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Holographic s-wave condensation and Meissner-like effect in Gauss–Bonnet gravity with various non-linear corrections

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ABSTRACT

In this paper we have studied the onset of holographic s-wave condensate in the $(4+1)$ dimensional planar Gauss–Bonnet-AdS black hole background with several non-linear corrections to the gauge field. In the probe limit, performing explicit analytic computations, with and without magnetic field, we found that these higher order corrections indeed affect various quantities characterizing the holographic superconductors. Also, performing a comparative study of the two non-linear electrodynamics it has been shown that the exponential electrodynamics has stronger effects on the formation of the scalar hair. We observe that our results agree well with those obtained numerically (Zhao et al., 2013).

1. Introduction and motivations

The AdS/CFT correspondence [1,2] has proven to be useful in describing several aspects of strongly coupled field theories from their weakly coupled dual gravity theories which lie in one higher dimension.[1] Over the past several years this correspondence has been extensively used to explore certain field theoretic phenomena where conventional perturbation methods fail to give consistent results [7].

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1 For excellent reviews on this correspondence see [3–6].

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Among many sectors where this correspondence has been applied successfully, strongly interacting condensed matter theory has been central to the discussion where conventional perturbation techniques appear to be unfaithful. Using this holographic conjecture a holographic model of high T_c superconductors has been proposed [8,9]. Further study of these phenomenological models reveal many of their interesting features which resemble that of the conventional superconductors [10].

Gravity theories in higher dimensions[2] (greater than four) have earned repeated attentions in the past several decades with the advent of string theory. The primary motivation comes from the fact that the consistent description of string theory requires the inclusion of higher dimensional space–time. Certain aspects of string theory are well described by associating gravity theories with it. The effect of string theory on gravity may be studied by considering a low-energy effective action which describes classical gravity [14]. This effective action must contain higher curvature terms and are needed to be ghost free [15]. The Lovelock action is found to be consistent with these criteria [16].

Along with the conventional Maxwell electrodynamic theory non-linear electrodynamic theories (NED), which correspond to the higher derivative corrections to the Abelian gauge fields, have also become interesting topics of research for the past several decades. The primary motivation for introducing non-linear electrodynamic theory was to remove divergences in the self-energy of point-like charged particles [17]. However, they have earned renewed attention over past several years since these theories naturally arise in the low-energy limit of the heterotic string theory [18–20].

Besides the conventional Born–Infeld non-linear electrodynamics (BINE) [17], two new types of NEDs have been proposed recently, namely the exponential non-linear electrodynamics (ENE) and the logarithmic non-linear electrodynamics (LNE), in the context of static charged asymptotic black holes [21,22]. In fact, the matter actions with ENE and LNE yield the higher derivative corrections to the usual Maxwell action. On the other hand these NEDs possess many unique properties which are quite different from the Maxwell electrodynamics. For example, while solutions with LNE completely remove divergences in the electric fields at $r = 0$, these divergences still remain in the solutions with ENE. But these divergences are much weaker than the usual Maxwell case [21,22]. Also, compared with Maxwell theory, solutions with LNE and ENE have different temperatures and electric potentials [21, 22]. Another novel property of these non-linear theories is that, their asymptotic black hole solutions are the same as that of a Reissner–Nordström black hole [22]. On top of that, these types of non-linear theories retain some interesting properties (alike BINE) such as, absence of shock waves, birefringence etc. [21,22]. One further advantage of studying ENE and LNE over the Maxwell theory is that they provide an enriched platform to investigate generalized versions of NEDs in a systematic manner so as to reveal some general features of the effects of higher derivative corrections to the gauge fields in the theory concerned.

At this point of discussion it must be stressed that while gravity theories with NEDs give rise to many interesting gravity solutions which in many respects are different from the solutions with usual Maxwell electrodynamics [23–36], these are also widely discussed in the context of gauge/string duality, specifically in the holographic study of condensed matter phenomena with holographic superconductors as specific examples. Holographic superconductors with non-linear electrodynamics [37–52] have been investigated alongside those with Maxwell electrodynamics [10]. These studies show that the non-linearity in the theory indeed modifies the behaviours of the holographic condensates in non-trivial manners which cannot be observed in the conventional holographic superconductors with Maxwell electrodynamics. In other words the higher derivative corrections to the Abelian gauge fields are manifested as effects on certain properties of the dual holographic models. This observation motivates us to study models of holographic superconductors with ENE and LNE and look for the modifications they make on certain properties of the models compared to the Maxwell case. This also encourages us to make a comparative study between holographic models with different NEDs regarding their effects on the condensation formation. In this regard consideration of holographic models with ENE and LNE is another motivation of the present paper.

[2] For good reviews on gravity theories in higher dimensions see [11–13].