Title
RELATIVISTIC MAGNETIC DIPOLE EMISSION: LIFETIME OF THE 1s2s3s STATE OF HELIUM-LIKE ARGON

Authors
Schmieder, Robert W.
Mirrus, Richard.

Publication Date
1970-08-01

Submitted to Physical Review
Letters

UCRL-19948 & errata
Preprint c.2

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Robert W. Schmieder and Richard Marrus

August 1970

AEC Contract No. W-7405-eng-48

LAWRENCE RADIATION LABORATORY
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October 13, 1970

ERRATA

To: All recipients of UCRL-19948

From: Technical Information Division

Subject: "Relativistic Magnetic Dipole Emission: Lifetime of the 1s2s $^3S_1$ State of Helium-Like Argon," by R. W. Schmieder and R. Marrus, dated August 1970.

Was	Should be	Location
172±15	172±30	Abstract, line 6 Page 2, second line from bottom Page 4, line 13
Schwartz	Swartz	Page 1, last line Ref. 5 (not Ref. 6!), p.6
(in press)	Phys. Letters 32A, 431(1970)	Ref. 8, p. 6

RELATIVISTIC MAGNETIC DIPOLE EMISSION: LIFETIME OF THE 1s2s $^3S_1$ STATE OF HELIUM-LIKE ARGON*

Robert W. Schmieder and Richard Marrus

Lawrence Radiation Laboratory
and Department of Physics
University of California
Berkeley, California 94720

August 1970

Abstract:

The lifetime of the 1s2s $^3S_1$ state of the helium-like atom Ar XVII has been measured by observing the decay in flight of the metastable component of a fast foil-excited beam. The decay occurs predominantly by relativistic magnetic dipole emission, a process first discussed by Breit and Teller. The result, $\tau(2^3S_1) = (172 \pm 15) \times 10^{-9}$ sec (95% confidence) is compared with a recent calculation by Drake of the M1 transition probability.

Until recently it was believed that the primary decay mode for the 1s2s $^3S_1$ state of two-electron atoms would be spin-orbit-induced double electric-dipole (2E1) emission. This process was first suggested by Breit and Teller,[1] and has been accurately calculated by Drake, Victor, and Dalgarno,[2] and Bely and Faucher.[3] However, in 1969 Gabriel and Jordan[4] reported the observation of solar coronal lines corresponding to the 1s2s $^3S_1$ - $1s^2$ $^1S_0$ energy separation for the helium isoelectronic sequence CV - Mg XI, and the Fe XXV line has been reported by Neupert and Schwartz,[5] indicating that the primary decay mode is single-photon emission. Single-photon emission also was discussed by Breit and Teller,[1] who pointed out that relativistic effects can lead to magnetic dipole radiation (this is identically zero in the nonrelativistic approximation). More recently Schwartz[6] and Drake[7] have studied this process and conclude that, to relative accuracy Z^{-1}, the dominant contributions come from kinetic energy and finite wavelength corrections to the magnetic dipole moment, which have non-zero matrix elements between the 1^1S_0 and 2^3S_1 states. Schwartz[6] has calculated the rate of this process using hydrogenic wave functions and energies. He obtains the asymtotic (to large Z) result $A_{M1}\ (2^3S_1 - 1^1S_0) = 1.66 \times 10^{-6}\ Z^{10}\ \mathrm{sec}^{-1}$, which yields, for argon $(Z = 18)$, $\tau_{M1}\ (2^3S_1) = 169$ nsec. More accurate calculations have been performed by Drake[7] using correlated wave functions and energies, with the result for argon, $\tau_{M1}\ (2^3S_1) = 194$ nsec.

The astrophysical importance of the lifetime of the 2^3S_1 state has recently been emphasized by Gabriel and Jordan.[9] These authors have developed a theory for deducing the electron density in the solar corona based on intensity measurements. A crucial parameter in this theory is the 2^3S_1 lifetime and they have derived a semi-empirical value[10] of $\tau_{M1}\ (2^3S_1) = 2.3 \times 10^{-10}\ \lambda^5$ sec (λ in Å) which yields for argon a value of 230 nsec. The $2^3S_1 - 1^1S_0$ transition in the helium-like ions Si XIII, S XV, and Ar XVII has been observed in the laboratory by Marrus and Schmieder[8] with the beam foil method, thus confirming the single-photon decay mode, but as yet no experimental lifetime of any 1s2s $^3S_1$ state has been reported.

