1-4. Theoretical Study

Various results have been obtained from theoretical and simulation studies on magnetically confined plasmas in the Large Helical Device (LHD) and other systems through the NIFS collaborative research programs.

Multi-scale MHD simulation studies are done for the LHD plasma including continuous heating and background pressure diffusion, and self-organization processes toward the high beta stable regime are discovered. Nonlinear MHD simulations are executed to reproduce the basic characteristics of the core density collapse events observed in the outward-shifted LHD operations. The helical pitch parameter γ dependency of equilibrium and the stability of the high beta plasma in the LHD type magnetic configuration is studied numerically. It is confirmed that the small γ configurations are favorable for the LHD-type fusion reactors in the point of robustness of high beta equilibrium, compatibility of easy ignition and high output power of core plasma, in addition to a sufficient space for blankets.

The detailed mechanism of the locking of the magnetic island rotation by the error field in tokamak plasmas is investigated numerically and analytically by considering the collisional drift-tearing mode based on a reduced set of Braginskii's two fluid equations. The drift kinetic equation solver KEATS is applied to ion (proton) energy transport in the magnetic field disturbed by resonant magnetic perturbations (RMPs) under the assumption of neglecting effects of an electric field, impurities and neutrals. The ion thermal diffusivity is evaluated from the radial energy flux given by the guiding center distribution function in five dimensional phase space. It is found that the diffusivity depends on both the strength of the RMPs and the collision frequency.

A benchmark test between the neoclassical transport simulation code FORTEC-3D and the gyrokinetic simulation code GT5D shows a good agreement on the neoclassical transport coefficient obtained for a simple tokamak geometry. FORTEC-3D is utilized to investigate the configuration dependence of GAM oscillation in LHD plasmas and to calculate the neoclassical toroidal viscosity in tokamaks with external perturbation magnetic fields. Analyses of neoclassical particle, heat diffusion and radial electric fields in high ion temperature LHD plasmas are done by using the GSRAKE code. The poloidal viscosity in Heliotron J is theoretically estimated as a function of the poloidal Mach number (Mp).

A turbulence diagnostic simulator is developed, which numerically simulates plasma turbulence and aids the development of the data analysis technique to deepen physical understandings of turbulence structural formation and self-regulated mechanism. For the first step to study fusion plasmas, simulations in cylindrical are carried out to identify the bifurcation phenomena of the turbulent structure. The collisionless response of the zonal-flow potential in helical systems with equilibrium radial electric fields driving the poloidal ExB rotation of helical-ripple-trapped particles is investigated. Theoretically predicted enhancement of the residual zonal-flow potential due to the ExB rotation is verified by the linear gyrokinetic Vlasov simulation using the poloidally global domain for a model magnetic geometry corresponding to the inward-shifted LHD configuration. The reduction of the turbulent transport due to the excitation of zonal flows is investigated by the transport code analysis in the core region of helical plasmas. The electron Internal Transport Barrier (e-ITB) in helical plasmas is shown to be formed by the mechanisms of the excitation of zonal flows which cause the suppression of the turbulent transport in conjunction with the e-ITB.

Linearized model collision operators for multiple ion species plasmas are presented that conserve particles, momentum, and energy and satisfy adjointness relations and Boltzmann's H-theorem even for collisions between different particle species with unequal temperatures. Entropy balance equations are derived from the gyrokinetic equation including the collision term. A set of basic kinetic equations to describe the strong plasma turbulence is derived introducing the memory functions and the fluctuating force.

Some of results described above were reported in the 4th IAEA technical meeting (IAEA-TM) on Theory of Plasma Instabilities. (Sugama, H.)