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The physics of how a minority runaway electron population can dominate the charge state balance and radiative cooling of a post thermal quench plasma[1]

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A mitigated tokamak disruption, as currently envisioned for ITER, will have a post thermal quench plasma that is cold and has a large population of high-atomic-number impurities. Runaway electrons in this case, even if they carry the full current, will be of minute density. Standard plasma kinetics tell us that the collisional effect diminishes as the relative speed between two colliding particles increases, but relativistic runaway electrons, at a speed near light speed, can dominate the charge balance in a cold plasma with significant high-Z impurities, despite a density that is 2-4 orders of magnitude smaller than that of background thermal electrons. The underlying cause is found to be the relativistic enhancement of the cross sections for both collisional ionization and excitation [1], a QED effect known since the seminal work of Mller, Breit, and Bethe. Collisional excitation is found to have a particularly subtle role here, for both radiative cooling and charge state balance. We illustrate this subtle physics through a collisional-radiative (CR) model that builds upon the popular FLYCHK code, and elucidate the impact on runaway dynamics itself [1]. We explore both steady-state and time-dependent CR evolutions, and outline the implications for accommodating these effects into plasma modeling. The impact of different atomic species and electron distributions is presented. By including the QED effects and with the help of uncertainty quantification, we demonstrate an improved predictive capability and a path forward for in-situ CR modeling of fusion plasma simulations.

[1] Garland et al. Physics of Plasmas 27, 040702 (2020)

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