# Ionization of High–Z Projectiles at Relativistic Energies ≤ 1000 AMeV

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K-Shell ionization is one of the most basic atomic reaction channels occurring in relativistic collision of high-Z ions with matter [1]. For cross-section estimates, the theoretical approach of Anholt [2] has been widely used during the last decade. These cross sections are derived from first–order time–dependent perturbation theory by applying semi–relativistic approximations to the wave functions of the projectile electrons. While this model has shown to provide reliable results for the total cross sections over a wide range of projectile energies, some deviations remain, in particular for energies ≤ 1000 AMeV [3]. To understand these discrepancies, a number of advanced, nonperturbative models , including lattice and coupled–channel calculations, were proposed in the past. Up to the present, however, these theoretical investigations are mainly restricted to individual impact parameters and, therefore, cannot be compared with existing experimental results. In contrast, no study has been carried out so far to explore the influence of Anholts semirelativistic approximations by using fully relativistic wave functions instead. Here, we report about relativistic calculations for projectile K-shell ionization for H-like high–Z ions, e.g. $Au^{78+}$ or $U^{91+}$. Our work has been motivated by recent results for K-shell excitation of high-Z ions, where magnetic effects have been found to be very important [4].

In the semiclassical approximation, an excitation or ionization of projectile electrons mainly occurs due to the nuclei of the target atoms. As seen by the projectile, the charge $Z_T$ of the target nucleus *cause* a short perturbation which may lead to the excitation or emission of electrons. In contrast, the target electrons are only of minor role because of the $Z^2$ scaling of the cross-sections. In more detail, the first–order transition amplitude for excitation and ionization is given by

$$A_{fi}(b) \;=\; i\,\gamma\,\alpha\,Z_T \int dt\, e^{i(E_f-E_i)t} \int d^{3N}\mathbf{r}\;\psi_f^{+}(\mathbf{r}) \times \left[ \sum_k^N \frac{1-\beta\,\alpha_{k,z}}{r_k'} \right] \psi_i(\mathbf{r}) \;. \qquad (1)$$

where $\psi_i(\mathbf{r})$ and $\psi_f(\mathbf{r})$ are exact Coulomb Dirac single electron wave functions for the initial and final states. Apart from these wave functions, the amplitudes depend on both, the nuclear charges of the target and the projectile as well as on the relative velocity $v$ of these particles. From the amplitudes (1), the differential ionization cross section is obtained from the expression

$$\frac{d\sigma_i}{dE_f} \;=\; 2\pi \int_0^\infty db\, b\, |A_{fi}(b)|^2 \qquad (2)$$

while the total ionization cross section $\sigma_{\rm tot}$ just follows from an integration over the energies of all final states. Note, that the complete Liénard–Wiechert potential (see the expression given in parenthesis in Eq. (1)) includes both, the electric *and* magnetic interaction as they arise from the relativistic motion of the projectile (respectively the target). As shown in relativistic structure calculations, an efficient discretization of the complete spectrum can be obtained by using a relativistic generalization of Gaussian– or Slater–type orbitals. Test calculations for the total cross sections (including a summation over the whole continuum) yield good agreement for both types of spinor sets. As an example, in figure 1 the calculated ionization cross-sections $\sigma_{\rm tot}$ are given for the impact of $Au^{78+}$ on carbon as function of the impact energy along with experimental data [4]. As can be observed in the figure, the theoretical results are in good agreement with the experimental result.

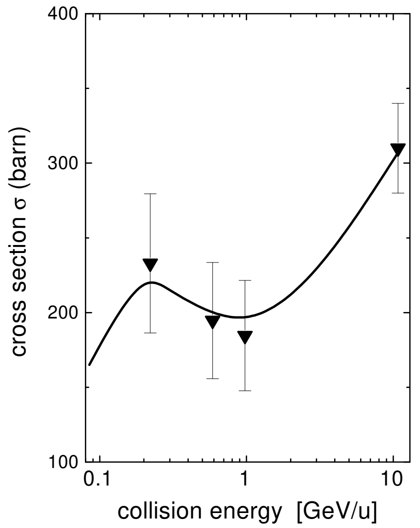


Figure 1: Total ionization cross section for $Au^{78+}$ impact on a carbon target (see text).

A detailed comparison with the most commonly used theoretical cross-section calculation for projectile ionization will be the subject of further studies. Apart from total cross sections, we like to stress, that the approach presented here allows one to calculate also energy and angle–differential cross sections which are of particular relevance for future experiments.

## References

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