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Enhanced Neoclassical Polarization and its Equivalence to the Pinch Effect

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Abstract

The absence of collisionless damping of so-called zonal flows accounts for their prominance in the saturation of ion temperature gradient (ITG) turbulence in tokamaks. In fact, a tokamak responds to zonal flows with a reactive, neoclassical polarization current.[1] This neoclassical polarization response is *small*, of order $\varepsilon^{3/2}$ times the neoclassical factor, $\frac{\omega_{pi}^2}{\omega_{ci}^2}\frac{q^2}{\varepsilon^2}$, where ε is the inverse aspect ratio. Any increase in this polarization, which shields the zonal flow potential, could have significant adverse effects on tokamak transport. Even if the polarization response remains reactive, the zonal flows produced by ITG turbulence would be reduced and thereby raise the saturated turbulence level. A new effect which increases this neoclassical polarization by a factor of order ε^{-1} is presented in this paper. We show that this neoclassical polarization is equivalent to the pinch effect driven by the toroidal electric field. This equivalence orginates with the replacement of the time varying radial electric field by an inertial toroidal force, $F_\zeta = -m_i c/B_p\,(\partial E_r/\partial t)$, from which one can compute the radial currents in an exact, to order ε, replica of the pinch effect. This calculation is carried out using the Lagrangian formulation of neoclassical transport[2] so that we can clearly understand, recognize and separate the collisionless flows of Rosenbluth and Hinton[1] (RH) from potentially new collisional processes. The smallness of the RH polarization is attributed to a kinematic cancelation recognized some time ago for the Ware effect.[2] Although trapped particles drift inward radially under the influence of the toroidal electric field, the circulating particles actually drift out, collisionlessly, canceling the Ware pinch completely, to leading order in $\varepsilon^{1/2}$. This same cancelation occurs for the RH polarization, leaving just the small residual, $\mathcal{O}\left(\varepsilon^{3/2}\right)$. The new effect proposed here, which increases the neoclassical polarization, is identical to the process which produces the actual pinch in neoclassical theory – a collisional process on circulating particles whereby velocity and radial scattering (of mean orbits) are correlated. It is interesting that the net neoclassical polarization, including the new effect, behaves as though the trapped particles respond in the obvious way, $v_\zeta \sim cE_r/B_p$, with no circulating particle response, just like the neoclassical pinch can appear to be the Ware pinch for trapped particles, with no circulating particle response. The true microscopic physics is in fact quite different. Simulation work is in progress to verify these predictions using GS2[3] and neoclassical codes.

[1] M.N. Rosenbluth and F.L. Hinton, Phys. Rev. Lett. **80**, 724 (1998).
[2] I.B. Bernstein and K. Molvig, Phys. Fluids, **26**, 1488 (1983).
[3] W. Dorland, F. Jenko, M. Kotschenruther, B.N. Rogers, Phys. Rev. Lett. **85**, 5579 (2000).