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

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A gyrocenter gauge kinetic theory that can be applied as an efficient numerical algorithm to simulate the physical processes of plasma heating and current drive with radio-frequency waves is developed. 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 and initial simulation results have confirmed the effectiveness of the algorithm.