumping experiments. Americium is a good candidate for such pumping experiments to determine the spins, hyperfine splittings, and isomer shifts of fission isomers.^{1,2} The atomic ground state, similar to that of the chemical homolog europium, consists mainly of a spherical $^8S_{7/2}$ configuration. This results in a long collisional relaxation time τ_R with inert gas buffer atoms.³ Thus it is attractive to study the long chain of Am fission isomers (having $1.5 \mu\text{s} < t_{1/2} < 14 \text{ ms}$) which can be produced via $(p, 2n)$ and $(d, 2n)$ reactions on targets of available plutonium isotopes. In such experiments the fission isomers are stopped in the buffer gas of an optical cell. The neutral americium fission isomers can be pumped with polarized laser light via an appropriate optical transition, and the fission fragment anisotropy can be recorded. In addition to the relaxation time τ_R the expected fission-fragment-anisotropy signal strongly depends on the laser intensity and the lifetime τ of the excited atomic level. Because of the small production cross sections, the isomer decay rates in the optical cell are very low ($\approx 0.1 \text{ s}^{-1}$). Thus long running times are required to obtain statistically significant results. To optimize the selection of experimental conditions, τ_R and τ should be known for as many excited states as possible. Unfortunately, to our knowledge, neither τ_R or τ have been previously measured for Am.

The estimates based on relative transition probabilities derived from line intensities observed in an electrodeless discharge⁴ are not sufficient for our purpose. We have therefore initiated the measurement of unknown lifetimes

of $J = \frac{5}{2}, \frac{7}{2}$, and $\frac{9}{2}$ atomic levels of Am I in the wavelength region between 4260 and 6405 Å. Our measurements were restricted to the investigation of electric $\Delta J = \pm 1, 0$ transitions from the ground state, since we are only interested in short-lived atomic levels, for which optical pumping is most efficient. These levels were selected according to unpublished spin assignments of Conway *et al.*⁵ Most of the many levels in Am I have not been identified; lifetime measurements are thus of intrinsic interest. We begin with a discussion of the experimental techniques and then return to the question of level lifetimes and determination of level configurations in Sec. IV.

II. EXPERIMENTAL METHOD

For measuring the lifetimes we chose the method of delayed single-photon counting following excitation with a pulsed dye-laser beam, similar to the technique described by Gustavsson *et al.*⁶ Am metal is highly reactive and immediately becomes oxidized to AmO₂ in the presence of air. To obtain the metal we had to first reduce this oxide under high-vacuum conditions using the following reaction:



Before reduction, the AmO₂ and La powders were mixed and pressed to a pill in a glove box. This required a pill mass of at least 10 mg. Because of the scarcity of the isotope and the toxicity associated with its high α activity, it was necessary to perform the experiment with a small sample containing only 300 μg of $^{243}\text{AmO}_2$ (corresponding to an α activity of 50 μCi). To reach the

desired 10-mg pill mass, Dy_2O_3 and a sufficient amount of La were added to the sample. Dysprosium oxide was chosen because it has a reaction temperature with lanthanum and a vapor-pressure dependence similar to americium.

To keep the difficult handling of the radioactive material to a minimum, an apparatus was built which permitted the measurement of all 14 lifetimes from a single-pill loading (see Fig. 1). It consisted of two parts. In the lower part the americium oxide was reduced using the geometrical arrangement shown in Fig. 2. The Am-Dy metal vapor was collected on a tantalum foil which was later moved into the upper part of the apparatus without breaking the vacuum. After reevaporation from the tantalum foil at a temperature of about $800^\circ C$, the atomic americium could interact with the laser beam (see Fig. 3). This two-step procedure has several advantages over a technique in which the spectroscopy would be performed directly on the reduced atoms. The oven-light emission which perturbs the photomultiplier is much smaller at $800^\circ C$ than at the direct reduction temperature of

