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LIFETIME OF THE 2^3S_1 STATE OF HELIUMLIKE ARGON†

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Abstract:

The $2^3S_1 \rightarrow 1^1S_0$ magnetic dipole transition of heliumlike Ar^{+16} has been studied by time-of-flight techniques at several values of the beam energy. From this data, the lifetime of the 2^3S_1 state is found to be $172 \pm 12 \times 10^{-9}$ sec where the stated error includes statistical and systematic effects. This value differs from the present theoretical value of 212.4×10^{-9} sec by more than three times the stated error.

— — —

The 2^3S_1 state of heliumlike ions decay to the 1^1S_0 ground state primarily by relativistically-induced magnetic-dipole radiation. The existence of this single-photon process was first noted by Breit and Teller[1] in connection with the metastable state of hydrogen, and the theory for radiative decay of heliumlike ions in the 2^3S_1 state has now been considered by many authors.[2] The most detailed calculations of the lifetime of this state have been made by G. W. F. Drake[3] who finds that $\tau(2^3S_1) = 212.4 \times 10^{-9}$ sec for heliumlike argon.

The single-photon decay of the 2^3S_1 state was first noted[4] in the x-ray spectra of heliumlike ions excited in the solar corona and has subsequently been observed in the laboratory in the spectra of Ar^{+16} (Ref. 5) and He I.[6] A beam-foil measurement of this lifetime in Ar^{+16} using the 412 MeV argon beam from the old Berkeley heavy-ion linear accelerator (HILAC) yielded as a result $\tau(2^3S_1) = 172 \pm 30 \times 10^{-9}$ sec in rough agreement with the theory. In this letter, the results of a new series of measurements on this lifetime are reported. The argon beam from the new Berkeley heavy-ion accelerator (super-HILAC) was used and measurements were made with beam energies of 96.4 MeV, 138.4 MeV, 183.2 MeV, and 288.4 MeV. Possible sources of systematic error were investigated and on the basis of these measurements, we report a value of $\tau(2^3S_1) = 172 \pm 12 \times 10^{-9}$ sec. The stated error includes both the statistical error and contributions from systematic effects. This result is in excellent agreement with the earlier measurement[5] but disagrees with the theoretical prediction by more than three times the stated error.

A schematic of the apparatus used is illustrated in Fig. 1, and is essentially identical with that employed in our previous work described in Ref. 5. The argon emerging from the super-HILAC is magnetically deflected into our apparatus and passes through a thin carbon foil (23 or 53 μgms/cm^2) mounted on a movable track with a total travel of 1.6 meters. The fraction of Ar^{+16} ions excited to the 2^3S_1 state by the foil is sufficient for experimentation over the energy range 2.4 MeV/AMU $\leq E \leq$ 7.2 MeV/AMU employed in this experiment. The beam subsequently passes in front of a pair of Si(Li) solid-state x-ray detectors. A pair of collimating slits mounted in front of the detectors permits them to detect x-rays emitted only by those argon ions which radiate in front of the open slits. The beam is then collected in a Faraday cup and the integrated current recorded. A 0.6 cm diameter collimating slit mounted between the track and the cup insured that any and all ions passing through the foil and between the detectors must also strike the Faraday cup. In this way, the integrated current measured at the cup provides a reliable normalization of the number of metastable ions passing in front of the detectors. That this is indeed the case was established by varying the aperture of the collimator and noting that the measured lifetime was independent of this parameter.

The spectrum associated with decays-in-flight of argon ions is shown in Fig. 1. A single clear peak is observed at an energy of 3.1 keV with a signal/noise ratio of at least 100:1. That this peak is associated with decay of 2^3S_1 of Ar^{+16} had already been established in our previous work.[5] The lifetime is determined by integrating the total number of counts under the peak for a fixed integrated beam current, and plotting this number versus foil-detector separation. Twenty-seven decay curves were taken with argon beams ranging in energy from 96.4 MeV to 288.4 MeV. The results of these decay curves are given in Table I.

The absence of other spectral lines is insured by placing the track so that the foil is never closer than 0.8 meters to the detectors. This is sufficiently far so that all other excited atomic levels of argon ions present in the beam will have become thoroughly depopulated by decay to the ground state. In this connection, it should be noted that the 2^3P_0 level of Ar^{+16} decays to the 2^3S_1 level with a theoretical lifetime of about 5.5×10^{-9} sec. In order that the measured lifetime of 2^3S_1 not be influenced by cascading from this state, it is important that sampling of the decay curve only be started after several mean lives have elapsed. Under this condition, it is possible to place an upper limit on the measured decay rates due to this cascading mechanism. For the geometry and beam energies used here, the effect on our lifetime will always be less than 0.5%, independent of the relative populations of the two states at the foil. The consistency of our measured lifetimes as a function of energy is empirical evidence that this is indeed true, and serves, moreover, to rule out long-lived cascades from states of very high principle quantum number. We note further that the non-existence in our spectrum of transitions from levels of higher principle quantum number to the ground state also implies that cascading is not important.

