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Effect of Cross-field Drifts and Core Rotation on Flows in the Main Scrape-off Layer of DIII-D L-mode Plasmas EX-D

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Deuterium flows measured in the scrape-off layer (SOL) in the region vertically opposite from the x-point, here defined as the crown, of low-confinement (L-mode) plasmas in DIII-D show a marked dependence on the ion ∇B drift direction with little sensitivity to core plasma rotation. In contrast, the parallel flow of low charge state carbon ions in the SOL was measured to be independent of both the ion ∇B drift direction and core plasma rotation, and thus appear to be de-coupled from the deuteron flow. These studies provide new insight into SOL flows, which play a key role in the migration of eroded material in the main and divertor chambers, playing an important role in T retention in co-deposited (C + T) films.

The experimental results of these studies can be summarized as follows (Fig. 1, Table 1): as the ion ∇B drift direction is changed, the deuteron flow parallel to the magnetic field **B** toward the inner plate reduces in magnitude from $M = 0.5$ to $M \sim 0$, while the magnitude of parallel carbon flow remains toward the inner plate and at approximately the same speed. The poloidal flow of singly ionized carbon, on the other hand, increases roughly three-fold when the ion ∇B drift direction is reversed (Table 1). Furthermore, the experimental data suggest that the coupling between core rotation and SOL flows is weak in L-mode plasmas at low collisionality ($\nu_{SOL} \sim 3\text{-}5$) in contrast to higher collisionalities in Alcator C-Mod [1].

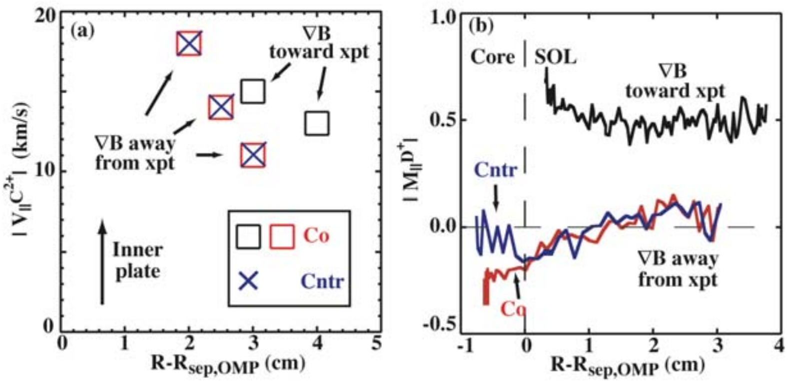

Fig. 1. Profiles of the parallel-**B** velocity of doubly charged carbon ions (a) and parallel-**B** Mach speed of deuterons (b) as function of the distance from the separatrix at the outer midplane. Data is shown for for configurations with the ion ∇B toward and away from the x-point, and co-current and counter-current core plasma rotation. Positive values refer to motion toward the inner target plate.

Table. 1. Summary of the parallel-**B** deuteron Mach speed, and parallel-**B** velocity of singly and doubly charged carbon ions in the SOL. Positive values refer to motion toward the inner target plate.

	∇B toward x-point	∇B away from x-point
$M_{\|}^{D^+}$	0.5	0.0-0.1
$V_{\|}^{C1^+}$ (km/s)	7.0	5.0
$V_{pol}^{C1^+}$ (km/s)	0.2-0.3	0.6-0.8
$V_{\|}^{C1^{++}}$ (km/s)	15.0	12.0

