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Kubo formula for a dissipative spin hydrodynamic framework with spin chemical potential as the leading order term in the hydrodynamic gradient expansion

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We present a first-order dissipative spin hydrodynamic framework, where the spin chemical potential $\omega^{\mu\nu}$ is treated as the leading term in the hydrodynamic gradient expansion, i.e., $\omega^{\mu\nu} \sim \mathcal{O}(1)$. We argue that for the consistency of the theoretical framework, the energy-momentum tensor needs to be symmetric at least up to order $\mathcal{O}(\partial)$. We consider the phenomenological form of the spin tensor, where it is anti-symmetric in the last two indices only. A comprehensive analysis of spin hydrodynamics is conducted using both macroscopic entropy current analysis and microscopic Kubo formalism, establishing consistency between the two approaches. A key finding is the entropy production resulting from spin-orbit coupling, which alters the traditional equivalence between the Landau and Eckart fluid frames. Additionally, we identify cross-diffusion effects, where vector dissipative currents are influenced by gradients of both spin chemical potential and chemical potential corresponding to the conserved charge through off-diagonal transport coefficients. Two distinct methods for decomposing the spin tensor are proposed, and their equivalence is demonstrated through Kubo relations.

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