Neoclassical Momentum Transport and Radial Electric Field in Tokamak Transport Barriers

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The radial electric field is widely believed to be responsible for establishing transport barriers in tokamak plasmas, leading to regimes of improved confinement. This field is controlled by the cross-field transport of toroidal angular momentum, which can be due to either turbulence or Coulomb collisions. Since turbulence is suppressed in transport barriers and ion thermal transport in such regions is observed to be comparable to the neoclassical prediction, the radial electric field is likely to be governed by neoclassical momentum transport. We calculate the transport matrix, including the classical contribution, for the case of a low-collisionality (banana-regime) plasma with collisional impurity ions, which is typically the experimental situation. The toroidal rotation velocity is taken to be larger than the diamagnetic speed and so large that the heavy impurity ions undergo poloidal redistribution under the action of the centrifugal force, however the bulk plasma remains subsonic.

Previously only rotation shear was considered to drive the radial angular momentum transport, with an associated momentum diffusivity typical of the Pfirsch-Schlüter regime (which is much smaller than the heat diffusivity in the banana regime).[1,2] The presence of impurities is seen to give rise to off-diagonal terms in the transport matrix, causing the plasma to rotate spontaneously, even in the absence of momentum sources in the core, with the rotation direction determined by the edge boundary condition. This result may shed light on recent experiments showing plasma rotation in the absence of neutral-beam injection.[3] The poloidal redistribution of impurities has previously been shown to have a dramatic effect on their transport, increasing it by a factor comparable to the aspect ratio,[4] and a similar effect has now been shown to occur in the angular momentum transport. At conventional aspect ratio the flux is increased by a factor up to $\varepsilon^{-3/2}$, where ε is the inverse aspect ratio, compared to the usual prediction, making it comparable to banana regime heat transport. Radial pressure and temperature gradients are the primary driving forces of the flux whilst the effect of rotation shear is enhanced only mildly over previous results. With strong impurity redistribution, a heat pinch arises, driven by rotation shear, which is comparable to the previously predicted level of heat transport. The classical transport is also seen to be enhanced by the impurity redistribution.

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References

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