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Neoclassical toroidal viscosity and error-field penetration in tokamaks[1]

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A model for field error penetration is developed that includes both resonant and non-resonant perturbed 3-D magnetic fields [1]. The non-resonant components give rise to a global neoclassical toroidal viscous [NTV] torque while a single resonant component produces a localized electromagnetic braking torque on its respective resonant surface. The NTV torque tries to keep the plasma flowing at a rate comparable to the ion diamagnetic flow. A phenomenological cross-field viscosity is included which resists the resonant electromagnetic torque in the vicinity of the resonant surface. Steady-state toroidal momentum balance across the resonant layer gives a solubility condition determining the "critical" resonant error-field strength—termed the *penetration threshold*—above which rotational shielding is lost and the resonant surface locks to the lab frame. Such locking occurs in low-density start-up tokamak plasmas [2], leading to plasma disruptions or confinement degradation and is a key issue for ITER. The toroidal momentum balance equation admits a WKB-type solution which implies that NTV acts to enhance cross-field viscosity in the vicinity of the resonant surface. This enhancement makes the plasma less sensitive to error-field penetration than previously predicted [3]. In particular, if $\tau_E \propto n_e$ (neo-Alcator-like) and the perpendicular momentum confinement time has no density dependence, we find the penetration threshold scales linearly with electron density—a result giving quantitative agreement for the first time between theory and experiment [2].

[1] A.J. Cole, C.C. Hegna, and J.D. Callen, to be published in PRL (2007).
[2] S.M. Wolfe, I.R. Hutchinson, et al., Phys. Plasmas **12**, 056110 (2005) and refs. cited therein.
[3] A.J. Cole and R. Fitzpatrick, Phys. Plasmas **13**, 032503 (2006) and refs. cited therein.

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