Behavior of Shear Viscosity from PNJL model

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I. INTRODUCTION

The strongly interacting exotic state of matter produced in the high-energy heavy ion experiments is expected to undergo a transition from confined state of colored charges to a partonic phase. This allows us to study various interesting properties including transport coefficients of such exotic state of matter. Here the whole work is done under the framework of 2+1-flavored Polyakov-Nambu-Jona-Lasinio (PNJL) Model [1–3], which is a QCD-inspired phenomenological model developed by coupling the Polyakov loop potential to the Nambu-Jona-Lasinio (NJL) model. Here the basic degrees of freedom are the Polyakov-loop fields and the chiral condensates. The Green-Kubo formalism, that we are going to adopt in our present work, needs the use of the spectral functions of the degrees of freedom involved. There are however other methods like Relaxation Time Approach [4] or the Chapman-Enskog formalism [5] to investigate the effects of transport coefficient in the evolution of such strongly interacting systems.

II. KUBO FORMALISM

Kubo formula for shear viscosity gives,

$$\eta(\omega) = \frac{1}{15T}\int_0^\infty dt e^{i\omega t}\int d\vec{r}(T_{\mu\nu}(\vec{r},t), T^{\mu\nu}(0,0))$$

where $T_{\mu\nu}$ is the (μ,ν) component of the E-M tensor of quark matter. Following the steps of [6] we come to,

$$\eta[\Gamma(p)] = \frac{16N_cN_f}{15\pi^3 T}\int_{-\infty}^{\infty} d\varepsilon \int_0^\infty dpp^6 \left[\frac{M^2\Gamma^2(p)f_\phi(\varepsilon)(1-f_\phi(\varepsilon))}{((\varepsilon^2-p^2-M^2+\Gamma^2(p))^2+4M^2\Gamma^2(p))^2}\right]$$

where, N_c is the no. of colors and N_f is the no. of flavors. f_ϕ is the modified Fermi-Dirac distribution function taking into account the effect of Polyakov loop fields and is given by,

$$f_\phi^\pm(E_p) = \frac{(\bar{\phi}+2\phi e^{-\beta(E_p\pm\mu)})e^{-\beta(E_p\pm\mu)}+e^{-3\beta(E_p\pm\mu)}}{1+3(\bar{\phi}+\phi e^{-\beta(E_p\pm\mu)})e^{-\beta(E_p\pm\mu)}+e^{-3\beta(E_p\pm\mu)}}$$

where the '±' refer to particle and anti-particle contributions respectively.

III. RESULTS

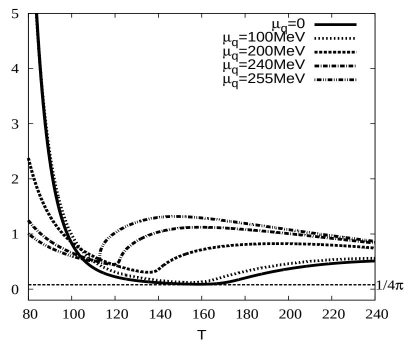

FIG. 1: $\frac{\eta}{s}$ as a function of temperature for a broad regime of quark chemical potentials

In Fig.(1) we see the behavioral pattern for $\frac{\eta}{s}$ for vanishing as well as non-vanishing chemical potentials. At or near critical temperature, which being responsible for infinite correlation length, creates the most difficult condition for momentum transfer making $\frac{\eta}{s}$ to acquire the minimum value which is $\frac{1}{4\pi}$ (KSS-bound) for $\mu_q = 0$. On the other hand in Fig.(2), as we move towards even higher chemical potentials

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it starts showing anomalies in terms of jump or discontinuities, which meets the general expectations quite well [7, 8].

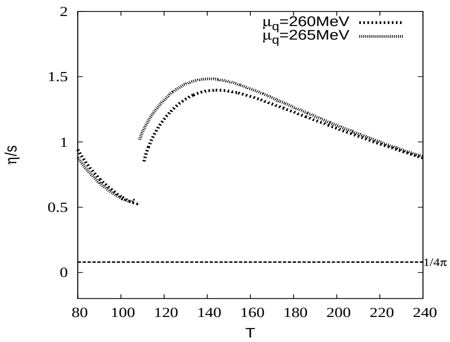

FIG. 2: $\frac{\eta}{s}$ as a function of temperature for even higher quark chemical potentials

Finally, it would be gripping to observe the response of η under the spectrum of contrasting experimental conditions. In the PNJL models the independent variables are Temperature and chemical potentials. Using the freeze-out parametrizations done by Redlich et. al. [9], we can compute the behavioral nature of specific shear viscosity as is shown in Fig. (3). As stated previously, $\frac{\eta}{s}$ decreases with temperature in the hadronic regime. Along the freeze-out line as one always resides in the hadronic region, this behavior is quite obvious. Our results match quite well with analysis of different experimental results [10]. It should nonetheless be recalled that this is the value of $\frac{\eta}{s}$ acquired when the system is in complete thermodynamic equilibrium at the given values of temperature and chemical potential. Along the freeze-out curve, we always reside in the hadronic phase. So, the value of $\frac{\eta}{s}$ in Fig.(3) corresponds to different conditions in the hadronic phase.

IV. ACKNOWLEDGEMENT

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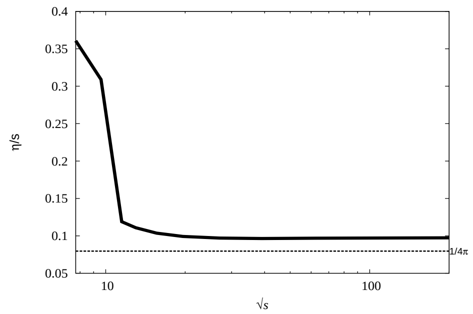

FIG. 3: $\frac{\eta}{s}$ under different experimental conditions along the freeze-out diagram

References

[1] S. K. Ghosh, T. K. Mukherjee, M. G. Mustafa and R. Ray, Phys. Rev. D, **73**, 114007 (2006); Phys. Rev. D **77**, 094024 (2008).

[2] S. Mukherjee, M. G. Mustafa and R. Ray, Phys. Rev. D, **75**, 094015 (2007).

[3] A. Bhattacharyya, P. Deb, S. K. Ghosh and R. Ray, Phys. Rev. D **82**, 014021 (2010).

[4] P. Chakraborty and J. I. Kapusta, Phys. Rev. C **83**, 014906 (2011).

[5] W. A. van Leeuwen, P. Polak, and S. R. de Groot, Physica **63**, 65 (1973).

[6] R. Lang and W. Weise, Eur. Phys. J. A (2014) **50** : 63; M.Iwasaki, H. Ohnishi and T. Fukutome, arXiv : hep-ph/**0606192v1** 19 Jun 2006.

[7] J. W. Chen and E. Nakano, Phys. Lett. **B 647** (2007) 371; A. Nakamura and S. Sakai, Phys. Rev. Lett. **94**, 072305 (2005).

[8] Phys.Rev. C **88** 6, 068201 (2013).

[9] F. Karsch and K. Redlich, Phys. Lett. B **695**, 136 (2011).

[10] R. A. Lacey et. al. Phys. Rev. Lett. **98**, 092301 (2007); D. Teaney, Phys. Rev. **C 68**, 034913 (2003); C. Gale et. al., Phys. Rev. Lett. **110**, 012302 (2013).