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Pellet Ablation Physics Studies for Disruption Mitigation

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The extreme energy content in ITER makes the disruptions a matter of grave concern. The current strategy of disruption mitigation in ITER relies on the injection of cryogenic pellets into the disruptive plasma [1]. Pellet ablation is an essential factor in disruption mitigation, which calls for dedicated theoretical support in modeling this process in the plasma and establishing related constraints on the disruption mitigation system.

This work addresses the following aspects of pellet-plasma interaction physics:

• high-Z pellet ablation;

• thermal electron response to the pellet during ablation;

• pellet interaction with runaway electrons.

We present a first principle kinetic calculation of the power deposition from energetic electrons into the cold halo of an ablating high-Z pellet. For high Z, the velocity distribution of the hot electrons is nearly isotropic, and we use this feature to simplify and solve the electron kinetic equation, including the effect of electron gyro-motion in a magnetic field [2]. The resulting ablation rate for the high-Z pellets can be estimated as

$$G \sim \frac{4\pi M}{\left(\pi e^4\right)^{2/3}} \left(\frac{1}{m^{1/2} M}\right)^{1/3} R_p^{4/3} \frac{n_\infty^{1/3} T_\infty^{11/6}}{Z^{7/6} (\ln \Lambda_{ei})^{1/2} (\ln \Lambda_{ee})^{1/6}},$$

where e and m are the electron charge and mass, M is the ion mass, R_p is the pellet radius, n_∞ and T_∞ are the density and temperature of the ambient electrons, and $\ln \Lambda_{ei}$ and $\ln \Lambda_{ee}$ are Coulomb logarithms for elastic and inelastic collisions.

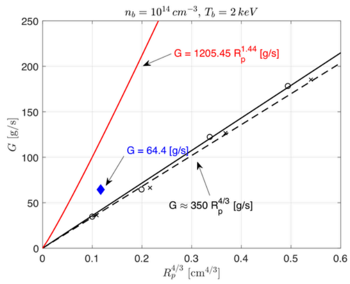

Figure 1: Reduction of ablation rate due to elastic scattering. Predictions by Sergeev et al. [3] (red line) are too high. The difference between our results (black lines) and those by Parks [4] (blue diamond) shows significant sensitivity of the heat deposition to elastic scattering.

This rate is much lower than the pre-existing estimates, as shown in Fig. 1. We find that strong elastic scattering of the incident electrons reduces the role of electrostatic shielding significantly. The new expression for the heat deposition provides an updated input for fluid simulations of the pellet ablation process.

We also consider the impact of pellets on plasma electrons [5]. The cold, dense pellet absorbs some of the incident hot electrons and emits secondary electrons to maintain quasi-neutrality. The required balance is provided by a sheath potential. The resulting electron distribution function in the ambient plasma may, therefore, deviate significantly from the Maxwellian (see Fig. 2), which can affect the heat flux into a low-Z pellet. The pellet also tends to modify the distribution of the incident electrons and the heat flux via energy-dependent absorption. This heat depletion is of particular interest for resonant magnetic surfaces.

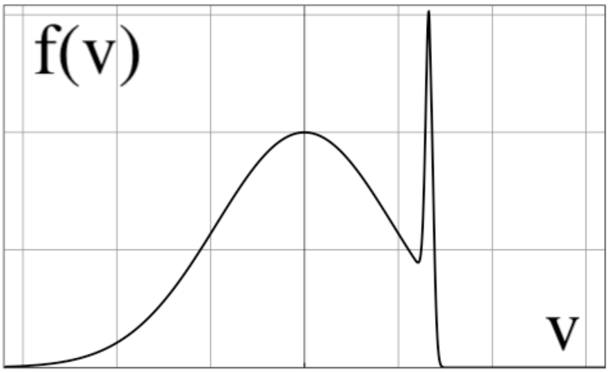

Figure 2: The stationary electron distribution in the plasma does not carry any current but carries a heat flux. This distribution is unstable, and the two-stream instability can thus affect the heat flux significantly.

In a cold post thermal quench plasma, runaway electrons can carry a significant fraction of the initial plasma current. Our first principle estimates show that any pellet injected to dissipate a 10 MA runaway electron current in ITER will evaporate virtually instantly to form a gas cloud once exposed to the runaway electrons. This is in line with the recent observations in DIIID, where there was no significant difference between the runaway electron dissipation by pellets or by massive gas injection [6].

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