Electric Field Induced Plasma Convection in Tokamak Divertors*

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Marked power and particle flux asymmetries between the inner and outer targets of poloidally diverted tokamaks have long been observed. The asymmetries are remarkably sensitive to the direction of the toroidal magnetic field $\mathbf{B}_T$. Although the origin of the $\mathbf{B}_T$ sensitivity was not known, it was used empirically to overcome carbon blooms in the first JET DT fusion campaign [1]. It was hypothesized that the $\mathbf{B}_T$ dependence arises from the $\mathbf{B}\times\nabla B/B^2$ and $\mathbf{E}\times\mathbf{B}_T/B^2$ particle drifts [2,3], but a strong physics basis for this dependence was lacking until recent numerical simulations [4] using the UEDGE edge and divertor code and the measurements presented here. The theory predicts that the $\mathbf{E}\times\mathbf{B}_T/B^2$ drift is more important than $\mathbf{B}\times\nabla B/B^2$.

We report recent direct, two–dimensional measurements of plasma potential, density and temperature in the DIII–D tokamak divertor region [5] that quantitatively support the strong role of $\mathbf{E}\times\mathbf{B}_T$ drift in the divertor asymmetry. Measurements of floating potential, electron temperature and density were obtained with a reciprocating probe and Thomson scattering in discharges with low (L–) and high confinement (H–) mode and for both $\mathbf{B}_T$ directions. Two-dimensional information was obtained by sweeping the divertor geometry across the fixed divertor diagnostic views and mapping the measurements onto magnetic surfaces reconstructed from magnetic data. The measurements permit the calculation of the electric field $\mathbf{E}$ and the resulting $\mathbf{E}\times\mathbf{B}_T/B^2$ drift particle flux. Perpendicular field strengths of ~5 kV/m are observed at the separatrix between the divertor private region and the scrape-off layer (SOL) in H–mode discharges and of ~1 kV/m in L–mode discharges. The $\mathbf{E}\times\mathbf{B}_T$ drift creates a poloidal circulation pattern along the separatrix from the outer divertor target to the X–point and to the inner divertor target. The drift convects about 10^{22} ion/s in the H–mode, which is about 50% of the total ion flow to a divertor target. The $\mathbf{E}\times\mathbf{B}_T$ driven circulation, which is reversed with reversal of $\mathbf{B}_T$, is strongest along the divertor separatrix which separates the private region from the inner and outer SOL and couples the various regions of the divertor, namely the X–point region, the outer and inner SOL and the private flux region.

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*Work supported by the U.S. Department of Energy under Contract Nos. DE-AC03-99ER54463, W-7405-ENG-48, DE-AC05-96OR22464, DE-AC04-94AL85000, and Grant No. DE-FG03-95ER54294.