14th Plasma Workshop for Young Scientists (March 2011)
Naka Fusion Institute – Japan Atomic Energy Agency

Hall MHD in a Magnetospheric, Weakly Ionized Plasma Device

Germán Vogel
Graduate School of Frontier Sciences, The University of Tokyo

Key words : Hall MHD – Plasmas – Dipole – Planets: Magnetospheres

Abstract

Upon observations of Jupiter's pressure profiles at its naturally-occurring dipole-like magnetosphere, Akira Hasegawa postulated that a hot laboratory plasma resembling the properties of such magnetic configuration could give way to a plasma immune to anomalous transport of energies and particles. As an approach to the former aim, we begin by focusing on a weakly-ionized plasma, in which interesting phenomena takes place due to the emergence of Hall MHD equilibrium structures, and seek to address the issue from an experimental perspective.

Non-ideal effects in a weakly ionized plasma make it necessary to address in detail the main contributors to the physics of this new regime. Most prominently are the Hall effect and the ambipolar diffusion, which operate in different density regimes. Summoning the equations of motion for charged particles as well as neutrals, and criteria for weakly ionized plasma, begets the equations for the velocity and magnetic field. One of its key results is the fact that the neutral fluid is affected by Lorentz force, due to the coupling that is raised from the collisional interaction between ions and neutrals. Alfvén unit normalizations can be made yielding dimensionless equations, and Hall effect and ambipolar diffusion terms can be extracted as well as the advective and dissipative contributions made explicit.

The scaling parameters determine to a large extent the Kolmogorov scales by defining the Reynolds number in general terms as the ratio of the advective and dissipative contributions belonging to each domain of either viscous, resistive or ambipolar diffusion dissipations.

When the energy injection rate and plasma parameters are specified, a comparison can be drawn between the different domains for the dissipation mechanisms, and we purport to show the applicability of each scale in a magnetospheric experimental device.

In terms of dipole confinement, the main advantages of the dipole over the tokamak approach are with regards to divertor, disruptions, steady state operation, β limits, neoclassical effects, and fueling (in principle admitting second generation fuels in the case of the dipole configutration).

A new device more closely adhering to Hasegawa initial postulates and exploring physical phenomena in low-ionized plasma are not sufficiently explored, reason why a new dipole confinement device has been proposed. The idea consists of using a ~0.5 T permanent rare-earth magnet in order to build a simple prototype that allows the study of feasibility. The technology to levitate the internal coil is spared, which is a big burden in present day dipole experiments such as the Ring Trap-1 (RT-1) device in the University of Tokyo and the Levitated Dipole Experiment (LDX) at Columbia/MIT.

For dipole magnetic fields, the flux resulting from the central current is proportional to the plasma stored energy, giving importance to the energy product (BH) factor of the permanent magnet. The heating is planned to be implemented with 2.5 GHz ECH microwaves at half plane. The new experimental device also takes interest in the phenomena rising from the weakly ionized nature, in a wide outer radial profile.

The continuation of the research envisages the implementation of diagnostics to put those assumptions to test, and looks for experimental confirmation of expected Kolmogorov scales for energy dissipation. A future drive for an electric field in order to achieve a through study of Keplerian accretion disks with deeper links to planetary and astrophysical plasmas is also among the aims.