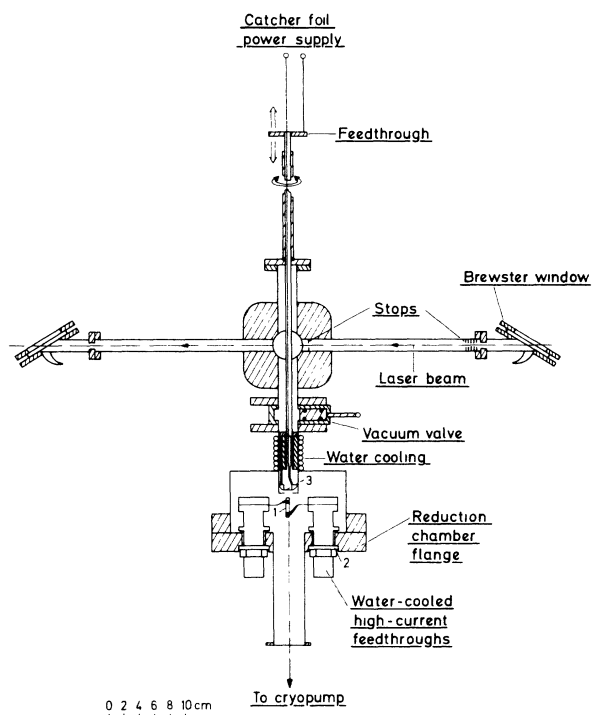


FIG. 1. Experimental setup. The reduction of the $AmO_2-Dy_2O_3-La$ pill was done in the lower part of the apparatus. After reduction in the tantalum crucible (1), the metal vapor was deposited on the tantalum catcher foil (3). The whole catcher-foil assembly was then raised into the upper part of the apparatus without breaking the vacuum. Here, the spectroscopy was performed after reevaporation of the Am metal from the catcher foil. The reduction chamber could be decoupled by closing the vacuum valve. Not shown in the drawing are the heat shields in the reduction chamber and a window for the observation of the tantalum crucible (1) with a pyrometer. During reduction, the chamber was cooled with liquid nitrogen in order to maintain the vacuum below 5×10^{-6} mbar. The high-current feedthroughs were electrically isolated from the reduction chamber by Teflon rings (2).

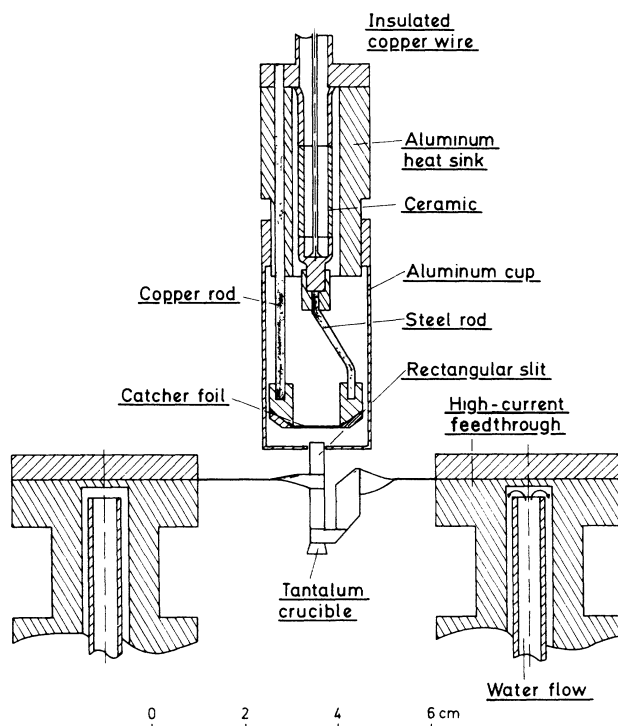


FIG. 2. Experimental arrangement depicted during the reduction procedure. The $AmO_2-Dy_2O_3-La$ pill was placed in the tantalum crucible, made from a 3-mm-diam, 25-mm-long Ta tube, and was heated by an electrical current of about 50 A. The metal vapor condensed on a 10×8 -mm tantalum foil of thickness 0.0075 mm. To avoid reevaporation of the Am metal, the catcher foil was connected via a copper rod to an aluminum heat sink.

$1500^\circ C$. Also, this resulted in a very efficient use of the limited amount of americium metal. In addition, the reevaporation could be controlled much better than the reduction process.

To protect the photomultiplier from the stray oven light, the electrically heated Ta foil was surrounded by a soot-blackened aluminum cylinder, as shown in Fig. 3. The exit slot for the Am atoms was 20×4 mm², which is approximately the opening for evacuating this part. To minimize the oxidation of the americium-dysprosium metal layer in the poorer-vacuum condition present while heating, the aluminum cylinder was brought into contact with a liquid N_2 -cooled rod.

The fluorescent light, originating from the interaction of the 2-mm-diam laser beam with the Am atoms, was focused using the optics indicated in Fig. 4 onto the cathode of a R-928 Hamamatsu side-on photomultiplier. The Fresnel lenses imaged the interaction region with a magnification of 1:1 onto a 10×5 mm aperture. This avoided directly viewing the illuminated exit slot of the Al cylinder and reduced the stray light background. Two smaller lenses were used to transmit this intermediate image with a magnification of 2 to the photomultiplier cathode. To further reduce the background due to the light from the heated Ta foil, a 2-mm-thick Schott color-

