The Hong Kong University of Science and Technology

Department of Mathematics

<u>PhD THESIS EXAMINATION</u>

Gas-kinetic Schemes for Partially Ionized Plasma Flows

By

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<u>ABSTRACT</u>

Partially ionized plasma (PIP) plays a crucial role in understanding significant scientific problems and advancing high-technology applications. PIP spans a broad range of spatial and temporal scales, making it challenging to design efficient numerical methods. Existing numerical methods are mostly single-scale, limiting its efficiency when the plasma flow is characterized by multiscale features. Gas-kinetic schemes present promising approaches for multiscale simulations of PIP. They have been extensively validated in the multiscale regimes and multiphysics scenes. In this thesis, we aim to present a set of gas-kinetic schemes for modeling PIP flows, consisting of both fluid field and electromagnetic field.

Firstly, we construct a coupled kinetic model for the neutral gas, electron and proton and develop the Gas-kinetic Scheme for PIP in the continuum flow regime. Secondly, the Unified Gas-kinetic Wave-Particle method is constructed for PIP. This method possesses both multiscale and Unified-Preserving properties. The multiscale property allows the method to capture a wide range of plasma physics, from the particle transport in the kinetic regime to the multi-fluid and magnetohydrodynamics in the near continuum regimes, with the variation of local cell Knudsen number and normalized Larmor radius. The unified preserving property ensures that the numerical time step is not limited by the particle collision time in the continuum regime for the capturing of dissipative macroscopic solutions of the resistivity, Hall-effect, and to the ideal MHD equations. Finally, we turn to Maxwell equation numerical solver. We present a gas-kinetic scheme based on discrete velocity space for solving Maxwell equations. The kinetic model is pure abstract and converges to the Maxwell equations as the relaxation parameter τ approaches zero. This method achieves spatial and temporal second-order accuracy as the Finite-Difference Time-Domain (FDTD) method on structured meshes, without the need for a staggered grid and leapfrog update. Besides, this method benefits from true multidimensionality due to its kinetic formulation and permits larger timesteps in multidimensional cases. Compared to the , FDTD this method is more stable in the presence of discontinuity. Furthermore, the kinetic formulation is easy to be extended to unstructured meshes.

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<u>Thesis Examination Committee</u>:

Chairman	:	**Prof. Qing CHENG, MAE/HKUST**
Thesis Supervisor	:	**Prof. Kun XU, MATH/HKUST**
Member	:	**Prof. Tiezheng QIAN, MATH/HKUST**
Member	:	**Prof. Yang XIANG, MATH/HKUST** *(via online mode)*
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(Open to all faculty and students)

The student's thesis is now being displayed on the reception counter in the General Administration Office (Room 3461).