The role of collisions and radiation transport on the emision signature from x-ray driven plasma

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High-intensity and femtosecond duration x-rays from Free Electron Lasers, enable the study of out-of-equilibrium states. As a pump, x-rays induce electronic changes that may lead to ionization and rapid isochoric heating, reaching extreme conditions such as warm and hot dense matter. Emission spectroscopy has been an important tool to diagnose these transient states [1]. We employed a rate equation model [2] and level-resolved atomic data that includes radiative and collisional processes [3] to simulate time-resolved spectra from neon gas driven into plasma by x-rays. We explored gas densities that extend beyond an isolated atom environment. Using experimentally relevant pulse duration and intensity values, simulations show that post-pulse electron impact drives the photo-ionized gas to further ionization. For excitation energy above neon's 1s ionization threshold, collisions culminate with an abundance of ground-state Ne 8+ ions in sub-nanoseconds. To assess the effects of collisions, we focused on the emission from He-like neon $1s2p\,^1P_1$ singlet and $1s2p\,^3P_1$ triplet. In the isolated atom limit, these states have distinct fluorescence lifetimes of $\sim$100 fs and $\sim$400 ps, respectively. In sub-nanosecond timescales and for the pressures explored, we find the gas maintains a high energy density state with electron temperatures $\sim$200–300 eV. These hot electrons, capable of core-level collision excitation from Ne 8+ $1s^2\,^1S_0$, populate the singlet in picosecond timescales and extend its effective lifetime. Selection rules hinder the same channel from feeding the triplet, and electron de-excitation suppresses the triplet's lifetime. We compared time-dependent and time-integrated calculations with preliminary experimental spectra obtained with a high-resolution spectrometer [4] at the European X-ray Free Electron Laser. The process revealed the importance of radiation propagation, electron collisions and electron-ion temperature relaxation that extend beyond the isolated atom approximation.

References

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