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Nuclear Physics A 979 (2018) 265–275
NUCLEAR PHYSICS A
www.elsevier.com/locate/nuclphysa

The fluctuation energy exchange of a heavy quark in a collisional quark–gluon plasma

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Received 9 February 2018; received in revised form 20 September 2018; accepted 20 September 2018
Available online 25 September 2018

Abstract

The polarization and fluctuation chromoelectromagnetic fields will be produced at the same time when a heavy quark travels through the quark–gluon plasma (QGP). These fields exerting in return on the heavy quark will cause energy loss to it. Collisions are one of the main sources of dissipation and are responsible for driving a system to approach equilibrium. We address the collision effects on the fluctuation energy exchange of the heavy quark in the medium. For this purpose, we apply the dielectric functions derived from the kinetic theory associated with the BGK collisional kernel which determine the fluctuation energy exchange. In that approach, the collision rate depicting the collision effects is embedded in the dielectric functions. Numerical results show that compared to the collisionless case, the collision rate remarkably augments the fluctuation energy gain.

Keywords: Quark–gluon plasma; Fluctuation energy loss; Collision rate; Dielectric function; BGK collisional kernel

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https://doi.org/10.1016/j.nuclphysa.2018.09.048
0375-9474/

1. Introduction

Quark–gluon plasma (QGP) is a special state of matter which is believed to be formed in ultrarelativistic heavy ion collisions in ground laboratory. One striking finding at the Relativistic Heavy-Ion Collider (RHIC) and Large Hadron Collider (LHC) is that the produced quark gluon matter behaves like a nearly perfect fluid with a small viscosity [1,2]. Jet quenching, phenomenon of energy loss suffered by the high energy partons created in initial hard scatterings traversing the formed hot medium, is regarded as one of the convictive signals for the QGP formation [3–8]. In recent years, the jet quenching and the related phenomena in a non-equilibrium and/or dissipative QGP system have attracted a gradual interest in heavy ion community [9–31].

QGP is a system composed of microscopic particles of quarks and gluons characterized of statistical fluctuations. When a fast quark travels through the QGP, the polarization and fluctuation chromoelectromagnetic fields will be induced at the same time in the medium. Those fields exerting in return on the fast quark will cause polarization and fluctuation energy loss to it respectively. In some situations, the fluctuation energy loss may be comparable with the polarization one [32]. Recently, the fluctuation energy exchange in a QCD plasma has aroused people's attention in the context of the ultrarelativistic heavy ion collisions [29,33–39].

In the previous investigations [29,33–39], the impact of dissipative effects on the fluctuation energy loss has been taken into account only in Ref. [29]. Collisions are one of the main sources of dissipation and are responsible for driving a system to approach equilibrium. In the present letter, we will study the collision effects on the fluctuation energy exchange of a fast heavy quark traveling through the QGP medium within the framework of the transport approach associated with a Bhatnagar–Gross–Krook (BGK) collisional kernel.

The BGK collisional kernel has been applied in the kinetic theory to study the plasma properties in an electromagnetic plasma for a long time [40]. Some people have extended the study of the transport theory with the BGK collisional terms to the QGP system recently [41,42]. In that description, one can derive analytic expressions for the dielectric functions, through which diverse properties of the QGP, for example, dispersion relation [41] or plasma collective modes [42,43], polarization energy loss [21] and wakes induced by the fast parton traversing the QGP [30,31], and electromagnetic response of the medium [44], have been studied recently. It should be noted that the fluctuation energy loss is determined by the dielectric functions of medium [32,35,29]. In the BGK description in the transport theory, the collision rate ν describing the collision effects is encoded in the dielectric functions, as shown later in Eqs. (20) and (21). As a result, it allows people to study the collision effects on the fluctuation energy loss.

The paper is organized as follows. In Section 2, we will give a brief derivation of the collisional energy loss suffered by the heavy quark traveling through the QGP including fluctuations of the chromoelectromagnetic field. Then, we will briefly review the derivation of the longitudinal and transverse dielectric functions with the kinetic theory with the BGK collisional kernel in the next section. In Section 4, we will evaluate the fluctuation energy loss and study the collision effects on it. Section 5 is summary.

The natural units $k_B = \hbar = c = 1$, the metric $g_{\mu\nu} = (+, -, -, -)$ and the notations $K = (\omega, \mathbf{k})$, $k = |\mathbf{k}|$ are used in the paper.

2. The fluctuation energy loss in the quark–gluon plasma

The motion equations of a parton in the chromodynamic field in the QCD plasma can be described by the covariant Wong equations [14,33,36]