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Berkeley, California

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We have used the foil-excitation technique recently employed by Kay[1] and Bashkin et al.[2] to measure directly the average of the lifetimes of the $1s^22p(^2P^o_{1/2})$ and $1s^22p(^2P^o_{3/2})$ states of C IV, N V, O VI, F VII, and Ne VIII ions in the lithium-like isoelectronic sequence. In each case a beam of ions accelerated to an energy of 0.97 MeV/nucleon by the Berkeley heavy-ion linear accelerator (Hilac) was further ionized and excited in an aluminum foil. The decay of radiation from the ^2S-$^2P^o$ transitions was then measured as a function of position downstream from the exciting foil, with a vacuum-uv monochromator with a sodium-salicylate-covered photomultiplier used as a photon detector.

These ^2S-$^2P^o$ transitions were selected for the following reasons: (a) Published data on equilibrium-charge-state distributions[3] suggest that at this energy a reasonable fraction of the beam (2 to 25%, depending on the ion) should be in the proper charge state after passing through the foil. (b) The upper states, $^2P^o$, are the first excited states of the ion and furthermore are very low-lying. Other excited states lie much higher and are therefore probably less likely to be populated by collisions in the foil. (c) The decay scheme is simple, as the only possible transition is directly to the ground state. Lifetime measurements may then be simply interpreted in terms of the transition

probabilities for ^2S-$^2P^o$ transitions, provided cascading from higher states is negligible. (d) The velocity of the beam is suitable for measuring transition probabilities in the range 10^8 to 10^9 sec^{-1}, characteristic of these transitions. (e) Several theoretical calculations of the pertinent transition probabilities, based on various approximate forms for the wave functions of the upper and lower states, are available.[4-6] These calculations show that the transition probabilities for the two states of the doublet are almost equal (within 2.5%); therefore it is possible to use an average transition probability in the analysis of the data.

EXPERIMENTAL ARRANGEMENT AND PROCEDURE

Ions C^{+2}, N^{+3}, O^{+3}, F^{+3}, or Ne^{+3} were accelerated to $\beta = 0.0457$ by the "prestripper" section of the Berkeley Hilac. The ions were deflected 15 deg and entered the experimental arrangement shown in Fig. 1 through a 1.27-cm-diameter collimator (A). The ion beam then passed through the stripper foil (B) and was monitored by the two Faraday cups C and D. Cup C, with a 1.9-cm diameter hole in its base, measured the angular spread of the beam and could detect any "wandering." Cup D received most of the beam (typically 80 to 90% for the greatest foil-cup separation). The signal from each of the Faraday cups was recorded by an integrating electrometer. The entire section from A through D was maintained at a pressure of 5×10^{-6} torr.

The stripper B was an aluminum foil, 2.54 cm in diameter and 140 $\mu g/cm^2$ thick. It was attached to a movable shaft that permitted 35 cm displacement along the beam line. The ions emerged from the

foil with an equilibrium charge distribution and in various states of electronic excitation. The radiation from these excited states was observed with a vacuum-uv scanning monochromator (E) (McPherson 0.5-meter Seya-Namioka) with 1.0 by 20 mm entrance and exit slits. The monochromator collected light from 1 cm of beam path and had a roughly triangular bandpass 32 Å wide at half maximum. With this choice of entrance and exit slits the components of the doublet could not be resolved. The detector (F) was a photomultiplier tube (Amperex XP1010) coated with sodium salicylate and cooled to -40° C to reduce thermal noise. Current pulses due to individual photons were registered by scaler circuits; to correct for the remaining noise, two sets of gated scalers were used. One set was gated on for 3.1 msec during the Hilac beam pulse and recorded photons plus photomultiplier noise; the other was gated on for 3.1 msec when there was no beam and recorded noise only. The difference in the two counts was taken to be the photon signal from the beam.

The monochromator was scanned in wavelength at a given foil position to locate the center of the doublet and to demonstrate that there were no other strong lines nearby. With the monochromator set at the wavelength corresponding to the center of the profile, photons were counted at a number of foil positions, and the integrated currents collected by each Faraday cup was recorded for normalization. Peak counting rates were about 4000 counts per minute for a beam current of the order of 1 microampere. Figure 2 shows the number of counts as a function of foil position for the F VII doublet at 890.8 and 883.1 Å. The foil comes into the field of view of the monochromator at about 4.8 cm and leaves it at about 5.8 cm; beyond this position the intensity

of the doublet is seen to decay exponentially with distance. Results for other ions in the lithium-like isoelectric sequence were similar.

