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Kinetics of Relativistic Runaway Electrons

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This overview talk covers recent developments in the theory of runaway electrons in tokamaks. Such electrons are known to be of serious concern with regard to safe operation of large-scale tokamaks in general and ITER in particular. They can quickly replace a large part of the bulk electron current during disruptions, and the corresponding magnetic energy exceeds the particle kinetic energy. This feature separates the time-scale of the runaway production from the time-scale of the current decay. The talk deals with the following physics aspects of the runaway evolution: (1) survival and acceleration of initially hot electrons during thermal quench, (2) effect of magnetic perturbations on runaway confinement, (3) multiplication of the runaways via knock-on collisions with the bulk electrons, (4) slow decay of the runaway current, and (5) runaway-driven micro-instabilities. Several theoretical groups internationally are currently addressing these aspects. The recent progress includes a first-principle description for the primary runaway electron production during the thermal quench, estimates of the runaway losses through partially destroyed magnetic flux surfaces, an improved description of fast electron collisions with heavy impurities within a Thomas-Fermi model for screening, a rigorous kinetic theory for relativistic runaways in the electric field that is close to the avalanche threshold, refined evaluation of the critical field for avalanche onset with a systematic description of knock-on collisions and radiative losses, demonstration of phase-space attractor that supports a peaked distribution function of the runaways, a model for current damping in a self-sustained regime of marginal criticality for the runaways, and reassessment of thresholds for the runaway-driven micro-instabilities. Some of these new theoretical findings are directly relevant to current experiments on DIII-D, ASDEX-U, and JET. They also provide an important input for ITER disruption modeling and runaway mitigation strategy.

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Primary author: Prof. BREIZMAN, Boris (The University of Texas at Austin)

Presenter: Prof. BREIZMAN, Boris (The University of Texas at Austin)

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