The Absorption Edge Technique at the Super-EBIT

A. Krämer [a,b] S.R. Elliott [c,d] R.E. Marrs [c] J.H. Scofield [c] Th. Stöhlker [a,b]

[a] *Institut für Kernphysik, August-Euler-Str. 6, D-60486 Frankfurt, Germany*
[b] *GSI-Darmstadt, Planckstr. 1, D-64291 Darmstadt, Germany*
[c] *Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94551, USA*
[d] *Department of Physics, Box 351560, University of Washington, Seattle, WA 98195-1560, USA*

In an experiment at the Super-EBIT in Livermore, the absorption edge technique has been applied for the investigation of the x-ray emission of heavy ions in a trap. The aim of the measurement was to resolve the Radiative Recombination transitions into the L-shell of the different ion species which are simultaneously present in the trap in order to measure directly their contribution to the charge state distribution. The energy resolution required was obtained by using a lead absorber foil in front of a solid state x-ray detector which constitutes a considerably improved resolution with respect to standard germanium detectors.

1. Experimental Method

The experiment was performed at the electron beam ion trap facility at the Lawrence Livermore National Laboratory [1]. The EBIT was designed for the study of atomic processes of highly charged ions by Levine et al. [2]. Highly charged uranium ions are trapped radially by the negative space charge potential of the electron beam and axially by different potentials at the drift tubes. The ions are held within the beam for times much longer than the time required to strip uranium ions to very high charge states. Hence the ionization balance reaches a steady-state equilibrium. Thus it is possible to produce and trap bare uranium ions [3]. A detailed description of the Super-EBIT can be found in Ref.[4]

For the determination of the charge state distribution in the EBIT it is possible to exploit the photon absorption characteristic of high-Z elements. Here the basic idea is that radiative recombination (RR) x-rays with different energies are differently absorbed in an absorber foil. Due to the various electron configurations of the several charge states in the trap, the recombination energies, and therefore the energy of the emitted photons, are slightly different. Thus it is possible to distinguish the L-RR transitions for the various charge states with a resolution essentially determined by the absorption edge width.

By variation of the electron beam energy (close to 60keV) the position of the n=2, j=3/2 RR lines can be tuned across the lead absorption profile. A scheme of the experimental setup used is depicted in Fig. 1. For the experiment

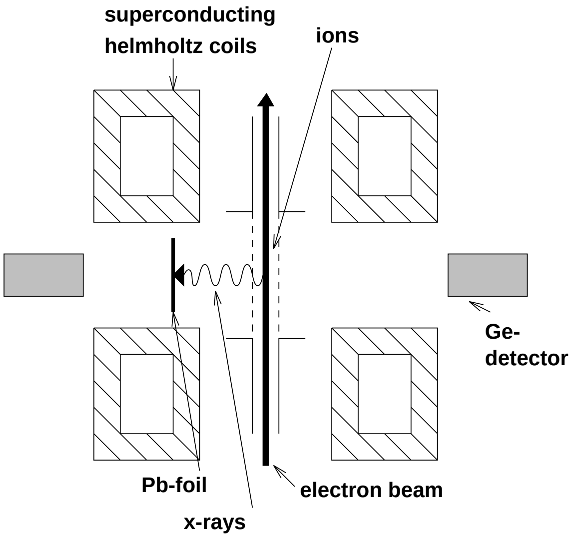

Figure 1.: Experimental setup for the absorption edge technique at the EBIT with two Ge-detectors and Pb-foil

two different germanium detectors were used. One detector viewed the x-ray emission zone through a 0.6 mm thick Pb absorber whereas the second was not equipped with an absorption foil. The latter detector served for normalization purposes. In total, x-ray spectra were recorded for 42 different beam energies in the range of 58.5 to 62.5 keV. For one fixed electron beam energy the RR spectra with and without foil are displayed in Fig. 2. The relative transmission of the RR photons through the Pb absorber was obtained by normalizing their line intensities of the detector equipped with the Pb absorber to the one without absorber. In Fig. 3 the result for the transmission of the n=2, j=3/2 RR photons are presented as a function of beam energy E_{kin} (see upper axis). The error bars given refer to the statistical uncertainty. As can be seen in the figure, the data exhibit distinctive structures caused by the RR transitions into the uranium ions

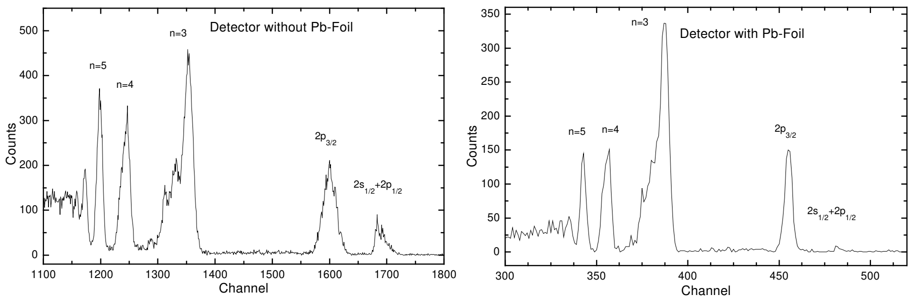

Figure 2.: Comparison of the x-ray spectra scanning the RR energy across the K-absorption edge of lead and as seen in the germanium detector at fixed electron beam energies. Left: Spectrum of the Ge-detector without absorber foil. Right: Spectrum of the detector with the 0.6-mm-thick Pb-foil in front.

