Kinetic effects of partially screened impurities in runaway-electron mitigation scenarios

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Runaway electrons constitute a significant threat to tokamak devices. Their mitigation by heavy-impurity injection has been experimentally shown to be more effective than would be expected from standard collisional theory [1]. In order to understand this effect and develop runaway mitigation schemes, more accurate kinetic models are needed to describe the interaction between electrons and partially ionized atoms. Such models require the partial screening of the nuclei by the bound electrons to be taken into account.

In this contribution, we analyze the dynamics of fast electrons in plasmas containing partially ionized impurity atoms. A generalized collision operator is derived from first principles using quantum-mechanical models. We obtain analytical expressions for the deflection and slowing-down frequencies. Even at sub-relativistic energies, these are increased by more than an order of magnitude compared to the results obtained with complete screening. Moreover, we implement the generalized collision operator in the continuum kinetic-equation solver CODE [2, 3] and demonstrate that interaction with partially ionized atoms greatly affects fast-electron dynamics by enhancing the rates of angular deflection and energy loss. In particular, we investigate the decay of a runaway-electron current coupled to a self-consistent electric field. The effect of the interaction with partially ionized impurities has important implications for the efficacy of mitigation strategies for runaway electrons in tokamak devices.

References

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