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Coherent effects in atomic K-shell ionization and characteristic X-ray emission by ultrashort high-energy electron bunches

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The coherent effects present in atomic K-shell ionization and the subsequent emission of characteristic X-ray radiation (CXR) induced by ultrashort relativistic electron bunches are investigated [1]. The approach distinguishing close and distant collisions was applied to calculate the K-shell ionization cross section. The cross section associated with close collisions is independent on the number of electrons in the bunch and can be calculated using the approximation of hard binary electron-electron collisions. Meanwhile, the cross section associated with distant collisions is affected by coherent effects and was of primary interest. It was calculated based on the Weizsäcker-Williams method of equivalent photons.

It was shown that the interference between the proper electromagnetic fields of single electrons can lead to a significant coherent enhancement of the ionization cross section in thin light-element targets, particularly beryllium and carbon. In particular, the case of a microbunched beam was investigated using a periodically modulated distribution of the bunch number of particles in longitudinal direction. According to calculations made for parameters of bunches achievable at modern X-ray free electron lasers, a strong resonant amplification of the cross section occurs. This leads to an enhancement of the ionization cross section by several orders of magnitude for a wide range of microbunching periods.

Moreover, the analysis was extended to targets of arbitrary thickness to study the evolution of the K-shell ionization cross section caused by the medium polarization (density effect) along the beam propagation path. It was found that the cross section decreases with increasing the depth of the beam penetration into the target, reaching a plateau when the penetration depth significantly exceeds the absorption length of a photon with an energy equal to the K-shell ionization threshold. Furthermore, it was shown that the main contribution to the CXR photons emitted from the target comes from a thin near-surface layer, whose thickness can be much smaller than the CXR attenuation length, unlike in the case of a single electron interacting with the target. The reasons for this are discussed.

The obtained results and the considered coherent effects could be applied to the development of new techniques for diagnostics of parameters of subfemtosecond electron bunches.

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