Calculation of Collisional Terms for Multi-Component, Multi-Temperature Plasma for Use in Scrape-Off Layer/Edge Applications

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Power exhaust is a key challenge in next step fusion devices. Reducing the peak heat fluxes on the plasma facing components to tolerable levels, to a large extent, relies on impurity radiation in the boundary layer of the tokamak. The impurity radiation pattern in turn depends on plasma transport, both parallel and perpendicular to the magnetic field. This problem is generally addressed by solving 2D plasma fluid models coupled to kinetic neutrals (e.g. with the Soledge2d-EIRENE, SOLPS code packages). In this contribution, we focus on the derivation of self-consistent fluid equations from the general kinetic equation, and their closure with an appropriate set of relations, which constitutes the basis of these numerical tools. We firstly rederive a closed set of moment equations for a plasma with multiple components, i.e. electrons, main ions, and impurities in multiple charge states, each with its own temperature, along the lines given by Zhdanov et al[1]. This works aims both at 1) checking formulas in Ref. [1], and 2) clearly identifying assumptions and their validity range. In fact, a number of versions of this closure, with certain approximations taken from Ref.[1], have been implemented in B2/SOLPS[2–4], EDGE2D[5], and more recently in Soledge2d-EIRENE[6], which solves an energy equation for each species (while other codes assume one common ion temperature). We present in particular the analytical calculation of the friction and thermal force terms arising from interactions of a plasma with multiple components (i.e. electrons, main ions, impurities in various charge states, all in different temperatures) using a Hermite polynomial expansion[7] method with the Boltzmann collision operator for a $21N$-moment limit (where N is the number of fluid components). This involves reduction of the linearized form of the Boltzmann collision operator into computable units[8–10], which has not been done before for a multi-temperature equilibrium case. Furthermore, we illustrate the linearization technique for the higher-moment equations derived by Zhdanov and Yushmanov in Ref. [1]. The force terms together with the linearized higher-order relations provide a closed set of $5N$-moment fluid-equations to solve.

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