Relativistic calculations of charge transfer probabilities in heavy-ion collisions using the basis set of cubic Hermite splines *

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Low-energy heavy-ion collisions provide a unique opportunity to test quantum electrodynamics effects in supercritical electromagnetic fields [1]. The investigation of related phenomena requires first the development suitable numerical methods for solving the two-center time-dependent Dirac equation in the external electromagnetic field generated by the colliding heavy ions. In previous works we developed a numerical method using the basis of atomic-like Dirac-Fock-Sturm orbitals [2, 3], which allows us to calculate charge transfer and electron excitation probabilities in ion-ion and ion-atom collisions.

Here we report on an alternative approach for the treatment of exact two-center Dirac problem based on utilizing the finite basis set of cubic Hermite splines on a two-dimensional uniform lattice. Previously, the Hermite splines have been employed for relativistic calculations of electron excitation probabilities within the monopole approximation [4]. An advantage of this basis set is, that only adjacent Hermite splines overlap. Accordingly, the Hamiltonian and overlapp matrix are sparse. Moreover, since the overlapping area is small, the matrix elements can be obtained by numerical integration at a smaller number of points. The Dirac equation is solved in the reference frame which rotates together with the internuclear axis. It allows using the two-dimensional lattice instead of a three-dimensional one. The influence of the rotational couplings is taken into account by the inclusion of the states with different projection of the total angular momentum into the basis set. The time-dependent Dirac equation is solved by expansion of evolution operator into the Taylor series.

At first, collisions of a bare nucleus U^{92+} (projectile) with one-electron ion $\mathrm{U}^{91+}(1\mathrm{s})$ (target) were considered. The target is considered to by at rest, while the projectile moves along a straight-line trajectory with a constant velocity. Charge transfer probabilities were calculated at the projectile energy $E = 6$ MeV/u for a wide range of the impact parameters b. The calculations were performed including several channels with different projection of the total angular momentum onto the internuclear axis. In the case of one channel the rotation of the internuclear axis is not taken into account. The results of calculations are shown in Fig. 1. As one can see from Fig. 1, the six channel results are in a good agreement with the corresponding values of Ref. [2]. We observed that four channels are quite sufficient to describe the charge transfer process. Since for impact parameter $b < 600$ fm the one-channel results differ significantly from those including six channels, we can conclude that the influence of the rotational coupling due to the rotation of the internuclear axis becomes essential for small values of b.

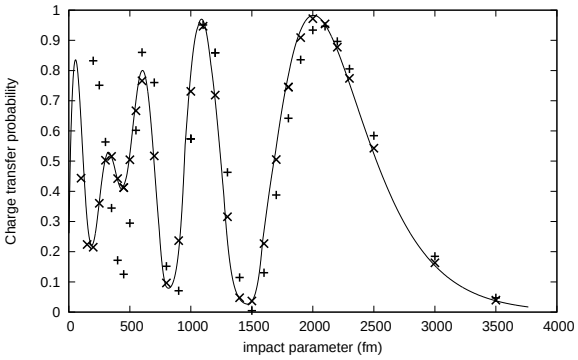

Figure 1: The charge transfer probability as a function of the impact parameter for $\mathrm{U}^{92+} - \mathrm{U}^{91+}(1\mathrm{s})$ collision at the projectile energy $E = 6$ MeV/u. Symbols "+" and "×" indicate the results of one- and six-channel calculations, respectively. The solid line indicates the results of Ref. [2]

We plan to extend the developed method to describe ionization and pair-creation processes in heavy-ion collisions. The negative-energy Dirac continuum will be considered to be fully occupied by electrons. The amplitudes of corresponding processes will be calculated utilizing many-body techniques as described in [5, 6]. We expect that this work will be required for the future experiments at GSI and FAIR.

References

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