LIFETIME OF THE $2^2S_{1/2}$ STATE IN HYDROGENLIKE KRYPTON

S.Cheng, R.W.Dunford, E.P.Kanter, H.G.Berry, D.S.Gemmell and B.J.Zabransky
Physics Division, Argonne National Laboratory, Argonne, Illinois 60439

A. E. Livingston
Department of Physics, University of Notre Dame, Notre Dame, Indiana 46556

L. J. Curtis
Department of Physics and Astronomy, University of Toledo, Toledo, Ohio 43606

J. Bailey and J. Nolen
National Superconducting Cyclotron Laboratory, Michigan State University,
East Lansing, Michigan 48824

ABSTRACT

We report a measurement of the lifetime of $2^2S_{1/2}$ level in hydrogenlike ^{84}Kr and the first determination of the branching ratio for the M1 decay for this Z=36 one-electron ion. The lifetime of this state was measured by the beam-foil time-of-flight method, in which the foil was moved relative to a fixed, collimated Si(Li) detector. An analysis based on the single photon spectra from a tightly collimated detector led to the measurements of the lifetime of $2^2S_{1/2}$, the two-photon emission rate, the M1 emission rate and the branching ratio of M1 decay. All these experimental results are in good agreement with the theoretical calculations of Parpia and Johnson, and Goldman and Drake.

INTRODUCTION

The $2^2S_{1/2}$ level in one-electron ions decays to the $1^2S_{1/2}$ ground state either by two-photon emission (2E1) or by single photon M1 emission. The two-photon decay rate dominates at low nuclear charge Z. The M1 decay is a completely relativistic phenomenon[1,2]. The branching ratio for this decay increases with Z and becomes equal to the two-photon decay rate at about Z=41. For krypton Z=36, the fully relativistic calculations[3-5] give a lifetime of 37.008 ps and a branching ratio of $\frac{M1}{M1+2E1} = 0.3643$. The relativistic value for the branching ratio is larger by 8% than the "nonrelativistic" result[6]. Thus, a measurement of the M1 branching ratio in Kr^{35+} provides a sensitive test of relativistic corrections to the decay rates.

EXPERIMENT

In the experiment, a beam of 30 MeV/amu $^{84}Kr^{15+}$ ions from the K1200 cyclotron at the National Superconducting Cyclotron Laboratory (NSCL) was stripped in a 3.4 $\mu g/cm^2$ aluminum target and the fully stripped $^{84}Kr^{36+}$ ions were magnetically selected. The lifetime of the $2^2S_{1/2}$ state was measured by moving the foil relative to the fixed, collimated Si(Li) detector (See Fig. 1).

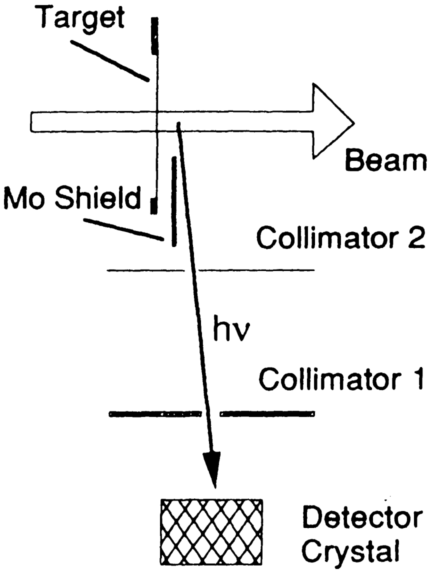

Fig. 1. Experimental setup showing the tightly collimated Si (Li) detector viewing the beam. The Mo shield prevents the detector from viewing the beam spot at the target foil.

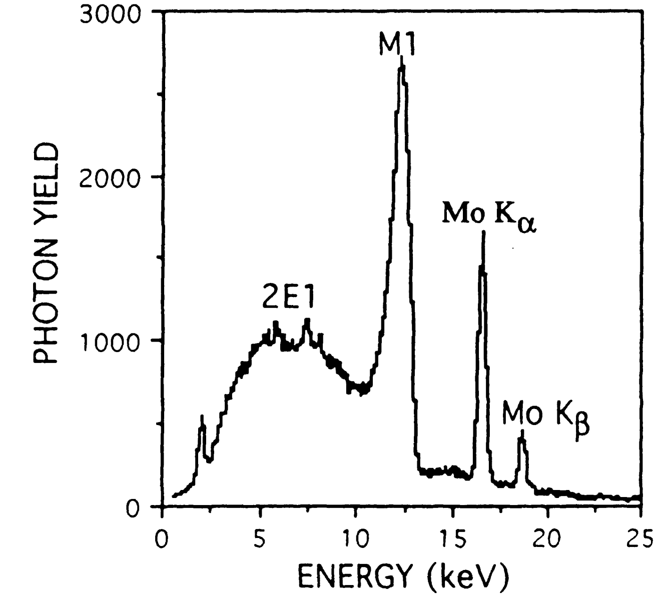

Fig. 2. Photon energy spectrum from the detector. The Mo K_α and K_β peaks result from characteristic X-rays from the shield, collimators and the target holder.

