Multiple Electron Capture from C-foils into Slow Highly-Charged Ions

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The differences in ion-atom collisions with gas targets on one side and solid targets on the other side constitute a well known problem in collision physics which is still not well understood [1]. With the availability of new ion sources like ECR and EBIS the interaction of slow (keV region), highly-charged ions with solids, i.e. with bulk material and with surfaces, has attracted increasing interest in the recent years [2, 3, 4]. The SIS-ESR facility at GSI with the newly installed charge state spectrometer in Cave A provides an ideal tool to extend these studies towards ultimately charged very heavy ions ($Z\alpha \rightarrow 1$) at moderate velocities down to about 15 MeV/u.

As a first experiment and a test of the charge state spectrometer we have measured total electron capture and projectile ionization cross sections for 46 MeV/u Pb^{81+} and 184 MeV/u Pb^{81+} traversing thin C, Al, Cu and Au foils of varying thickness. The setup as used for the total cross section measurements is shown schematically in fig. 1. The low energy beam, has been extracted after deceleration from the ESR by charge exchange in the cooler section [5]. The high energy beam was delivered directly from the SIS. After traversing the target the final charge states were analyzed by the new charge state spectrometer consisting of a quadrupole doublet and a bending magnet and detected with a position sensitive multi-channel plate detector. Fig. 2 shows the detector image of the charge state distribution for 46 MeV/u Pb^{81+} on Au. Up to 8 charge states can be simultaneously detected on the detector, allowing the direct measurement of relative cross sections. Absolute cross sections were measured by detecting also the direct beam with the detector. While the detector system can handle an overall rate of over 10^6 ions/s the strong localization of the charge states on the detector restricts the count rate to about 10^4 ions/s per charge state to avoid local efficency problems.

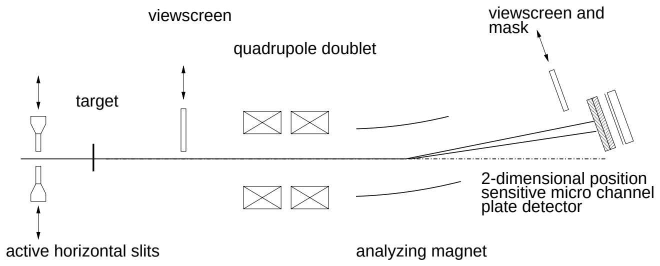

Figure 1: *Experimental setup for total cross section measurements on multiple electron capture and projectile ionization in Cave A.*

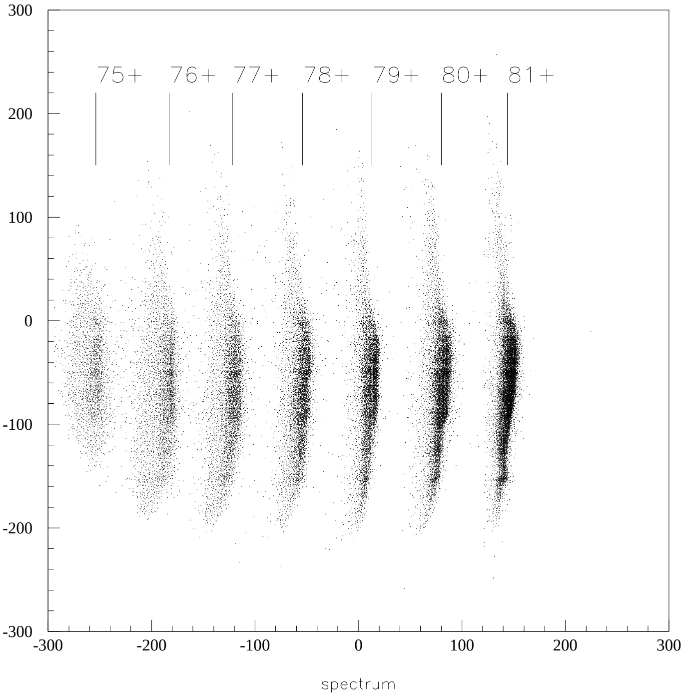

Figure 2: *Detector image of the projectile charge state distribution after the collision 46 MeV/u Pb^{81+} on Au.*

Fig. 3 shows the total cross sections for single, double and triple capture as well as projectile ionization as a function of target thickness for 46 MeV/u Pb^{81+} on C. Within the error bars single capture and projectile ionization show no dependence on the target thickness. This indicates single collision conditions in the targets used. Furthermore, the measured cross section of 54 barn for projectile ionization is in good agreement with SCA calculations based on the IONHYD code by Trautmann (see references in [6]) and PWBA calculations [7] as shown in fig. 4.

For multiple electron capture, however, we obtain a significant dependence of the total cross section on the target thickness. As is shown in fig. 3 the cross sections for multiple electron capture increase with *decreasing* target thickness below 20 $\mu g/cm^2$. The capture of 4 and 5 electrons could also be observed and shows a similar dependence on target thickness.

