Impact of free-electron quantum effects on collisional rates in plasmas

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A plethora of scientifically and practically relevant plasma environments exist at a temperature and density in which quantum mechanics shapes the behavior of the free electrons. In these conditions, quantum effects can influence any bound electron transitions to or from the free-electron continuum. However, a full quantum mechanical treatment of the bound and free electrons is computationally impossible. Instead, we parameterize the quantum effects and include them in existing collisional radiative models, allowing a tractable way to model ionization dynamics in these exotic plasmas. We present the theoretical framework and supporting experimental evidence for these effects.

The use of x-ray free electron lasers to create and characterize solid density plasmas has opened a new window to the microphysics of extreme states of matter. W use this method to explore the impact of free-electron degeneracy on the collisional rates in solid density plasmas. We observe experimentally ion satellites of the k-alpha transition in warm dense aluminum with a magnitude far above those predicted with standard collisional-radiative treatments. We attribute the prominence of the ion satellites to a reduction in collisional recombination within the L-shell, due to the degeneracy of the free electrons. This effect can be included in existing codes in the form of correction factors to the various transition rates. We show that by including a correction factor in the collisional-radiative code FLYCHK, a much-improved fit to the experimental data is found.