Electrostatic potential variations along flux surfaces as an ingredient of radial impurity transport

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A profound physical understanding of the physics of radial impurity transport is necessary to make the requirements of highly radiative divertor and reliable steady state operation compatible. Impurity species display some distinct behaviour as compared to the main hydrogen ions. Because of their larger charge they tend to be more collisional than ions and develop density variations within flux surfaces. Indeed, in the last years experimental reports of asymmetries in the impurity density and parallel flow have fostered both in tokamaks [1, 2] and stellarators [3]. For the same reason, impurities are sensitive to even small in-surface variations of electrostatic potential that cause electrostatic trapping and $E \times B$ radial drifts. These can become comparable to magnetic trapping and drift for medium and high-Z impurities. Recent kinetic simulations have shown that these impurity-specific terms can importantly affect their radial fluxes [4].

We will present the first measurements of electrostatic potential variations along a flux surface in the edge of a toroidal magnetic confinement device [5]. These were taken with two distant Langmuir probe arrays whose precise positioning is aided by the simultaneous detection of radially localized zonal-flow like structures. The edge floating potentials measured at the two probe locations display significant differences (tens of Volts) in electron-root wave-heated plasmas. The differences are reduced for higher densities and lower electron temperatures after the ion-root electric field forms at the plasma edge. The order of magnitude and phase of the differences, as well as the observed dependencies on the electric field root, are well reproduced by neoclassical Monte Carlo calculations of the non-constant part of the electrostatic potential with the EUTERPE code [4]. The radial $E \times B$ flux of impurity depends on the spatial phase relation between the non-constant part of impurity density and electrostatic potential. We will discuss some of the causes of asymmetry in the electrostatic potential (drift-kinetic ion dynamics, radio-frequency heating) and in the impurity density (ion-impurity friction in steep pressure-gradient regions, centrifugal forces in rapidly spinning plasmas or potential asymmetries themselves).

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