Title

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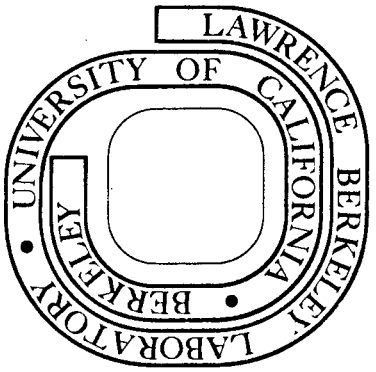

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LIFETIME OF THE 2^3S_1 STATE OF HELIUM-LIKE ARGON (Z = 18) AND HELIUM-LIKE TITANIUM (Z = 22)*

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Abstract:

The $2^3S_1 \rightarrow 1^1S_0$ magnetic dipole transition in the helium like atoms Ar^{+16} and Ti^{+20} has been studied by a time-of-flight technique. The lifetime of the 2^3S_1 state is found to be $172(12) \times 10^{-9}$ sec in Ar^{+16} and $25.8(1.3) \times 10^{-9}$ sec in Ti^{+20} where the stated errors include statistical and systematic effects. These values can be compared with theoretical values of 212.4×10^{-9} sec for Ar^{+16} and 27.4×10^{-9} sec for Ti^{+20}.

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The 2^3S_1 state of helium-like ions decays 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 helium-like 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 helium-like argon and $\tau(2^3S_1) = 27.4 \times 10^{-9}$ sec for helium-like titanium.

The single-photon decay of the 2^3S_1 state was first noted[4] in the x-ray spectra of helium-like 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 decay are reported.

The systems studied were helium-like Ar^{+16} and Ti^{+20} obtained from the new Berkeley heavy-ion accelerator (superHILAC). A schematic of the apparatus used is illustrated in Fig. 1. It is similar in basic idea to that employed in our previous work described in Ref. 5, but much of the hardware has been rebuilt and some of the dimensions changed. The argon emerging from the superHILAC is magnetically deflected into our apparatus and passes through a thin carbon foil (23 or 53 $\mu gms/cm^2$) mounted on a movable track with a total travel of 1.6 meters. The fraction of two-electron ions excited to the 2^3S_1 state by the foil is sufficient for experimentation over the energy range $2.4 \text{ MeV/AMU} \leq E \leq 7.2 \text{ MeV/AMU}$ employed in this experiment. The beam subsequently passes in front of a pair of collimating slits mounted in front of the detectors which 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 spectra associated with decays-in-flight of the two beams is shown in Fig. 1. For the argon, a single peak is observed at an energy of 3.1 keV with a signal/noise ratio of about 100/1. A similar single peak at an energy of 4.7 keV is observed with the titanium beam. That this peak is associated with the decay of the 2^3S_1 state 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, and eight decay curves were taken with titanium, at energies of 115.7 and 346 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 or titanium 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 decays to the 2^3S_1 level with a theoretical lifetime of about 5.5×10^{-9} sec for Ar^{+16} and about 4.5×10^{-9} sec for Ti^{+20}. 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.

Pressure quenching as a possible source of error has been investigated. The lifetime measurements were performed at an ambient pressure of about

3×10^{-6} Torr. By increasing the pressure to 10^{-5} Torr, we find that the effect on the lifetime due to pressure quenching is less than 0.5%.

A further possible source of systematic error arises from detector pile-up. It is noted during the runs with the argon beam 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 statically 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 of 2.5×10^{-9} sec was made to all of our measured argon lifetimes, and the error in this correction is incorporated into our stated error. The detectors were modified for runs with the titanium beam and no measurable pile-up effect was observed. The modified detectors were also used in an argon run and no significant change in the lifetime was found.

Table I contains a summary of the lifetime data. The final results are: For Ar^{+16} $\tau(2^3S_1) = 172(12) \times 10^{-9}$ sec, Ti^{+20} $\tau(2^3S_1) = 25.8(1.3) \times 10^{-9}$ sec. The lifetime values represent 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 stated error contains a two

standard deviation contribution from statistics, a contribution from uncertainty in the pile-up correction for the argon 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.

