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LAWRENCE RADIATION LABORATORY
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LIFETIME OF THE 2^1S_0 STATE OF HELIUMLIKE ARGON*

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Measurement of the lifetime of the 2^1S_0 state of the heliumlike atom Ar XVII in a beam-foil experiment is reported and compared with recent experimental and theoretical results.

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The metastability of the 2^1S_0 state of helium was first discussed by Breit and Teller [1] who showed that it probably decays solely by double-photon emission (2E1) with a rate comparable to the 2E1 decay of metastable hydrogen. Several authors [2] have accurately computed the 2E1 spectra and rates for the helium isoelectronic sequence $2 \leqslant Z \leqslant 10$ in the nonrelativistic approximation. For helium (Z = 2), the result is A_{2E1} (Z = 2) = 51.3 sec^{-1}.

Two experimental results have appeared recently, both obtained by pulsing. A slow beam of thermal helium atoms to measure the range, of the metastable state, and therefore its lifetime. Pearl [3] obtained A_{2E1} (Z = 2) = 26 ± 6 sec^{-1}, while Van Dyck, Johnson, and Shugart [4] obtained A_{2E1} (Z = 2) = 50 ± 5 sec^{-1}.

For Z >> 1, the rate can be written

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

$$A_{2E1}(Z) = 2(8.23)\,(Z - \sigma)^6\ \mathrm{sec}^{-1} \quad . \tag{1}$$

In formula (1), the 2 arises from using properly symmetrized wavefunctions, the factor 8.23 is the nonrelativistic hydrogenic value obtained by Spitzer and Greenstein [5] and others [6], and σ is a correction for shielding of the nucleus by the 1s electron. Although the continuous 2E1 spectrum for neon (Z = 10) apparently has been observed in a laboratory plasma [7], no experiments have been reported which test the Z-dependence of eq. (1), or resolve the approximate factor of 2 disagreement between the helium experiments.

We report here the measurement of the lifetime of the 2^1S_0 state of helium-like argon (Z = 18). Our results are in agreement with the nonrelativistic prediction (eq. (1)) and tend to support the measurement on helium by Van Dyck, *et al*.

The apparatus used in this measurement has been described previously [8]. In brief, the beam from the Berkeley HILAC was passed through a thin carbon foil, and the photons from the decay of the metastable components were detected downstream with a high-resolution Si(Li) x-ray detector. The decay rate could be measured by varying the foil-detector distance, since the mean beam velocity is known (v/c = 0.145).

The spectrum of single photons observed with various foil-detector separations has been published [9]. We have performed coincidence measurements on this continuum to show that it truly arises from double-photon emission (for details of this technique, see ref. [10]).

In fig. 1 we have plotted the number of photons detected in the energy range $1.0 \leqslant E \leqslant 2.5$ keV, which should include only the 2E1 continuum, as a function of foil-detector distance. The line is a least-squares fit to the points after subtracting the asymptotic background, and yields the mean (1/e) lifetime $\tau(2^1S_0) = 2.6 \pm 0.3$ nsec, or A_{2E1} $(Z = 18) = 3.85 \times 10^8$ sec^{-1}. The error represents a 95% confidence, and includes statistical and instrumental uncertainties.

One of the largest instrumental uncertainties in these data is the contribution to the continuum of the 2E1 spectrum from the $2^2S_{1/2}$ state of hydrogenlike Ar XVIII. This spectrum overlaps the Ar XVII 2E1 spectrum, and cannot be separated if single photons are detected. However, the Ar XVIII spectrum is present only to the extent that Ar XVIII metastables are present. We have measured the (non-equilibrium) charge distribution of the beam after passing through our foil, and find it to be +14(24%); +15(45%), +16(27%), +17(4%). Thus, there was present an unavoidable contamination of Ar XVIII of about +17/+16 = 1/6. Since the $2^2S_{1/2}$ 2E1 rate is about half the 2^1S_0 2E1 rate, the measured decay will not be a pure exponential, and will yield a slightly incorrect decay rate. We estimate the error thus introduced to be about 10%, assuming that roughly equal fractions of Ar XVII and Ar XVIII are in the metastable states. Our coincidence measurements in which the sum energy of the two photons was observed ($\hbar\omega_1 + \hbar\omega_2 = 3.1$ keV for Ar XVII, 3.3 keV for Ar XVIII), are roughly consistent with a contamination of about this amount. Correction for this effect leads to A_{2E1} $(Z = 18) = 4.26 \pm 10^8$ sec for our experimental result.

