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A field theory approach to plasma self-organization

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Self-organization is concerned with the spontaneous emergence of large-scale structures in physical systems. A fundamental conjecture, borrowed from the mathematics of topology, is the invariance of a global property during the process of self-organization: for example, a system relaxes to reduce energy constrained by a constant value of the helicity of the canonical momentum. This paper [1] presents a unifying field-theory framework that reformulates the single-particle, kinetic and fluid equations governing plasma dynamics as a single set of generalized Maxwell's equations and Ohm's law for canonical force-fields. The new Lagrangian includes terms representing the coupling between the motion of particle distributions, between distributions and electromagnetic fields, with relativistic contributions. The formulation shows that the concepts of self-organization and canonical helicity transport are applicable across single-particle, kinetic, and fluid regimes, at classical and relativistic scales. The framework shows that a species' canonical helicity is well conserved compared to the species' energy in shallow density gradients but not in steep density gradients (in the simplest case of an isolated, dissipative system). These results suggest that in the edge of multi-species, collisionless, kinetic plasmas, magnetic helicity can couple to ion canonical helicity, spontaneously generating flowing structures when density gradients are of the order of the ion skin depth. This field theory approach to helicity and energy evolution suggests that electrical engineering methods used for analyzing magnetostatic configurations can be extended to flowing magnetized (or non-magnetized) plasmas and flowing neutral fluids with finite vorticity. The driving circuits can be any combination of gravitational, pressure, kinetic or electrical supplies since these power supplies are simply enthalpy sources for a canonical Maxwell cicuit. This work is supported by by US DOE Grant DE-SC0010340.

[1] S. You, Phys. Plasmas, **23**, 072108 (2016)