Nonlinear Compton Scattering Probabilities

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Abstract: A method is proposed to easily compute the total probability of nonlinear Compton scattering by a whole-cycle plane-wave laser pulse. We manage to greatly reduce the numerical complexity with the help of some analytical integrals. The dependence of this probability on the pulse's characteristics is thoroughly studied. The idealized case of an infinite periodic wave (e.g. monochromatic) is also considered.

1. Introduction

Due to the advances in laser technology, the high-intensity, low-energy regime of QED can now be investigated experimentally. One of the simple processes observed [1] is Nonlinear Compton Scattering (NLCS) consisting in the emission of one photon by the electron scattered by a background field. Others include multi-photon NLCS, Møller scattering, and trident pair production [2].

For beams not too tightly focussed, modelling the laser pulse by a plane wave allows for a non-perturbative (with respect to the laser field) approach to these processes, using Volkov wavefunctions and propagators. A semi-classical (tree level) computation of scattering amplitudes can thus be performed.

When using quantum computations, the effects of radiation reaction have been neglected in the literature until recently. Their rigorous treatment would involve the difficult task of evaluating the probability P(n) of emission of an arbitrary number n of photons. But, starting from n=2, this becomes infrared divergent. In [3] an incoherent-sum approximation was used to study RR.

2. NLCS probability

For the one-photon NLCS in a laser pulse, the distributions of photons and electrons have been devoted a detailed study [4],[5], [6]. The particle's probability distribution, that involves a highly oscillatory integral, was then integrated over either energy, or solid angle to get an angular or energy distribution, respectively. The influence of spin states has also been detailed, for instance in [7].

However, fully integrating over the momenta of the outgoing particles to get the total probability is very time-consuming to compute. We considered, as usual, only so-called whole-cycle pulses, where the integral of the field across the pulse vanishes. These lead to a finite probability. Otherwise, in the generic case, there is a logarithmic divergence that must be addressed.

Our purpose is to find out a fast way to compute this probability. Its dependence on the laser pulse may help test the limits of the theory. If the pulse is very intense or long, the probability may surpass unity, so then, at least, the method must clearly be amended.

3. Method and results

The numerical complexity of the problem is reduced by analytically performing the integral over the emitted photon's momentum. A different kind of regularization is now needed, due to the change in the integration order.

This leaves us with just two integrals that are numerically evaluated for a variety of pulses.

To check the validity of our procedure in a particular case, a simple model pulse was used, for which the usual integration also goes faster, due to the possibility of partially analytical quadrature.

The influence of the pulse shape, lengths and intensity on the NLCS probability is analyzed and plotted. For a few-cycle pulse, the shape can be described in terms of a carrier and envelope, so the influence of the carrier-envelope phase is shown

In these calculations we neglected spin effects, averaging/summing over the spin of the initial and final particles, respectively. However, our method also works when keeping the information about the spins.

A formula is also written for the transition probability per period in the idealized case of a periodic plane wave. The example of a monochromatic plane wave is discussed and the dependence on frequency and intensity is illustrated.

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