Interelectronic-interaction effect on the radiative recombination of an electron with a heavy He-like ion

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In energetic atomic collisions between highly charged high-Z ions and low-Z target atoms, radiative electron capture (REC) is one of the most important reaction channels. In the limit of a loosely bound target electron, REC is identical with radiative recombination (RR). Reactions of this type have been extensively studied in recent years for heavy highly charged projectiles up to bare uranium. The relativistic theory of REC in the one-electron approximation is well established at present ([1] and references therein), and results of numerical calculations are in excellent agreement with experiment [2]. While radiative recombination of an electron with a bare nucleus is well understood theoretically, the process involving an ion with several electrons is complicated by the interelectronic interaction. The REC process into the L-shell of He-like uranium was measured in [3].

We systematically investigated the interelectronic-interaction effect on radiative recombination of an electron with a heavy He-like ion. Here, the number of electrons (N=3) is much smaller than the nuclear charge number Z and therefore their mutual interaction is by a factor $1/Z$ smaller than that with the Coulomb field of the nucleus. To zeroth approximation, the interelectronic-interaction can be neglected and thus the process is equivalent to RR of an electron with a bare nucleus, studied thoroughly in [1]. Here, we investigated the correction of first order in $1/Z$ due to the interelectronic interaction.

We consider RR of an electron with a definite momentum and polarization with a heavy He-like atom in the ground state located at the origin of the coordinate frame. The final state of the system is a Li-like ion in the state $(1s)^2v$, where v denotes a valence electron. The first-order (in $1/Z$) interelectronic-interaction correction to the process under consideration can be represented by a set of Feynman diagrams shown in Fig. 1. Here, the operator of the photon emission and the operator of the electron-electron interaction are combined in all possible ways. We evaluate these diagrams directly, including the summation over the whole spectrum of the Dirac equation and the full electron-electron interaction that consists of the Coulomb, Breit and retarded parts. The details of the derivation are given in [4]. Here, we present the results of the evaluation.

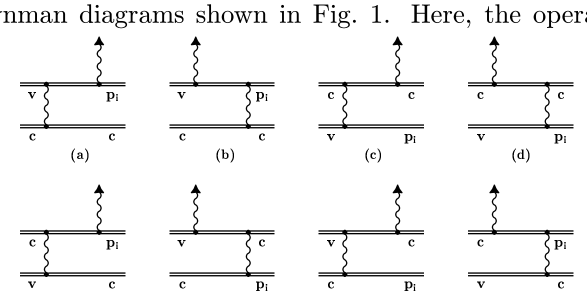

Fig. 1. Feynman diagrams representing the interelectronic-interaction corrections of first order in $1/Z$ to radiative recombination of an electron with a He-like atom. $\mathbf{p_i}$ denotes the incoming electron in the continuum spectrum, **v** and **c** indicate the valence and the core electrons, respectively. The line terminated by a triangle represents the emitted photon.

Table 1. Zeroth-order total cross section $\sigma^{(0)}$ and the first-order interelectronic-interaction correction in different evaluations, in barns. $\sigma^{(1)}_{\rm zeff}$ denotes the interelectronic-interaction correction calculated in the effective-nuclear-charge approximation with parameter $Z_{\rm eff}=90.3$, $\sigma^{(1)}_{\rm scr}$ corresponds to the screening-potential approximation, $\sigma^{(1)}_{\rm int}$ indicates the results of the rigorous relativistic treatment.

	E [Mev/u]	$\sigma^{(0)}$	$\sigma^{(1)}_{\rm zeff}$	$\sigma^{(1)}_{\rm scr}$	$\sigma^{(1)}_{\rm int}$
	10	504.65	−17.390	−19.635	−21.392
$2s_{1/2}$	100	41.203	−1.880	−1.393	−2.055
	700	2.457	−0.1768	−0.0979	−0.1051
	10	656.95	−38.523	−34.978	−35.396
$2p_{1/2}$	100	33.041	−2.975	−2.535	−3.088
	700	1.065	−0.1336	−0.1022	−0.0861
	10	854.82	−38.620	−39.671	−40.008
$2p_{3/2}$	100	31.489	−2.259	−2.275	−2.896
	700	0.622	−0.0600	−0.0568	−0.0489

The numerical results for the interelectronic-interaction correction to the total RR cross section of an electron with He-like uranium are presented in Table 1. The calculation is carried out for projectile energies of 10-700 MeV per nuclear mass unit. The results of the rigorous relativistic treatment are compared with the calculations based on an effective-nuclear-charge approximation and on the screening-potential approximation (for a discussion cf. [5]). The comparison shows a decreasing accuracy of the approximate methods for increasing projectile energy. On average, the screening-potential approximation is found to be more reliable than the effective-nuclear-charge approximation. Its typical deviation from the rigorous treatment is about $10-20$ % of the interelectronic-interaction correction, i.e., about $1-2$ % of the cross section of the process. Therefore, fully relativistic calculations are needed to obtain an accuracy better than a few percent of the cross section of the process.

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