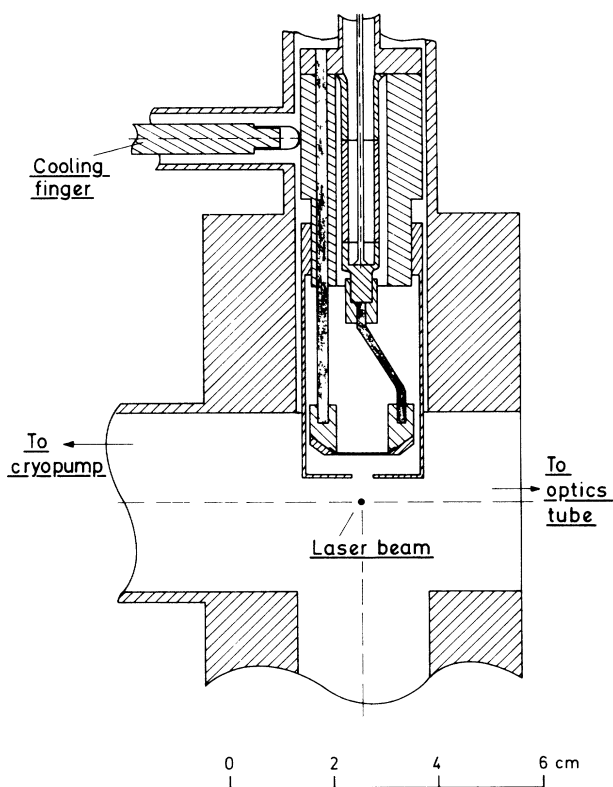


FIG. 3. Experimental arrangement in the upper part of the apparatus as used for the lifetime measurement. The laser beam entered the interaction region perpendicular to the plane of the drawing. The americium metal was reevaporated by heating the Ta foil electrically with a current of about 6.5 to 8.5 A (corresponding to a temperature of about 740 to 870 °C). To avoid degassing problems and the associated rapid oxidation of the Am-Dy metal layer, the whole catcher-foil assembly was brought into contact with a liquid-N₂-cooled copper finger.

glass filter BG 38 and appropriate interference filters, having a transmission band of 10 nm [full width at half maximum (FWHM)], were positioned between these lenses in the parallel optical-ray path. The photomultiplier was also cooled with ice water, resulting in a reduction of the dark count rate to about 300 to 600 s⁻¹. The efficiency of detecting a photon emitted in the interaction region was about 10⁻³.

For the excitation of the americium atoms we used a Coherent 699-29 Autoscan cw single-mode ring dye laser pumped by an argon-ion laser. In the 5300- to 6400-Å range, the wavelength was determined with an accuracy of 4×10^{-7} with the aid of an internal wavemeter. In the 4200- to 5000-Å range, a Burleigh WA-20 wavemeter (accuracy 2×10^{-6}) was used. The laser beam was chopped with an optoacoustic modulator (Crystal Technology Model 3200, carrier frequency 200 MHz) having a static-contrast ratio of 1000:1. The beam-on period varied from 0.3 to 12 μs, the repetition frequency from 9 to 830 kHz, depending on the lifetime of the atomic level under investigation.

The electrical pulses were handled with standard nuclear electronics. A time-to-amplitude converter (TAC) was used in connection with a multichannel analyzer to record the delayed coincidences between the resonance fluorescence photons and the laser-beam pulse. The start pulse was derived from the pulser driving the optoacoustic modulator; the stop pulse, from the photomultiplier. Calibration was performed with an Ortec 462 time calibrator. The fall time of the laser-light intensity after switching off the optoacoustic modulator was minimized by observing the stray light of the laser beam when the beam was steered off the optical axis. An example of such a measurement is shown in Fig. 5(a). For a beam diameter at the optoacoustic modulator of about 0.2 to 0.3 mm, a fall time from 90% to 10% of about 30 to 60 ns was measured. This was sufficiently fast for the investi-

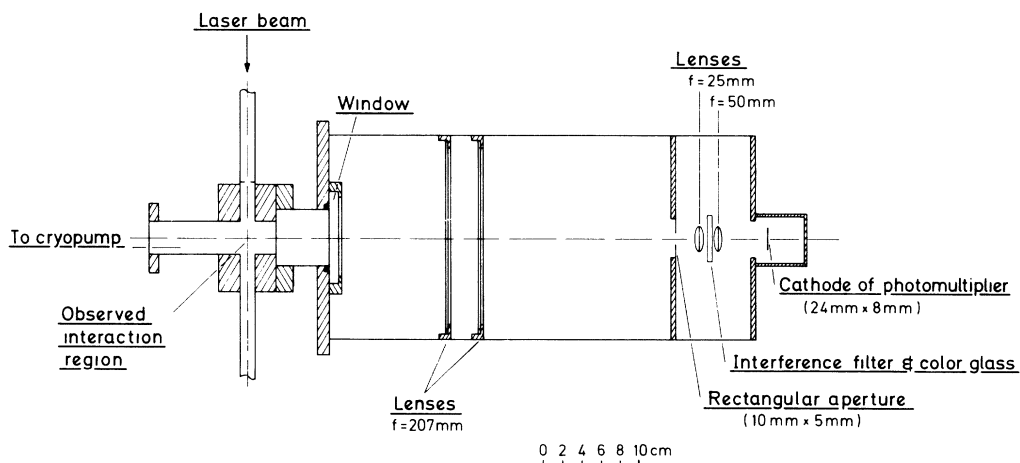


FIG. 4. Optical assembly for detection of fluorescent light. The glass window was positioned 10 cm away from the interaction region to avoid opaqueness resulting from condensation of the chemically reactive Am-Dy metal vapor. This geometry requires large Fresnel lenses, as shown. The collected light was made parallel a second time between the two small lenses to allow insertion of the various interference filters needed to suppress the light from the heated Ta foil.

gated atomic levels.

