Classical theory of laser-assisted spontaneous bremsstrahlung

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Synopsis At low energies the classical trajectories for electron motion in a combined Coulomb and ac fields are affected by the Coulomb focusing. This leads to a strong enhancement of the laser-assisted bremsstrahlung cross section as compared to the field-free case.

Laser-assisted spontaneous bremsstrahlung is a process of creation of a photon with frequency $\Omega$ due to electron-atom scattering in the presence of an ac field of a lower frequency $\omega$, $F = F_0 \cos(\omega t + \phi_0)$, i.e. the process

$$nh\omega + e + A \rightarrow n'h\omega + h\Omega + e + A$$

which is equivalent to the harmonic generation in the continuum. The process is most efficient when the atomic system $A$ is a bare nucleus or a positive ion.

This process has been studied since 1970s. Most of these and more recent papers, particularly those dealing with relativistic electrons, were treating the electron-ion interaction in the first order of perturbation theory. Others were concentrating on the resonance processes when the frequency of the emitted photon equals an integer times the laser frequency.

In the present paper we investigate another feature of the process due to the Coulomb focusing \cite{1}. The action of the Coulomb potential, in combination with multiple electron returns due to the laser field, focuses parts of the electron wave function, increasing the efficiency of such processes as multiphoton ionization. Similar effects can occur in continuum-continuum transitions.

In contrast to the ionization problem, the bremsstrahlung problem can be treated purely classically with a very good accuracy \cite{2}. In our treatment we launch electron trajectories parallel to the polarization of the ac field ($z$ axis) at a distance from the Coulomb center, where the Coulomb interaction can be neglected, and calculate the radiation probability per unit frequency as a function of the impact parameter $b$. Integration over $b$ allows determination of the bremsstrahlung cross section per unit frequency of the emitted photon $S(\Omega)$ for a given initial phase $\phi_0$ of the ac field. The radiation spectrum is averaged then over $\phi_0$. This averaging is equivalent to averaging over the initial starting point in the $z$ direction \cite{2}. The results for the probability as a function of $b$ exhibit interesting features related to chaotic behavior of electron trajectories in a combined Coulomb and ac fields \cite{3}. After integration over $b$ and averaging over $\phi_0$ these features are significantly smeared out.

As an example, we calculate radiation spectrum due to the Coulomb field of charge $Z=1$ for the ac field intensity 100 TW/cm$^2$ ($F_0 = 0.05338$ a.u.) and the wavelength $3.1 \mu$m ($\omega = 0.0147$ a.u.), and compare it with the field-free $S(\Omega)$ for electron energy 6.35 a.u. corresponding to a typical kinetic energy of electron acquired by the ac field (about twice the ponderomotive energy $E_p = 3.30$ a.u.) when it approaches the Coulomb center.

Although the average over $\phi_0$ decreases the cross section by an order of magnitude, we still observe a two order of magnitude gain as compared to the field-free cross section due to the Coulomb focusing. In particular, the laser-assisted cross section $S(\Omega)$ varies from $10^{-3}$ to $0.5 \times 10^{-4}$ a.u. in the frequency range between 0.1 and 3 a.u. whereas the field-free cross section decreases from $1.1 \times 10^{-5}$ to $0.18 \times 10^{-6}$ a.u. in the same range.

References

\textsuperscript{[1]} Brabec T \textit{et al} 1996 \textit{Phys. Rev. A} \textbf{54} R2551

\textsuperscript{[2]} Fedorov M V and Ivanov M YU 1993 \textit{Laser Physics} \textbf{3} 365

\textsuperscript{[3]} Wiesenfeld L 1990 \textit{Phys. Lett. A} \textbf{144} 467

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