Ion heating by collisional damping of tearing modes

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Abstract

Strong self-heating of ions is observed in the reversed field pinch (RFP). For example, during a sawtooth crash the ion temperature can spontaneously triple in ~100 μs. Large-scale tearing instabilities have long been considered to underlie plasma relaxation and dynamo processes in the systems with magnetic self-organization such as the RFP and spheromak. In the Madison Symmetric Torus (MST) RFP experiments, the amplitudes of magnetic and flow velocity fluctuations are characterized by the periodic sawtooth peaks in their time dependence. The heating may arise from tearing instabilities due to irreversible transfer of kinetic flow energy into heat caused by ion-ion collisions. The standard viscous stress tensor calculations are not applicable for high temperature plasmas because the ion-ion collision time ν_{ii}^{-1} is larger than the tearing mode growth time γ^{-1} and the characteristic time of sawtooth crashes. To treat this regime, we employ a hot dielectric tensor in tearing mode theory. We applied the formalism to calculate the absorption rate of a wave in plasma. For the case of interest, $\nu_{ii} << \gamma$, $v_{Ti} << \gamma / k_{||} << v_{Te}$ the ion-ion collisional corrections to the dielectric tensor are found from the Fokker-Plank kinetic equation by a perturbation method while the electron absorption is negligible [1]. Even rare (in comparison with the growth rate) ion-ion collisions lead to a significant anti-Hermitian part of the dielectric tensor that may explain fast ion heating during the sawtooth events. The mode amplitude used in the analysis corresponds to the experimentally measured value of the magnetic field fluctuations in MST and the radial profiles of different field components are found from numerical analysis. For the case of purely growing tearing modes and localized eigenfunctions, the rate of ion heating is comparable to that observed in the MST experiments. The heating rate is proportional to the square of the ion Larmor radius such that it is strong in the low magnetic field configurations. We also analyze the effectiveness of this mechanism in comparison with ion heating based on parallel and perpendicular viscosities, and magnetic pumping in a time varying guide field.

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[1] A. F. Aleksandrov, L. S. Bogdankevich, A. A. Rukhadze, Principles of plasma electrodymamics, Springer-Verlag, New York, 1984