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The Ginzburg-Landau Free Energy in Holographic Superconductor

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The approach to study holographic superconductor with the *Gauge/ Gravity correspondence* is a novel method to explore the strong coupled system, for instance, the research to high temperature superconductor. It triggers an instructive thought to tackle strong coupled system. Holographic superconductor system is composed of gravitational field; gauge field and complex scalar field. A lot of researches are done since the mechanism of holographic superconductor was posed by Gubser et.al. in 2008, and many of numerical computations and simulations reveal the Ginzburg-Landau paradigm is obeyed near the critical temperature. However the analytic formulas of the order-parameter and Ginzburg-Landau free energy were not obtained.

Our motivation is to analytically derive the Ginzburg-Landau free energy from holographic superconductor action and seek the general expression of order-parameter. A conundrum of the coupled fields is there exist no analytic solution for their motion of equations. However all information about condensate and phase transition are concealed within those equations . To tackle this difficult problem, we change the differential equation of gauge field into an integral form and obtain its iterative solution, substituting the iterative solution of gauge field in a specified ensemble, we switch the holographic superconductor action into functional of scalar field. Performing a variation, we have a non-linear integro-differential equation of scalar field to describe its behavior deviating from the critical temperature, where the asymptotic coefficients correspond to the one-point function on AdS boundary theory. On the other hand, at the critical point, the gauge field has an exact analytic solution and the EoM of the scalar field becomes a standard Sturm-Liouville problem, this differential equation is a Fuchian equation with **Five** singularities, its leading eigenvalue is related to the critical temperature. We employ the complete functions from the Sturm-Liouville equation to expand the solution of the integro-differential equation and obtain the relation between the order-parameter and expansion coefficients. At last, the analytic formulas of order-parameter and Ginzburg-Landau coefficients are obtained in (grand) canonical ensemble with conformal dimension one and two, respectively.

We verify the consistency between our formulation and the fundamental thermodynamic relation. Utilizing our formulas, we calculate the scaling coefficients of order-parameter and Ginzburg-Landau coefficients in s-wave holographic superconductor. For the canonical ensemble part, the scaling coefficient has been computed via numerical simulation since 2008, our results is in close good agreement with the results from computation. The difference of the scaling coefficients between the two thermodynamic ensembles is revealed manifestly from our formulas. By comparing with the situation in classically weak coupled BCS theory, we interpret this difference results from the feature of strong coupled system. Further, the Ginzburg-Landau free energy in inhomogeneous space is studied.

Summary

- The **analytical formulas** of *Order-Parameter* in G.C.E and C.E.
- The **on-shell** and **off-shell** *Ginzburg-Landau Free Energy* are achieved.
- The **Ginzburg-Landau coefficients** are obtained.
- The **difference** of order-parameter between *G.C.E and C.E.* reveals the *Strong-coupling feature* of holographic superconductor.
- The **criterion** of *Thermodynamic Consistency* is deduced.

- The GL free energy in **inhomogeneous space** is considered.

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