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In contrast to nonrelativistic collisions between two composite atomic systems which both carry electron(s), neither the plane-wave Born treatment nor the semiclassical formalism were formulated for relativistic collisions of such systems [1]. We have recently attempted [2] to extend the first order plane-wave Born and semi-classical approximations to treat relativistic collisions between composite atomic systems (the simplified version of the semi-classical treatment was given in [3]). In order to describe collisions between a (single-electron) projectile-ion and a target-atom which are subject to the electromagnetic interaction in the collision, we start with the transition S-matrix element

$$S_{fi} = \left(-\frac{i4\pi}{c^2} \int d^4x d^4y J^I_\mu(x) D_F(x-y) J^\mu_A(y) \right)_{fi}, \quad (1)$$

where $J^I_\mu(x)$ and $J^\mu_A(y)$ are the electromagnetic 4-currents of the projectile-ion at a space-time point x and of the target-atom at a space-time point y, respectively, and $D_F(x-y)$ is the propagator for electromagnetic radiation. The cross section of a process, where the electron of the projectile-ion makes a transition from the ground state ψ_0 (with energy ε_0) to a final state ψ_n (ε_n) of the ion and the electrons of the atom a transition from the ground state φ_0 (ϵ_0) to a final state φ_m (ϵ_m) of the atom, is obtained to be

$$\sigma^{0\to m}_{0\to n} = \frac{4}{v^2\gamma^2} \sum_{s_I} \sum_{s_A} \int d^2\mathbf{q}_\perp \times$$

$$\frac{\mid F^I_\mu(n0; -\mathbf{q}_\perp, -q_{min})\, \Lambda^\mu_\nu F^\nu_A(m0; \mathbf{q}_\perp, Q_{min}) \mid^2}{\left(q^2_\perp + q^2_{min} - \frac{(\varepsilon_n - \varepsilon_0)^2}{c^2} \right)^2}. \quad (2)$$

The integration in (2) runs over the two-dimensional transverse vector $\mathbf{q}_\perp$ with $0 \leq q_\perp < \infty$ and $\mathbf{q}_\perp \cdot \mathbf{v} = 0$, where $\mathbf{v}$ is the collision velocity. Further, F^I_μ and F^ν_A, ($\mu, \nu = 0, 1, 2, 3$) are the four-component form-factors of the projectile-ion (given in the rest frame of the ion) and of the target-atom (given in the rest frame of the atom), respectively. Λ^μ_ν is the Lorentz transformation matrix between these two frames, $\gamma = (1 - v^2/c^2)^{-1/2}$ is the Lorentz factor, $q_{min} = \frac{\varepsilon_n - \varepsilon_0}{v} + \frac{\epsilon_m - \epsilon_0}{v\gamma}$ and $Q_{min} = \frac{\epsilon_m - \epsilon_0}{v} + \frac{\varepsilon_n - \varepsilon_0}{v\gamma}$. The summation indicated in (2) runs over the spin degrees of freedom of the electron of the ion and those of the atom.

If the final intrinsic state of the atom is not observed, one has to sum over all possible states of the atom. The resulting cross section can be split into the screening ($m = 0$) and antiscreening (all $m \neq 0$) contributions to the total cross section for the transition $0 \to n$ of the electron of the ion.

Figure 1 displays cross sections for the electron loss from a Pb^{81+} projectile in collisions with a neutral carbon atomic target as a function of the collisions energy. The experimental points at lower energies are from [4], the high-energy point is from [5]. In our calculations we neglected the space components of the atomic form-factor, $F^l_A = 0$, $l = 1, 2, 3$ and used semi-relativistic wavefunctions for the electron states in the ion. In addition, the contribution of the antiscreening mode to the total cross section was evaluated within the closure approximation which, for the collision system in question, is expected to be a reasonable approximation for $\gamma \gtrsim 2 - 3$. For the collision system the antiscreening mode is expected to give a negligible contribution at collision energies below 0.2 GeV/nucleon.

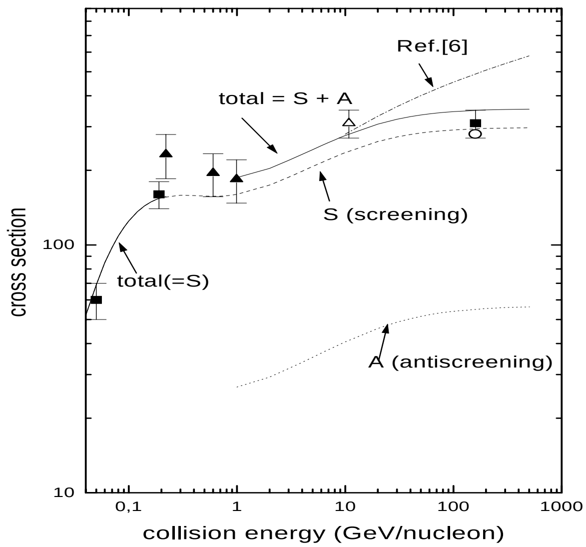

Figure 1: Loss cross section for Pb^{81+} impact on a carbon target; squares: experimental data from [4] and [5]; dashed, dotted and solid curves: our calculations for the screening, antiscreening and total contributions to the loss, respectively; dash-dotted curve: results of [6]; open circle: an estimate of [7]. For additional information experimental results from [8] and [9] on the electron loss from a Au^{78+} projectile in collisions with carbon are also shown (solid and open triangles, respectively).

References

[1] J.Eichler and W.E.Meyerhof, *Relativistic Atomic Collisions* (Academic Press, 1995)

[2] A.B.Voitkiv, N.Grün and W.Scheid, Phys.Rev.A, accepted for publication; A.B.Voitkiv, M.Gail and N.Grün, J.Phys.B, to be published

[3] A.B.Voitkiv, N.Grün and W.Scheid, Phys.Lett. **A 260** 240 (1999)

[4] H.Bräuning et al., to be published.

[5] H.F.Krause et al., Phys. Rev. Lett. **80** 1190 (1998)

[6] R.Anholt and U.Becker, Phys.Rev. **A 36** 4628 (1987)

[7] A.H.Sørensen, Phys.Rev. **A 58** 2895 (1998)

[8] Th.Stölker et al., NIM **B 55** 124 (1997)

[9] N.Claytor et al., Phys.Rev.**A 55** R842 (1997)