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Theory of the Poloidal Spin-up Precursor to Internal Transport Barrier Formation

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The phenomenon of a sudden change in the poloidal flow prior to the reduction in transport and the steepening of temperature and density profiles has been observed both at the edge (high-modes) and in the core enhanced reversed shear (ERS) modes of tokamaks. The poloidal spin-up precursor is narrowly localized in the (radial) direction across magnetic flux surfaces. Although the reduction of turbulent transport is consistent with the theory of ExB flow shear suppression, the localized poloidal spin-up precursor has not been explained by the theory until now. It will be shown that the observed flow pattern is well described by a new class of bifurcation to the momentum balance equations. The new physics follows from extending the standard neoclassical theory of poloidal flow damping to include the turbulent viscous stress. The new bifurcation results from balancing the non-linear turbulent viscous stress with the linear poloidal flow damping due to the neoclassical parallel viscous stress. The new bifurcation results in a mono-polar ExB flow structure (with a large poloidal component) which is narrowly localized in the radial direction. This flow pattern will be referred to as a jet. The equations, which result in the jet bifurcation, are dual to the usual Ginzburg-Landau phase transition theory. The non-linearity appears in the gradient of the field (kinetic energy) rather than in the field (potential energy). The jet solution is a type of topological soliton. Whereas the Ginzburg-Landau equations have the property that once a phase transition is favorable a perturbation of the new phase will expand to fill all space, the jet bifurcation remains localized, saturating at finite width. An analytic model of the perpendicular turbulent viscous stress is constructed based on the properties of drift wave instabilities. This model is then solved for the jet bifurcation and compared with data* from an ERS transition. It is found that the peak flow velocity and the width of the observed flow pattern can be fit with the model using realistic values of the drift-wave linear growth rate, the effective diffusivity due to the drift-wave turbulence and the neoclassical poloidal damping rate. The observed experimental phenomenology of poloidal spin-up precursors is well explained by the jet bifurcation. The jet forms at the neoclassical poloidal flow damping rate which is faster than the energy or particle transport rate. The peak in the jet flow is shown to reduce and finally disappear as the diamagnetic velocity shear increases. A seed perturbation is required to initiate the jet bifurcation. The spin-up precursor is most likely to occur in a plasma with balanced neutral beam heating and is unlikely to occur when there is a strong toroidal momentum source. A jet is not required for a transport barrier to form. A new feature predicted by the theory, but not yet observed, is the existence of a toroidal flow excursion in the same location as the poloidal jet. This feature is due to the strongly off-diagonal nature of the turbulent viscous stress tensor predicted from drift-wave theory.

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*R.E. Bell, F.M. Levinton, S.H. Batha, E.J. Synakowski and M.C. Zarnstorff, Phys. Rev. Lett. **81** (1998) 1429.

Prefer Oral