The kinetic SOL: Understanding the sheath physics in tokamaks - progress in PIC modelling

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Kinetic modelling of the SOL plasma in fusion devices has more than three decades long history starting from simplified Particle-In Cell (PIC) models of the divertor plasma [1, 2] and SOL [3, 4] till our day massively parallel simulations of complex SOL geometry [5, 6]. PIC simulations, which can correctly describe the sheath in front of a divertor plate, require finest resolution in time and space and are computationally very expensive. Therefore, the PIC models of the SOL are continuously updated by inclusion of new sophisticated processes and optimizing of numerical schemes.

The aim of this work is to describe PIC technique for SOL simulations and present the recent results of the corresponding modelling. The atomic and molecular reactions play important roles in the SOL, e.g., recycling, radiative cooling, detachment etc., and the modelling for these reactions have been developed by introducing various Monte-Carlo techniques. These simulations including A&M processes have indicated that the parallel transport, as well as the cross-field drift transport, can significantly deviate from the classical one. Two main reasons for these deviations are: i) the presence of a super-thermal non-Maxwellian particle population carrying significant amount of the energy flux, and ii) strong cross-field gradients in the SOL, when the gyro-averaging approximation fails. These effects strongly influence divertor sheath physics too, e.g., the plasma and potential profiles are not necessarily monotonic in the pre-sheath and sheath, as it is usually assumed, and the normalized heat fluxes to the divertor plates (so called sheath heat transmission factors) can exceed the classical values by a factor of magnitude. PIC simulations have demonstrated that not only the stationary SOL but also the transient behaviors of the sheath and the SOL transport are affected strongly by the kinetic effects.

We quantify these effects and identify which of them have to be taken into account for studying of the plasma and impurity transport in the SOL. PIC results are compared with simplified analytical models and possible ways of their implementation into the analytical/numerical models of the SOL with lower computational costs are described too.

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