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Gauge Invariance and Conservation Laws in the Variational Formulation of Macro-Particle Plasma Models

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Recently there has been significant interest in formulations of macro-particle models using variational methods. This is attractive because many of the inherent pathologies of traditional PIC methods are avoided. Broadly, there are two approaches to constructing these models that on the surface appear incompatible: a Lagrangian method based on the Low Lagrangian and a Hamiltonian method based on the noncanonical Vlasov–Maxwell Poisson bracket. In both cases, a reduction is performed on the distribution function, which is replaced by a finite sum of macro-particles with a fixed spatial structure and definite momentum. The distribution is thus replaced as dynamical variable by a collection of marco-particle positions and momenta. In the Lagrangian formulation, it is natural to represent the fields on a grid. Doing so yields an algorithm that is of the same computational cost as the traditional PIC algorithm but is free of grid-heating. It does not appear possible to introduce a grid for the field in the noncanonical formulation. Instead, a basis function expansion is used based on discrete exterior calculus. Here we resolve the apparent discrepancy between the two approaches and show that the noncanonical Hamiltonian formulation can be transformed into a canonical Hamiltonian system and careful treatment of the variational principle in both the Lagrangian and Hamiltonian settings is necessary to maintain charge conservation. In the Lagrangian setting, introducing a grid (which is required to be computationally performant) breaks gauge invariance leading to an unusual structure of the variational principle.

Working group

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