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Energy change of a heavy quark in a viscous quark–gluon plasma with fluctuations

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Abstract

When a heavy quark travels through the quark–gluon plasma, the polarization and fluctuating chromoelectric fields will be produced simultaneously in the plasma. The drag force due to those fields exerting in return on the moving heavy quark will cause energy change to it. Based on the dielectric functions derived from the viscous chromohydrodynamics, we have studied the collisional energy change of a heavy quark traversing the viscous quark–gluon plasma including fluctuations of chromoelectric field. Numerical results indicate that the chromoelectric field fluctuations lead to an energy gain of the moving heavy quark. Shear viscosity suppresses the fluctuation-induced energy gain and the viscous suppression effect for the charm quark is much more remarkable than that for the bottom quark. While, the fluctuation energy gain is much smaller than the polarization energy loss in magnitude and the net energy change for the heavy quark is at loss.

Keywords: Quark–gluon plasma; Collisional energy loss; Shear viscosity; Dielectric function; Chromohydrodynamics

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1. Introduction

Quark–gluon plasma (QGP) is a special state of matter, which is believed to be produced in ground laboratory by colliding nuclei with an energy density above 1 $\mathrm{GeV/fm^3}$. The initial energy density that the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC) can achieve is much higher than that one [1]. There are two striking findings at the RHIC and the LHC. The first one is the strong jet quenching, which is regarded as a potential signal for the QGP formation. The other one is that the produced hot QCD plasma behaves as a nearly perfect fluid with a small viscosity [2–4].

Bjorken has anticipated the jet quenching phenomenon in QCD medium by investigating the collisional energy loss of high energy partons suffered by binary elastic scatterings off thermal quarks and gluons [5]. Then, in light of the plasma physics technique [6–8], Thoma and Gyulassy have developed a semi-classical formalism for collisional energy loss which is caused by the color Lorentz force from the chromoelectric field induced by the moving test parton reacting on itself [9]. In that formalism the energy loss comes from the polarization chromoelectric field and is dominated by the longitudinal and transverse dielectric functions, which is also called polarization energy loss [7,8]. One advantage of that formalism is that infrared divergence is self-regulated due to the plasma collective effect, while it is cut off by introducing a reasonable minimum momentum transfer about Debye mass scale by hand in Bjorken's framework. Later, by combining the Thoma–Gyulassy formalism with parton scattering kinematics, some people have attempted to construct a consistent approach to study collisional energy loss including both plasma collective effect and close collisions of the test parton with the QCD plasma constituents [10–12]. That goal is achieved in a systematic field theory way formulated by Braaten and Thoma [13,14]. Nevertheless, the Thoma–Gyulassy formalism has been applied in Refs. [15,16] to study collisional energy loss of nonasymptotic parton jets, and in Refs. [17,18] to address viscous corrections to the collisional energy loss of parton traversing the viscous QGP (for dissipative effect on energy loss or heavy quark transport coefficients in some different situations, please refer to Refs. [19–22]). In addition, some authors have performed the calculation of the collisional energy loss with the Thoma–Gyulassy formalism associated with hard thermal loop resummation approach to investigate the momentum broadening in an anisotropic plasma [23]. Recently, parton energy loss in an anisotropic QGP [24] and in a two stream plasma [25,26] has been addressed within a similar semi-classical framework—the linearized Wong's equations associated with the Yang–Mills equation.

The electromagnetic fluctuations in a plasma can reflect important information on the plasma properties. They can be described by means of the correlation functions which are usually determined by dielectric permittivity tensor in a homogeneous plasma in equilibrium [7,8]. When a fast test charge is introduced into the plasma, besides the polarization electric field, the fluctuating electric field will be produced in the plasma at the same time. Similar to the case of the polarization electric field, the fluctuating electric field exerting on the fast test charge will cause energy loss to it. It is argued that in some situation fluctuation energy loss may be comparable with the polarization one [7,8].

The propagation of massive colored particles in color medium in the external stochastic chromoelectric field has been investigated some time ago, it is shown that the massive particles can either lose or gain energy depending on the model adopted for the description of medium [27]. In the case of perturbative QCD plasma, one of us Jia-rong Li and his previous collaborator have investigated nonlinear response of the QGP to the fast partons and color dipole with weak turbulent theory. They have found that fluctuation or turbulence will lead to an acceleration of the