In this letter we report the measurement of the lifetime of the 1s2s $^3S_1$ state of Ar XVII, using the beam-foil method. The result

$$\tau(2^3S_1) = 172 \pm 15 \text{ nsec} \qquad (95\% \text{ confidence}) \quad ,$$

may indicate a marginal disagreement with the calculation by Drake.

The apparatus used in this measurement is illustrated in Fig. 1. Argon-40 ions in the +14 charge state having an energy of 10.3 MeV/nucleon ($\beta = 0.148$) are obtained from the Berkeley HILAC and are magnetically deflected into the high vacuum region, where the pressure is a few microtorrs. The beam is passed through a 100 $\mu g/cm^2$ Be foil mounted on a movable track, emerging with the approximate charge distribution +16 (25%); +17 (50%); +18 (25%). Some of the ions emerging with +16 or +17 charge will be excited, and will quickly de-excite to the 1S ground states or the 2S metastable states. Ions in the 1s $^2S_{1/2}$ (hydrogen-like) and 1s2s $^1S_0$ (helium-like) states decay to their ground states with 1/e decay lengths of a few cm (for our beam velocity $v = 0.148\ c$), and at distances over 75 cm, only the 1s2s $^3S_1 - 1s^2\ ^1S_0$ decay (with 1/e length $\cong$ 750 cm) is appreciably present. The photons ($E \cong 3.1$ keV) emitted in flight are detected with a windowless Si(Li) x-ray detector of the type normally used for nuclear gamma spectroscopy. The resolution of this device (cooled to 77°K) is about 200 eV at 3 keV, but we purposefully permitted a large doppler broadening so the detector would have a large angular field of view. The broadening is of no consequence to this measurement since only the total number of counts within the peak was used in determining the lifetime.

Pulse shaping and timing is performed with conventional electronics, and pulse-height analysis is performed with an analog-to-digital converter and a PDP-7 computer. Signal (No. counts within full-width at 0.1 maximum of peak) was normally 50 to 100 times background (No. counts within equal width, away from peak). A typical spectrum is shown in Fig. 2; further information on the identification of this line is given in Ref. 8.

The lifetime was determined by plotting the count rate (peak minus background) for several foil-detector distances between 75 cm and 200 cm. The rates were normalized to a total charge of beam passing the detector (0.030 namp-hr), as measured by an integrating electrometer driven by the Faraday cup which stops the beam. In order to compensate for slow variations in the beam and/or apparatus, the data was accumulated in short time intervals (∿ 3 min), moving the foil cyclically through 5 or 6 positions. Successive counts for each position were then averaged. Also, two independent detectors (facing each other) were used, and the results averaged. In each of six independent runs, about 10^5 photons were recorded for each foil-detector distance.

A typical decay curve obtained in this way is shown in Fig. 3. Although the total decay is small, the count rate appears to decay exponentially. The lifetime was computed by performing a least-squares fit of the data to the function ae^{-bx}, determining b, and thus $\tau = 1/bv$. The final result, $\tau(2^3S_1) = 172 \pm 15$ nsec, was obtained as a weighted average of the results of the independent runs. The error quoted here is 2 times the mean error, or roughly 95% confidence. The main contributions to the mean error are believed to be due to slow drifts in beam and/or foil properties, and other systematic errors such as foil tracking, beam current integration, and detector efficiency (nominally 80%). The beam velocity, necessary for converting the mean decay length to a mean lifetime, is known from time-of-flight measurements to within 2%. Correction for velocity degradation by the foil has been made. Background corrections were typically 1%.

In order to test the pressure dependence of the measurements, the pressure was increased by a factor of 2.5. No significant deviations in the count rates were observed, implying that collision quenching between the foil and detector (typically ∿ 10^{13} residual gas atoms per cm^2) is negligible. We have also shown that these results are independent of foil material (a 15 μg/cm^2 C foil and a 600 μg/cm^2 Ni foil were also used), beam burrent, count rate, detector operation, etc.

The chief uncertainty in the interpretation of the data in Fig. 3 is whether the decay is truly exponential. Although this difficulty is unresolvable at the present time, reasonable arguments can be made that "feeding" of the 2^3S_1 state from higher states should be quite negligible beyond 100 cm ($\tau \sim 25$ nsec). Furthermore, we have observed decays of other long-lived states ($2^2s_{1/2}$, 2^3P_2) which are exponential over many mean lives. It is unlikely that Fig. 3 represents any decay but the pure 2^3S_1 state.