Our result compares favorably with the non-relativistic calculations mentioned above. If we assume complete shielding, formula (1) (with $\sigma = 1$) yields A_{2E1} $(Z = 18) = 3.96 \times 10^8$ sec^{-1}, or $\tau(2^1S_0) = 2.52$ nsec. Drake [11] has performed a more accurate calculation by using variational results for $Z = 10$ to estimate σ. He finds $\sigma = 0.797$, and from formula (1),

A'_{2E1} $(Z = 18) = 4.26 \times 10^{8}$ sec, or $\tau(2^{1}S_{0}) = 2.35$ nsec. Drake estimates the errors inherent in this calculation to be ±1%.

In fig. 2 we have plotted the results of our experiment and that of Van Dyck, et al., and the nonrelativistic predictions of Drake. Our result clearly verifies the factor 2 in formula (1), and, within the experimental error, the Z scaling law.

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Figure Captions

Fig. 1. Decay of the 2^1S_0 state. The open circles are the raw data, the solid circles obtained by subtracting the asymptotic background from the raw data. The line is a best fit to the solid circles, corresponding to a lifetime of 2.6 nsec. These data do not take into account contamination of the decay by hydrogenlike ions.

Fig. 2. Theoretical decay rates of the 2^1S_0 states vs Z, and the reciprocals of two experimentally determined lifetimes.