At the beginning of a lifetime measurement, the hyperfine pattern of the selected optical transition was scanned with a dc laser beam having an intensity of a few mW/mm². A typical scan is shown in Fig. 6. The hyperfine pattern was compared to that of Conway *et al.*,⁵ verifying that the desired transition was found. In the next step, the laser frequency was tuned onto the most intense hyperfine component and the laser beam

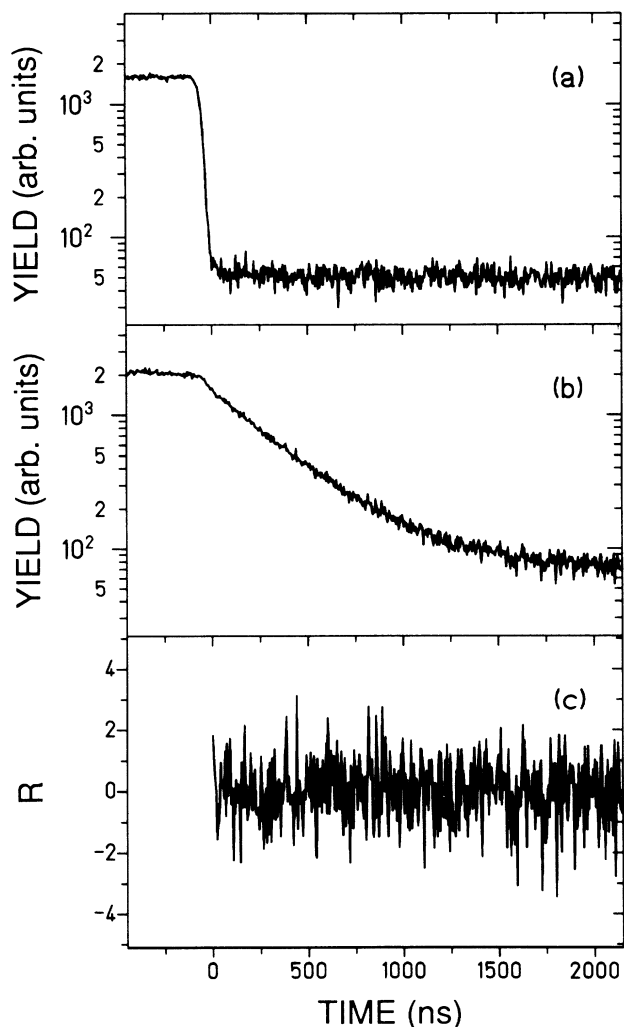


FIG. 5. Lifetime measurements of the $J = \frac{5}{2}$, $\bar{\nu} = 17858 \text{ cm}^{-1}$ transition. The laser beam was tuned at the most intense $F = 5$ hyperfine transition, cf. Fig. 6. (a) Prompt decay curve after switching off the laser light with the optoacoustic modulator. For this measurement the Am vapor pressure was negligibly small and the laser beam was steered off axis to increase the stray light. The counts for $t > 0$ are due to the photomultiplier dark current. (b) Lifetime measurement at a catcher foil temperature of about 720°C (measuring time 328 s). A best fit to Eq. (2) was performed in the interval $0 < t < 3876 \text{ ns}$. The χ^2 per degree of freedom is 1.08. (c) Relative deviation R of the measured values from the fit normalized with respect to the statistical error. No systematic deviation, such as those from oscillations due to quantum beats, can be observed in this measurement.

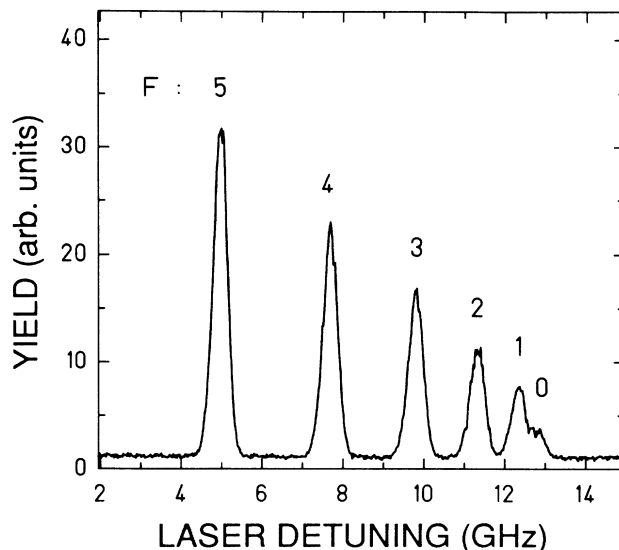


FIG. 6. Hyperfine pattern of the $\bar{\nu} = 17858 \text{ cm}^{-1}$ ground-state transition. The hyperfine splitting is caused by the $J = \frac{5}{2}$ excited state since the ground-state hyperfine splitting is only about 0.4 GHz [L. Armstrong and R. Marrus, Phys. Rev. **144**, 994 (1966); see also Ref. 4]. The hyperfine components are assigned by the total angular momentum quantum number F (the nuclear spin of ^{243}Am is $I = \frac{5}{2}$).

was chopped with the optoacoustic modulator. The density of the americium atoms in the laser-interaction region was controlled by adjusting the temperature of the Ta foil so that the probability of detecting a photon in the laser-off period was less than 2%. This low value was chosen to keep “pileup” corrections to a minimum since the TAC could only accept one stop signal during the laser-off period. If there were a high probability for detection of multiple photons during a beam-off period, this would bias the results to give an apparent lifetime that was too short. By maintaining our stop rate at less than 2% of the start rate, we make this effect rather small in our experiment. We nevertheless corrected for it using the formalism described in Ref. 7. Typical corrected spectra are shown in Fig. 5. To collect a spectrum of the statistical significance shown, a counting time of 300–1200 s was required.

