sumption that β_1 is the theoretical value of Sliv[28] or Rose,[29] one finds that for all possible values of δ within the experimental error, $\alpha_{2\,\mathrm{exp}}$ is slightly smaller than the theoretical $E2$ conversion coefficient. With the same values of α_K and δ, but $\beta_{1\,\mathrm{theor}}$ lowered by 10% from the Sliv or Rose values, as indicated by the Kisslinger calculation, $\alpha_{2\,\mathrm{exp}}$ is equal to the theoretical $E2$ conversion coefficient within experimental error. Thus, our experimental results for the mixing amplitude δ do not suggest that experimental $E2$ K-conversion coefficients are larger than the theoretical predictions. Recent measurements[30] of $E2$ transitions in Pt^{194}, Pt^{196}, and Hg^{198} actually indicate that experimental $E2$ conversion coefficients in these nuclei are 10% lower than the theoretical values.

[28] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Reports, 1956 [translation: Reports 57ICC K1 and 58ICC L1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].
[29] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).
[30] C. DeVries, E. J. Bleeker, and N. Salomons-Grobben, Nuclear Phys. 18, 454 (1960).

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Lifetime of the 279-kev State of Tl^{203}†

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The lifetime of the first excited state of Tl^{203} at 279 kev has been measured using the delayed coincidence technique. From analysis of the exponential decay observed with an electronic time-to-pulse-height converter, the mean life was determined to be $(4.05\pm0.08)\times10^{-10}$ sec. The decay of this state was observed using sources of Hg^{203} and Pb^{203}, both sources yielding the same mean life within statistical errors. This value of the lifetime agrees very well with the recent determination by Deutsch and Metzger utilizing the resonance fluorescence method.

INTRODUCTION

THE lifetime of the first excited state of Tl^{203} has been measured many times both directly by delayed coincidence methods and indirectly by resonance fluorescence and Coulomb excitation.[1,2] Since the various coincidence measurements showed very poor consistency it was never possible to either compare the methods or to be sure of the lifetime of this state. Further, the transition from the first excited state is known to display anomalous internal conversion coefficients. Although consideration of nuclear systematics as well as the internal conversion data would not admit the existence of two states near 279 kev, such a situation might have explained both the anomalous conversion coefficients as well as the dispersion in lifetime measurements.

Although there is no reason to suspect that nuclear lifetimes and the state widths as determined from nuclear resonance fluorescence would not conform to the usual uncertainty relation such a discrepancy has been suggested.[3] The transition in Tl^{203} is particularly suited to checking this point, especially in view of the recent improvements in the delayed coincidence method which allows the direct observation of the exponential decay without recourse to centroid measurements. Both the fluorescence and the electronic measurements can now be performed with errors of less than 5%. The resonance measurement is reported by Deutsch and Metzger in the preceding paper.

In an attempt to clarify the situation we have remeasured this lifetime using the improved fast coincidence technique.[4,5] In order to obviate any experimental difficulties as well as to prove the singularity of the 279-kev state, we have observed the exponential decay of this state when it is populated by the β^- decay of Hg^{203} and, in a second measurement, when populated by the γ decay of the 680-kev level of Tl^{203} which is fed in the K capture of Pb^{203}.

$Hg^{203} \rightarrow Tl^{203}$ MEASUREMENT

Hg^{203} (47-day) was obtained from Oak Ridge National Laboratory. β^--γ delay measurements were obtained using the fast-coincidence system described previously[4,5] in connection with measurements of the first excited states of O^{17} and F^{17}. A diphenyl acetylene scintillator $\frac{3}{8}$ in diam$\times\frac{1}{8}$ in. thick was mounted on a 56AVP phototube for the detection of β^- particles. The γ detector was a $1\frac{1}{2}$ in.$\times1\frac{1}{8}$ in. plastic scintillator (Pilot B) mounted on an RCA 7264 phototube.

The time spectrum obtained as well as a comparison with the spectrum obtained with identical energy channels using a Au^{198} source is shown in Fig. 1. The data analysis was performed by analysis of the exponen-

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] For a review of earlier work see E. Bashandy, T. R. Gerholm, and J. Lidskog, Arkiv Fysik 17, 421 (1960).
[2] A summary of the more recent measurements is given by B. Deutsch and F. Metzger, preceding paper [Phys. Rev. 122, 848 (1961)].
[3] V. Knapp, Proc. Phys. Soc. (London) A71, 194 (1958).
[4] R. E. Bell and M. H. Jorgensen, Nuclear Phys. 12, 413 (1959).
[5] J. V. Kane, R. Pixley, R. Schwartz, and A. Schwarzschild, Phys. Rev. 120, 162 (1960).

