Anisotropic Quark Gluon Plasma: Dissociation of Quarkonium States

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Introduction

From the last few decades the relativistic heavy ion collision experimental program have made enormous efforts to create QGP and study its properties. In this new phase of matter partons (quarks and gluons) are deconfined. Heavy quarkonia are important probes of the QGP since they are produced in the early stage of the relativistic heavy-ion collision and their survival is affected by the surrounding medium. Recently the concept of momentum anisotropy created at the early stage of collisions is resurrected due to the asymptotic free expansion in the longitudinal (beam) direction, thus it becomes worthwhile to study the effect of momentum anisotropy on the properties of quarkonium states, which is the central theme of our work. The brief outline of the thesis is as follows:
we have studied the properties of quarkonium states in a hot QGP medium, which exhibits a local anisotropy in momentum space by using the kinetic theory approach. To encode the momentum anisotropy in the medium, we first obtain gluon-self energy tensor using the linear response theory and derive the potential by correcting both the Coulombic and linear terms in the Cornell potential, *not the Coulomb term alone as usually done in the literature*, by the static limit of hard-loop resumed gluon propagator. The potential obtained is found to be screened less than in isotropic medium, as a result quarkonium states become more tightly bound. In addition, the anisotropy in the momentum space introduces a characteristic angular dependence in the potential and thus the potential in anisotropic medium becomes nonspherical in contrast to the spherically symmetric potential in isotropic medium. Therefore one cannot simply obtain the energy eigenvalues by solving the radial part of the Schrodinger equation alone. In the weak-anisotropy limit, the anisotropic correction is small and thus can be treated as a perturbation. So, using the first-order perturbation theory, we estimate the shift in energy eigen values due to the small anisotropic correction to the energy eigen values from the spherically-symmetric part in isotropic medium and determine their dissociation temperatures [1] .

Besides the binding energy as the dissociation criteria decay width obtained from the imaginary part of the potential is another criteria to calculate the dissociation temperature. Therefore, we explored the dissociation of quarkonia by a complex potential which is obtained by correcting both the perturbative and non-perturbative terms of the $Q\bar{Q}$ potential at $T = 0$ through the dielectric function in real-time formalism. The presence of the confining non-perturbative term even above the transition temperature makes the real-part of the potential more stronger and hence the quarkonia become more bound. The presence of the confining non-perturbative term makes the real-part of the potential more stronger and hence the quarkonia become more bound. The confining term also enhances the magnitude of imaginary-part, which in turn increases the thermal width more *compared to the medium-contribution of the perturbative term alone*. These cumulative observations result an increase in the dissociation temperatures of quarkonia. Finally we extend our calculation to a medium, exhibiting local momentum anisotropy by calculating the leading anisotropic corrections to the propagators in Keldysh representation, like the kinetic theory

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approach. The presence of anisotropy makes the real-part of the potential stronger but the imaginary-part is weakened slightly, overall the anisotropy makes the dissociation temperatures higher, compared to isotropic medium [2] .

Nowadays the medium produced at RHIC and LHC experiments is understood as a strongly-coupled liquid, unlike a weakly-interacting gas. Moreover an interest has been renewed to study the potential either for a static $Q\bar{Q}$ pair in a moving medium or for a moving $Q\bar{Q}$ pair in a static medium. However the limitations of the weak-coupling regime and the additional scales associated with the motion of the pair complicate the calculations in effective field theories. Thus we resort for the holographic correspondence to calculate the potential for a moving $Q\bar{Q}$ pair in a strongly-coupled medium, we work on a metric in the gravity side, *viz.* OKS-BH geometry with an UV cap, whose dual in the gauge theory side runs with the energy and hence proves to be a better background for thermal QCD and obtain the potential by extremizing the action, known as Nambu-Goto action. The obtained potential has confining terms both in vacuum and in medium, in addition to the Coulomb term usually reported in the literature. We found that as the velocity of the pair is increased the screening of the potential becomes weaker. The crucial observation of our work is that beyond a critical separation of the heavy quark pair, the potential develops an imaginary part which is the main source of dissociation. With the imaginary part of the potential, we have estimated the thermal width for the ground and first excited states and found that non-zero rapidities lead to an increase of thermal width, which therefore implies that the moving quarkonia are dissociated more efficiently than the static ones. [3].

Since the study of transport coefficients of strongly interacting matter got impetus after the discovery of perfect fluid created at ultra-relativistic heavy ion collision experiments so we deal with one of the transport coefficients, *namely electrical conductivity* as an additional probe of the anisotropy of the medium, apart from the properties of quarkonia. Electrical conductivity of QCD medium has recently become important due to the strong electric field created in the collision zone of RHIC experiments. The large electric field affects the behavior of the medium and its effect depends on the magnitude of electrical conductivity. Electrical conductivity is responsible for the production of electric current generated by the quarks in the early stage of the collision. The momentum anisotropy is also produced in the early stage of the collision and lasts for at least $\tau \leq 2fm/c$. Therefore, it is worthwhile to incorporate the effect of momentum-space anisotropies in the calculation of the electrical conductivity. Relativistic Boltzmann's kinetic equation has been solved in the relaxation-time approximation to obtain the electrical conductivity, where the medium properties is incorporated by the quasiparticle description. We have compared our model results with the corresponding results obtained in different lattice as well as other model calculations. Furthermore, we extend our model to calculate the electrical conductivity at finite chemical potential [4].

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