The measured value of the argon lifetime is in good agreement with our previous measurement[7] but in apparent disagreement with the theory, whereas the titanium result reflects a possible disagreement. Therefore, a thorough search for systematic effects was made which might explain the disagreement. During one or more of the runs, the following parameters were varied: foil thickness and material, foil holder diameter, collimator diameters, collimator material, collimator-detector separation, separation between collimators, direction of foil travel, distance of the detectors from beam center line, Faraday cup target, and residual gas pressure. No systematic effect was found. We can not, of course, rule out the possibility that the discrepancy is somehow an artifact of the basic experimental method. Although we have not been able to find a plausible model to suggest that this is the case, we are nevertheless currently attempting to remeasure these lifetimes by an independent method. In this connection, it should be noted that both the argon and titanium lifetimes were measured with the identical apparatus. We are also planning measurements of this lifetime in higher-Z elements.

Many people have contributed to the success of this work. It is a pleasure to acknowledge the encouragement and support of Albert Ghiorso. The nuclear chemistry electronics group directed by Fred Goulding provided and serviced the solid-state detector systems. Douglas McDonald was primarily responsible for the engineering and Warren Harnden, Mike Nitschke, William Davis and Richard Eppley 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			

Lifetimes of the 2^3S_1 state of heliumlike titanium measured at different beam energies.

115.7 MeV	346 MeV
25.2 ± 0.5	26.7 ± 1.0
25.9 ± 0.9	25.9 ± 1.0
24.7 ± 1.0	27.2 ± 0.8
24.9 ± 0.7	27.4 ± 0.8

FIGURE CAPTIONS

Fig. 1. Schematic of the apparatus.

Fig. 2. Energy spectrum of the observed x-rays.

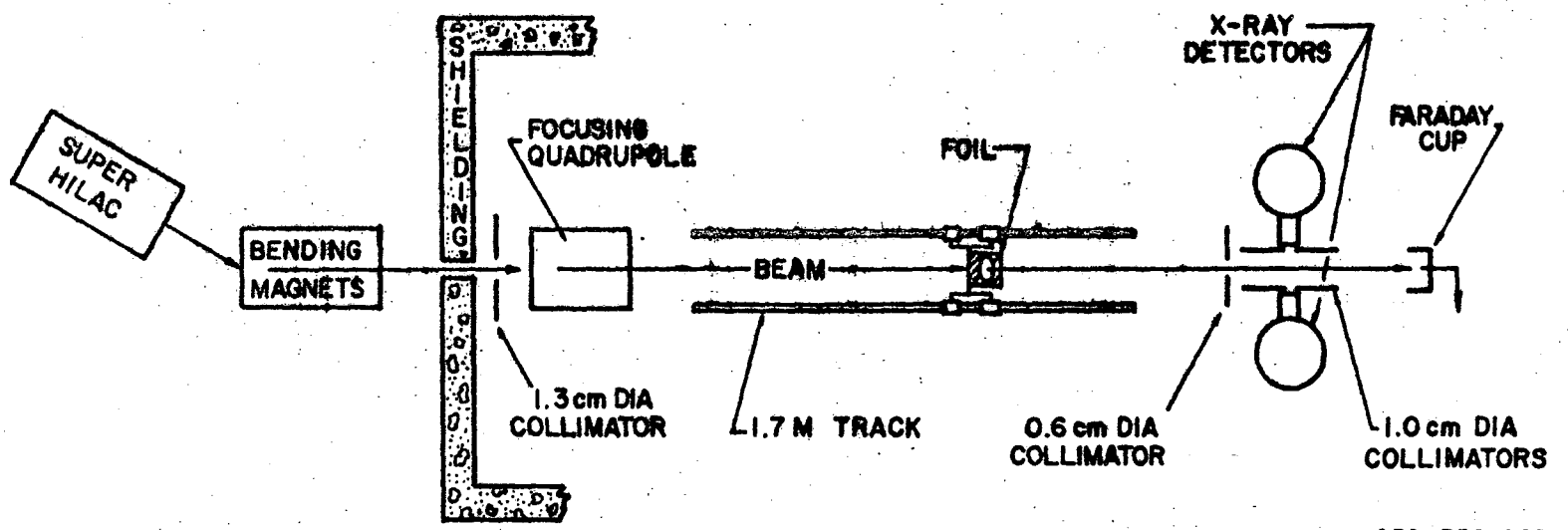
SUPER HILAC
BENDING MAGNETS
SHIELDING
FOCUSING QUADRUPOLE
FOIL
X-RAY DETECTORS
FARADAY CUP
BEAM
1.3 cm DIA COLLIMATOR
1.7 M TRACK
0.6 cm DIA COLLIMATOR
1.0 cm DIA COLLIMATORS
LBL 732-197