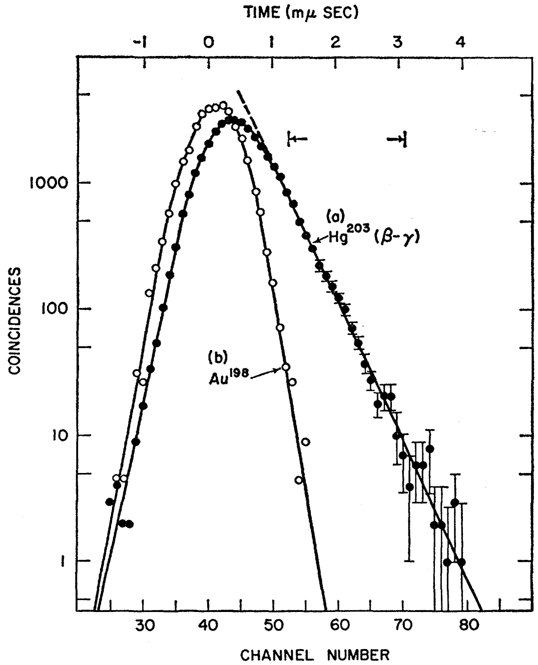

FIG. 1. Time distribution of coincidences. (a) Hg^{203} source and (b) Au^{198} source. Accidental coincidences (~1 count per channel) have been subtracted from the Hg spectrum.

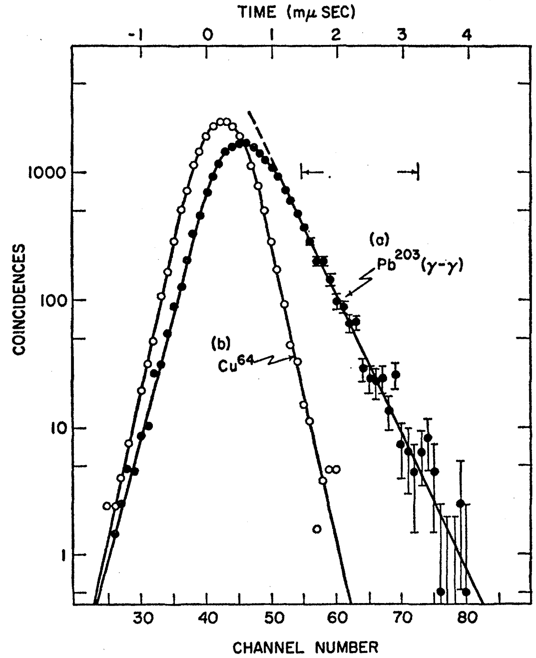

FIG. 2. Time distribution of coincidences. (a) Pb^{203} source and (b) Cu^{64} source (annihilation radiation). Accidental coincidences (~4.5 counts per channel) have been subtracted from the Pb spectrum.

tial tail over the range of delays shown in Fig. 1 by the arrows. This measurement gives a mean life for Tl^{203*} of $(4.06\pm0.08)\times10^{-10}$ sec. The least-squares fit to the logarithmic decay resulted in an external error equal to 0.97 times the internal error.

$Pb^{203} \rightarrow Tl^{203}$ MEASUREMENT

The equipment employed in this measurement was identical to that used for the Mass 17 measurements.[4] γ-γ coincidences were obtained from the 401-kev-279 kev cascade. Absorbers mounted on the 401-kev detector to minimize backscattering of 680-kev photons from the 404-kev detector. This effect could simulate a cascade transition as far as the energy channels were concerned but would appear like a nearly prompt source of coincidences in the time spectrum. With a 2-g/cm^2 (Pb-Cd-Cu) graded absorber in front of the 401-kev detector, it was found that the centroid shift of the prompt vs delayed coincidence curves was consistent with the lifetime determined from the exponential decay. Figure 2 exhibits the time spectrum obtained as well as that due to coincidences of annihilation radiation obtained from a Cu^{64} source. The best fit to this curve using the least-squares method is given by a mean life for Tl^{203*} of $(4.02\pm0.14)\times10^{-10}$ sec. The least-squares fit to the logarithmic decay exhibited an external error of 1.2 times the internal error.

TIME CALIBRATION AND SYSTEMATIC ERRORS

Until recently the delayed-coincidence method, when used to determine lifetimes under 10^{-9} sec, depended upon the observation of the displacement in the centroid of the time spectrum of the delayed radiation relative to that of a known prompt cascade. In principle, this method can provide accurate results[6]; in practice extreme care must be taken to avoid systematic errors. The main sources of systematic error which have been difficult to evaluate were centroid shifts due to (1) variation of counting rate, (2) differences in pulse spectra of the prompt and delayed source, (3) differences in the spatial distributions of interactions within the scintillators, (4) scattering of radiations from one scintillator to the other, (5) variation of the system gain, and (6) errors in time calibration. If the exponential decay is observed, the main systematic errors in the observed slope are expected to be due only to (5) and (6) above. We have taken great care to stabilize the operating conditions of our system. In addition, we intersperse time calibrations with the measurements of the time spectra of the delayed radiation. We have observed that the time calibration (i.e., mμ sec per channel) changes by only a few percent in several days (even though the centroid positions at a given delay may change by 2×10^{-10} sec over this period). This effect is shown in Fig. 3.

