Shear viscosity and Reynolds number of a magnetized thermal QCD medium within BGK collision integral

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Introduction

In the extreme conditions of temperature and/or density, hadrons get melted into a novel phase of matter known as Quark gluon plasma (QGP). A strong magnetic field (of the order of m_π^2-$15m_\pi^2$) is also produced in the non-central collisions at RHIC and LHC. To study the hydrodynamical evolution of the hot QGP/QCD medium, we need a good understanding of the transport coefficients, which act as input parameters. In this work, we have calculated the shear viscosity of the strongly magnetized hot QCD medium in the kinetic theory approach where the collisional aspects in the relativistic Boltzmann transport equation (RBTE) have been incorporated using the BGK collision term which ensures the conservation of particle number and charge instantaneously unlike the commonly used relaxation time approximation (RTA). We have further evaluated the Reynolds number, which gives an idea about the nature of the flow pattern of the fluid. We have exploited a quasi-particle model to incorporate the interactions among the partons. The medium generated masses of the quarks and gluons have been obtained from the poles of the resummed propagators which have been calculated using the perturbative thermal QCD with a strong magnetic field in the background.

The time evolution of the plasma system in strong magnetic field is governed by RBTE which reads as

$$p^\mu \partial_\mu f_i^B = C[f] \tag{1}$$

where $f_i^B = f_{\text{eq},i}^B + \delta f_i^B$. i stands for various quark flavors and gluon. $C[f]$ is the collision integral, which is given in the BGK prescription as

$$C[f] = -\frac{p^\mu u_\mu}{\tau_i^B}\left(f_i^B - n_i^B {n_{\text{eq},i}^B}^{-1} f_{\text{eq},i}^B\right), \tag{2}$$

where τ_i^B and $n_{\text{eq},i}^B$ refer to the relaxation time and the equilibrium number density, respectively. BGK collision term approaches to RTA when $n_i^B/{n^B}_{\text{eq},i}$ becomes unity. It shows an improvement over the RTA in the sense that it conserve the particle number and charge instantaneously *i.e.*

$$\int \frac{d^3p}{(2\pi)^3} C[f] = 0. \tag{3}$$

Shear viscosity with BGK collision integral

The shear viscosity of the strongly magnetized hot QCD medium with the BGK collision term can be decomposed as [1]

$$\eta_B = \eta_B^{\text{RTA}} + \eta_B^{\text{corr}} \tag{4}$$

where

$$\begin{aligned}\eta_B^{\text{RTA}} &= \frac{\beta}{4\pi^2}\sum_i g_i|q_iB|\int dp_3\ \frac{p_3^4}{\omega_i^2}\tau_i^B {f^B}_{\text{eq},i}(1-f_{\text{eq},i}^B)\\ &+\frac{\beta}{15}g_g\tau_g\int\frac{d^3p}{(2\pi)^3}\frac{p^4}{\omega_g^2}\ f_{\text{eq},g}(1+f_{\text{eq},g}) \end{aligned}\tag{5}$$

$$\begin{aligned}\eta_B^{\text{corr}} &= \frac{\beta}{4\pi^2}\sum_i g_i^2|q_iB|{n^B}_{\text{eq},i}^{-1}\int dp_3\ \frac{p_3^2}{\omega_i(p_3)}{f^B}_{\text{eq},i}(p_3)\\ &\times\int_{p_3'}\frac{{p_3'}^2}{\omega_i(p_3')}\tau_i^B(p_3'){f^B}_{\text{eq},i}(p_3')(1-{f^B}_{\text{eq},i}(p_3'))\\ &+\frac{\beta}{15}g_g^2\ n_{\text{eq},g}^{-1}\ \tau_g\int\frac{d^3p}{(2\pi)^3}\frac{p^2}{\omega_g(p)}\ f_{\text{eq},g}(p)\\ &\times\int_{p'}\frac{p'^2}{\omega_g(p')}f_{\text{eq},g}(p')(1+f_{\text{eq},g}(p')), \end{aligned}\tag{6}$$

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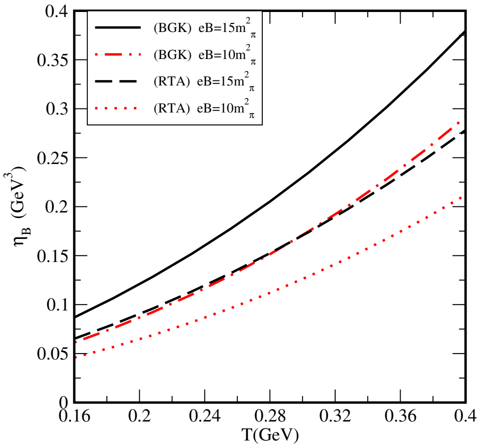

FIG. 1: Variation of shear viscosity with temperature

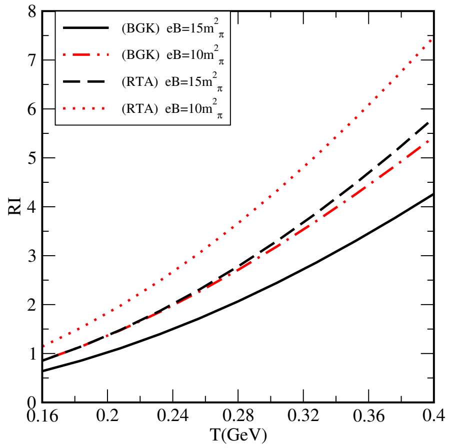

FIG. 2: Variation of Reynolds number with temperature

Figure 1 depicts the variation of shear viscosity (η_B) as a function of temperature in BGK as well as RTA collision terms for two strengths of the magnetic field *i.e.* $eB = 10m_\pi^2$ and $eB = 15m_\pi^2$. In this study, we have used the quasi-particle mass of i^{th} flavour as [2]: $m_i^2 = m_{i0}^2 + \sqrt{2}m_{i0}m_{iT,B} + m_{iT,B}^2$, where m_{i0} and $m_{iT,B}$ correspond to the current quark mass and medium generated mass, respectively. The temperature and magnetic field dependent mass ($m_{iT,B}$) has been calculated as $m_{iT,B}^2 = \frac{g^2|q_iB|}{3\pi^2}\left[\frac{\pi T}{2m_{i0}} - \ln(2)\right]$. We notice that η_B increases with temperature in both the collision integrals but its magnitude gets enhanced in BGK in comparison to RTA. It also increases with the strength of the magnetic field. We have shown the Reynolds number (RI $= Lv/(\eta/\rho)$, where L and v correspond to the characteristic length and the relative velocity, respectively. ρ refers to the mass density, which has been calculated using the phase space distribution functions of the partons). Reynolds number increases with the temperature (see Fig. 2). BGK collision integral reduces the value of the Reynolds number. It is found to be around $1-8$ in the temperature range $160-400$ MeV for $eB = 10m_\pi^2$ and $eB = 15m_\pi^2$. Reynolds number also gets reduced as we increase the strength of B.

References

[1] S. A. Khan and B. K. Patra, arXiv:2205.00317 [hep-ph].
[2] V. M. Bannur, J. High Energy Phys. 09 (2007) 046.