This behaviour can be explained by a very large probability to capture electrons from the entrance surface into very high lying states, which are easily removed inside the bulk either be re-ionization in collisions or by autoionization. Thus these electrons contribute to the final charge state only for very thin targets. The much lower cross sections for thicker targets, where all electrons cap-

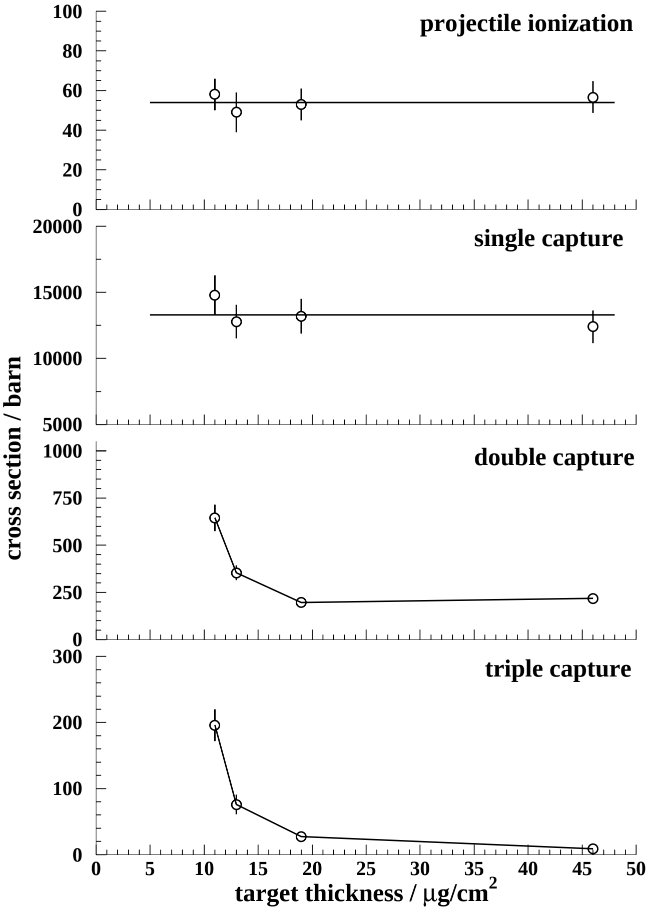

Figure 3: *Projectile ionization and multiple electron capture cross sections as a function of target thickness for 46 MeV/u Pb^{81+} on C. The lines are meant to guide the eye only.*

tured from the surface are already lost again, indicates, that the probability for electron capture in the target bulk is much smaller than from the surface. In addition the data indicate a difference in capture probability from the entrance and exit surface. If the probability would be identical, the ratio in yield between the thinnest target, where electrons from the entrance and exit surface contribute, and the thickest target, where in the extreme case only the exit surface contributes, should be no more than 2. While this is true for double capture, in the case of triple capture the ratio is about 4.6. This suggests that the probability to capture electrons from the exit surface is reduced, maybe by electron depletion due to the wake field.

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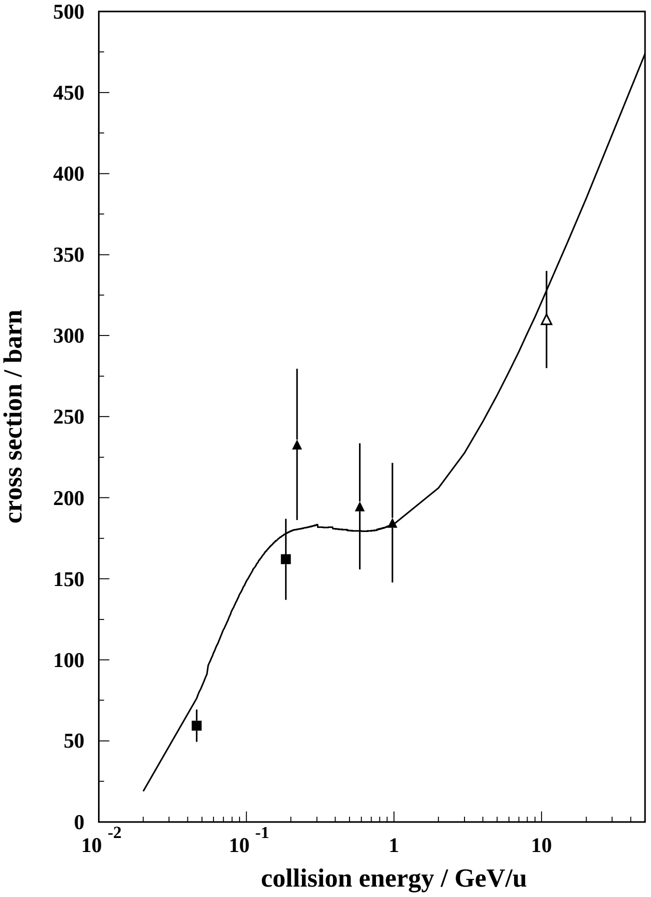

Figure 4: *Measured projectile ionization cross sections for Pb^{81+} (filled squares, this work) and on Au^{78+} (filled triangles [8] and open triangle [9]) on C in comparison to PWBA calculations from [7, 8].*

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