Pressure quenching as a possible source of error has also been investigated. The lifetime measurements were performed at an ambient pressure of $\approx 3 \times 10^{-6}$ Torr. By increasing the pressure to 10^{-5} Torr we find that if τ_Q is the lifetime associated with quenching of the 2^3S_1 state by any mechanism at the ambient pressure, then $\tau_Q \geqslant 200\ \tau_{meas}$, and the effect on the lifetimes is less than 0.5%.

A further possible source of systematic error arises from detector pile-up. It is noted that the normalized count rate in the detector decreases if the argon beam current is increased. This effect arises from occasional multi-MeV particles (probably neutrons) which enter the detectors. Detector recovery from these events is very slow, giving rise to a dead time. These nuclear events are produced when the argon beam strikes metal surfaces that are present, principally the lead collimating slits, and the number of these events noticeably decreases when the energy of the argon beam is decreased to 2.41 MeV/AMU: slightly below the coulomb barrier for the lead-argon system. A study was made at 2.41 MeV/AMU to determine if there was a dependence of the measured lifetime on the average beam current. A small, but statistically significant effect was observed. Over the observed range of beam currents, it was found that the measured lifetime increased with increased beam current at a rate of about $5(3) \times 10^{-9}$ sec per namp. The data reported in this experiment was taken mainly at 0.5 namp. A correction for this effect was made to all of our measured lifetimes, and the error in this correction is incorporated into our stated error.

Table I contains a summary of all the lifetime data. The final result is $172(12) \times 10^{-9}$ sec. The lifetime value represents a weighted average of all the individual results, where the weighting factor is the statistical one, and is independent of our method for handling background subtraction. The weighted average of all of our runs yields a standard deviation of 4 nsec. The stated error contains a two standard deviation contribution from statistics, a contribution from uncertainty in the pile-up correction and a contribution from uncertainty in the velocity. The final result is corrected for degrading of the beam energy by the foil and relativistic time dilation.

We believe that this result establishes convincingly a discrepancy between theory and experiment. Drake[2] and Feinberg and Sucher[2] have both pointed out that there exists corrections to the present theory of order $Z\alpha$ to the two-electron terms and a radiative correction of order $\alpha \ell n \alpha$. Further theoretical work is clearly needed to see if these corrections are indeed responsible for the discrepancy.

Many people have contributed to the success of this work. It is a pleasure to acknowledge the encouragement and support of Al Ghiorso. The nuclear chemistry electronics group of Fred Goulding provided and serviced the solid-state detector system. Doug MacDonald was primarily responsible for the engineering and Warren Harnden and William Davis assisted in various phases of the work.

FOOTNOTES AND REFERENCES

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Table I. Lifetimes of the 2^3S_1 state of heliumlike argon measured at different beam energies

96.4 MeV	138.4 MeV	183.2 MeV	288.4 MeV
163 ± 17	188 ± 18	183.5 ± 21	178.5 ± 38
174 ± 34	173 ± 9	213 ± 17	186.5 ± 34
154 ± 32	164 ± 8	171 ± 15	192 ± 26
158.5 ± 23	177 ± 11	212 ± 28	183 ± 32
169 ± 13		200 ± 17	167 ± 14
163.5 ± 11			136 ± 12
174 ± 24			135 ± 25
170 ± 13			
172 ± 12			
173 ± 26			
179 ± 13			
169 ± 7	171 ± 6	193 ± 9	156 ± 10

FIGURE CAPTIONS

Fig. 1. Schematic of the Apparatus.

Fig. 2. Energy Spectrum of the Observed X-Rays.

