Seminar

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Institute for Plasma Research

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Title: Exploring electron plasmas confined in toroidal magnetic field: A 3D particle-in-cell simulation study

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Abstract

Straight cylindrical trap, sometimes also called Penning-Malmberg traps, with uniform external axial magnetic field for radial confinement and appropriate electric field end-plugs for axial confinement, routinely trap electrons/ions. Pure electron or ion plasmas confined in such traps exhibit near absolute thermal equilibrium state under certain conditions. In complete contrast, confinement of pure electron plasmas using only a toroidal magnetic field with its natural radial inhomogeneity, poses interesting unsolved physics problems. For example, what are the prospects of finding theoretically and/or numerically, a quiescent, inhomogenous equilibrium state with excellent confinement properties, akin to cylindrical traps? If found, will this novel state be stable, for example, to the presence of ions and/or neutrals? Is there a way to obtain 3D temperature and 3D density profiles of such a state? Can one arrive at scaling laws useful for experiments? Are there novel quasi-steady states for futuristic applications, for example, extremely miniaturised, ultracold electron and ion clouds?

In the present Thesis, several of the above mentioned open problems are addressed using high fidelity 3D3V Particle-inCell simulation for an electron plasma confined in a toroidal tight aspect ratio axisymmetric trap and in a partial toroidal trap. In the first part of the Thesis, a set of three numerical experiments are conducted by loading the axisymmetric toroidal electron cloud at varying major-radial distances from the central axis at the vertical midplane. It is demonstrated that relatively better confinement of electron plasma is achieved by loading the initial plasma at the vertical midplane, close to the inner wall of the chamber, supporting mean-field theoretical predictions. Following this discussion, the existence of a quiescent quasi-steady state in an axisymmetric toroidal trap is demonstrated using combination of a mean field theoretic extremum entropy solution and inertia effects in Particle-in-Cell simulation. It is demonstrated that the global particle confinement time for this novel state is typically greater than 10^6 times the so-called toroidal Diocotron time. Further, role of ions is investigated based on collision-less (preloaded ion) and collisional mechanisms which suggests that the quiescent state discovered may suffer toroidal ion resonance-like instability, which is found to grow algebraically in time. In the second part, the numerical experiments discussed earlier for axisymmetric toroidal trap is performed in a 3D non-axisymmetric toroidal trap with electrostatic end plugs. To investigate the electron dynamics under similar conditions as typical experimental devices, further studies have been performed in nonaxisymmetric toroidal traps, resulting in a new empirical scaling law for the toroidal Diocotron frequency as a function of mean density. Finally several unresolved problems in this Thesis work are identified, pointing towards plausible future direction.