Influence of hadronic interactions and magnetic field on the bulk properties of matter produced in heavy-ion collision

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Introduction

Quantum Chromodynamics (QCD) is the fundamental theory of strong interactions. QCD predicts that at high temperature and density, strongly interacting matter undergoes a phase transition from a state of hadronic constituents to a deconfined state of quarks and gluons called the quark-gluon plasma (QGP). By colliding heavy-ions at ultra-relativistic energies, one expects to create matter under conditions that are sufficient for deconfinement to happen. It has been known that QGP behaves like a nearly perfect fluid with a small value of the shear viscosity η_s to the entropy density s ratio η_s/s. However, theoretically, the value of η_s/s ratio is temperature-dependent. Hence, a systematic study of transport coefficients throughout the evolution, i.e., starting from the QGP stage and ending at the hadronic stage is important to assess the effect of transport properties on the bulk evolution of matter.

The ideal hadron resonance gas (HRG) model is successful in reproducing the zero μ_B LQCD data of bulk properties of the hadronic matter like pressure, energy density etc. at temperatures below $T_c \sim 156.5$ MeV. The partition function of a hadronic gas can be decomposed into a free and interacting part. Considering that only the resonances contribute to the interacting part, it can be shown that the net effect of the interacting part is equivalent to considering all these hadronic resonances as free particles in a narrow resonance width approximation. This is the basic premise of ideal HRG. However, when the temperature is close to T_c , ideal HRG model does not agree with the lattice QCD data for observables like second-order charge susceptibility (χ_Q^2), the difference between the second and the fourth-order baryon susceptibility ($\chi_B^2 - \chi_B^4$) and the baryon-strange correlator (C_{BS}) etc. These observables are sensitive probes of the deconfinement and provide information about the thermal condition of QCD. Interaction among the constituent hadrons is expected to affect these observables. We have implemented interactions among hadrons in the HRG model using the S-matrix framework. The results of the calculation will be discussed later.

An alternative mechanism that may be responsible for a small viscosity of QCD matter is when the interacting plasma is subjected to an external electromagnetic field. Ultra-intense transient electromagnetic fields are generated in the initial stages of high energy heavy-ion collisions. The transport coefficients which are isotropic in the absence of external fields become anisotropic in the presence of a magnetic field. The second part of this dissertation deals with the calculation of these anisotropic transport coefficients and the observable effect of these coefficients.

Results and discussion

Here, we are highlighting the important results which will give a glimpse of the works done in the thesis. The detailed results will be shown in the conference.

1. Using the S-matrix formalism we have incorporated interactions among hadrons in the HRG model. The main highlights of the formalism being, the preservation of unitarity of the scattering matrix, inclusion of both attractive and repulsive interactions and most importantly good agreement between results from S-matrix formalism and the

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lattice QCD data for higher-order susceptibilities along with the speed of sound and the interaction measure etc. even beyond T_c for many observables. This should be seen in the light of ideal HRG which fails to describe these observables or other models which although incorporate interactions using additional parameters, nevertheless, the assumptions involved in such models are always debatable [1, 2].

2. We also used the above formalism in calculating transport quantities for the hadronic phase. In such a framework, the hadron gas would contain multiple component mixtures of stable hadrons which are interacting within themselves by resonance formation. Our results of bulk viscosity η_v over entropy density s, η_v/s is an increasing function of T for $T < 150$ MeV and decreasing for $T > 150$ MeV. Similarly, we found that η_s/s decreases with temperature consistent with previous results in the literature, but the value of η_s/s is lower than previous results for all values of temperature. Our findings on transport coefficients in the temperature range of $T = 80 - 110$ MeV are in fair agreement with that from the transport models [3].

3. Part of this thesis work was devoted to seeing the effects of the magnetic field produced in the initial stages of heavy-ion collisions on the hadronic phase notably, on the transport coefficients. Although the initial magnetic field will decay within a few fm and becomes 3-4 order smaller than the initial value, however since the QGP and hadronic phase has finite conductivity, which would delay the decay of these transient fields and it might have a sizeable magnitude till the hadronic phase. We found thirteen transport coefficients at one-derivative order or the so-called Navier Stokes limit. The main finding being, in the presence of magnetic field, the values of transport coefficients are smaller than in the absence of the field. This could be an alternative mechanism that may be responsible for a small viscosity of QCD matter when subjected to an external electromagnetic field [4].

4. Finally, we also tried to see the implications of hadronic interactions and the influence of magnetic field on experimental observables, e.g., invariant transverse momentum spectra and v_2 as a function of p_T. We found from transverse momentum spectra that the effective contribution from the temperature-dependent η_s/s, lies between $\eta_s/s = 1/(4\pi)$ and $\eta_s/s = 2/(4\pi)$. However, the suppression of v_2 for $p_T > 1$ GeV using the temperature-dependent η_s/s is even larger than using $\eta_s/s = 2/(4\pi)$. Similarly, one notices sizable correction to the invariant spectra and v_2 when the magnetic field is present than without it [5].

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