We are grateful to A. Ghiorso for his encouragement of this work, to F. Goulding and J. Walton for assistance with the detectors, to F. Grobelch for providing the foils, to R. Diamond and F. Stephens for use of the computer, to D. MacDonald for engineering in all phases of the apparatus, to W. Harnden and W. Davis for assistance in taking the data, and to the operating staff of the Berkeley HILAC throughout these measurements. G. W. F. Drake kindly sent a preprint of his calculations prior to publication.

FOOTNOTES AND REFERENCES

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

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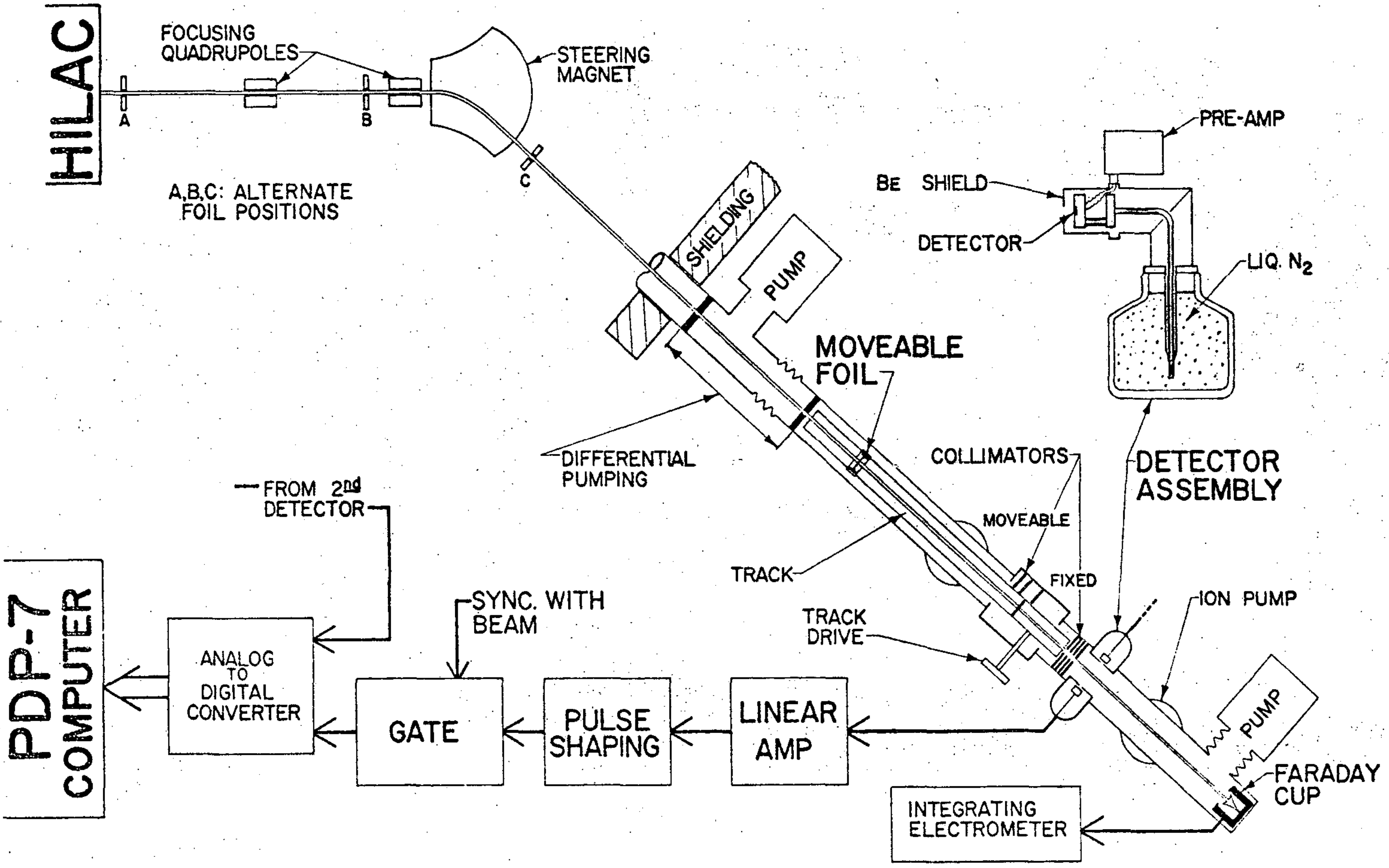
FIGURE CAPTIONS

Fig. 1. Schematic diagram of the apparatus.

