Medium modified heavy quark potential in anisotropic QGP

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Introduction

Statistical QCD predicts that strongly interacting matter undergoes a deconfining transition to a new state, the quark-gluon plasma, in which the colored quarks and gluons are no longer bound to colorless hadrons. With the help of the modern generation particle accelerators, both at BNL RHIC and CERN LHC, it seems possible to create this state of matter in experiments. RHIC experiments have strongly suggested the existence of this new phase of matter showing a strong elliptic flow, from which a very low viscosity to entropy density ratio has been inferred. This suggests that QGP may be a strongly interacting system of quarks and gluons which is also confirmed by the lattice studies of equation of state(EOS). The main probes considered so far are real or virtual photons, the p_T distribution of secondary hadrons, heavy flavor mesons ($Q\overline{q} = \overline{Q}q$ states), quarkonia ($Q\overline{Q}$ pairs), and jets (energetic partons) and the relative production rate of strange particles. One of the most important features of QGP formation is the color screening of the static chromo-electric field [1].
Many properties of QGP are still poorly understood. The most debated question is that whether or not the system will thermalize fast enough to allow a thermodynamic description of the system during the central part of its evolution in relativistic heavy ion collision. However, recent hydrodynamical studies [2] have shown that due to the poor knowledge of the initial conditions there is a sizable amount of uncertainty in the estimate of thermalization or isotropization time. It is suggested that (momentum) anisotropy driven plasma instabilities may speed up the process of isotropization [3] in that case one is allowed to use hydrodynamics. The hot and dense matter created after the collision is rather small in transverse extent and expands very rapidly in the longitudinal direction. As a consequence, large momentum-space anisotropies are developed at early-times. The subsequent rapid longitudinal expansion of the matter (along the beam line) causes it to much colder in the longitudinal direction than in the transverse direction. Longitudinal cooling occurs because initially, the longitudinal expansion rate is larger than the parton interaction rate and as a result, a local momentum space anisotropy is included with $\langle p_L^2 \rangle \ll \langle p_T^2 \rangle$ in the local rest frame. Thus it would be interesting to study the effects due to the presence of an anisotropy. Such effects will change the properties of the QGP system and make differences when comparing with the usually studied isotropic QGP.

Quarkonia at finite temperature are an important tool for the study of the status of matter formed in heavy ion collision. Many efforts have been devoted to determine the dissociation temperature of $Q\overline{Q}$ states in the deconfined medium, using either lattice calculation of quarkonium spectral functions [4] or non relativistic calculation based on some effective (screened) potentials. The calculation of the heavy quark potential has since been extended to the case of a plasma with finite momentum-space anisotropy. Properties of heavy quarkonia at finite temperature can play an important role to study the in-medium modification of inter-quark forces

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and help to understand the phenomenon of non-Abelian Debye screening in quark-gluon plasma. There are different potential models. However, all of these models are restricted to a plasma in which the parton distributions are isotropic in momentum space. For such a system, the screening effect is described by the Debye mass which has a form of $m_D = g^2T^2(N_f + 2N_c)/6$ in leading perturbative calculation.

For some deviation from the ideal isotropic distribution, the effective screening mass gets modified and thus the properties of quarkonium states will also change due to the anisotropic momentum distribution. To study the perturbative potential with an anisotropic parton distribution, we can calculate the self energy in anisotropic medium. For example, using the Hard Thermal Loop (HTL) approximation, it is possible to derive the gluon propagator in an anisotropic system. In Ref. [5], Agotiya et al. have derived a medium-modified heavy quark potential by correcting the full Cornell potential not its Coulomb part alone with a dielectric function encoding the effects of the deconfined medium. The medium modification enters in the the Fourier transform of heavy quark potential as

$$\tilde{V}(k) = \frac{V(k)}{\epsilon(k)} \quad , \tag{1}$$

where $\epsilon(k)$ is the dielectric permittivity. By inverse Fourier transform one obtains the r-dependence of the medium modified potential as

$$\begin{aligned} V(r) &= \left(\frac{2\sigma}{m_D^2} - \alpha\right)\frac{exp(-m_D r)}{r} - \frac{2\sigma}{m_D^2 r} \\ &+ \frac{2\sigma}{m_D} - \alpha m_D \end{aligned} \tag{2}$$

All of these works, however, have been performed with the assumption of an isotropic thermal medium. To study the effect of anisotropy on the above-mentioned in-medium modified potential we have to find the self energy in anisotropic medium which, in turn, gives the dilectric permittivity. With the specified anisotropic distribution function, we have computed the gluon self-energy analytically and thus finally obtained the medium modified potential in anisotropic QGP. Thereafter we have solved Schrödinger equation with the above medium modified potential and calculated the binding energies. Using the dissociation criteria [5], dissociation temperatures of the ground and the first excited states of charmonium and bottomonium spectra have been estimated.

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