Lifetime Measurement of the Metastable 2^3P_0 state in He-like Au^{77+}

S. Toleikis[1], B. Manil[2], E. Berdermann[1], H.F. Beyer[1], B. Birkett[4], F. Bosch[1],
M. Czanta[1], R.W. Dunford[6], P. Indelicato[2], C. Kozhuharov[1], D. Liesen[1], X. Ma[1],
R. Marrus[4], P.H. Mokler[1], D. Schneider[5], A. Simionovici[3], Th. Stöhlker[1], Y. Zou[7]
[1] *GSI, Darmstadt, Germany,* [2] *Université P. et M. Curie, Lab. Kastler Brossel, Paris, France,*
[3] *European Synchrotron Radiation Facility (ESRF), Grenoble, France,* [4] *University of California, Berkeley, U.S.A.,*
[5] *Lawrence Livermore National Laboratory, Livermore, U.S.A.,* [6] *Argonne National Laboratory, Argonne, U.S.A.,*
[7] *Jiaotong University, Shanghai, China*

The $2^3P_1 - 2^3P_0$ fine-structure splitting has been and still is a subject of experimental and theoretical interest in atomic physics. While in low-Z systems for neutral helium and Li$^+$ very accurate calculations have been carried out in the 70´s, for helium-like high-Z ions new methods were needed to determine this fine structure splitting. Meanwhile, different theoretical approaches exist [1, 2, 3] and one aim of the experiment is to test which approach can give the correct values for the fine structure. For the high-Z region, only few measurements are available so far [4, 5]. Although this fine structure splitting is not directly measurable presently, it has been shown that this splitting can be determined indirectly by measuring the hyperfine-quenched lifetime of the 2^3P_0 state [6]. Due to the hyperfine interaction, the metastable 2^3P_0 state couples to the prompt 2^3P_1 state and the coupling strength depends on the $2^3P_1 - 2^3P_0$ fine-structure splitting. Thereby, the lifetime of the pure 2^3P_0 state is reduced and the fine-structure splitting can be determined.

The basic method to measure the lifetime of the hyperfine quenched 2^3P_0 state is beam foil spectroscopy. This rather simple method is illustrated in Figure 1, where the setup of the experiment performed at Cave A in August 2000 is shown. A hydrogen-like gold beam with an energy of 194.8 MeV/u ($\beta = 0.5621$) passes through a target foil (1.5 mg/cm^2 Ni) and hereby produces excited helium-like ions by electron capture. The radiation of the subsequent decay of the excited states is detected downstream of the foil by two Ge(i) detectors, located on opposite sides of the beam. The position of one detector is fixed while the other detector is moveable. By varying the distance between the target foil and the moveable detector and by measuring the ratio of counts of the $2^3P_0 - 1^1S_0-$transition in the moveable detector relative to the fixed detector, a decay curve can be traced out. Measuring the ratio allows normalization to the ion population in the excited state of interest and has the additional advantage that most systematic errors are eliminated.

In contrast to the old experiment performed in 1994 [7], now for the first time, it was possible to measure the x-rays in coincidence with the down-charged helium-like ions, because recently a charge state spectrometer consisting of a quadropole doublet and a bending magnet has been installed in Cave A. An experiment to determine projectile ionization cross setcions, performed one year ago, has served as a comissioning test and has shown the ability of the spectrometer to separate the different charge states [8]. In order to benefit from the charge state separation one also needs a position sensitve particle detector. Therefore a newly developed 32-fold strip diamond detector with a detection area of 60*40 mm^2 has been installed after the bending magnet. The advantages of this new type of particle detector are its time resolution below 50 ps and especially its single-particle count-rate capability of up to 10^8 ions/s [9].

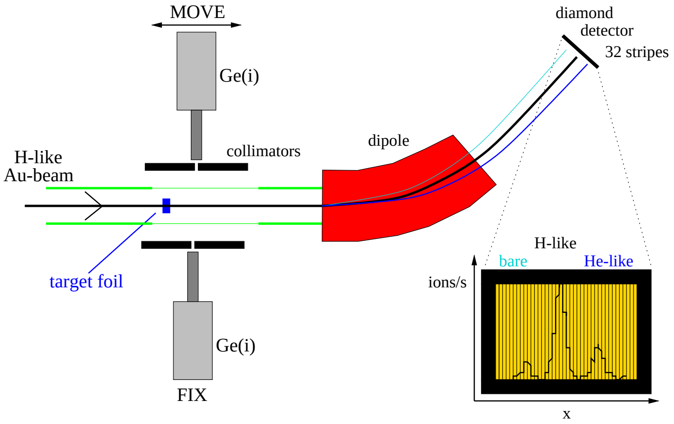

Figure 1: Experimental setup in Cave A.

