Neoclassical impurity transport in stellarators

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The accumulation of heavy impurities in the core of fusion plasmas must be avoided. The favourable outward drive of the radial impurity flux due to the temperature gradient in a tokamak, that is the neoclassical *temperature screening* effect, was understood to be absent in stellarators. Stellarators are not intrinsically ambipolar, and the inward radial electric field which develops in the presence of the high level of neoclassical transport can drive a strong inward impurity flux [1].

However, such predictions were obtained with approximate collision operators, which do not always capture the mixed collisionality regime of practical interest: where the bulk ion mean free path is long, whilst that of highly charged impurities is relatively short. We have developed an analytical calculation of the neoclassical impurity transport in such a mixed collisionality stellarator plasma. This is complemented by a recently developed numerical code, SFINCS, which solves the drift kinetic equation with the full linearised Landau collision operator, in general stellarator geometry, for an arbitrary number of species [2].

We see from both approaches that highly charged, collisional impurities can benefit from neoclassical temperature screening in a stellarator. As in a tokamak, a sufficiently steep temperature gradient is required. When the bulk ions are in the $1/\nu$ regime and the impurities are in the Pfirsch-Schlüter, the direct drive of the impurity flux by the radial electric field is eliminated. With reducing bulk ion collisionality, the radial electric field acts to reduce the net impurity flux driven by the bulk parameter gradients, and also produces a direct drive. The net impurity transport thus depends sensitively on the plasma parameters and we present examples of impurity behaviour in configurations typical of W7-X.

Finally, we note that the analysis presented is also relevant to the study of impurity behaviour in a tokamak, specifically in the core region where flux surface distortions commonly appear [3].

References

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