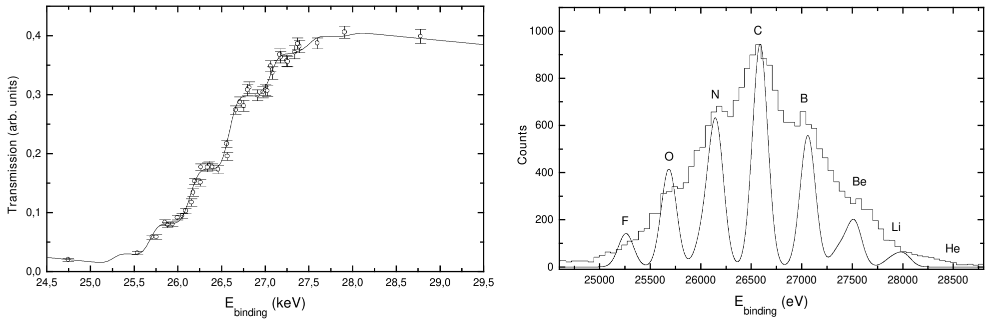

Figure 3.: Left: Ratio of x-ray counts with and without lead foil in front of the detector with error bars. The solid curve is a least-squares fit as explained in the text.
Right: Comparison of the germanium detector spectrum at 60keV electron energy with no absorber and the derivation of fit curve from the left plot.

with different charge states. The solid line in this figure refers to a least squares fit, using an error function [5], of the data points. The first derivative of this fit result is depicted in figure 3 (right figure), which show the relative transmission strength of the various RR lines at 90 degree observation angle. In addition the figure shows the n=2, j=3/2 RR x-ray lines observed at an electron beam energy of 60keV with the Ge-detector not equipped with an absorber. This comparison, depicted in the figure, demonstrates the resolution obtained by the applied technique. It is very impressive that due to this method the resolution increases from ≈ 450eV to ≤ 100eV.

The charge state distribution in the trap can be determined from the measured relative intensities, by considering the differential cross section of RR into

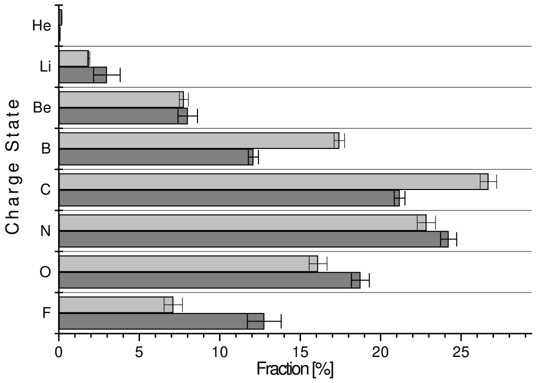

Figure 4.: Comparison of the charge state distribution in the Super-EBIT at an electron energy of 60keV. The light gray histogram shows the distribution which was calculated in respect to a fit of the RR lines into the j=3/2 state of the target ions. The dark gray histogram results from the fit of the data points of the absorption edge.

the L-shell levels [6] for the observation angle of 90 degree. In figure 4 a comparison between the charge state distributions obtained by the absorption edge technique and the one deduced directly from the RR x-ray spectrum is given. For a detailed description of the method used for data analysis, we refer to reference [1]. Fig. 4 shows small differences between both methods. These were caused by the slightly changing electron beam energy and therefore the slightly different radiative recombination and charge exchange cross sections. With respect to this point, we did not expect a perfect agreement between the two charge state distributions obtained with the two different methods.

2. Summary and Conclusion

In this experiment we demonstrated the possibilities of the absorption edge technique for the determination of the charge state distribution in the Super-EBIT. With the achieved resolution it might be even possible to measure binding energies with an accuracy of about 1eV by comparing two adjacent charge states.

References

[1] Th. Stöhlker, A. Krämer, S.R. Elliott, R.E. Marrs and J.H. Scofield, Phys. Rev. **A56**, 2819 (1997)

[2] M.A, Levine, R.E. Marrs, D.A. Knapp and M.B. Schneider, Phys. Scr. T22, 157 (1988)

[3] R.E. Marrs, S.R. Elliott and D.A. Knapp, Phys. Rev. Lett. 72, 4082 (1994)

[4] D.A. Knapp, R.E. Marrs, S.R.Elliott, E.W. Magee and R. Zasadzinski, Nucl. Instrum. Methods A334, 305 (1993)

[5] J.H. Lupton, D.D. Dietrich, C.J. Hailey, R.E. Steward and K.P. Ziok, Phys. Rev. **A50**, 2150 (1994)

[6] J.H. Scofield, private communication (1996)