In these studies, the transport of carbon and deuterium ions in the crown has been assessed in upper single-null L-mode plasmas with the ion ∇B drift both toward and away from the divertor x-point in low density plasmas, $n/n_{GW} \sim 0.3$. A reciprocating Langmuir probe located at the bottom of the DIII-D tokamak was used to measure the deuteron Mach speed parallel to the magnetic field, **B**, at the crown. Parallel flow velocities of singly and doubly charged carbon ions parallel to **B** were inferred in the SOL from Doppler spectroscopy of CII and CIII emission lines. Analysis of images of the CI and CII emission at the crown, enhanced by toroidally symmetric injection of methane, was applied to infer the poloidal velocity of singly ionized carbon. Shown in Fig. 2, the poloidal shifts of the observed CII centroid relative to the CI centroid indicate significantly higher flow velocities toward the inner divertor when the configuration has the ion ∇B drift away from the divertor. These observations are qualitatively consistent with the direction of the **E**x**B** cross-field drift at the crown due to the presence of a radial electric field in the SOL.

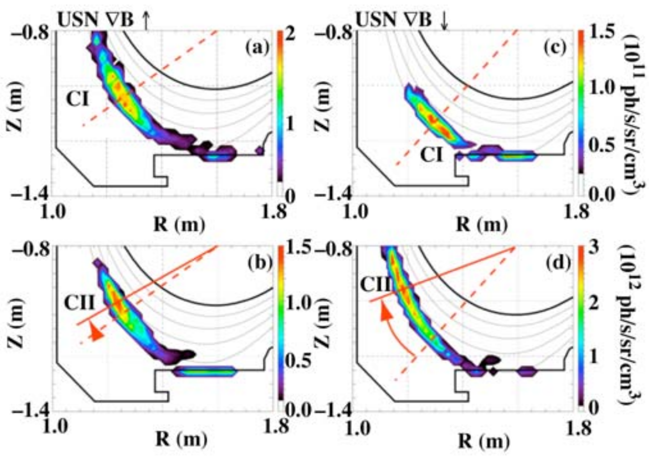

Fig. 2. Poloidal emission profiles of CI-910 nm (a,c) and CII-515 nm (b,d) measured in the crown of upper single-null plasmas with the ion ∇B drift toward the x-point (left boxes) and away from the x-point (right boxes) during toroidally symmetric, methane injection. The arrows indicate the poloidal shift of the peak CII emission vs CI emission.

Reversing the core plasma rotation in low-density L-mode plasmas does not affect the flow of deuterons and carbon in the SOL. Varying the core plasma rotation with neutral beam injection from co- to counter-plasma current caused no changes in the flow velocities of the deuterons and low charge state carbon ions (Fig. 1). Similarly, the poloidal flow of singly charged carbon ions does not change with core rotation. In contrast, just inside the separatrix, both the carbon and deuteron flow respond to change in applied torque. For these studies, neutral beam injection was switched from co-current to counter-current injection at a roughly comparable torque value of ~1.2 N-m, causing the toroidal rotation of fully stripped carbon ions in the edge region to reverse from 15 km/s co-current to 20 km/s counter-current.

Scrape-off layer transport simulations with the UEDGE code for the L-mode plasma with the ion ∇B drift toward the x-point do not consistently predict the measured deuteron and carbon flows at the crown. This highlights the need for improved SOL models and their thorough validation to adequately predict the divertor performance and impurity migration in future devices. In these simulations we assumed diffusive radial transport with ad-hoc, radially varying diffusivities and cross-field drifts due to **E**x**B** and **B**x∇B; poloidally varying radial transport coefficients were not imposed. Impurity transport is included by solving a force balance equation for each ionization state in the parallel-**B** direction, cross-field drifts, and ad-hoc diffusion in the radial direction. Plasma pressure imbalance between the high field and low-field x-point regions, and the crown can produce significant deuteron flows in the SOL; however, at the crown the flow becomes stagnant because of radial, ion **B**x∇B-induced particle drift across the separatrix. Low charge state carbon ions at the crown are predicted to flow in the direction of the outer divertor, opposite to the observation. On the other hand, higher charge state carbon ions, carrying the bulk of the total carbon flow, are calculated to flow toward the high-field divertor.

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[1] B. Labombard, *et al.*, Nucl. Fusion **44**, 1047 (2004).