Fast-electron dynamics in the presence of weakly ionized impurities

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Runaway electrons constitute a significant threat to tokamak experiments. To minimize the risk of damage, it is crucial to understand the runaway-electron dynamics, which during runaway mitigation can be heavily influenced by the interaction with partially ionized atoms. Experiments have shown that mitigation via heavy-impurity injection is more effective than would be expected from standard collisional theory [1], highlighting the need for more accurate kinetic models. To achieve this, partial screening of the nuclei by the bound electrons must 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, and show that they are increased by more than an order of magnitude compared to the results obtained with complete screening, already at sub-relativistic electron energies. Moreover, we implement the generalized collision operator in the continuum kinetic-equation solver CODE [2] and demonstrate that interaction with partially ionized atoms greatly affects fast-electron dynamics by enhancing the rates of angular deflection and energy loss. This has important implications, not only for the efficacy of mitigation strategies for runaway electrons in tokamak devices, but also for example for energy loss during relativistic breakdown in lightning discharges.

References

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