The intensity of the decay radiation was measured as a function of the foil-detector distance in order to determine the lifetime. The small decay length of the state (2.7 mm) provided a challenge in this measurement. It was necessary to observe the decay radiation within 12 mm of the foil in order to get a reasonable statistical accuracy without allowing the detector to look directly at the beam spot on the foil. In order to achieve this, a special geometry was chosen, in which the beam passed through a "shield" (See Fig. 1) before entering the detection region. The shield served to block the detector from viewing the beam at the foil while allowing the detector to view the region a few mm downbeam of the foil. The detector was tightly collimated so as to minimize the Doppler width but at the price of a reduced solid angle. The shield and detector collimators are made of thin molybdenum sheet. This material was chosen because there are no characteristic X-rays in the spectral region of interest for this experiment (K_α = 17.44 keV, K_β = 19.60 keV, L X-rays: from 2.29 to 2.62 keV). The charge collected in the beam dump was used to normalize the data. Digital pulses from an integrator of the Faraday cup current were counted and a preset number of pulses was required at each foil position. Pileup and deadtime in the electronics and computer data processing had been carefully considered.

RESULTS

The singles spectra in the detector were clean and provided a good measurement of the $2^2S_{1/2}$ lifetime. The spectra from the detector had relatively narrow line widths which allowed separation of the H-like and He-like single photon lines. Also, the absolute efficiency of the detector had been measured and so the singles spectra from this detector provided an opportunity for making a direct determination of the branching ratio for the single photon M1 decay of the one-electron $2^2S_{1/2}$ level.

A typical spectrum from the detector is shown in Fig. 2. The lifetime of the $2^2S_{1/2}$ level was determined by analyzing the continuum region from 6.4 keV to 11.2 keV. The lower boundary was chosen so as to be well separated from the $nl \rightarrow 2l$ transitions and the high energy boundary was chosen so as to avoid the He-like single-photon decays and the Si escape peak associated with the H-like M1 photons. The counts in this region were corrected, at each foil-detector separation, for pileup, cascades, and contributions from the two-photon decay of heliumlike ions. After all corrections were applied, the data were fitted to a single exponential plus a background. A typical fit is shown in Fig. 3.

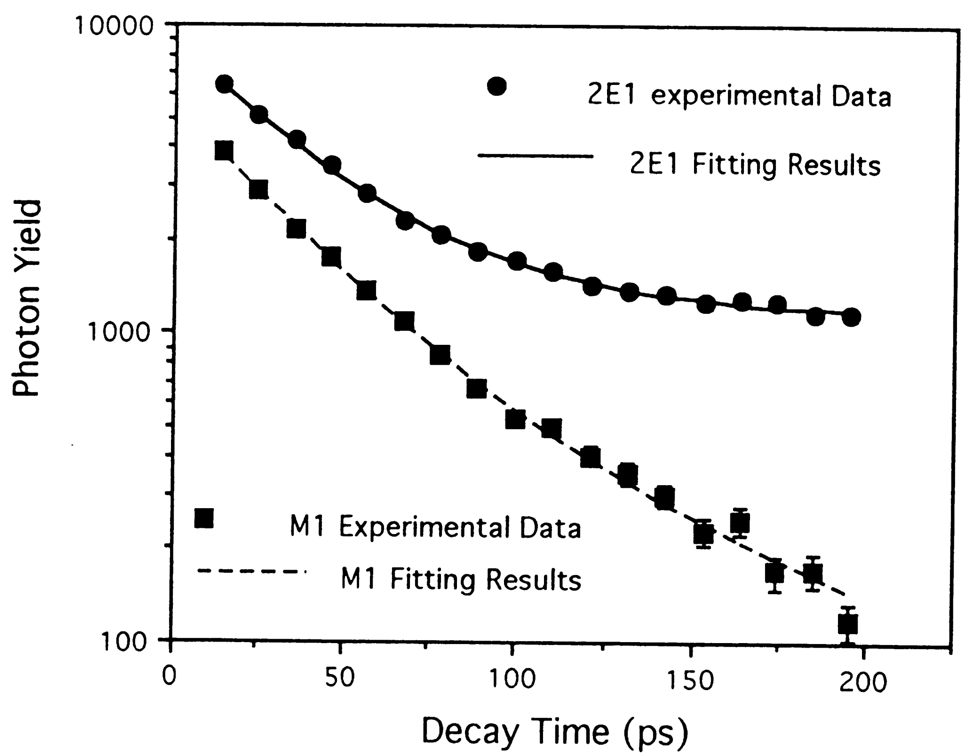

Fig. 3. Photon yield vs. decay time for 2E1 and M1 decays in hydrogenlike Krypton.

In order to determine the M1 branch of the $2^2S_{1/2}$ decay, the one-electron component of the 13.4 keV peak was found at each foil-detector separation by a peak-fitting procedure. We fitted the resulting decay curve to obtain a value for the intensity of the M1 component.

The experimentally measured emission rates, lifetime and branching ratio, as well as the theoretical results are listed in Table I.

Table I. Experimental and theoretical results for the $2^2S_{1/2}$ level of $^{84}Kr^{35+}$.

	Experiment	Theory
Lifetime (ps)	36.8 ± 1.4	37.008
M1 branching ratio	0.356 ± 0.015	0.3643
M1 decay rates($10^9 s^{-1}$)	9.68 ± 0.55	9.844
2E1 decay rates($10^{10} s^{-1}$)	1.750 ± 0.078	1.7184

The theoretical results in the table are interpolated from Parpia and Johnson's fully relativistic calculations of both the two-photon and the M1 decay rates including finite nuclear size effects and a small correction for nuclear-recoil[7,8]. The nuclear mass correction is negligible for krypton to the number of figures quoted. There is good agreement between theory and experiment in all cases.

ACKNOWLEDGMENTS

We are indebted to the staff of NSCL for excellent technical assistance during this experiment. We particularly thank N. Anantaraman, D. Sanderson, R. Blue, R. Fox, J. Rugis, and R. Ronningen. This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences under Contract Nos. W-31-109-ENG-38 (ANL) and DE-FG05-88ER13958 (Univ. of Toledo).

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