Our time calibrations are performed by observations of the centroid of the distribution obtained from a prompt cascade as a function of inserted delay. The delay is produced by variation of two (120-ohm) air-core trombones. The air-core trombones have a velocity

[6] T. D. Newton, Phys. Rev. **78**, 490 (1950).

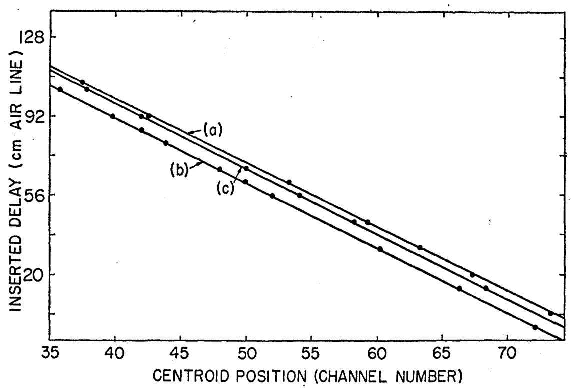

FIG. 3. Calibration runs using an annihilation radiation source (Cu^{64}), taken on three consecutive days. (a) Monday, (b) Tuesday, (c) Wednesday. The apparatus was left running continuously over this period.

for our signals of c, within 1%, as measured with a source of annihilation radiation.[5] We were able to obtain a linear delay vs centroid position over a 4×10^{-9}-sec range (Fig. 3), the deviation of any point from the best-fit straight line being less than 3×10^{-11} sec.

DISCUSSION

Table I presents the results of our measurements. In addition to the value of the exponential slopes we also present the centroid shifts of the delayed relative to prompt distribution. (The Au^{198} cascade is not truly prompt and our results are corrected assuming a lifetime of 3×10^{-11} sec for the 411-kev state of Hg^{198}.) The errors presented for the centroid shifts are based on the observed reproducibility of the results. For the reasons mentioned above, we do not consider the centroid shifts to be as systematically reliable as the exponential decay.

TABLE I. Results of the separate lifetime measurements.

Source	Mean life and error (standard deviation) (10^{-10} sec)
	Exponential decay
Hg^{203}	4.06±0.08
Pb^{203}	4.02±0.14
	Centroid displacement
Hg^{203}	4.2±0.1
Pb^{203}	4.3±0.1

Our estimation of systematic errors precludes the combination of the two slope measurement for purposes of reducing the quoted error. We therefore give the final value $(4.05\pm0.08)\times10^{-10}$ sec for the mean life of this state. There is no visible support for the idea that this state is really two closely spaced states.

This measurement is in very good agreement with recent measurements using other techniques.[2] Discussion of this point, as well as the significance of the measured value, is given in this last reference.

During the course of this work another measurement of the lifetime, utilizing equipment similar to ours, was reported by Gorodetsky *et al.*[7] It is significant that within the small errors quoted our results agree with theirs.[8]

[7] S. Gorodetsky, R. Manquenouille, R. Richert, and A. Knipper, Compt. rend. **251**, 65 (1960).

[8] *Note added in proof.* After submitting this paper a very recent publication by E. C. B. Pederson and R. E. Bell in Nuclear Phys. **21**, 393 (1960) has come to our attention. This paper reports a measurement of the Tl^{203*} lifetime using techniques similar to ours. Their result yields $\tau_m=(3.48\pm0.15)\times10^{-10}$ sec which is significantly smaller than our result. We have no explanation for the discrepancy. From the appearance of the data presented, it would seem that the only possible source of this difference can be in the time calibration.

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Nuclear Interactions in Deuterium Fluoride*

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The deuteron and fluorine magnetic resonance spectra in the molecule DF have been studied using the molecular beam method. The observed resonance patterns have been compared with those calculated on a UNIVAC computer. The parameters of the calculation were adjusted until the theoretical and the experimental curves matched. In this manner the spin-rotational interaction constant of fluorine in DF was assigned the value $|c_F|=160\pm1$ kc/sec and the quadrupole coupling constant of the deuteron in DF was assigned the value $|d_2|=34\pm4$ kc/sec, which corresponds to $|eqQ/h|=340\pm40$ kc/sec.

I. INTRODUCTION

THE Hamiltonian for a $^1\Sigma$ diatomic molecule in an external magnetic field has been discussed by Ramsey and Lewis.[1] The detailed theory of the molecule DF in a strong magnetic field is formally identical to that of the molecule HD under the same conditions and that theory has been discussed by Quinn, Baker, LaTourrette, and Ramsey,[2] as well as by Ramsey and Lewis.[1] However, in the case of DF, resolution of the various transitions is not accomplished experimentally.

To aid in the interpretation of the composite reso-

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[1] N. F. Ramsey and H. R. Lewis, Phys. Rev. **108**, 1246 (1957).

[2] W. E. Quinn, J. M. Baker, J. T. LaTourrette, and N. F. Ramsey, Phys. Rev. **112**, 1929 (1958).