Bulk Viscosity for Quark-Gluon Plasma using Dual QCD Thermal Bag

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Introduction

The equation of state (EOS) from lattice QCD calculation shows a rapid change for the temperature range $T \simeq 170 - 220$ MeV [1] and is responsible for the smoothness of the transition from quark to hadrons. However, in addition to the EOS, the transport coefficients [2] must need to be addressed which govern the transport of energy and momentum and are thus clearly of high value. The present paper mainly deals with the investigation of the bulk viscosity for QGP phase within the framework of dual QCD thermal bag.

Dual QCD Thermal Bag

The mathematical foundation for the dual QCD formulation [3–6] evolves from the fact that the non-abelian gauge symmetry always allows an internal symmetry called magnetic symmetry and the associated gauge covariant magnetic symmetry condition may be expressed in the following form,

$$D_\mu \hat{m} \equiv 0, \ \ i.e \ \ (\partial_\mu + g\mathbf{W}_\mu \times)\hat{m} = 0, \qquad (1)$$

where $\hat{m}$ is the magnetic killing vector which forms an adjoint representation of the gauge group G and $\mathbf{W}_\mu$ is the gauge potential of the gauge group G. The gauge potential and the associated field strength under the following gauge transformation $U = exp(-\alpha t_2 - \beta t_3)$ is expressed in the following form,

$$\mathbf{W}_\mu \xrightarrow{U} (A_\mu + B_\mu)\hat{\xi}_3, \ \ \mathbf{G}_{\mu\nu} \xrightarrow{U} (F_{\mu\nu} + B^{(d)}_{\mu\nu})\hat{\xi}_3 \, . \qquad (2)$$

Using the dual magnetic potential $B^{(d)}_\mu$ for the magnetic part, we obtain the dual QCD Lagrangian in the following form,

$$\pounds = -\frac{1}{4}B^2_{\mu\nu} + \left| \left[\partial_\mu + i\frac{4\pi}{g}(A^{(d)}_\mu + B_\mu) \right] \phi \right|^2 - V, \qquad (3)$$

where V is the effective potential responsible for the dynamical breaking of magnetic symmetry and forces the magnetic condensation of the QCD vacuum which leads to a definite flux tube structure to the dual QCD vacuum. As a result of the magnetic condensation of QCD vacuum the estimate for the masses of vector and scalar glueballs as a function of α_s are shown in table 1 [3]. Further extending the low energy effective theory of QCD to the thermal domain in order to investigate the structure of the QCD phase diagram let us start using the grand canonical ensemble formalism in which the volume (V), the temperature (T), and the chemical potential (μ) are fixed variables and the corresponding partition function is given in the following form,

TABLE I: The masses of vector and scalar glueballs as a functions of α_s using Quadratic potential.

α_s	$\phi_0(GeV)$	$m_B(GeV)$	$m_\phi(GeV)$	$\kappa^{(d)}_{QCD}$
0.12	0.143	2.11	4.20	1.8
0.22	0.149	1.51	2.22	1.4
0.47	0.167	1.21	1.22	1
0.96	0.181	0.929	0.655	.7

$$Z = Tr\left[\exp\left(-\frac{1}{T}(\hat{H} - \mu\hat{N})\right)\right]. \qquad (4)$$

The grand canonical partition function for the QGP phase consisting of a perturbatively interacting gas of quarks and gluons can be written in the following form, $lnZ_{QGP} = lnZ^0_{QGP} + lnZ^{Vac}_{QGP}$, where the term lnZ^0_{QGP}

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is the zeroth order contribution and lnZ_{QGP}^{Vac} represents the non-perturbative vacuum contribution in the form of a T-dependent bag constant $B(T)$ and is given by,

$$B^{1/4}(T) = (\frac{12}{\pi^2})^{1/4} \frac{m_B^{(T)}}{8}, \quad (5)$$

where $m_B^{(T)}$ is the temperature dependent vector glueball mass derived using path-integral formalism [7].

Bulk Viscosity for QGP Phase

In order to understand the nature of strongly interacting form of QGP, a strong correlation between bulk viscosity and thermodynamical quantities has been provided as per Kubos formalism [8], related to the correlation functions of the trace of the energy momentum tensor T_μ^ν as,

$$\zeta = \lim_{\omega \to 0} \frac{1}{9\omega} \int_0^\infty dt \int dr^3 < [T_\mu^\nu(x), T_\mu^\nu(0)] > e^{i\omega t} \quad (6)$$

For a narrow frequency region, $\omega \to \omega_0 \equiv \omega_0(T) \sim T$, the bulk viscosity reads as,

$$\zeta = \frac{1}{9T}\left[T^5 \frac{\partial}{\partial T}\left(\frac{\epsilon_p - 3P_p}{T^4}\right) + 16|\epsilon_v|\right], \quad (7)$$

where ϵ_v is the vacuum energy density for QGP phase of the hadronic matter. The thermal response of specific bulk viscosity (ζ/s) has been depicted in figure 1 for coupling $\alpha_s = 0.12, 0.22, 0.47$ and 0.96 in infrared sector of QCD. It has been observed that the ζ/s takes a sufficiently high value in the region close to T_c which can be attributed to an increase of $\epsilon_p - 3P_p/T^4$ near T_c and as the temperature increases, the value of ζ/s decreases and attains a value nearly zero, which is its conformal value. Above T_c, ζ/s, rises with the temperature due to emergent chromomagnetic monopoles and in this scenario, magnetically charged particles are important component possibly contributing to the physical properties of the strongly interacting QGP [9]. The numerical value of ζ/s at T_c has been calculated and found to be around 2

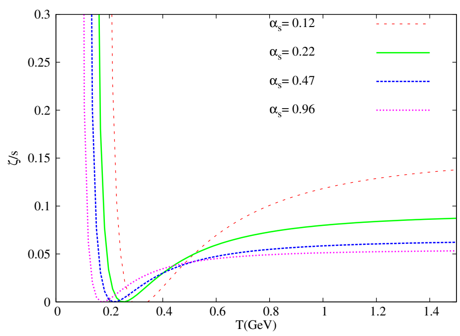

FIG. 1: Variation of specific bulk viscosity with temperature for different coupling.

for $\alpha_s = 0.12, 0.22, 0.47$ and 0.96 coupling respectively. It is quite interesting to note that strongly interacting system has been identified by large ζ/s ratio which rises dramatically up to the order of 1.0 near the T_c [8, 10] related with large non-conformal behavior.

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