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Parasitic Momentum Flux in the Tokamak Core

T. Stoltzfus-Dueck

Princeton University, Princeton, NJ 08540, USA

Abstract

Tokamak plasmas rotate spontaneously in the absence of applied torque. This so-called 'intrinsic rotation' may be very important for future low-torque devices such as ITER, since rotation can stabilize certain instabilities. In the mid-radius 'gradient region,' which reaches from the sawtooth inversion radius out to the pedestal top, intrinsic rotation profiles are sometimes flat and sometimes hollow. Profiles may even transition suddenly between these two states, an unexplained phenomenon referred to as rotation reversal. Theoretical efforts to identify the origin of the mid-radius rotation shear have focused primarily on quasilinear models, in which the phase relationships of some selected instability result in a non-diffusive momentum flux ("residual stress"). In contrast to these efforts, the present work demonstrates the existence of a robust, fully nonlinear symmetry-breaking momentum flux that follows from the free-energy flow in phase space and does not depend on any assumed linear eigenmode structure. The physical origin is an often-neglected portion of the radial ExB drift, which is shown to drive a symmetry-breaking outward flux of co-current momentum whenever free energy is transferred from the electrostatic potential to ion parallel flows [1]. The resulting rotation peaking is counter-current and scales as temperature over plasma current. As originally demonstrated by Landau [2], this free-energy transfer (thus also the corresponding residual stress) becomes inactive when frequencies are much higher than the ion transit frequency, which may explain the observed relation of density and counter-current rotation peaking in the core. Simple estimates suggest that this mechanism may be consistent with experimental observations, in both hollow and flat rotation regimes. [1] T. Stoltzfus-Dueck, Phys. Plasmas 24, 030702 (2017). [2] L. Landau, J. Phys. (U.S.S.R.) 10, 25 (1946).