III. EVALUATION OF DATA

In order to determine the mean lifetime τ a function

$$f(t) = a_1 + a_2 \exp(-t/\tau) \quad (2)$$

was fitted to the “pileup” corrected data. The time interval for analysis began when the scattered laser light approached the background level after switching off the laser beam, and ended at the maximum time accepted by the TAC. An example of such a fit is shown in Fig. 5(b) and 5(c). The lifetime-measurement procedure was checked by measuring the lifetime of the $^6\text{P}_{7/2}$ level of Eu I ($\lambda = 5765 \text{ \AA}$). This lifetime has been determined by pulsed dye-laser excitation and time-resolved observation of the fluorescence light to be $875 \pm 25 \text{ ns}$ (Ref. 6) or

760±50 ns.⁸ Our experimental results of 839±9 and 846±11 ns determined with a stop rate of 1.8% and 0.56% of the start rate, respectively, are in accord with these measurements. The lifetimes of the various americium levels are presented in Table I. For the transitions with lifetimes longer than 1 μs, the fit over the whole TAC range represented only a lower limit to the lifetime since excited americium atoms could migrate out of the space observed by the photomultiplier before deexcitation. An exact correction for this flight-out-of-view effect was not possible. However, a correct lifetime could be obtained in some cases by a fit of the experimental data with Eq. (2) in the limited time interval $0 \leq t \leq 0.8 \mu\text{s}$, for which the flight-out-of-view effect was estimated to be negligible. (An americium atom with the most probable velocity for a temperature $T=1000$ K traverses the 4-mm slit observed by the photomultiplier in 15 μs.) In these fits the background parameter a_1 was kept constant to its known value. For the $\bar{\nu}=21\,846 \text{ cm}^{-1}$ transition, the statistical significance of the data in the limited time interval was only sufficient to estimate a lower limit of the lifetime from the fit in the total time domain.

The measured distributions of the $\bar{\nu}=15\,608$, 16 512, 18 504, and 21 354 cm^{-1} transitions indicate weak oscillating deviations from the fit function, Eq. (2). These oscillations probably originate from quantum beats in the

earth's magnetic field, for which we did not compensate. However, model calculations showed that fits with pure exponentials to data exhibiting such oscillations result in uncertainties in the lifetime of the order of less than 2%. The errors on these four lifetimes have been increased accordingly. In addition, to compensate for nonlinearities of the analog-to-digital converter and uncertainties in the time calibration, a systematic error of 1% was added quadratically to the statistical error of all lines quoted in Table I.

IV. DISCUSSION

In contrast to the chemical homolog europium, most of the terms of Am I have not been identified. The reason is that in Am I the $5f^6d7s^2$ configuration is energetically nearly degenerate with the $5f^77s7p$ configuration.^{4,9} This fact complicates the level structure since both configurations have even parity and, therefore, are subject to strong configuration mixing. Therefore the $z^{10}P_{7/2,9/2,11/2}$, $z^8P_{5/2,7/2,9/2}$, $z^6P_{3/2,5/2,7/2}$, and $y^8P_{5/2,7/2,9/2}$ terms of the $5f^7(^8S_{7/2})7s7p(^3P)$ configuration may have strong admixtures of the $5f^6d7s^2$ configuration. For this reason only the $z^{10}P_{7/2,9/2}$ term of the $5f^77s7p$ configuration⁴ and the $^8F_{5/2}$ term of the $5f^6d7s^2$ configuration⁵ have been identified out of the

TABLE I. Results of the lifetime measurements. Included are wave numbers $\bar{\nu}_{241}$, wavelengths λ for ²⁴¹Am, isotope shifts, and spin assignments J .

$\bar{\nu}_{241}$ (cm^{-1}) ^a	λ (Å) ^a	J ^b	$(\bar{\nu}_{243} - \bar{\nu}_{241})$ (10^{-3} cm^{-1}) ^a	Lifetimes This work (ns)	Configuration ^{a,b}
00 000.000		$\frac{7}{2}$	(600)		$5f^77s^2(^8S_{7/2}^o)$
15 608.15	6405.1	$\frac{7}{2}$	364	772±23	$5f^77s7p(^{10}P_{7/2})$
16 511.69	6054.6	$\frac{9}{2}$	398	190±3	$5f^77s7p(^{10}P_{9/2})$
17 858.18	5598.1	$\frac{5}{2}$	763	349±4	$5f^6d7s^2(^8F_{5/2})$
18 429.09	5424.7	$\frac{5}{2}$	577	299±3	
18 504.40	5402.6	$\frac{7}{2}$	447	239±4	
18 701.44	5345.7	$\frac{7}{2}$	821	4250±400	
19 993.60	5000.2	$\frac{7}{2}$	842	1810±50	
20 031.33	4990.8	$\frac{5}{2}$	649	432±5	
21 239.91	4706.8	$\frac{9}{2}$	747	243±8	
21 354.01	4681.7	$\frac{9}{2}$	543	133.4±1.5	
21 440.38	4662.8	$\frac{7}{2}$	600	51.3±0.6	
21 845.97	4576.2	$\frac{9}{2}$	854	> 7200	
23 307.50	4289.3	$\frac{9}{2}$	738	65.1±0.7	
23 437.04	4265.6	$\frac{9}{2}$	756	63.9±0.7	
27 217.06	3673.1	$\frac{5}{2}$	523		$5f^77s7p(^8P_{5/2})^c$
28 009.78	3569.2	$\frac{7}{2}$	527		$5f^77s7p(^8P_{7/2})^c$
28 480.85	3510.1	$\frac{9}{2}$	606		$5f^77s7p(^8P_{9/2})^c$

^aSee Ref. 4.

