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Kinetic modelling of runaways in fusion plasmas

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Runaway electrons (REs) are a pressing issue for ITER due to their significant potential to cause damage. Improved knowledge of RE formation mechanisms, their dynamics and characteristics, as well as transport or loss processes that may contribute to RE suppression and control, will benefit the fusion community and contribute to a safe
and reliable operation of reactor-scale tokamaks.

In this work we discuss bremsstrahlung radiation emission and knock-on collisions, and describe an accurate theoretical framework for studying their effect on the RE distribution. These processes, together with synchrotron radiation reaction, have important implications for the understanding of many phenomena, such as the effective critical electric field for RE generation and the formation of non-monotonic features in the RE tail. Starting from the Boltzmann transport equation, we derive a collision operator for bremsstrahlung radiation reaction, fully accounting for the finite energy and emission angle of the emitted photons. The Boltzmann bremsstrahlung operator allows the REs to reach energies several times higher than the previously used mean-force model, and the emission of soft photons shifts part of the momentum-space distribution function towards higher perpendicular momenta.

Avalanche runaway generation is the phenomenon whereby REs are generated due to large-angle collisions of already existing REs with thermal electrons, leading to an exponential growth of the runaway current. Here we describe a new large-angle collision operator, derived as the high-energy limit of the linearized relativistic Boltzmann collision integral. This operator generalizes previous models of large-angle collisions to account for the full momentum dependence of the primary distribution, and conserves particle number, momentum and energy, while also avoiding the double counting of small and large-angle collisions. We investigate the effect of the operator on the evolution of the RE distribution and find that the change to the RE growth rate can be large, especially during the early stages of the runaway acceleration process, and the likelihood of a given runaway seed transforming into a serious runaway beam can thus potentially be affected.

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