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The role of scattering on atomic nucleus and of electron state entanglement in single ionization of He by ion impact

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Synopsis

The DWA scattering amplitude is presented in a form where different interactions are essentially separated. This form permits also to treat in the regular way the motion of nuclei quasiclassically. It is argued that, due to the entanglement of electron states, the screening by all except of the active electron is not effective.

Recently the data for single ionization in 100 MeV/amu C$^{6+}$+He collisions measured by reaction microscope have been mainly reconciled with the first Born description [1]. However, the treatment of elastic scattering in the semiclassical terms is not justified in the FBA picture. Also, the question is left why the distorted wave approaches (DWA) are not capable to reproduce some features of FDCS. These problems are addressed in the present contribution where a method is proposed how to separate different interactions in the DWA, to apply the quasiclassical approach for the projectile motion and, finally, to treat accurately the interaction with two electrons.

The first problem is solved by insertion into the scattering matrix

$$T_{fi} = \langle \chi_{p_f}^+ | U_{if}(R) | \chi_{p_i}^+ \rangle$$

the sum of the closure relation for the states of the projectile scattering on the atomic core $\chi_{p_i}^+$:

$$T_{fi} = \sum_p \langle \chi_{p_f}^+ | \chi_{p}^+ \rangle \langle \chi_{p_i}^+ | U_{if}(R) | \chi_{p}^+ \rangle$$

(1)

($U_{if}(R)$ in (1) is the matrix element for electron transition, $R$ the projectile coordinates). The first factor in (2) is the scattering matrix for elastic scattering on the atomic core,

$$\langle \chi_{p_f}^+ | \chi_{p}^+ \rangle =$$

$$= \delta(p - p_f) + \frac{i}{2\pi p_f} \sum_p f_{pp_f} \delta(|p| - |p_f|),$$

(3)

where $f_{pp_f}$ is the ordinary amplitude of elastic scattering. With this the amplitude (2) is represented as a sum of two terms:

$$T_{fi}^e = \langle \chi_{p_f}^+ | U_{if}(R) | \chi_{p_i}^+ \rangle,$$

(4)

$$T_{fi}^{\delta} = \frac{i}{2\pi p_f} \times$$

$$\times \sum_p f_{pp_f} \delta(|p| - |p_f|) \langle \chi_{p_f}^+ | U_{if}(R) | \chi_{p_i}^+ \rangle;$$

the former presents mainly the scattering on electrons while the latter accounts for the sequential scattering on electrons and on the atomic core. At large energies the states $\chi_{p_i}^+$ can be described by plane waves (as in FBA).

The second advantage of (4) and (5) is that the entering matrix elements for the states of the same orthogonal basis can be treated quasiclassically [2]. The result is that the matrix elements are presented as Fourier transformation of the semiclassical transition amplitude. It is also shown that $T_{fi}^{\delta}$ is presented as a product of the amplitude of elastic scattering by the amplitude of electron transition. Thus we have a surprising result: two terms $T_{fi}^e$ and $T_{fi}^{\delta}$ commonly identified as alternative forms of the transition matrix must be summed in the correct result.

Finally, as far as we treat the interaction of the projectile with both electrons as perturbation, the states $\chi_{p_i}^+$ should describe scattering on the bare atomic nucleus (effective charge is equal to $Z_2 = 2$). The consequence is that, in the elastic collisions, $U_{ij}(R)$ presents effect of screening of atomic nucleus modifying the scattering on the Coulomb potential. In inelastic scattering, due to the orthogonality of one-electron states, the transitions of different electrons are summed in the amplitude with all other electrons non-active. Such "undressing" effect is due to assumed entanglement of the states of atomic electrons and its signatures have been recognized in the measurements relating to the energy loss-deflection angle correlations [3].

References