^bSee Ref. 5.

^cProposed in this work.

various levels listed in Table I for which we have measured the lifetime. For the term identification, the isotope shifts are of essential importance because of their dependence on the configurations. According to Hartree-Fock calculations of the electron densities,¹⁰ the isotope shifts are 0.650, 0.360, and 0.890 cm^{-1} for the $(5f^7 7s^2)$, $(5f^7 7s 7p)$, and $(5f^6 6d 7s^2)$ configurations, respectively. The ${}^8F_{5/2}$ term of the $5f^6 6d 7s^2$ configuration at $\bar{\nu}=17858 \text{ cm}^{-1}$ has a rather short lifetime and, therefore, must have strong admixtures of the $5f^7 7s 7p$ configuration. In this context, it is interesting to note that the three levels with the largest isotope shifts, at $\bar{\nu}=18702$, 19993, and 21846 cm^{-1} , also have the longest lifetimes. This could indicate that these terms are rather pure $5f^6 6d 7s^2$ configurations. The deduced oscillator strengths of the $z {}^{10}P_{7/2,9/2}$ terms are about a factor of 2.9 and 5.3 larger than for europium,¹¹ reflecting the well-known breakdown of the LS -coupling scheme in heavy atoms.

As already mentioned, the resonance transitions (i.e., allowed transitions with the largest transition rates to the ground state) are of special importance for optical-pumping experiments on Am fission isomers. These transitions, originating from the $y {}^8P_{5/2,7/2,9/2}$ terms, give rise in europium to three strong lines at $\lambda=4661.9 \text{ \AA}$ ($J=\frac{5}{2}$), 4627.2 \AA ($J=\frac{7}{2}$) and 4594.0 \AA ($J=\frac{9}{2}$). Where are the homologs of these lines in americium? In trying to answer this question we first of all note that the measured lifetimes of the Am I levels, as collected in Table I, are at least one order of magnitude longer than those expected for the resonance transitions (5.6 ns in Eu I). This indicates that the resonance transitions in Am are not in the wavelength region accessible to our laser, but most probably are located in the ultraviolet. This finding is in contradiction to the conjecture of Fred and Tomkins⁴ that the strong lines at 21240, 21354, and 21440 cm^{-1} are probably the homolog transitions. Also, the spin assignments $\frac{9}{2}$, $\frac{9}{2}$, and $\frac{7}{2}$, respectively, of Conway *et al.* for these visible transitions are also at variance with the conjecture of Fred and Tomkins.

To identify the resonance transition in americium, we use the line intensity estimates I_{ki} deduced from an electrodeless discharge tube.⁴ Assuming a local thermal equilibrium with electrons in the discharge (see Ref. 12), the line intensity I_{ki} from an atomic level with energy E_k and a statistical weight g_k to a level with energy E_i and a statistical weight g_i is (see, e.g., Ref. 13)

$$I_{ki} = C [A_{ki} g_k / (g_i \lambda_0)] \exp(-E_k / kT), \quad (3)$$

where A_{ki} is the spontaneous transition probability, λ_0 the wavelength of the transition, and k the Boltzmann constant. To determine the unknown electron temperature T in the discharge and the constant C , the quantity $\log_{10}[I_{ki} \lambda_0 g_i / (A_{ki} g_k)]$ is plotted in Fig. 7 as a function of the energy E_k . The spontaneous transition probability was approximated by $A_{ki} = 1/\tau_k$, assuming that branches to other excited levels can be neglected. The lifetimes τ_k , statistical weights $g = 2J + 1$, and energies E_k were taken from Table I; the intensities I_{ki} from Ref. 4, assuming an uncertainty of $\pm 35\%$. Although the experimental inten-

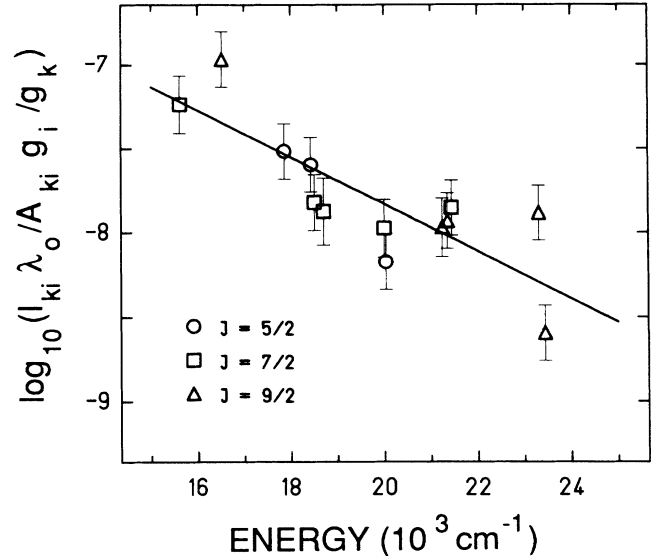


FIG. 7. Quantity $\log_{10}[I_{ki} \lambda_0 g_i / (A_{ki} g_k)]$ as a function of the level energy E_k in an electrodeless discharge. The line intensities I_{ki} are taken from Ref. 4, all other quantities from Table I of this work. The solid line represents a best fit using the rearranged equation (3).

sities fluctuate somewhat (probably due to systematic errors in the line-intensity determinations), a best fit with the rearranged equation (3) yields a reasonable¹² temperature $T=4481(13) \text{ K}$ and a constant $C=9.7(3.4) \times 10^{-6} \text{ cm s}$.

