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Collective excitations of massive flavor branes

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Abstract

We study the intersections of two sets of D-branes of different dimensionalities. This configuration is dual to a supersymmetric gauge theory with flavor hypermultiplets in the fundamental representation of the gauge group which live on the defect of the unflavored theory determined by the directions common to the two types of branes. One set of branes is dual to the color degrees of freedom, while the other set adds flavor to the system. We work in the quenched approximation, *i.e.*, where the flavor branes are considered as probes, and focus specifically on the case in which the quarks are massive. We study the thermodynamics and the speeds of first and zero sound at zero temperature and non-vanishing chemical potential. We show that the system undergoes a quantum phase transition when the chemical potential approaches its minimal value and we obtain the corresponding non-relativistic critical exponents that characterize its critical behavior. In the case of $(2+1)$-dimensional intersections, we further study alternative quantization and the zero sound of the resulting anyonic fluid. We finally extend these results to non-zero temperature and magnetic field and compute the diffusion constant in the hydrodynamic regime. The numerical results we find match the predictions by the Einstein relation.

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1. Introduction

There is hope that the gauge/gravity holographic duality could serve to characterize new types of compressible states of matter, *i.e.*, states with non-zero charge density which vary continuously with the chemical potential. Indeed, holography provides gravitational descriptions of strongly interacting systems without long-lived quasiparticles, situations which cannot be accommodated within the standard Landau's Fermi liquid theory. Although the field theories with known holographic dual are very different from those found so far in Nature, there are good reasons to believe that these studies could reveal generic universal features of strongly interacting quantum systems [1].

In this paper we approach this problem in a top-down model of intersecting branes of different dimensionalities. We will consider a stack of N_c color Dp-branes which intersect N_f flavor Dq-branes ($q \geq p$) along n common directions. This configuration, which we will denote by $(n \,|\, p \perp q)$, is dual to a $(p+1)$-dimensional $SU(N_c)$ gauge theory with N_f fundamental hypermultiplets (quarks) living on a $(n+1)$-dimensional defect [2]. In the context of holography, we will work in the large N_c 't Hooft limit with $N_f \ll N_c$. In this limit the quarks are quenched and the Dq-branes can be treated as probes, whose action is the Dirac–Born–Infeld (DBI) action, in the gravitational background created by the Dp-branes. The embedding of the flavor branes is parameterized by a function which measures the distance between the two types of branes. The field theory dual of this distance is the mass of the hypermultiplet. Moreover, in order to engineer a system with non-zero baryonic charge density, we must switch on a suitable gauge field on the worldvolume of the flavor brane [3]. We will also study the influence of a magnetic field directed along two of the spatial directions of the worldvolume.

In [4] we studied the collective excitations of generic brane intersections corresponding to massless quarks and we uncovered a certain universal structure. The purpose of this article is to extend the results of [4] to the case in which the quarks have a non-zero mass. We will study first the system at zero temperature and non-zero chemical potential. This is the so-called collisionless quantum regime, in which the dynamics is dominated by the zero sound mode. This mode is a collective excitation, first found in the holographic context in [5,6]. These results were generalized to non-zero temperature in [7,8] and to non-vanishing magnetic field in [9,10] (see [11–28] for studies on different aspects of the holographic zero sound). In [4] we developed a general formalism which included all possible intersections $(n \,|\, p \perp q)$ and, in particular, we found an index λ (depending on n, p, and q) which determines the speed of zero sound for massless quarks. This is intimately related with the fact that λ determines the scaling dimension of the charge density or to put it slightly differently, λ acts as the polytropic index in the equation of state for the holographic matter.

In the case of massive quarks the embedding of the Dq-brane is non-trivial and must be determined in order to extract the different physical properties. When the charge density is non-vanishing, the brane reaches the horizon of the geometry, *i.e.*, we have a black hole embedding. This embedding depends on a function which parameterizes the shape of the flavor brane in the background geometry and, in general, must be found by numerical integration of the equations of motion of the probe. However, in the case of intersections $(n \,|\, p \perp q)$ which preserve some amount of supersymmetry at zero temperature T and chemical potential μ some remarkable simplification occurs. Indeed, as shown in [29], in these intersections one can choose a system of coordinates such that the embedding function is a cyclic variable of the DBI Lagrangian when $T = 0$ and $\mu \neq 0$. As a consequence, the embedding function and the physical properties of the configuration, can be found analytically. In particular, one can study the zero temperature ther-