Scaling of a Coupled Electron-Ion-Neutral Boltzmann System for Hall Thrusters

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We investigate the kinetic theory of a multi-component plasma. We introduce a scaling for a coupled electron-ion-neutral Boltzmann system, specifically tailored for modeling multi-species plasmas such as those found in Hall effect thrusters. The physics of these systems is fundamentally characterized by significant variations in certain key physical quantities of interest, such as species densities or the electric field, which can vary greatly in intensity depending on the specific zone within the thruster [1]. This leads us to consider different zones corresponding to different physical regimes. As a result, we identify the following regimes : one for the neutral gas injection zone, a second for the gas ionization zone, and finally, one for the ion acceleration zone and plasma plume. By taking into account the multi-component nature of the plasmas in our scaling, we observe the emergence of small parameters, such as the mass ratio between heavy species and electrons, the Hall parameter, or the density ratio between charged species and neutral species (as in [4]). This allows us to proceed with a Hilbert expansion of the distribution functions in these small parameters. The system is then studied at successive orders of approximation, each corresponding to a characteristic physical time. We give special attention to considering a highly magnetized regime, as it is characteristic of this type of thruster. Then, we find that the first-order term that emerges corresponds to the electromagnetic term, which can be addressed using a gyrokinetic approach ([2], [3]).

ACKNOWLEDGMENT : This work is funded by CIEDS through OpenNumDef project.

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