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Drag force in a D-instanton background

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Abstract

We study the drag force and diffusion coefficient with respect to a moving heavy quark in a D-instanton background, which corresponds to the Yang–Mills theory in the deconfining, high-temperature phase. It is shown that the presence of the D-instanton density tends to increase the drag force and decrease the diffusion coefficient, reverse to the effects of the velocity and the temperature. Moreover, the inclusion of the D-instanton density makes the medium less viscous.

Keywords: AdS/CFT; QGP; Drag force; Diffusion coefficient

1. Introduction

Heavy ion collisions at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) are believed to produce a new state of matter so-called strongly-coupled quark gluon plasma (QGP). It was shown that the life-time of QGP is very short (∼5–10 fm/c), hence direct detection of QGP is not possible. Thus, one needs to rely on indirect measurement using suitable probes. Heavy quarks are considered good probes to study the properties of QGP due to their large mass and other unique properties, and there are extensive experimental and theoretical efforts in the field of heavy-flavor probes, for recent reviews on this topic, see e.g. [1–3].

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Anti-de-Sitter space/conformal field theory (AdS/CFT), which maps a d dimensional quantum field theory to its dual gravitational theory, living in $d+1$ dimensional, has yielded many important insights for studying different aspects of QGP [4–6]. In this approach, the drag force on a moving heavy quark in $\mathcal{N}=4$ supersymmetric Yang–Mills (SYM) plasma was first studied in [7,8]. Therein, the energy loss of the quark is understood as the momentum flow along the string into the horizon. Subsequently, there are many attempts to address the drag force in this direction. For instance, the effect of chemical potential on the drag force is discussed in [9,10]. The effect of non-commutativity on the drag force is addressed in [11]. The finite coupling corrections on the drag force are analyzed in [12]. The drag force in three charges non-extremal black hole model is studied in [13]. The drag force in AdS/QCD models is investigated in [14–16]. Other related results can be found, for example, in [17–23].

In fact, there is another check of gauge/gravity duality, the correspondence between non-perturbative objects such as instantons. It was shown [24,25] that the Yang–Mills instantons are identified with the D-instantons of type IIB string theory. The near horizon limit of D-instantons homogeneously distributed over D3-brane at zero temperature has been studied in [26]. The holographic dual of uniformly distributed D-instantons over D3-brane at finite temperature has been analyzed in [27]. It was argued that the features of D3–D(-1) configuration are similar to QCD at finite temperature. For instance, the chiral symmetry breaking exists in the D-instanton background. The dual gauge theory of the background has a confinement property with the linear quark–antiquark potential. Thus, one expects that the results obtained from these theories could provide qualitative insights into analogous questions in QCD. For that reason, many quantities have been studied in the D-instanton background, such as phase transitions [27], light flavor quark [28], jet quenching parameter and heavy quark potential [29].

In this paper, we study the drag force and diffusion coefficient with respect to a moving heavy quark in the D-instanton background. More specifically, we would like to see how the D-instanton density affects the drag force as well as the diffusion coefficient. This is the purpose of the present work.

The organization of this paper is as follows. In the next section, we briefly review the geometry of the D-instanton background at finite temperature. In section 3, we study the effect of the D-instanton density on the drag force. In section 4, we discuss the relaxation time and the diffusion coefficient in this background as well. In the last section, we end up with some discussions.

2. Background geometry

In this section we briefly review the D-instanton background. The geometry is the one which is a finite temperature extension of D3/D-instanton background given in [28]. The background has an axion field and a five-form field strength which couples to the D-instanton and D3, respectively. In Einstein frame the ten dimensional super-gravity action is found to be [30,31]

$$S=\frac{1}{16\pi G_{10}}\int d^{10}x\sqrt{g}(\mathcal{R}-\frac{1}{2}(\partial\Phi)^2+\frac{1}{2}e^{2\Phi}(\partial\chi)^2-\frac{1}{6}F_{(5)}^2), \tag{1}$$

where G_{10} is the 10-dimensional gravitational constant. $\mathcal{R}$ denotes the Ricci scalar. Φ represents the dilaton. χ refers to the axion. $F_{(5)}$ stands for the field strength associated with Abelian gauge connection.