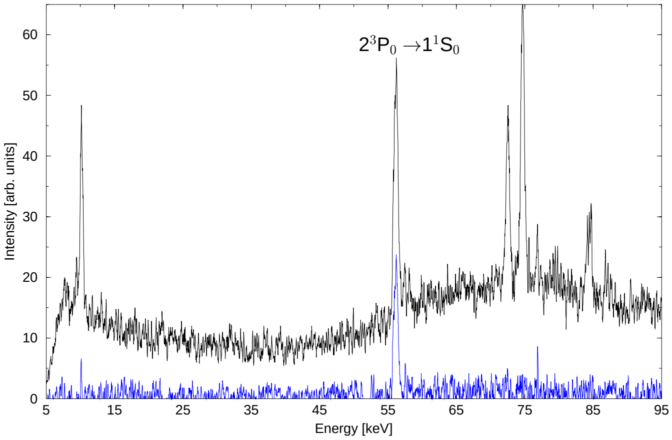

Figure 2: A raw and a coincidence spectrum obtained with the moveable Ge(i) detector.

Figure 2 now shows two sample energy spectra of the moveable x-ray detector. The upper spectrum shows a raw energy spectrum without coincidence condition while the lower one shows an energy spectrum obtained in coincidence with helium-like ions. The advantage of the coincidence technique is obvious.

The results of a prelimimary analysis of the obtained data can be seen in Figure 3. Decay curves at two different positions of the fixed detector resulting in different normalisations have been traced out, covering almost three decay lengths. In addition, to have a comparison with the old experiment also a decay curve without concidence requirement has been mea-

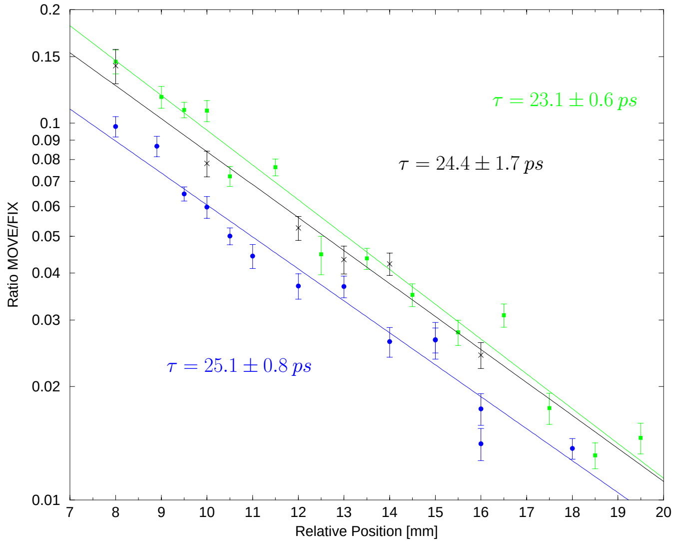

Figure 3: Measured decay curves of the $2^3\mathrm{P}_0$ state. The upper and the lower decay curves have been obtained for different normalizations detecting the x-rays in coincidence with He-like ions, while the decay curve in the middle has been obtained only detecting single x-rays.

2^3P_0	Theory		Experiment	
	[3]	[2]	this work	[7]
τ [ps]	24.66	23.66	23.9±0.5	32±4

Table 1: Comparison of the lifetime τ of the 2^3P_0 state between experiment and theory. Our experimental value is the weighted mean of all three decay curves.

sured, but only for one normalisation position. The error bars of the measured ratios are due to the statistical uncertainty at a 1σ confidence level. In order to extract the decay length l out of the decay curves, the data points have been fitted to a single exponential. With the extracted decay length l, the value for the speed of light c and the velocity of the ions β one can determine the lifetime in the laboratory frame:

$$\tau_{Lab} = \frac{1}{l\beta c}$$

This has to be transformed into the emitter frame, resulting in

$$\tau_{c.m.} = \frac{\tau_{Lab}}{\gamma}$$

for the lifetime of the 2^3P_0 state. The determined lifetimes of the different decay curves are also printed in Figure 3.

The given errors for the lifetimes are associated with the fitting procedure and are assumed to be the sole major contribution to the total experimental error. As one value overlaps with another value within the error bars, we took the weighted mean of all three values as a final result for the lifetime. The experimental results and the theoretical expectations are summarized in Table 1. Our final value agrees very well within the theoretical predictions. The results are only preliminary as the evaluation of the fine-structure splitting is still in progress.

One reason for the disagreement between the old and the new experiment may be the fact that the beam quality in the old experiment was very poor. As a consequence, the signal to background ratio was to low to get a reasonable result for the lifetime. In the new experiment the signal to background ratio has been enhanced roughly by a factor of four due to the improved beam quality. And now, even from detecting single x-rays one obtains a value for the lifetime, which agrees very well with the values that one obtains if one is using the coincidence technique.

Nevertheless, the reached accuracy of 2% looks promising concerning the planned experiment to measure the unqenched lifetime of the 2^3P_0 state in helium-like ^{238}U in the nuclear ground state from which the n=2 Lamb shift can be determined. Here the aim is to study the QED effects for the 2s-levels in a high-Z system with high accuracy.

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