A study on some aspects of hot and dense anisotropic QCD matter

Ritesh Ghosh[1]*
[1] *Theory Division, Saha Institute of Nuclear Physics,*
A CI of Homi Bhabha National Institute,
1/AF, Bidhannagar, Kolkata 700064, India

Under extreme conditions such as high temperatures and densities, composite state of hadrons e.g. protons, neutrons, kaons, pions etc lose their identity and turn into a new state of their constituent elements quarks and gluons. This novel phase is called quark-gluon plasma (QGP) [1]. Such kind of state is presumed to be created after a few fraction of microseconds of the big bang having temperature higher than 10^{12} K and small net baryon number. It can also exist in the core of the neutron stars where the mass densities (10^{15} gm/cm^3) are much higher than the normal matter density. Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) and the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) are designed to explore the properties of QGP state. The produced high temperature QGP phase at very low baryon densities mimics the early universe. Fixed target experiments are underway in FAIR (Facility for Antiproton and Ion Research) at GSI, Germany and NICA (Nuclotron-based Ion Collider Facility) at Joint Institute for Nuclear Research (JINR), Dubna to investigate the QCD phase diagram at high baryon density and low temperature. After the nuclear impact the system is in non-equilibrium and gradually expands and cools down. The local equilibriated QGP is formed and the dynamics of the system can be described by the hydrodynamics. The phase transition to the hadronic phase occurs and finally after the freeze-out the particles come out to the detector.

Main objective of this study is to explore the characteristics of various anisotropic systems created in several stages of heavy ion collisions. Broadly, we have studied two scenarios: One is the momentum space anisotropy created due to the rapid longitudinal expansion after the nuclear impact as the system expands along the collisional direction making the system much cooler in the longitudinal direction than the transverse direction. The other one is the anisotropy due to the background magnetic field. The former is studied by modeling of the non-equilibrium distribution function from the equilibrium case by suitable squeezing or stretching. The non-equilibrium plasma properties is described by studying the collective modes [2] of the quasi-partons in the framework of hard thermal loop perturbation theory. Due to the presence of non-equilibrium momentum distributions in QGP medium, existence of kinetic instabilities is expected. In this study covariant structure of gluon propagator has been formulated in presence of two anisotropy directions. The general structure is obtained in terms of six basis tensors. The collective modes can be calculated from the pole of the effective propagator. The collective modes and instability are discussed for ellipsoidal momentum anisotropy case.

The covariant structure of gluon propagator mentioned earlier can be used not only for the anisotropy arising from modeling of the non-equilibrium distribution function but also for the presence of the external magnetic field creating anisotropy in the medium. In recent time, more research interests are growing in non-central heavy ion collisions where the magnetic field is produced in the direction perpendicular to the reaction plane and the system becomes anisotropic [3]. To study the

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[*] Electronic address: `riteshghosh1994@gmail.com`

magnetized QGP and hadronic matter is another direction of study which is explored in this work. Along with the temperature (T), the presence of the magnetic field (B) introduces extra scale in the system. Theoretically, one can work in different regimes of magnetic field strength. Initially after the collision, very strong magnetic field is created. In the calculation one can use lowest Landau level (LLL) approximation as the magnetic field pushes the higher Landau levels to infinity compared to th LLL. The magnetic field decays rapidly with time depending upon the conductivity of the medium and one can work using weak field expansion. In weak field limit, we have calculated chiral susceptibility and photon damping rate in hot magnetized QCD/QED medium. Chiral susceptibility [4] estimates the response of the chiral condensate with the variation of current quark mass and this quantity is important in study of chiral phase transition. The damping rate of the hard photon is associated with the mean free path of photon and hard photon production rate in QGP. So the study of those quantities is important in presence of magnetic field. In these studies Schwinger propagator and effective hard thermal loop (HTL) fermion propagator in weak field limit have been used. Here we worked in the scale hierarchy $\sqrt{|q_fB|} < gT < T$, where q_f is the charge of the quark with flavor f. In strong magnetic field, we have studied shear viscosity of hadronic matter using linear sigma model (LSM). The viscous coefficient is calculated in relaxation time approximation (RTA) where the point-like interaction rates of hadrons are evaluated through the S-matrix approach in the LLL approximation to obtain the temperature and magnetic field dependent relaxation time. In this case we use scale hierarchy $\sqrt{|q_fB|} > T$. We didn't confine ourselves only in the limiting cases i.e. strong and weak field limits, we have calculated heavy quark antiquark potential in the regime of arbitrary magnetic field strength i.e. considering all the Landau levels [5]. Heavy quarkonia i.e. bound state of quark antiquark pair is an important signature of QGP and we have calculated the imaginary part of the heavy quark potential and the dissociation of heavy quarkonia in presence of arbitrary magnetic field. Here we have used the general structure of the gauge-boson propagator in a hot magnetized medium. We get the anisotropic structure of the complex heavy quark potential, which explicitly depends on the longitudinal and transverse distance.

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