Preface

The worldwide effort to develop the fusion process as a new energy source has been going on for about a half century and has made remarkable progress. Now construction stage of "International Tokamak Experimental Reactor", called ITER, already started. Primary objective of this textbook is to present a basic knowledge for the students to study plasma physics and controlled fusion researches and to provide the recent aspect of new results.

Chapter 1 describes the basic concept of plasma and its characteristics. The orbits of ion and electron are analyzed in various configurations of magnetic field in Chap. 2.

From Chap. 3 to Chap. 7, plasmas are treated as magnetohydrodynamic (MHD) fluid. MHD equation of motion (Chap. 3), equilibrium (Chap. 4), and confinement of plasma in ideal cases (Chap. 5) are described by the fluid model.

Chapters 6 and 7 discuss problems of MHD instabilities whether a small perturbation will grow to disrupt the plasma or will damp to a stable state. The basic MHD equation of motion can be derived by taking an appropriate average of Boltzmann equation. This mathematical process is described in Appendix A. The derivation of useful energy integral formula of axisymmetric toroidal system and the analysis of high n ballooning mode are introduced in Appendix B.

From Chap. 8 to Chap. 13, plasmas are treated by kinetic theory. Boltzmann's equation is introduced in Chap. 8. This equation is the starting point of the kinetic theory. Plasmas, as mediums in which waves and perturbations propagate, are generally inhomogeneous and anisotropic. It may absorb or even amplify the wave and perturbations.

Cold plasma model described in Chap. 9 is applicable when the thermal velocity of plasma particles is much smaller than the phase velocity of wave. Because of its simplicity, the dielectric tensor of cold plasma can be easily derived and the properties of various waves can be discussed in the case of cold plasma.

If the refractive index of plasma becomes large and the phase velocity of the wave becomes comparable to the thermal velocity of the plasma particles, then the particles and the waves interact with each other. Chapter 10 describes Landau damping, which is the most important and characteristic collective phenomenon of plasma. Waves in hot plasma, in which the wave phase velocity is comparable to the thermal velocity of particles, are analyzed by use of dielectric tensor of hot plasma. Wave heating (wave absorption) in hot plasmas and current drives are described in Chap. 11. Non-inductive current drives combined with bootstrap current are essential in order to operate tokamak in steady state condition.

Instabilities driven by energetic particles (fishbone instability and toroidal Alfvén eigenmodes) are treated in Chap. 12. In order to minimize the loss of alpha particle produced by fusion grade plasma, it is important to avoid the instabilities driven by energetic particles and alpha particles.

Chapter 13 discusses the plasma transport by turbulence. Losses of plasmas with drift turbulence become Bohm type or gyro Bohm type depending on different magnetic configuration. Analysis of confinement by computer simulations is greatly advanced. Gyrokinetic particle model and full orbit particle model are introduced. Furthermore it is confirmed recently that the zonal flow is generated in plasmas by drift turbulence. Understanding of the zonal flow drive and damping has suggested several routes to improving confinement. Those new topics are included in Chap. 13.

In Chap. 14, confinement researches toward fusion plasmas are reviewed. During the last two decades, tokamak experiments have made a remarkable progress. Chapter 15 introduces research works of critical subjects on tokamak plasmas and the aims of ITER and its rationale are explained. Chapter 16 explains reversed field pinch including PPCD (pulsed parallel current drive), and Chap. 17 introduces the experimental results of advanced stellarator devices and several types of quasi-symmetric stellarator. Boozer equation to formulate the drift motion of particles is explained in Appendix C. Chapter 18 describes open-end systems including tandem mirrors. Elementary introduction of inertial confinement including the fast ignition is added in Chap. 19.

Readers may have an impression that there is too much mathematics in this book. However, it is one of motivation to write this text to save the time to struggle with the mathematical deduction of theoretical results so that students could spend more time to think physics of experimental results.

This textbook has been attempted to present the basic physics and analytical methods comprehensively which are necessary for understanding and predicting plasma behavior and to provide the recent status of fusion researches for graduate and senior undergraduate students. I also hope that it will be a useful reference for scientists and engineers working in the relevant fields.

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