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Double relaxation via AdS/CFT

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Abstract

We exploit the AdS/CFT correspondence to investigate thermalization in an $\mathcal{N} = 2$ strongly coupled gauge theory including massless fundamental matter (quark). More precisely, we consider the response of a zero temperature state of the gauge theory under influence of an external electric field which leads to a time-dependent current. The holographic dual of the above set-up is given by introducing a time-dependent electric field on the probe D7-brane embedded in an $AdS_5 \times S^5$ background. In the dual gravity theory an apparent horizon forms on the brane which, according to AdS/CFT dictionary, is the counterpart of the thermalization process in the gauge theory side. We classify different functions for time-dependent electric field and study their effect on the apparent horizon formation. In the case of pulse functions, where the electric field varies from zero to zero, apart from non-equilibrium phase, we observe the formation of two separate apparent horizons on the brane. This means that the state of the gauge theory experiences two different temperature regimes during its time evolution.

1. Introduction and results

The AdS/CFT correspondence states that type IIB string theory on $AdS_5 \times S^5$ background is dual to $\mathcal{N} = 4$ $SU(N)$ super Yang–Mills theory living on the boundary of AdS_5 which is a $3 + 1$-dimensional spacetime [1,2]. In the large-N and large 't Hooft coupling limit the above

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correspondence reduces to a relation between a strongly coupled gauge theory and a classical gravity. In the mentioned limits, the main and significant property of the correspondence is its strong/weak nature, indicating that one can acquire information about a strongly coupled gauge theory by using its corresponding classical gravity. This duality can be applied at zero temperature as well as at non-zero temperature. As a matter of fact, (thermal) vacuum state in the gauge theory corresponds to the $AdS_5 \times S^5$ (AdS-Schwarzschild black hole) background where gauge theory temperature is identified with the Hawking temperature of AdS-Schwarzschild black hole [3]. Moreover, using the above correspondence, one can study the strongly coupled gauge theories whether in or out of thermal equilibrium. Altogether, the AdS/CFT correspondence has proven itself as a suitable candidate to study strongly coupled gauge theories.

AdS/CFT correspondence, or more generally gauge/gravity duality, has been extensively used to study the issue of quantum quench in strongly coupled gauge theories [4]. Quantum quench is defined as the process of (rapidly) altering a physical coupling of a quantum system. Since the time dependence of the coupling, both duration and form, is arbitrarily chosen, the system under consideration is driven out of equilibrium and therefor investigating the evolution of the system becomes an interesting issue. When the coupling changes fast, the so-called fast quench, a universal behavior has been reported for the strongly coupled gauge theories with holographic dual [5]. However, for slow quenches, an adiabatic behavior is observed [6].

The original AdS/CFT correspondence contains only fields in the adjoint representation of the $SU(N)$ gauge group. To describe QCD-like theories, one needs to add matter fields (quarks) in the fundamental representation of the $SU(N)$ gauge group. In the gravity side, this can be done by introducing D-branes in the probe limit into the background [7]. By probe limit we mean that the back-reaction of the brane on the background is negligible or, in other words, the background we are dealing with remains unchanged.[1] If one turns on a constant external electric field on the probe D-brane, matter fields will couple to the electric field and therefore an electric current emerges on the probe brane[2] [8]. Generalization of the above idea to a time-dependent electric field, resulting in a time-dependent current on the brane, has been studied in [9]. It is shown that due to energy injection into the system, an apparent horizon forms on the brane at late times, and therefore one can define a time-dependent temperature depending on the location of the apparent horizon.

Electric field quench, i.e. a time-dependent electric field that varies from zero to a constant final non-zero value during a transition time, is considered in [11] at zero temperature and in [12] at non-zero temperature. It is shown that for fast electric field quenches a universal behavior emerges, indicating that the equilibration time does not depend on the final value of the time-dependent electric field. On the other hand, for slow electric field quenches, the system behaves adiabatically.

Various types of electric field quenches are identified by the form of the functions chosen for the time-dependent electric field. These functions are usually infinitely differentiable (C^∞). It would be interesting to study more general functions that don't enjoy this property (i.e. are not C^∞). In this paper we investigate the effects of more general functions on the apparent

[1] When the background is $AdS_5 \times S^5$ (zero temperature), one should worry about the validity of the probe limit in the presence of the external electric field. A simple way to solve this problem is to introduce a small temperature in the background which does not affect the main results.

[2] In fact there are two sources that cause an electric current on the probe brane in the presence of an electric field: free charges and Schwinger pair production. In this paper we do not consider free charges and therefore the pair production is the only contributor to the current. For a more detailed explanation cf. [8–10].