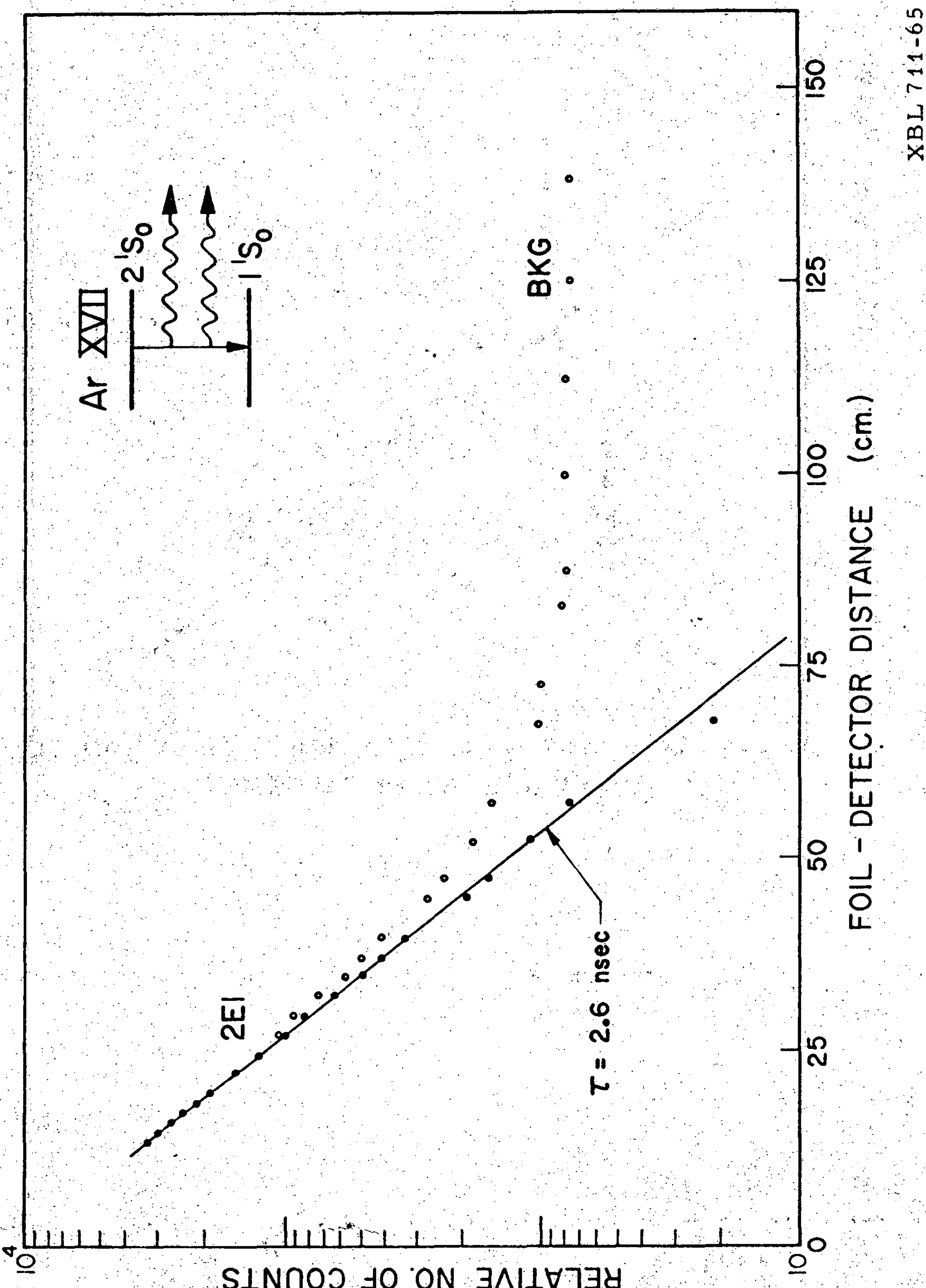
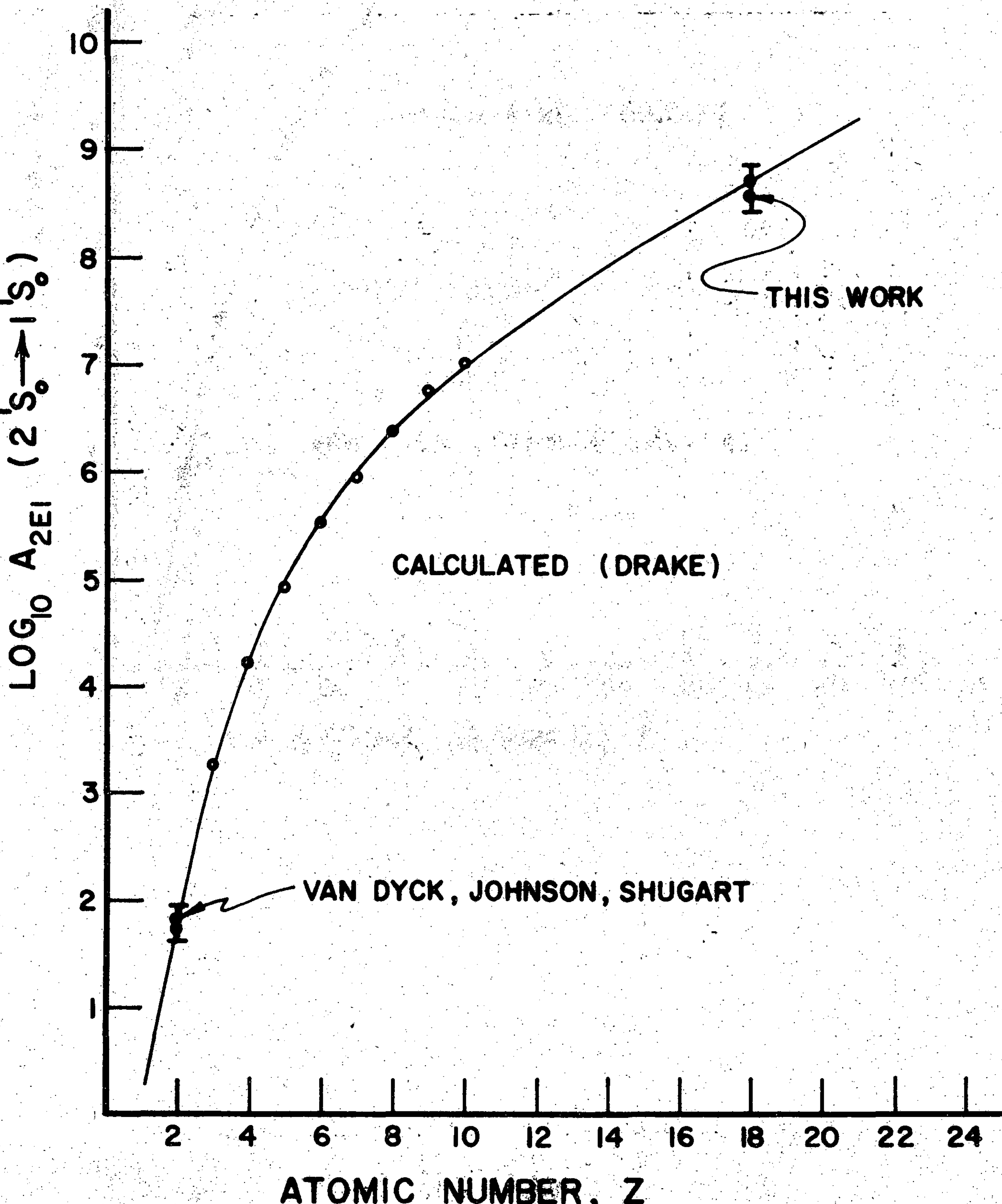

Ar XVII
$2\,^1S_0$
$1\,^1S_0$
BKG
2E1
τ = 2.6 nsec
RELATIVE NO. OF COUNTS
10^4
10^0
FOIL - DETECTOR DISTANCE (cm.)
0
25
50
75
100
125
150
XBL 711-65

Fig. 1


LOG10 A2EI (2 1S0 → 1 1S0)
10
9
8
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1
THIS WORK
CALCULATED (DRAKE)
VAN DYCK, JOHNSON, SHUGART
2
4
6
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24
ATOMIC NUMBER, Z

Fig. 2

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