1-4. Theoretical Study

A wide range of theoretical studies on helical devices like LHD and other magnetically confined devices has been carried out in this fiscal year. In order to comprehensively understand the physics mechanism of plasma confinement in toroidal devices, theoretical researches on distinct experimental devices and pioneering theories of confinement plasmas are promoted.

An MHD equilibrium solver HINT2, which is a improved version of HINT, is used for investigating both MHD equilibrium with magnetic islands and stochastic magnetic field in LHD and a finite β tokamak with toroidal rippled. The linear stability analysis of high-n ideal ballooning modes is performed in Super Dense Core-Internal Density Barrier; SDC-IDB, LHD plasmas, leading to the fact that the ideal MHD stability results is not simply related to the formation of SDC with IDB. A model is proposed where the fast change in the MHD equilibrium by the nonlinear saturation of interchange modes is coupled with the evolution of MHD equilibrium by external heating. A modeling for the dynamics of Edge Localized Mode (ELM) crash in the spherical tori such as MAST and NSTX has been proposed, where it is found that the ballooning nature is essential for the formation mechanism of the observed filamentary structure. Moreover, a HL-2A tokamak disruption forecasting model based on an artificial neural network is firstly proposed.

The DKES code for neoclassical diffusion coefficients has been revisited in order to reconsider the accuracy estimation, incorporate the DKES into Sugama-Nishimura method, and apply DKES to evaluate ambipolar radial fluxes, flows, current, and radial electric field, in the SDC-IDB LHD plasmas with comparison to the results by the GSRAKE code. A new transport simulation code, KEATS, treating the neoclassical theory in the island region is being developed, where Monte-Carlo scheme based on the δf method is used. In the tokamak plasma with (m/n) =(1/1) global magnetic island, the ion energy flux is evaluated on the basis of the unperturbed flux surfaces.

Eigenmode analysis of Geodesic Acoustic Mode; GAM and Zonal Flow; ZF based on the linear response function has been continuously performed taking account of finite electron temperature. Various types of GAM eigenmodes, namely, zero-frequency ZF, standard GAM, a branch of low-frequency mode, and a series of ion sound wave ISW-like modes exist depending on the degree of compressibility of poloidal $E \times B$ flow. As a nonlocal stability analysis of micro-instabilities, integral eigenmode equation formalism is reviewed. Simulations of Electron Bernstein Waves; EBW in helical systems is in progress related to experiments. Linear gyrokinetic Vlaos simulations of ITG modes and zonal flow evolution in multiple-helicity helical fields have been performed in order to understand the geometrical effects on ITG growth rate and damping rate of ZF. The longer ZF life time of the inward shifted configuration together with an ITG instability growth rate level similar to that of the standard case suggests a more efficient regulation of the Anomalous Transport (AT) in the former one, as observed in the experiment. Similar investigations are performed on the basis of a neoclassical transport code FORTEC-3D, which solves the drift-kinetic equation and time evolution of radial electric field in helical plasmas by the δf method, which indicates that the GAM frequency and the damping rate can be controlled by the axis shift in LHD plasma. A novel kinetic-fluid model is presented, which describes collisionless time evolution of zonal flows in toroidal plasmas. The new zonal-flow closure relations are derived from the gyrokinetic model and they can reproduce the gyrokinetic long-time zonal-flow responses to the initial condition and to the turbulence source. The new kinetic-fluid model is used to study time evolution of zonal flows driven by either ion or electron temperature gradient (ITG or ETG) turbulence. The gyrokinetic and fluid simulation results both show a good agreement with the predicted zonal-flow level. In order to study a selection rule for a radial wavelength of the zonal flow, the nonlinear evolution of the zonal flow is analyze by the initial value problem in the one-dimensional model. It is shown that, when the initial condition is at a small amplitude and random in space, the periodicity length of a finial state is dominated by a particular length. Theoretical study on the interplay between magnetic configuration property and zonal flow, GAM oscillations and fluctuations in LHD is also reported.

By developing a 3-D simulation code called 'Numerical Linear Device' (NLD), which describes the resistive drift wave turbulence in a linear device, a nonlinear simulation has been performed to examine the saturation mechanism of the resistive drift wave turbulence. A resistive drift wave can be excited with a small ion-neutral collision frequency, and is saturated by the quasi-linear effect of density flattening, and the modification of the electrostatic potential profiles. The first report is presented to clarify that the collisional damping rate of the ZFs governs the transition of global confinement of toroidal plasmas including the experimental test. This gives an answer to the basic question, in the laboratory plasma turbulence and in the planetary zonal flows, of how turbulent transport and frictional damping couple to each other in generating zonal flows. The transport code analysis of LHD plasma with e-ITB is performed. By taking into account of the effects of the zonal flow with the damping rate of ZF's caused by the collisional process and the self-nonlinearity of zonal flows, the reduction of thermal conductivity in the core plasma is explained. Two- dimensional electric field structures has been studied by extending the 1-D model in tokamak H-modes, and constructed a transport model including the 2-D effect to reveal the self-consistent mechanism of the density pedestal formation on the L/H transition. The generation of a particle pinch associated with the poloidal shock structure can give a rapid density increase if the phase difference δ is substantial, where δ is the phase delay between the potential and the density.

(Nakajima, N.)