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Thermal quench at finite 't Hooft coupling

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Abstract

Using holography we have studied thermal electric field quench for infinite and finite 't Hooft coupling constant. The set-up we consider here is D7-brane embedded in (α' corrected) AdS-black hole background. It is well-known that due to a time-dependent electric field on the probe brane, a time-dependent current will be produced and it will finally relax to its equilibrium value. We have studied the effect of different parameters of the system on equilibration time. As the most important results, for massless fundamental matter, we have observed a universal behaviour in the rescaled equilibration time in the very fast quench regime for different values of the temperature and α' correction parameter. It seems that in the slow quench regime the system behaves adiabatically. We have also observed that the equilibration time decreases in finite 't Hooft coupling limit.
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1. Introduction

Understanding the properties of a system out-of-equilibrium is a long-standing problem in physics, especially when it comes to strongly coupled systems. Quark–gluon plasma (QGP) produced at RHIC or LHC by colliding two heavy nuclei such as gold or lead, at relativistic speeds,

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is a good example of such systems [1]. Strongly coupled nature of the field theory describing such systems, makes the usual known perturbative techniques incapable of analyzing their properties. Therefore one needs to rely on other techniques such as lattice gauge theory or AdS/CFT correspondence [1,2]. In this paper we will concentrate on the AdS/CFT approach where the time-dependent systems can be dealt with in real time.

AdS/CFT correspondence states that $\mathcal{N} = 4$ Super-Yang–Milles (SYM) theory in four dimensions is dual to string theory on $AdS_5 \times S^5$ background. In the most used version of this duality a strongly coupled field theory (infinite 't Hooft coupling constant (λ) and infinite number of colours (N_c)) is dual to classical gravity. In fact the vacuum state in field theory is dual to pure *AdS* solution in gravity and a thermal state to *AdS*-black brane or black hole. The field theory temperature is identified with the black brane or black hole temperature.

Strongly coupled matter produced in the lab is not infinitely strongly coupled. For instance, in the hot QCD results, the appropriate 't Hooft coupling is in the range 10–40 which is not a huge number [12]. Therefore it is reasonable to use gauge/gravity duality in the limit where the effect of the finite 't Hooft coupling constant is considered. In the dual gravity side this is realized as α' corrections to the classical gravity action, which represent the stringy effects [3]. Thus in order to study the effect of the finite 't Hooft coupling constant in the field theory, one needs to do the analysis based on the background solution obtained from the gravity action in the presence of α' corrections. Such a solution has been given in (14).

An out-of-equilibrium system is usually produced by the injection of energy in a finite time interval. One way to simulate this situation in gauge/gravity duality is to apply a time-dependent electric field which varies from zero to a finite constant amount [4–6]. Such system evolves from the equilibrium state of an initial Hamiltonian to an equilibrium state of the modified Hamiltonian due to the presence of a time-dependent electric field. If the initial state is at non-zero temperature this time-dependent process is usually called thermal quench [7].

Applying a time-dependent external electric field will produce a time-dependent current. It starts from zero and relaxes to the equilibrium value, corresponding to the final amount of the electric field [4]. This current is the result of interaction between the fundamental degrees of freedom and the electric field. In order to introduce the fundamental matter in the AdS/CFT framework, we have to add probe branes to the background dual to the strongly coupled system under study [8].

In this paper we are interested in studying the effect of temperature and finite 't Hooft coupling on the equilibration in a strongly coupled system. In the problem we investigate here, as will be explained in details later on, the temperature of the bulk is kept fixed during the quench. The electric field lives on the probe brane. During the electric field quench, due to apparent horizon formation on the probe brane, one can define an effective temperature which varies during the energy injection [4]. Regarding [7], since initially the induced metric on the probe brane has non-zero temperature, equal to the bulk one, we call this process thermal quench.

The observable that can be examined to see how the system equilibrates, is the behaviour of time-dependent current produced in the system [5]. This time-dependent current will reach its equilibrium value after some time which we call it equilibration time. We will see how this equilibration time modifies with the change in the parameters of the system.

2. Time-dependent external electric field

Here we consider a general class of black hole metrics of the form

$$ds^2 = G_{tt}dt^2 + G_{xx}d\vec{x}^2 + G_{zz}dz^2 + G_{ss}d\Omega_5^2, \qquad (1)$$

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