With these values we are able to determine the ground

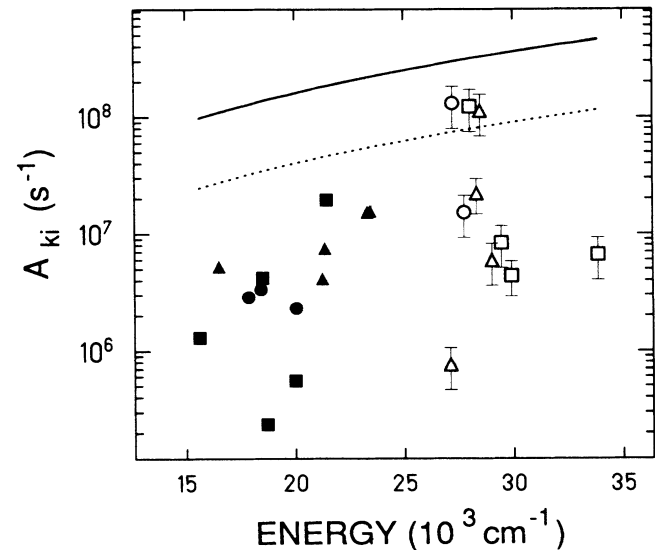


FIG. 8. Open symbols, transition probabilities A_{ki} as a function of level energy from Eq. (4) using intensities I_{ki} of an electrodeless discharge tube spectrum (see Ref. 4). The electron temperature $T=4481(13) \text{ K}$ and the constant $C=9.7(3.4) \times 10^{-6} \text{ cm s}$ were taken from the best fit shown in Fig. 7. Closed symbols, transition probabilities from this work. Spin assignments are indicated as in Fig. 7. The solid line was calculated from Eq. (5) assuming $f_{\text{red}}=0.64$, $\alpha_i^{\text{Am}}=0.882$, and $|\alpha_k^{\text{Am}}|=1$; dotted line, assuming $(\alpha_k^{\text{Am}} \alpha_i^{\text{Am}})^2=0.25$.

state transition probabilities A_{ki} from the known intensities I_{ki} of Ref. 4 by calculating

$$A_{ki} = [I_{ki} \lambda_0 g_i / (C g_k)] \exp(E_k / kT). \quad (4)$$

The results are shown in Fig. 8. The quoted standard deviations include the uncertainties in the intensities of Ref. 4 and the fit values of T and C . This graph strongly suggests that the homologs of the strong Eu I transitions from the $y^8P_{5/2,7/2,9/2}$ terms to the ground state, are also the three lines with the largest intensity in Am I. These transitions originate from the levels at $\bar{\nu} = 27\,217$, $28\,010$, and $28\,481\text{ cm}^{-1}$ (also added in Table I) which have, according to Conway *et al.*, the right spin assignments: $J = \frac{5}{2}$, $\frac{7}{2}$, and $\frac{9}{2}$, respectively. For the $J = \frac{7}{2}$ and $\frac{9}{2}$ levels this assignment was proposed independently by Dembczynski.¹⁴

This assignment is corroborated by the ground-state-transition probabilities as estimated from the line intensities. Assuming that the reduced oscillator strength $f_{\text{red}} = f_{ki} / (\alpha_k^2 \alpha_i^2)$ for homologous transitions is constant (see, e.g., Ref. 15), the transition probabilities in americium can be calculated from the measured A_{ki} values in europium,⁸ the amplitudes $|a_k^{\text{Eu}}| = 0.865$ of the pure $y^8P_{5/2,7/2,9/2}$ LS term in the excited states,¹⁶ and the amplitude $\alpha_i^{\text{Eu}} = 0.9876$ (Ref. 17) of the pure $^8S_{7/2}$ LS term in the ground state,

$$A_{ki} = f_{\text{red}} [8\pi^2 e^2 / (m_e c \lambda^2)] (\alpha_k^{\text{Am}} \alpha_i^{\text{Am}})^2. \quad (5)$$

The analysis of the ground-state hyperfine structure¹⁸ yields $\alpha_i^{\text{Am}} = 0.882$. On the other hand, it can be concluded from the rather large isotope shifts that the $y^8P_{5/2,7/2,9/2}$ terms must have considerable admixtures, probably again from the $(5f^6 6d 7s^2)$ configuration. The full line in Fig. 8 was calculated with Eq. (5), using $f_{\text{red}} = 0.64$ and assuming that the $y^8P_{5/2,7/2,9/2}$ terms in americium are pure- LS terms, i.e., $|\alpha_k^{\text{Am}}| = 1$; the dotted line corresponds to $(\alpha_k^{\text{Am}} \alpha_i^{\text{Am}})^2 = 0.25$. This value should be a lower limit. It can clearly be seen that only the three

lines at $27\,217$, $28\,010$, and $28\,481\text{ cm}^{-1}$ fall within this band, corroborating again the proposed assignment.