RESULTS

As both the initial beam energy and the energy loss in the foil are known, the beam velocity can be calculated; the slope of the decay curve (see Fig. 2) then yields immediately the lifetime of the ^2P states and in this simple case the average transition probability to the ^2S state. The transition probabilities were obtained by least-squares fitting the data points with a computer program to an exponential plus a constant background. In every case a single exponential fits the data very well and the computer-selected background was consistent with estimates derived from the observed counting rate before the foil came into the field of view of the monochromator. Whether the data were normalized to the total charge collected by only the central Faraday cup or to the total charge collected by both Faraday cups made, on the average, a difference of only 2% in the value of the transition probability. In the final results these two values were averaged and an uncertainty of 3% assigned, sufficient to include both the uncertainty in normalization and the uncertainty in curve fitting. The only other source of uncertainty is the calculation of the velocity from the accelerator parameters and the calculated energy loss in the foil ($\Delta E/E \approx 0.05$). An uncertainty of ±1.5% is assigned to the calculated velocities.

The average transition probabilities for the $1s^2 2s\,(^2S_{1/2})$-$1s^2 2p\,(^2P^o_{1/2,3/2})$ transitions of C IV, N V, O VI, F VII, and Ne VIII are shown in Table I. Also shown are theoretical values calculated by Varsavsky (screening approximation), Griem (Coulomb approximation), and Weiss

(Hartree-Fock method and a presumably more accurate method employing 45-term configuration interaction wave functions). The wavelengths and the various authors' estimates of the reliability of their values are included.

Within the estimated uncertainties, all the theoretical values, even those derived from the Coulomb approximation, agree well with our measurements.

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FOOTNOTE AND REFERENCES

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

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Table I. Average transition probabilities for $1s^2 2p(^2S_{1/2}) - 1s^2 2p(^2P^o_{1/2,\,3/2})$.

Spectrum	λ(Å)	Transition probability $\times 10^{-8}$ (sec^{-1})				
		Measured	Screening approximation (Varsavsky)	Coulomb approximation (Griem)	Hartree-Fock (length form) (Weiss)	Configuration-interaction (length form) (Weiss)
C IV	1550.7 1548.2	2.97 ± 0.11	2.78	2.64	2.681	2.645
N V	1242.8 1238.8	3.34 ± 0.12	3.46	3.40	3.416	3.373
O VI	1037.6 1031.9	3.94 ± 0.14	4.37	4.14	4.144	4.055
F VII	890.8 883.1	4.48 ± 0.16	5.07	----	4.872	----
Ne VIII	780.3 770.4	5.55 ± 0.19	5.94	----	5.591	----
Estimated uncertainty		3.5%	≥10%	≥20%	5-15%	2-4%

FIGURE CAPTIONS

Fig. 1. Experimental arrangement (A) 1.27-cm-diameter collimator, (B) aluminum foil, (C) and (D) Faraday cups, (E) monochromator, (F) cooled, sodium-salicylate-coated photomultiplier tube, (G) ionization gauge.

Fig. 2. Counts vs foil position for the F VII doublet at 890.8 and 883.1 Å. The line is the computer result for the best fit to the data.