Fig. 2. Typical spectrum obtained with the foil at 190 cm. The peak at 3.10 keV is the $2^3S_1 - 1^1S_0$ M1 line; the rise below 500 eV is noise of electronic origin. The line is doppler-broadened to about twice the detector resolution.

Fig. 3. Typical decay curve (semilog scale). The line represents the mean lifetime determined by least squares from several such plots, obtained independently. The statistical error on each point is roughly the size of the points.



XBL 708-1790

Fig. 1

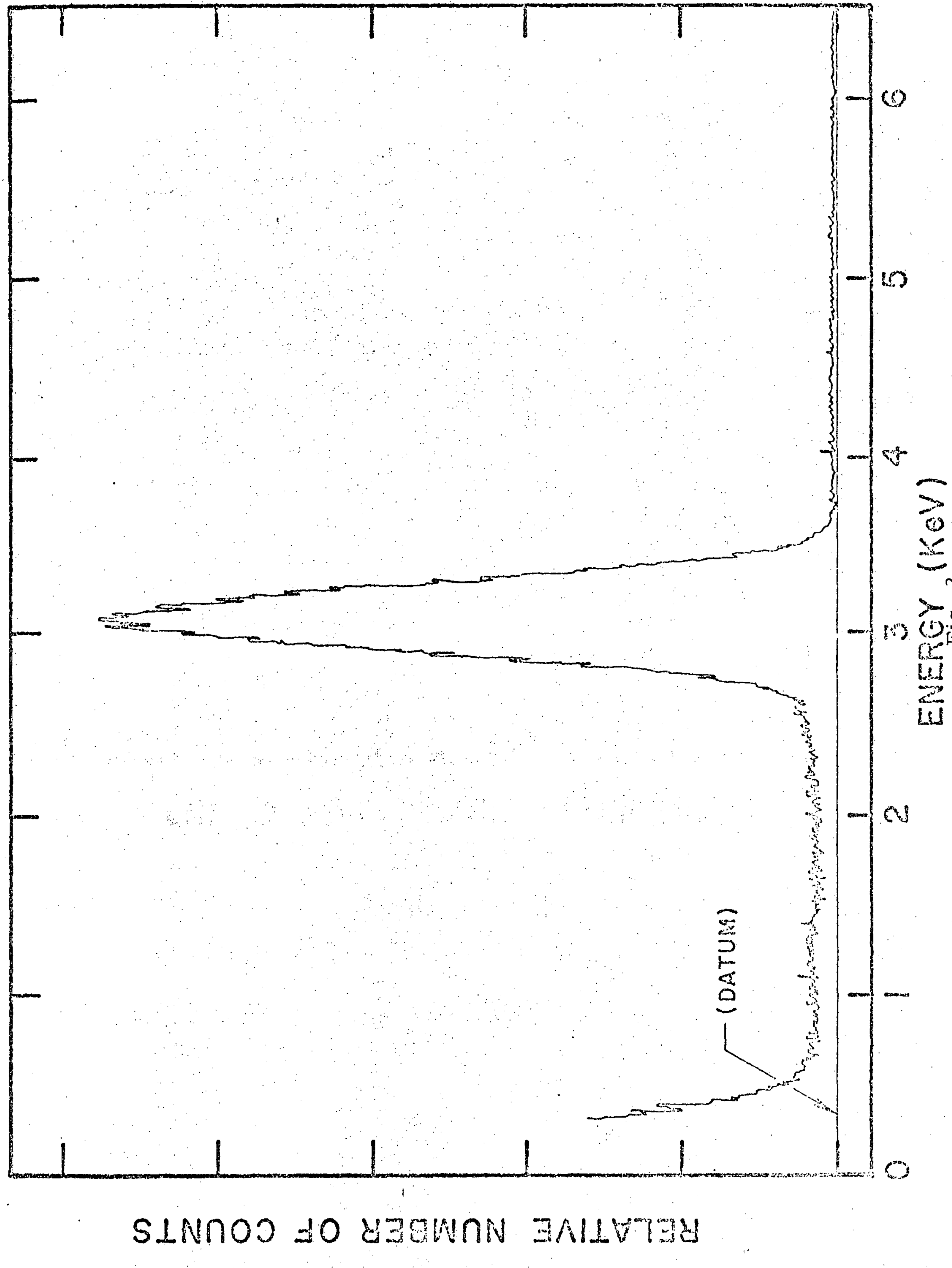
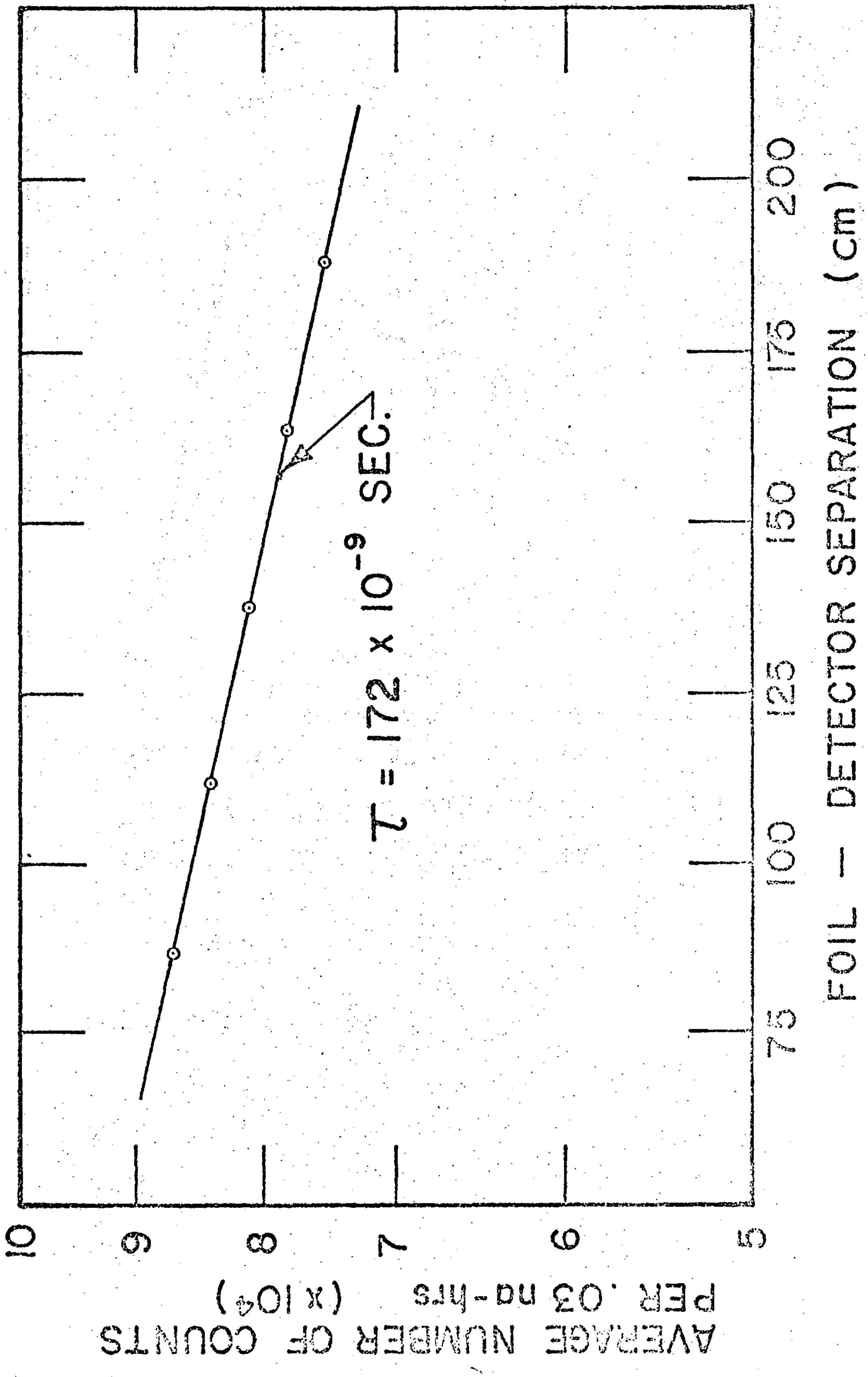


Fig. 2



τ = 172 x 10^{-9} SEC.
FOIL — DETECTOR SEPARATION (cm)
75
100
125
150
175
200
AVERAGE NUMBER OF COUNTS
PER .03 na-hrs (x 10^4)
10
9
8
7
6
5

Fig. 3

TECHNICAL INFORMATION DIVISION
LAWRENCE RADIATION LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720