Gyrocenter Gauge Kinetic Theory and Algorithm for Radio-Frequency Waves in Plasmas*

Hong Qin

Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ 08540

To a large extent, the success of next generation magnetic fusion experiments, such as the international ITER experiment, depends on our capability of heating plasma and driving current with radio-frequency waves in these devices. However, it is impossible to carry out numerical simulations of these processes based on first principles even with the most powerful parallel computer available today. This is because the fast time-scale gyromotion is the crucial physics for these processes and it is too time consuming to resolve particle's fast gyromotion in a realistic tokamak geometry. Recently, we developed a theory called gryocenter gauge kinetic theory [1] that can be applied as an efficient numerical algorithm to simulate physical processes of plasma heating and current drive with radio-frequency waves. The gryocenter gauge kinetic theory gives a kinetic description of magnetized plasmas in the gyrocenter coordinates which is fully equivalent to the Vlasov-Maxwell system in the particle coordinates. In particular, provided the gyroradius is smaller than the scale-length of the magnetic field, it can treat high frequency range as well as the usual low frequency range normally associated with gyrokinetic approaches. The gyrocenter gauge kinetic susceptibility for arbitrary wavelength and arbitrary frequency electromagnetic perturbations in a homogeneous magnetized plasma is shown to recover exactly the classical result obtained by integrating the Vlasov-Maxwell system in the particle coordinates. This demonstrates that all the waves supported by the Vlasov-Maxwell system can be studied using the gyrocenter gauge kinetic model in the gyrocenter coordinates. Besides the usual gyrokinetic distribution function, the gyrocenter-gauge kinetic theory emphasizes as well the gyrocenter-gauge distribution function, whose importance has not been realized previously. The gyrocenter-gauge distribution function enters Maxwell's equations through the pull-back transformation of the gyrocenter transformation, which depends on the perturbed fields. This theoretical formalism enables the direct particle-in-cell simulations of radio-frequency wave physics relevant to plasma heating and current drive in laboratory. The efficacy of the gyrocenter gauge algorithm is largely due to the fact that it decouples particle's fast gyromotion from the slow gyrocenter motion in the gyrocenter coordinates. Simulation particles only need to move along the slow gyrocenter orbits, whereas the gyrophase dependant part of the distribution is captured by the gyrocenter gauge distribution function. The gyrocenter gauge algorithm has been recently implemented [2], and initial simulation results have confirmed the effectiveness of the algorithm.

*Work supported by U.S. Department of Energy.

[1] H. Qin, W. M. Tang, and W. W. Lee, Physics of Plasmas **7**, 4333 (2000).

[2] R. A. Kolesnikov, W. W. Lee, H. Qin, and E. A. Startsev, *High Frequency Gyrokinetic Particle Simulation,* Submitted to Physics of Plasmas (2007).