PASER: particle acceleration by stimulated emission of radiation

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Abstract

Cherenkov radiation occurs when an electron traverses a passive dielectric material at a velocity which exceeds the phase velocity of an electromagnetic wave in the medium; thus the electron is decelerated. It is shown that if the electron traverses an active medium it may be accelerated. The acceleration is proportional to the population inversion.

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When an electron moves along a vacuum channel in a dielectric material it may cause radiation to be emitted provided that its velocity is greater than the phase velocity of an electromagnetic plane wave in the medium. This is Cherenkov radiation. What a remote observer measures as electromagnetic energy comes at the expense of the particle's kinetic energy, this is to say that the particle is decelerated. For a better understanding of the deceleration force, one has to examine the field distribution in the vicinity of the particle. Ignoring for a moment the presence of the dielectric, a point charge generates in its rest frame of reference an electrostatic field which transforms in the laboratory frame into an infinite spectrum of evanescent waves. As these waves hit the discontinuity between the vacuum channel and the dielectric, a so-called secondary field is generated. This is the reaction of the medium to the presence of the charged particle. It is the action of this secondary field which decelerates the electron.

In this Letter we present results of an analysis which shows that if instead of a passive dielectric medium, an active medium is used, the action of this secondary field may cause the particle to accelerate. In this context an active medium is a medium in which the population of atoms whose electrons are in the lowest state is smaller than these in the excited state. Thus energy stored in the medium can be transferred to the moving electron.

An additional way to examine the proposed acceleration scheme is to consider the microscopic processes. As indicated above, attached to a moving charge there is an infinite spectrum of evanescent waves; these can be viewed as a spectrum of virtual photons continuously emitted and absorbed by the electron. These photons impinge upon the excited atom which is conceived here as a two level system in its upper state. Since the spectrum of waves attached to this particle includes the resonance frequency of the medium, a photon with the adequate energy may stimulate the atom. As a result, two correlated photons are emitted: one is virtual as the initial one and the other is a real photon. Since the two are practically identical, the real photon is absorbed by the moving electron causing acceleration to the latter one. The inverse process is also possible: if the virtual photon encounters an atom in the ground state and excites it, the moving