Shear viscosity calculation in Polyakov-Quark-Meson model

Pracheta Singha[1],* Aman Abhishek[2], Guru Kadam[3], Sabyasachi Ghosh[4],† and Hiranmaya Mishra[2]
[1]Center for Astroparticle Physics and Space Science, Bose Institute, Block EN, Sector V, Salt Lake, Kolkata 700091, INDIA
[2]Theory Division, Physical Research Laboratory, Navrangpura, Ahmedabad 380 009, INDIA
[3]Indian Institute of Technology, Gandhinagar-382355, Gujarat, India and
[4]Department of Physics, University of Calcutta, 92, A. P. C. Road, Kolkata - 700009, INDIA

This work presents the numerical investigations of the coefficient of shear viscosity (η) of the quark and hadronic medium using Polyakov Quark Meson model.
In Polyakov Quark Meson model the lagrangian is given by,

$$\mathcal{L} = \bar{\psi}(i\not{D} - M_Q)\psi - g[(i\bar{\psi}\gamma_5\vec{\tau}\psi)\vec{\pi} + (\bar{\psi}\psi)\sigma] + \frac{1}{2}(\partial^\mu\pi\partial_\mu\pi + \partial^\mu\sigma\partial_\mu\sigma) - U_P(\Phi,\bar{\Phi}) - [\frac{\lambda}{4}(\pi^2+\sigma^2-v^2) - c\sigma] , \quad (1)$$

where parameters c, v, λ are tuned by using the relations $c = f_\pi m_\pi^2$, $v^2 = f_\pi^2 m_\pi^2/\lambda$ and $m_\sigma^2 = m_\pi^2 + 2\lambda f_\pi^2$ for the experimental values of $m_\pi = 138$ MeV, $m_\sigma = 600$ MeV and $f_\pi = 93$ MeV.

The covariant derivative suggest the coupling of quark field to a temporal background gauge field that represents the polyakov loop dynamics. The loop L is a matrix in color space which has the form, $L(x) = \mathcal{P}(\int_0^\beta dx_0 A_0(x_0,\vec{x}))$. The Polyakov loop variable, $\Phi = \Phi(\vec{x}) = \frac{1}{N_c}\langle tr_c L(\vec{x})\rangle_\beta$ behaves as the approximate order parameter for confinement deconfinement transition. The polyakov loop potential, given by,

$$U_p(\Phi,\bar{\Phi}) = T^4\big[-\frac{b_2(T)}{2}\bar{\Phi}\Phi - \frac{b_3}{2}(\Phi^3+\bar{\Phi}^3) + \frac{b_4}{4}(\bar{\Phi}\Phi)^2\big] , \quad (2)$$

can be evaluated with the parameters fixed from the lattice QCD calculation.

Once the lagrangian is constructed, we can proceed for finite temperature extension, where thermodynamic potential is our matter of interest to calculate different thermodynamic quantities like pressure, energy density and entropy density (s).

The analytic expressions for η for quark and mesonic components are respectively given by,

$$\eta_Q = \frac{2g_Q\beta}{15}\int\frac{d^3\mathbf{k}}{(2\pi)^3\Gamma_Q}\left(\frac{\mathbf{k}^2}{\omega_Q^k}\right)^2 f_Q\{1-f_Q\} , \quad (3)$$

$$\eta_M = \frac{g_M\beta}{15}\int\frac{d^3\mathbf{k}}{(2\pi)^3\Gamma_M}\left(\frac{\mathbf{k}^2}{\omega_M^k}\right)^2 n_M\{1+n_M\} , \quad (4)$$

where f_Q is Polyakov loop distribution of quark with energy $\omega_Q^k = \{\mathbf{k}^2 + M_Q^2(T)\}^{1/2}$ and n_M is Bose-Einstein distribution of mesons with energy $\omega_M^k = \{\mathbf{k}^2 + m_M^2(T)\}^{1/2}$. The $\Gamma_{Q,M}$ and $g_{Q,M}$ are thermal widths and degeneracy factors of quark and mesons.

We have done the numerical investigations by using the expressions of η for constant values of thermal widths of medium constituents to highlight the effects arising from

*Electronic address: pracheta.singha@gmail.com
†Electronic address: sabyaphy@gmail.com

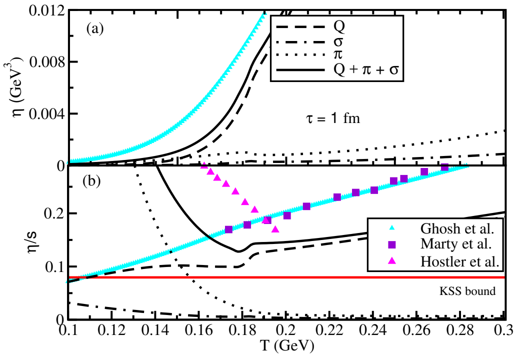

FIG. 1: Temperature dependence of η (a) and η/s (b) for quark, pion, sigma individually and their total for constant relaxation time $\tau = 1$ fm, along with the comparison with Refs. [3] [4] [5] . The straight horizontal red line indicates the KSS bound.

the phase space structure in the expressions of shear viscosity, given in Eqs. (3), (4). The results of $\eta(T)$ for constant Γ_Q, Γ_π and Γ_σ are plotted in Fig. 1(a). The relaxation times $\tau_{(Q,\pi,\sigma)} = 1/\Gamma_{(Q,\pi,\sigma)}$ have been fixed to the value of 1 fm as a typical value. The total shear viscosity $\eta_t = \eta_Q + \eta_\pi + \eta_\sigma$ exposes the dominant contribution of the quark component, compared to the other components. $\eta(T)$ of all components and their total have appeared as increasing functions of T but they face some changes in their rate of increments near the transition temperature T_c.

The Fig. 1(b) shows the variation for η/s with temperature for respective components and their total, where we notice that mesonic components decrease and quark component increases with temperature. Both the increasing trend of total η/s at quark temperature domain and the decreasing trend of the ratio below the transition temperature are in agreement with other theoretical results [2, 3, 6]. Total η/s is above the so-called KSS bound [1].

In summary, we have investigated the role of PQM dynamics in calculations of shear viscosity of quark and hadronic medium. Starting with the standard expressions of η using constant values of Γ, we have found the phase-space effect of PQM dynamics on its numerical value. The thermal behavior of η obtained from our calculation are in well agreement with the other earlier theoretical results.

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