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Parasitic momentum flux in the tokamak core[1]

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Tokamak plasmas rotate spontaneously without applied torque. This intrinsic rotation is important for future low-torque devices such as ITER, since rotation stabilizes certain instabilities. In the mid-radius 'gradient region,' which reaches from the sawtooth inversion radius out to the pedestal top, intrinsic rotation profiles may be either flat or hollow, and can transition suddenly between these two states, an unexplained phenomenon referred to as rotation reversal. Theoretical efforts to explain the mid-radius rotation shear have largely focused on quasilinear models, in which the phase relationships of some selected instability result in a nondiffusive momentum flux ("residual stress"). In contrast, 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 fully nonlinear derivation relies only on conservation properties and symmetry, thus retaining the important contribution of damped modes. The resulting rotation peaking is counter-current and scales as temperature over plasma current. As first 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 allows sudden transitions between hollow and flat profiles. Simple estimates suggest that this mechanism may be consistent with experimental observations. [1] T. Stoltzfus-Dueck, Phys. Plasmas 24, 030702 (2017). [2] L. Landau, J. Phys. (U.S.S.R.) 10, 25 (1946).

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