Fig. 1

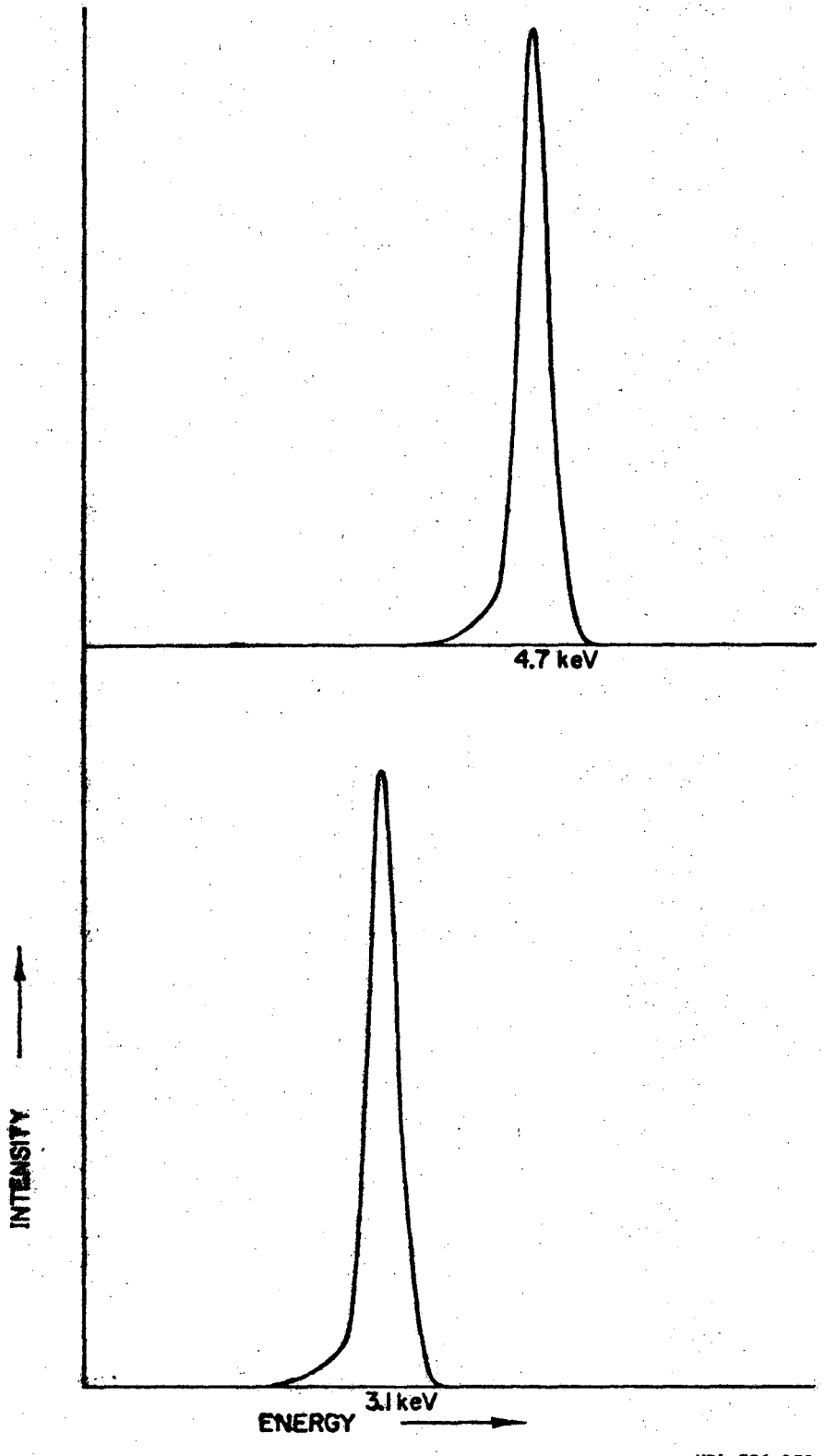

Fig. 2

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