V. CONCLUSIONS

Lifetimes have been measured for 14 levels of Am I having electric dipole transitions to the ground state in the visible-wavelength range. These results have been combined with an analysis of the line intensities in an electrodeless discharge tube measured in earlier work and extending into the ultraviolet. The conclusion is that the resonance transitions lie in the ultraviolet. These resonance transitions, which should be best suited for optical-pumping experiments on Am fission isomers, therefore can currently be excited only by frequency doubling of a dye-laser beam. On the other hand, there are a few short-lived levels in the visible that may be of use in optical-pumping experiments, should the effort of frequency doubling not be warranted.

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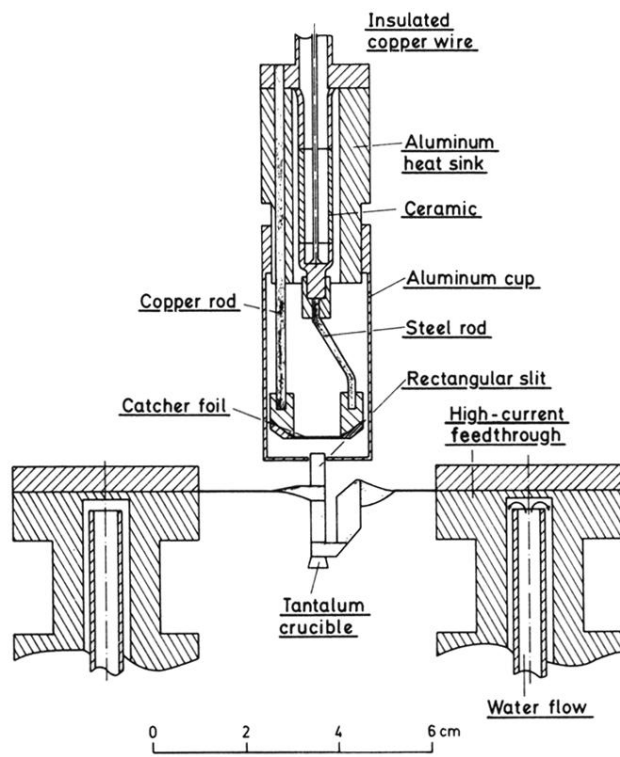


FIG. 2. Experimental arrangement depicted during the reduction procedure. The $\text{AmO}_2\text{-Dy}_2\text{O}_3\text{-La}$ pill was placed in the tantalum crucible, made from a 3-mm-diam, 25-mm-long Ta tube, and was heated by an electrical current of about 50 A. The metal vapor condensed on a $10 \times 8\text{-mm}$ tantalum foil of thickness 0.0075 mm. To avoid reevaporation of the Am metal, the catcher foil was connected via a copper rod to an aluminum heat sink.

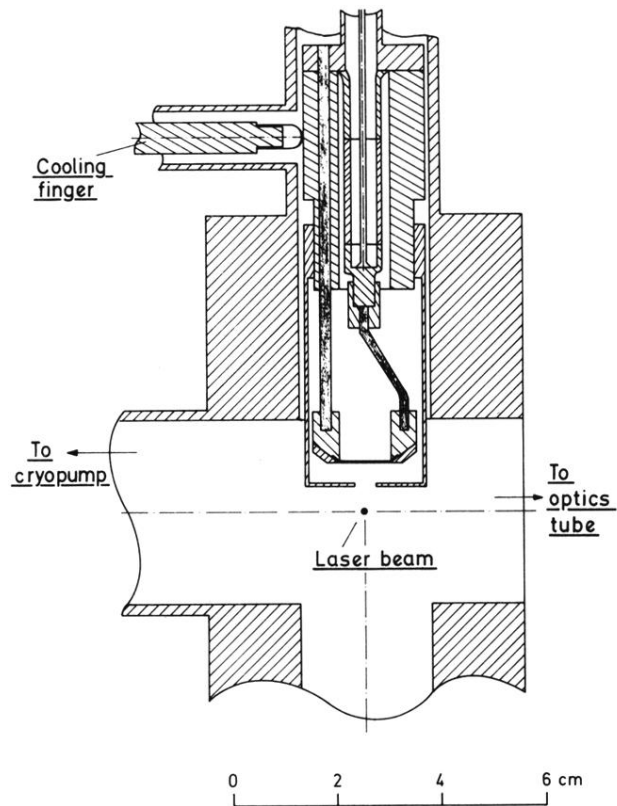


FIG. 3. Experimental arrangement in the upper part of the apparatus as used for the lifetime measurement. The laser beam entered the interaction region perpendicular to the plane of the drawing. The americium metal was reevaporated by heating the Ta foil electrically with a current of about 6.5 to 8.5 A (corresponding to a temperature of about 740 to 870 °C). To avoid degassing problems and the associated rapid oxidation of the Am-Dy metal layer, the whole catcher-foil assembly was brought into contact with a liquid-N₂-cooled copper finger.