On the strongly couple nature of hadron resonance gas

Sumana Bhattacharyya[1],* Snigdha Ghosh[2],† and Sabyasachi Ghosh[3]‡
[1] Center for Astroparticle Physics and Space Science, Bose Institute, Block EN, Sector V, Salt Lake, Kolkata 700091, INDIA
[2] Theoretical Physics Division, Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata - 700064, INDIA and
[3] Department of Physics, University of Calcutta, 92, A. P. C. Road, Kolkata - 700009, INDIA

The underlying purpose of our work is to calculate the transport coefficients of hadronic matter incorporating the contributions of all mesons (M) and baryons (B) using Hadron Resonance Gas (HRG) model. The expression of total shear viscosity η, obtained from relaxation time approximation (RTA) in kinetic theory approach or one-loop diagram in quasi-particle Kubo approach, is given below [1]

$$\eta = \sum_B \frac{g_B}{15T}\int \frac{d^3\mathbf{k}}{(2\pi)^3}\tau_B\left(\frac{\mathbf{k}^2}{\omega_B}\right)^2 [n_B^+(1-n_B^+) + n_B^-(1-n_B^-)] + \sum_M \frac{g_M}{15T}\int \frac{d^3\mathbf{k}}{(2\pi)^3}\tau_M \left(\frac{\mathbf{k}^2}{\omega_M}\right)^2 n_M(1+n_M)~, \quad (1)$$

where $n_B^\pm$ are Fermi-Dirac distributions of baryon and anti-baryon with energy ω_B, n_M is Bose-Einsein distribution of meson, $g_{B,M}$ and $\tau_{B,M}$ are degeneracy factors and relaxation times for B and M respectively.

Now the hadron family, which we have considered in our calculation, has been classified into two categories - non-resonance (π, K and N) and resonance (rest of the family members) particles. Keeping in the mind about finite life time of RHIC or LHC matter (10 fm approximately), we have considered only those resonance particles, whose mean life times (τ) are less than the life time of the medium and using their times as relaxation times in Eq. (1).

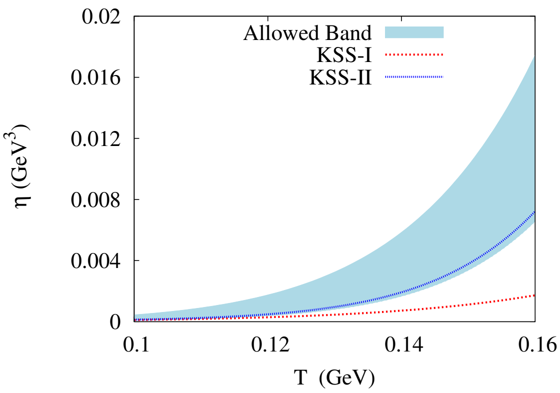

FIG. 1: Temperature dependence of shear viscosity η for KSS-I (red dotted line) and KSS-II (blue dotted line) inputs, given in Table (I). Cyan color presents the approximated numerical band of η because of upper and lower limit consideration of relaxation times for non-resonance component.

Now, for non-resonance particles - pion, kaon and nucleon, we have taken interest on a band by searching approximated upper and lower limits of their relaxation times. we have approximated the upper bounds of their relaxation times by considering $\Gamma_{\pi,K,N}$ = 0.0197 GeV as a minimum thermal width or $\tau_{\pi,K,N}$ = 10 fm as a maximum relaxation time. Whereas, for generating the lower bound of transport coefficients of non-resonance particles, we have considered the Compton lengths as mean free paths and used their masses as maximum thermal widths i.e. $\Gamma_{\pi,K,N} = m_{\pi,K,N}$. These approximated limiting values of thermal widths or relaxation

*Electronic address: response2sumana91@gmail.com
†Electronic address: snigdha.physics@gmail.com
‡Electronic address: sabyaphy@gmail.com

times of non-resonance particles are used to estimate a band for shear viscosity η, shown in Fig. (1) by cyan color and shear viscosity to entropy density (s) ratio η/s in Fig. (2) by cyan color, where s is calculated from the ideal (non-interacting) HRG model.

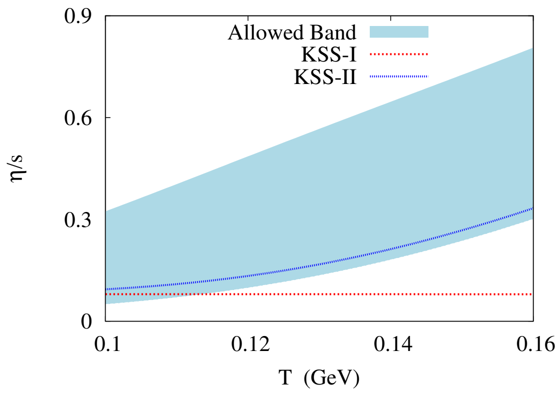

FIG. 2: Same as Fig. (1) for η/s.

TABLE I: Tabulated picture of different sets for relaxation time of non-resonance and resonance component.

	Non-resonance component	Resonance component
Set-1	$\tau(T)$ by fixing total $\eta/s = 1/4\pi$	$\tau < 10$ fm
Set-2	$\tau(T)$ by fixing $\eta/s = 1/4\pi$ for non--resonance component only	$\tau < 10$ fm

After constructing the numerical band, we have focus on some specific estimated curves, which are named as KSS-I and KSS-II and their corresponding inputs are addressed in Table (I).

In Fig. (2) red dotted horizontal line is evaluated by imposing the resonance and non-resonance contributions with the KSS value $\frac{\eta}{s} = \frac{1}{4\pi}$, predicted as a lower bound of η/s in Ref. [2]. Corresponding η is shown by red dotted line in Fig. (1) and we found that this estimation is unphysical because non-resonance component carry a negative contribution to get total $\eta/s = 1/4\pi$. It indicates that η/s of hadron resonance gas never reach the KSS value. Next in KSS-II, we have considered the non-resonance component with the KSS value and then add it with resonance component. The blue dotted lines in Fig. (1) and (2) are displaying this KSS-II estimation of η and η/s.

In summary, we have tried to sketch an approximated numerical band of η and η/s of hadron resonance gas, where we impose upper and lower limit on relaxation times of non-resonance particles - pion, Kaon and Nucleon. For resonance particles, we consider those which will take participation in dissipation inside the RHIC or LHC matter. Then, we focus on some specific estimations, where we have understood that η/s of hadron resonance gas can never reach its quantum lower bound or KSS value.

Acknowledgments

SB and Snigdha Ghosh are supported from CSIR and DAE respectively. Sabyasachi Ghosh is financially supported from University Grant Commission (UGC) Dr. D. S. Kothari Post Doctoral Fellowship (India) under grant No. F.4-2/2006 (BSR)/PH/15-16/0060.

References

[1] S. Ghosh, Int. J. Mod. Phys. A **29**, 1450054 (2014).
[2] P. Kovtun, D. T. Son, and A. O. Starinets, Phys. Rev. Lett. **94**, 111601 (2005).