QED corrections to the radiative electron capture in heavy ion-atom collisions

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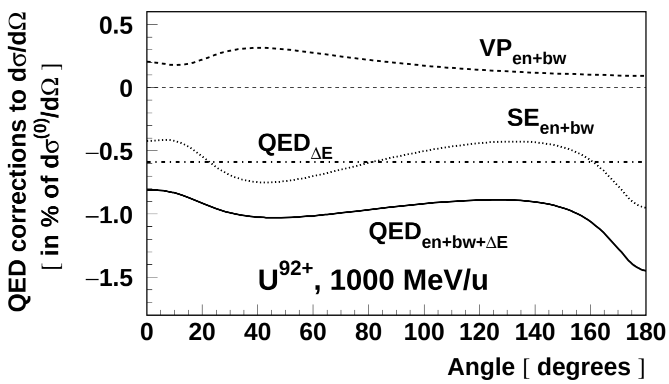
Recently, investigations of radiative-electron-capture (REC) processes in heavy ion-atom collisions became possible at GSI [1]. In these processes a quasi-free target electron is captured by a heavy ion. The REC process therefore is almost equivalent to the radiative recombination (RR) process or its time-reversed analogon, the photoeffect. The relativistic theory of the REC was considered in detail in Refs. [2, 3]. The results of this theory are in excellent agreement with experiments. In particular, the spin-flip contribution to the REC, calculated in [2, 3], was recently identified in angular-resolved measurements [4].

In view of the increasing experimental accuracy and the well-defined theoretical description, it is tempting to search for QED effects supplementing the existing theory. Heavy ions are known to be good systems for testing the quantum electrodynamic (QED) effects in strong electric fields. However, until now, in heavy ions these effects were investigated only for bound states (see Ref. [5] and references therein). On the other hand, QED corrections to the photoeffect were considered only to the lowest order in αZ in Refs. [6, 7]. Since calculations based on an αZ-expansion are not valid for high-Z systems, it is necessary to perform calculations for the complete αZ-dependence.

A systematic QED theory of the RR processes has been worked out in Ref. [8]. In the present work, we apply this theory to derive the complete formulas for the QED corrections to the first order in α to the radiative recombination of an electron with a bare nucleus. Comparing the resulting formulas with the related expressions from Refs. [6, 7], we found that a non-zero contribution from the reducible part of the diagram with the self-energy (SE) loop on the outgoing electron line was omitted in Refs. [6, 7]. The general formulas for the self-energy and vacuum-polarization corrections suffer from ultraviolet (UV) and infrared (IR) divergences. While the UV divergences can be eliminated by the standard renormalization procedure, the IR divergences are more difficult to remove. We demonstrate that all the IR divergences are cancelled in the total cross section by allowing for the emission of an unobserved soft photon with an energy less than the finite photon-energy resolution ΔE. As a result, the QED correction to the total RR cross section depends on ΔE, assuming that the energy spread in the initial electron beam is much smaller than the finite photon-energy resolution. However, this is not the case for the present REC experiments [1, 4], where the energy spread of a quasi-free target electron is much larger than the finite photon-energy resolution. In that case, the QED correction to the total RR cross section depends on the form of the energy distribution of the target electron. Since the form of this distribution is not well determined, the only way to study the QED effects in REC processes is to investigate the cross section into a photon-energy interval ΔE which is chosen to be much larger than the effective energy spread of the quasi-free target electrons and much smaller than the energy of the emitted photon. For the impact energy 1 GeV we can choose ΔE to be 50 keV in the projectile frame.



We numerically evaluated the Uehling part of the vacuum-polarization correction to the RR cross section and also a part of the self-energy correction. In the Figure, we present the results of our numerical calculations for the QED corrections to the differential cross section for the radiative recombination into the K-shell of bare uranium at a projectile energy of 1GeV/u, expressed in percents of the zeroth-order cross section. $\mathrm{VP}_{\mathrm{en+bw}}$ is the part of the vacuum-polarization correction which results from the corresponding changes in the bound-state energy and the bound-state wave function. $\mathrm{SE}_{\mathrm{en+bw}}$ denotes the corresponding self-energy correction. $\mathrm{QED}_{\Delta E}$ indicates the correction which depends on the photon-energy interval. Details are published separately [9]. Financial support by DFG and RFFI is gratefully acknowledged.

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