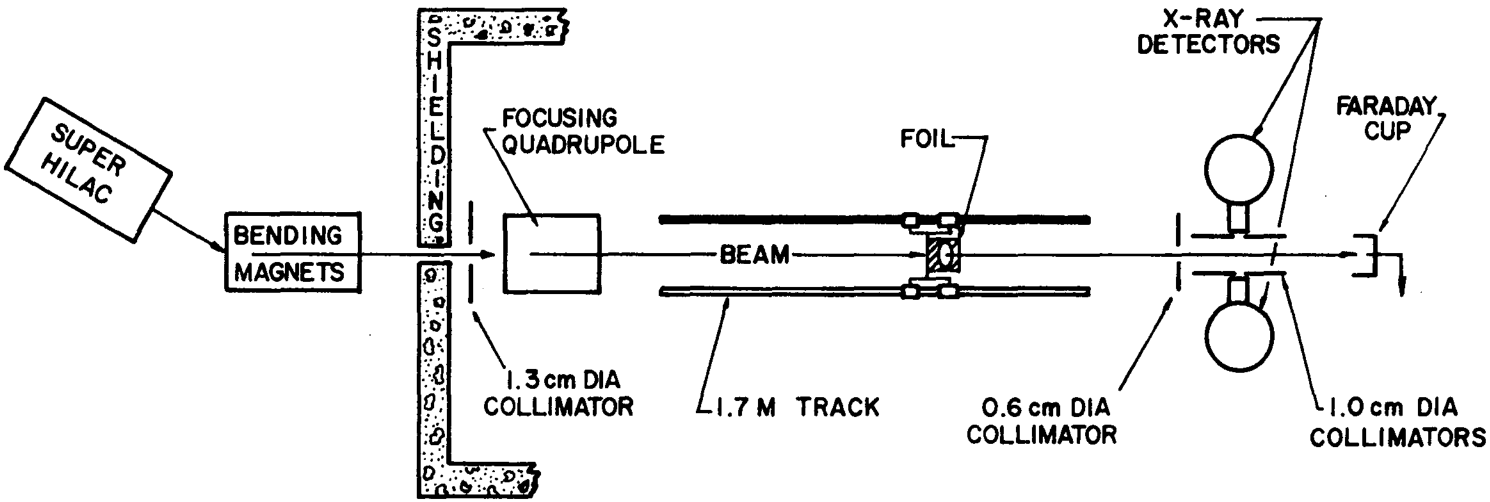

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Fig. 1

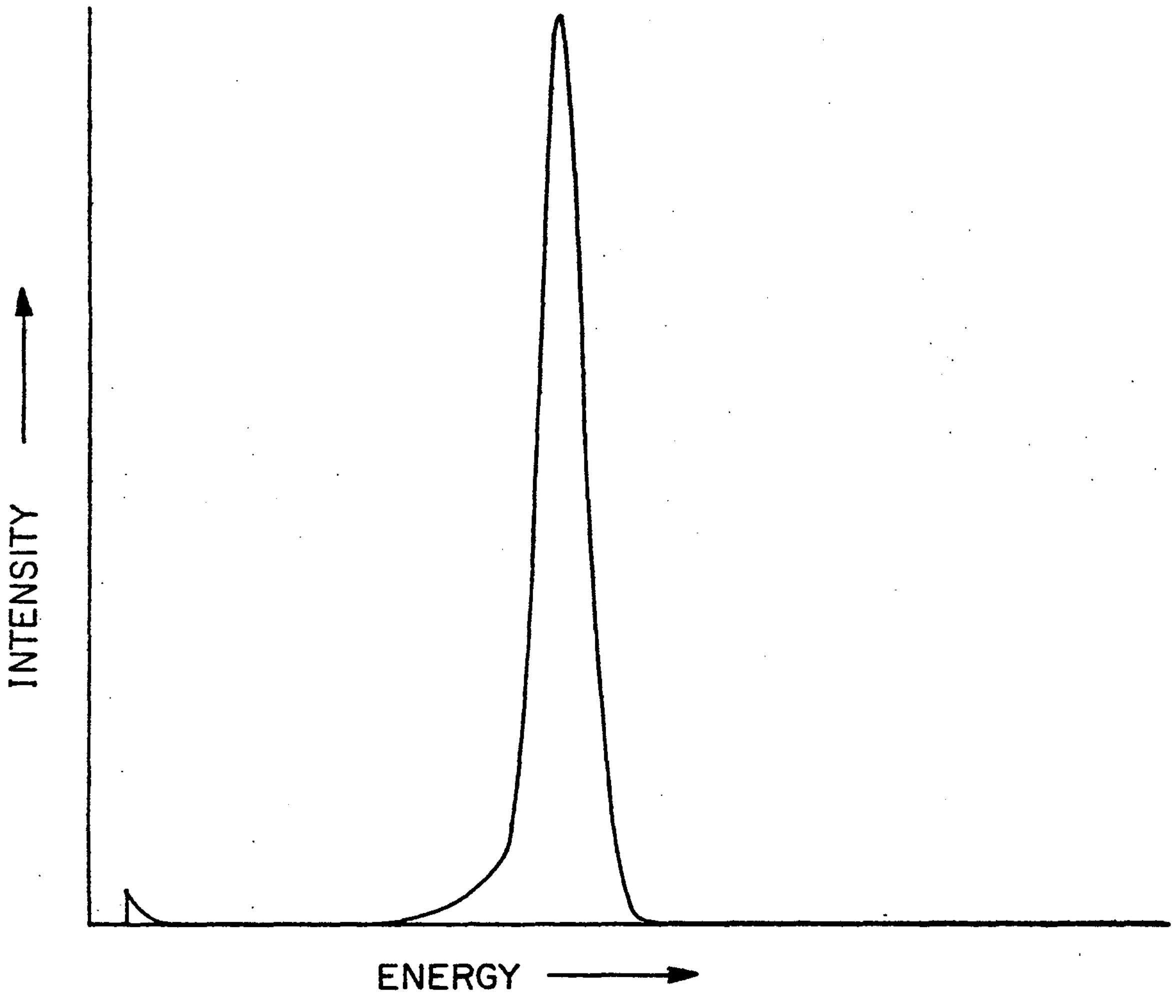

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Fig. 2

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