Asymptotic energy dependence of projectile inner-shell excitation cross sections in relativistic ion-atom collisions

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In recent years atomic collisions with ions moving with velocities close to the velocity of light have become experimentally feasible. While in the first place we are interested in a basic understanding of atomic phenomena for their own sake, a precise knowledge of the cross sections for collision processes is needed for certain aspects of the design and operation of accelerators. As an example, Coulomb excitation of electrons which is essential for stopping power investigations, is also an important production process for characteristic projectile photons in ion-atom encounters.

In particular, Coulomb excitation of heavy projectile ions enable the investigation of the influence of relativistic bound state wave functions on the dynamics in relativistic ion-atom collisions. In addition, such studies provide detailed information on the effects associated with the Liénard-Wiechert interaction between the active electron and the target nucleus [1]. Thus, with increasing energy spin-flip mediated transitions where shown to become quite important above roughly 100 MeV/u such that contributions associated with the velocity dependent (magnetic) part of the time dependent interaction are quite relevant. In contrast to ionization where measured total cross sections are available for highly-charged ions up to uranium for more than one decade, it was only recently that detailed experimental data on the K-shell excitation of high-Z projectile ions were reported [1, 2].

In the present investigation we elucidate further details of the mechanisms associated with the Coulomb excitation of high-Z_P projectiles by considering the asymptotic energy dependence of the relevant cross sections. Specifically, we extend our previous results into the extreme relativistic energy domain with energies of hundreds of GeV/u. The numerical calculations are complemented by an analytic representation of the asymptotic energy dependence of cross sections which brings additional insight. The projectile ion is chosen as the origin of the coordinate system such that the target provides the time dependent perturbation mediating the transition.

In Figure 1 we show the energy dependence of reduced cross sections σ/Z_T^2 for exciting a K-shell electron in hydrogen-like gold colliding with an atomic target with charge number Z_T. The cross sections are divided by Z_T^2 which is the scaling behavior in lowest-order perturbation theory. We consider the (Ly-α_1) transition of a $1s_{1/2}$ spin-up electron ($\mu_i = 1/2$) to the $2p_{3/2}(\mu_f = \pm 1/2, \pm 3/2)$ states of the projectile ion (Au^{78+}). The upper curve (Σ) is associated with the total Ly-α_1 cross section, the dashed (short-dashed) curve corresponds to the transition with $\Delta\mu = \mu_f - \mu_i = +1(-1$, splin-flip), and the dotted (dott-dashed) curve is related to $\Delta\mu = +2(0)$.

The present numerical results demonstrate that cross sections associated with transitions where the magnetic quantum number changes by one unit ($\Delta\mu = \pm 1$) *increase* with increasing energy roughly as $\ln E$ in the region above 1 GeV/u. In contrast, the cross sections associated with the other types of transitions ($\Delta\mu = 0, 2$) *decrease* with increasing collision energy, and approach zero in the asymptotic energy region. Note that the inclusion of screening would lead to different energy dependence [3]. As a result, the cross section for the unscreend Ly-α_1 transition is provided solely by the $\Delta\mu = \pm 1$ transitions for collision energies in the GeV/u region and higher.

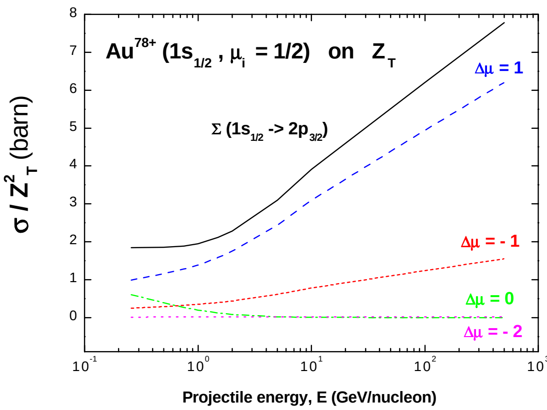

Figure 1: Reduced cross sections σ/Z_T^2 for projectile excitation as functions of the laboratory energy.

An interesting parallel can be made with a computationally simple treatment of the excitation process in the Fermi-Weizsäcker-Williams (FWW) approximation. There the actual electromagnetic field created by the moving ions is approximated by the field associated with a swarm of real photons. In addition, a free parameter which is related to the maximum photon energy is to be fixed (in some sense arbitrary), such that the domain of applicability of the method is often not clear. From Figure 1 one can see that above roughly 3 GeV/u only transitions with $\Delta\mu = \pm 1$ provide a nonzero contribution to the cross section. Thus, the present investigation provides a quantitative measure of the range that can be treated safely in a computationally simple FWW scheme.

References

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