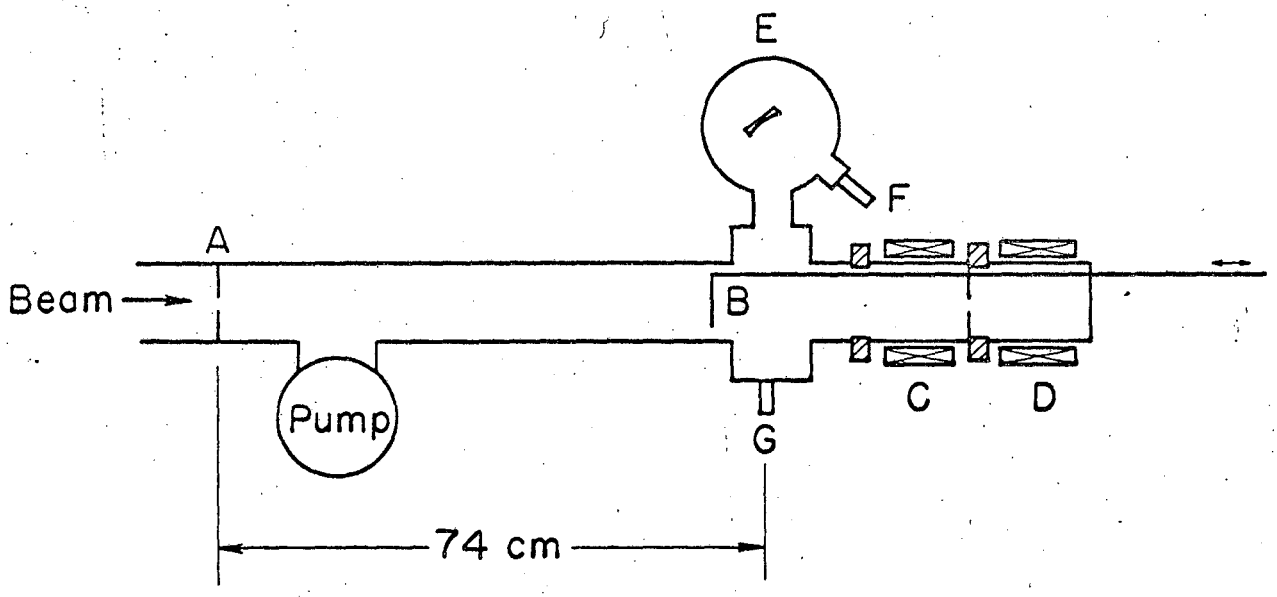

Fig. 1

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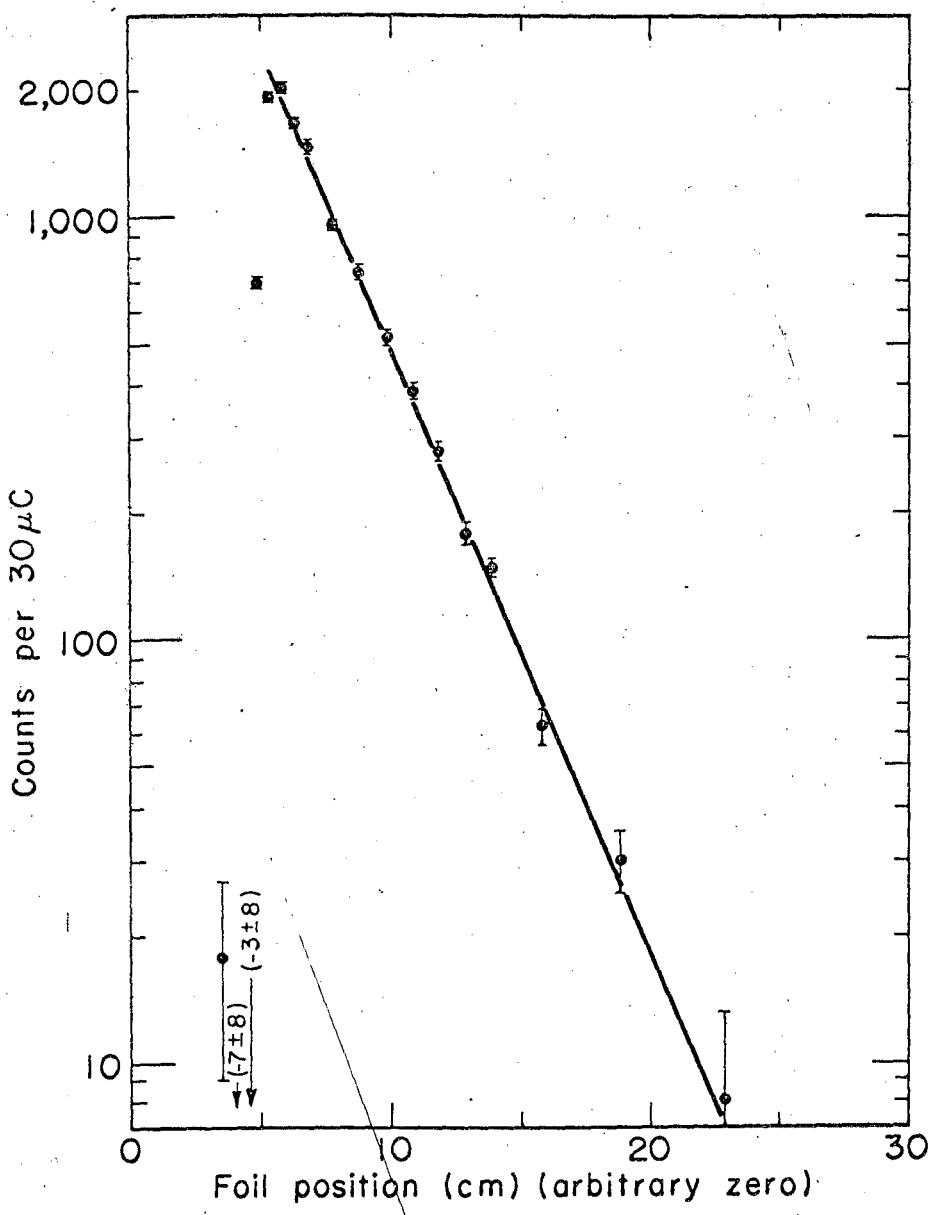

Fig. 2

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