Using a microcalorimeter to measure the Lamb shift in hydrogenic gold and uranium on cooled, decelerated ion beams

E. Silver [a], H. Schnopper[a], G. Austin[a], R. Ingram[a], G. Guth[a], S. Murray[a], N. Madden[b], D. Landis[b], J. Beeman[b], E. E. Haller[b], F. Bosch[c], C. Kozhuharov[c], M. Steck[c], and Th. Stöhlker[c]

[a]*Smithsonian Astrophysical Observatory*

[b]*Lawrence Berkeley National Laboratory*

[c]*Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany*

Lamb Shift measurements at high-Z can precisely test Quantum Electrodynamics in the strong field domain [1]. The accuracy of these experiments is currently limited by the energy resolution of conventional solid state germanium detectors. A further limitation arises from the uncertainty in the correction for the Doppler shift from highly charged ions moving at velocities close to 30% or even 50% of speed of light The error associated with the statistical precision of the 1s transition energy calibrations can be reduced by using a crystal spectrometer [2] or a microcalorimeter [3] with an energy resolving power that is at least an order of magnitude higher than a Ge detector can provide. This approach will improve the error in the centroid determination, but it will not address the error due to the Doppler shift correction. Here we report on a technique that improves the absolute energy determination and reduces the systematic uncertainties due to the Doppler effect. This technique is based on a measurement of the Balmer line emission with a broad band, high resolution microcalorimeter. The Balmer series includes several emission lines that are not subject to QED effects. High resolution measurements of these shifted, but known lines can be used to determine the Doppler correction with high precision. This internal calibration of the Doppler shift eliminates the complex geometrical corrections associated with prior experiments [1]. Using a microcalorimeter with an energy resolution of 10 - 20 eV in the 10 - 20 keV energy band can reduce significantly the uncertainties in the energy calibration including the Doppler correction.

In March 2003, we measured the Balmer lines of hydrogenic Au with a microcalorimeter and cryostat installed at the SIS/ESR synchrotron storage ring at GSI. The ions had velocities of 0.44 c and Doppler-shifted x-ray energies for the Balmer transitions range between 7 and 14 keV at an azimuthal viewing angle of 145 degrees. The 1 x 3 microcalorimeter array and its cryostat were completely enclosed in a copper EMI shield. The shield was placed next to the 145 degree view port on the ESR jet-target leaving a small air gap. The solid angle subtended by the detector at the source was 5×10^{-8} sr. We accumulated data for a total of 17 hours over a four day period and collected 327 photons; a low number but not surprising for an experiment with a solid angle of 5×10^{-8} sr at the ESR. The spectrum including all of these events is shown in Figure 2 (histogram). The spectrum obtained with the GSI germanium spectrometer, scaled down by a factor of 2000 is superimposed (smooth black line). The nominal resolution of these microcalorimeters is about 20 eV at 10 keV. But with only 327 detected photons over the entire energy band, we combined the data into 16 eV bins. With essentially zero background, the microcalorimeter is able to detect the same spectral features as seen by the much larger germanium spectrometer.

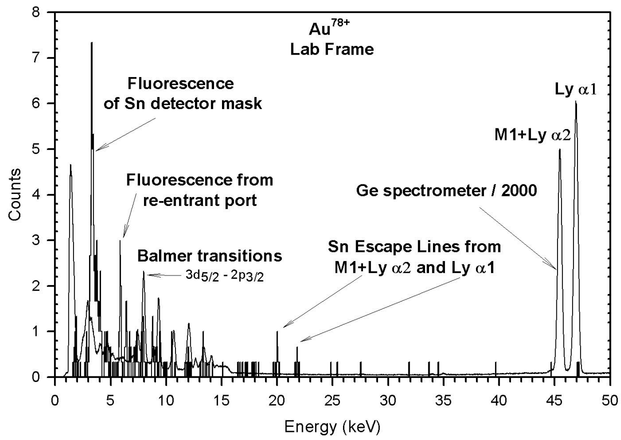

Figure 1. *The microcalorimeter spectrum (histogram) obtained from Au* $^{78+}$ *. The spectrum measured by a germanium detector reduced by a factor of 2000 is superimposed (smooth solid line).*

Although the statistical precision of this first microcalorimeter measurement is low, we have been able to show how a measurement of one of the more distinct Balmer line energies that are QED insensitive can be used to determine the Doppler correction and estimate the Lyman energies. In future measurements, several such Balmer lines will be used to reduce the uncertainty further.In particular, we can expect to increase the solid angle of collection by increasing the number of detectors from 3 to 16 and moving the instrument from the ESR port at 145 deg to the port at 90 deg. This moves the detectors closer to the interaction volume. In addition, a further deceleration of the ions to velocities close to about 0.3c or even 0.2c will reduce the relativistic Doppler corrections for the x-rays. The overall increase in the solid angle will be at least 56 times.

References:

[1] Th. Stöhlker et al.,Phys. Rev. Lett., 85,15, (2000) 3109.
[2] H.F. Beyer et al., GSI Scientific Report (1999).
[3] P. Egelhof et al., Nucl. Instr. & Meth A, 370, (1996),263.
[4] T.Beier et al., Phys. Lett A, 236, (1997),329.