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The gauge-invariant description of the alpha-alpha bremsstrahlung with initial and final state interactions included

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One of motivations in studying the $\alpha + \alpha \to \alpha + \alpha + \gamma$ bremsstrahlung is to get a supplementary information on a strong part of the alpha-alpha interaction. Our departure point in describing this reaction is to use the Fock-Weyl criterion and a generalization of the Siegert theorem [1,2]. Along the guideline we obtain the gauge-independent bremsstrahlung amplitude in a nonrelativistic cluster picture. This amplitude can be expressed through the alpha particle form factor $F_{CH}(q)$ and the three dimensional overlap integral $I(\mathbf{k}', \mathbf{k}; \mathbf{q}) = \langle \chi^{(-)}_{\mathbf{k}'} | e^{-i\frac{1}{2}\mathbf{qr}} | \chi^{(+)}_{\mathbf{k}} \rangle$, where the "distorted" wave $\chi^{(-)}_{\mathbf{k}'}$ ($\chi^{(+)}_{\mathbf{k}}$) describes the α-α scattering in the final (entrance) channel. The corresponding interaction operator $V = V_S + V_C$ consists of the strong nuclear interaction between alpha particles V_S, while V_C describes the Coulomb repulsion between them. Such a consideration leads to the division $I = I_C + I_{CS}$ with the Coulomb integral I_C responsible for the Coulomb bremsstrahlung and the mixed Coulomb-strong one $I_{CS} = I - I_C$ (cf. [3]). In its turn, the Coulomb integral is given by the analytical expression [4], while the integral I_{CS} can be reduced to the summation of its partial wave expansion with the simple radial integrals. A distinctive feature of our approach is to provide the convergence of the expansion. The numerical calculations of the radial integrals are performed with help of the contour integration method [5]. In order to demonstrate to which extent the obtained results depend on the choice of the model interaction V_S we show in Fig.1 the cross section $d\sigma = d^5\sigma/dE_\gamma d\Omega_{1i} d\Omega_{1f}$ for the coplanar kinematics in which one of the outgoing alphas is detected in coincidence with the emitted photon. In such a kinematics all momenta have a coplanar disposal, where the photon momentum is directed along the Z-axis and the rest lie in the XZ-plane, viz.,$\hat{\mathbf{k}}_{1i} = (\theta_{1i}, 0), \hat{\mathbf{k}}_{1f} = (\theta_{1f}, \pi)$. We see, first, that the strong interaction effects can be dominant to compared the pure Coulomb interaction and, second, measurements of such a correlation function can bring a supplementary information on the strong part of the interaction between alpha particles.

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