First-Order Strong-Field QED Processes Including the Damping of Particle States

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Volkov states are exact solutions of the Dirac equation in the presence of an arbitrary plane wave. Accounting for the interaction between the Dirac field and the electromagnetic field, however, Volkov states, as well as free photon states, are not stable in the presence of the background plane-wave field but “decay” as electrons/positrons can emit photons and photons can transform into electron-positron pairs. Using the solutions of the corresponding Schwinger-Dyson equations within the locally constant field approximation, we compute the probabilities of nonlinear single Compton scattering and nonlinear Breit-Wheeler pair production by including the effects of the decay of electron, positron, and photon states. As a result, we find that the probabilities of these processes can be expressed as the integral over the light-cone time of the known probabilities valid for stable states per unit of light-cone time times a light-cone time-dependent exponential damping function for each interacting particle. The exponential function for an incoming (outgoing) either electron/positron or photon at each light-cone time corresponds to the total probability that either the electron/positron emits a photon via nonlinear Compton scattering or the photon transforms into an electron-positron pair *via* nonlinear Breit-Wheeler pair production until that light-cone time (from that light-cone time on). It is interesting that the exponential damping terms depend not only on the particle’s momentum but also on their spin (for electrons/positrons) and polarization (for photons). This additional dependence on the discrete quantum numbers prevents the application of the electron/positron spin and photon polarization sum rules.