Broken Symmetry in Neoclassical Transport Theory

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Abstract

A formulation of Neoclassical transport theory is given that is consistent with the traditional formulation and yet has broken "Onsager" symmetry[1] for conjugate terms involving the electron heat flux and bootstrap currents. This is demonstrated for the electron Lorentz transport model for the purely collisional theory. Such a symmetry breaking has been previously suggested[2] but the argument invoked turbulence effects. The terms involved in the present theory are not the ones discussed in the previous work. We show that the symmetry can be mathematically restored by adding certain reactive flow terms to both the Ohmic heating and the electron heat flux, but such an artifice does not represent a clear picture of physical reality (it requires adding non-dissipative terms from the collisionless bootstrap current to the Ohmic heating). We claim that the non-symmetric formulation gives the clearest picture of physical reality, i.e. Neoclassical transport should not be considered an Onsager symmetric theory. The main contribution of the formulation presented is to clarify physically the microscopic processes involved and to distinguish collisionless orbit effects (like the Ware pinch and certain banana-diamagnetic bootstrap current terms), which do not have Onsager symmetry from collisional processes that do. Such understandings are important, we claim, as theory is applied in more complex geometries and extended to include turbulence and collisions in combination.

[1] L. Onsager, Phys. Rev. **37**, 405(1931); **38**, 2265 (1931).
[2] K. Molvig, L. M. Lidsky, K. Hizanidis, and I.B. Bernstein, Comm. Mod. Phys.Part E **7**, 1134 (1982).