Quantum field theoretical approach to relativistic hydrodynamics from local Gibbs ensemble

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論文の内容の要旨

Quantum field theoretical approach to relativistic hydrodynamics from local Gibbs ensemble

(局所ギブス分布に基づく相対論的流体力学に対する場の量子論的アプローチ)

本郷　優

Relativistic hydrodynamics is a low-energy effective theory which universally describes macroscopic behaviors of relativistic many-body systems. Its application covers the broad branches of physics such as high-energy physics, astrophysics, and condensed matter physics. Nevertheless, its derivation from underlying microscopic theories, especially from quantum field theories, has not been clearly clarified. Furthermore, it is recently pointed out that novel transport phenomena such as the chiral magnetic effect, which originates from the quantum anomaly in the underlying quantum field theories, take place in the macroscopic hydrodynamic regime.

In this thesis, we derive relativistic hydrodynamics from quantum field theories on the basis of the recent development of nonequilibrium statistical mechanics. In order to derive the hydrodynamic equations we introduce an assumption that the density operator is given by a local Gibbs distribution at initial time, and decompose the energy-momentum tensor and charge current into nondissipative and dissipative parts. This leads to a generalization of the Gibbs ensemble method canonically employed in equilibrium statistical mechanics. Our formalism is also applicable to the situation in the presence of the quantum anomaly, and we can describe the anomaly-induced tranport phenomena.

As a basic tool of our formalism, we first develop a path integral of the thermodynamic potential for locally thermalized systems. We show microscopically that the thermodynamic pontential, which is shown to be the generating functional of systems in local thermal equilibrium, is written in terms of the quantum field theory in the curved spacetime with one imaginary-time direction. The structure of this thermally emergent curved spacetime is determined by hydrodynamic variables such as the local temperature, and fluid-four velocity, and possesses notable symmetry properties: Kaluza-Klein gauge symmetry, spatial diffeomorphism symmetry, and gauge symmetry. With the help of the symmetry argument, we can construct the nondissipative part of the hydrodynamic equations including the anomaly-induced transport phenomena. By the use of the perturbative calculation, we evaluate the anomalous transport coefficients at one-loop level. Furthermore, we also construct a solid basis to study dissipative corrections to hydrodynamic equations. In particular, by performing the derivative expansion, together with the result on nondissipative part of the constitutive relations, we derive the first-order dissipative hydrodynamic equations, that is, the relativistic Navier-Stokes equation. Our formalism also provides the quantum field theoretical expression of the Green-Kubo formulas for transport coefficients.