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Multi-Species Plasma-Electromagnetic Models for Pulsed Power Applications

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Many problems of interest in plasma modeling are subject to the 'tyranny of scales', specifically, problems that encompass physical processes that operate on timescales that are separated by many orders of magnitude. At the lowest frequency the plasma is in the regime of magnetohydrodynamics and has been the focus of extensive research in fluid plasma modeling in the past few decades. At somewhat higher frequencies, the electrons and ions can move relative to each other, behaving like two charge separated, interpenetrating fluids. This is the regime of high-frequency, non-neutral two-fluid physics and is relevant to high-density, fast MHD phenomena encountered in pulsed-power devices like dense plasma focus, Z-pinches, plasma thrusters and field-reversed configurations.

Although initial work has been done on efficiently solving fast magnetohydrodynamic phenomena, several open research problems remain. For example, implicit schemes developed for application in slow magnetohydrodynamics can not be applied directly as pulsed-power devices commonly exhibit shocks and other sharp features in the flow. To meet this need, a range of different schemes have been investigated, including physics-based preconditioning combined with Jacobian-Free Newton Krylov solvers, or alternatively, implicit-explicit schemes. Here, we describe the development of these approaches for a variety of fluid-plasma equation systems, including two-fluid electrostatics, magnetohydrodynamics and a two-fluid models coupled to full-wave Maxwell systems. We describe verification efforts for these systems and highlight the challenges of associated with high order discretizations. Finally, we describe recent efforts to develop hybrid fluid-kinetic models of multi-species plasma systems for this application area and highlight some of the challenges involved.

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