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Turbulent Equipartition Theory of Toroidal Momentum Pinch[1]

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The turbulent convective flux (pinch) of the toroidal angular momentum density is derived using the nonlinear toroidal gyrokinetic equation which conserves phase space density and energy[1], and a novel pinch mechanism which originates from the symmetry breaking due to the magnetic field curvature is identified. A net parallel momentum transfer from the waves to the ion guiding centers is possible when the fluctuation intensity varies on the flux surface, resulting in imperfect cancellation of the curvature drift contribution to the parallel acceleration. This pinch velocity of the angular momentum density can also be understood as a manifestation of a tendency to homogenize the profile of "magnetically weighted angular momentum density," $nm_iRU_\parallel/B^2$. This part of the pinch flux is mode-independent (whether it's TEM driven or ITG driven), and radially inward for fluctuations peaked at the low-B-field side, with a pinch velocity typically, $V_{Ang}^{TEP} \sim -2\chi_\phi/R_0$. We compare and contrast the pinch of toroidal angular momentum with the now familiar "turbulent equipartition" (TEP) mechanism for the particle pinch[2] which exhibit some relevance in various L-mode plasmas in tokamaks. In our theoretical model[3], the TEP momentum pinch is shown to arise from the fact that, in a low-β tokamak equilibrium, $B^2\mathbf{u}_E = c\mathbf{B}\times\nabla\delta\phi$ is approximately incompressible, so that the magnetically weighted angular momentum density ($m_inU_\parallel/B^3 \propto m_inU_\parallel R/B^2$) is locally advected by fluctuating $\mathbf{E}\times\mathbf{B}$ velocities, to the lowest order in $O(a/R)$. As a consequence $m_inU_\parallel R/B^2$ is mixed or homogenized, so that $\frac{\partial}{\partial\psi}m_inU_\parallel R/B^2 \to 0$.

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