Radiation reaction effects in non-linear Thomson scattering

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Abstract: We study radiation reaction effects on the radiation emitted by a free electron with initial relativistic energy in interaction with very intense electromagnetic radiation (laser field). Working in the formalism of classical electrodynamics, we use the solution of the Landau-Lifshitz (LL) equation, analytically solved for a plane wave laser pulse, or determined numerically for a focused pulse. We also investigate the validity range of the LL equation by checking to what extent the LL solutions we use obey the Lorentz-Abraham-Dirac equation. We also present preliminary results based on a quantum treatment of the radiation reaction.

1. Radiation reaction effects on electron motion and emitted radiation

The emission of radiation by an electron accelerated by an external laser field, which explains Thomson scattering in classical electrodynamics (CED), affects both the electron trajectory and the emitted radiation. These are radiation reaction (RR) effects. The electron motion is governed by the Lorentz-Abraham-Dirac (LAD) equation ; in order to avoid a number of known problems raised by this equation, the Landau-Lifschitz (LL) equation [1] is used instead in several calculations. The LL equation has recently been solved exactly in closed form [2] for the case of a plane wave laser pulse (a pulse with finite extension along the propagation direction, and infinite in the plane orthogonal to the propagation direction). This has made possible new calculations of the radiation spectrum in CED [3].

In our work, we study the effects of the inclusion of RR on electron motion and the radiation emitted for both a plane-wave pulse and a focused one, describing the electron motion with solutions of the LL equation. The regime we consider is that of a pulse with frequency ω in the optical range, with the dimensionless intensity parameter $\eta=eE_0/mc\omega$ (E_0 being the electric field) of the order of several hundreds (i.e. an intensity of the order of 10^{23} W/cm^2 at a frequency of about 1eV). The relativistic factor of the electron γ is also taken to be of the order of hundreds. In this way, we consider the regime with $\eta\sim\gamma>>1$ less studied up to now which is relevant for proposed experiments to be performed in future [4]. In this regime the process is essentially classical, the quantum effects being negligible.

For a plane wave pulse we have studied the dependence of the final electron energy on the pulse duration, using the analytical expression of the solution of LL equation given in [2]; the pulse envelope has very short Gaussian wings and a central region of constant intensity. As for a plane wave laser pulse if RR is ignored the final energy of the electron is identical to the initial one, the decrease the electron energy that we obtain is the effect of RR. Figure 1 illustrates our results, for the case of a head-on collision between a relativistic electron and a circularly polarized laser pulse. The parameters considered in our example are: $\gamma=50$, $\eta=100$, $\omega=1.17$ eV.

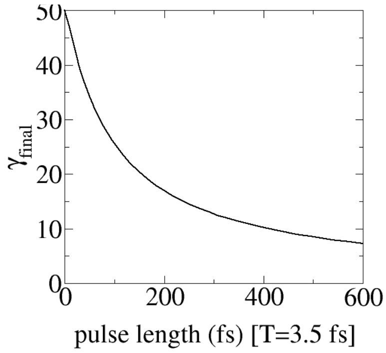

Fig. 1. The electron final energy as a function of the pulse length for the conditions given in text.

We have also investigated the effect of the pulse shape and focusing on the final electron energy for several collision geometries; our calculations shows that in the case of a head-on collision, at constant intensity, the focusing of the laser has a very small effect, even if the waist-size is as small as a few wavelengths.

For the radiation emitted by the electron, we have calculated the radiation spectrum and the angular distribution. We present the results for the angular distribution in the plane of the polar angles (θ,ϕ), a representation we found useful in a study in which RR effects were neglected [5], which has the merit of displaying the relation between the trajectory of the electron velocity and the shape of the angular distribution of the emitted radiation .

For illustration, we present Fig. 2 showing the angular distribution of the emitted radiation for the conditions mentioned before; the electromagnetic pulse has Gaussian wings and a flat central part of length equal to 10 optical periods. If RR is ignored, then this central part of the pulse gives rise to the bright line at constant θ; with RR taken into account the bright line smears over an interval of angles, due to the reduction of the electron energy during the interaction with the laser.

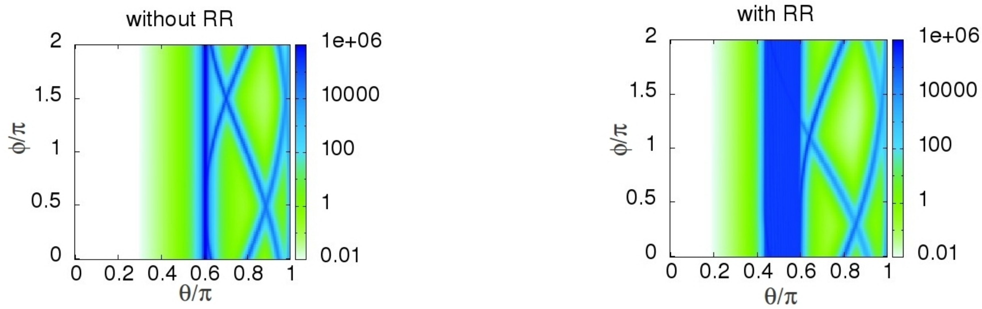

Fig. 1. The angular distribution of the emitted radiation without (left) and with (right) RR included; the parameters are given in text.

2. LL vs LAD equation

In order to assess the validity of the LL approximation, we evaluate the difference between the RHS and LHS of the LAD equation for a given solution of the LL equation (analytically known for a plane wave pulse or calculated numerically for a focused pulse). We have found that the agreement is good for the range of intensity and electron energies considered here.

3. Quantum description

From the several approaches used in the literature with the purpose to cover the mechanism of RR in quantum theory, we have decided to work with the approach of DiPiazza *et al.* who identify RR "with multiple photon recoils experienced by the laser-driven electron due to consecutive incoherent photon emission" [6]. We follow the effect of the successive collisions on the electron energy distribution. We display not only the electron distribution after a sufficiently large number of steps, but we also study its evolution after an intermediate number of steps.

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