Transport properties for Hot Hadronic Matter using Non-extensive statistics

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Introduction

The space-time evolution of a system from non-equilibrium to equilibrium state is governed by its transport properties. The elliptic flow measurement at RHIC has found that the shear viscosity to entropy ratio (η/s) is close to the KSS bound, which developed intense interest in transport properties of quantum chromodynamics (QCD). Also, a peak in bulk viscosity to entropy ratio (ζ/s) is expected near QCD critical temperature (T_c), where conformal symmetry breaking might be significant as expected by various effective models. In an equilibrium Boltzmann Transport Equation (BTE), one assumes that a non-equilibrium system relaxes to an equilibrium system after a certain relaxation time τ. Here, we investigate a non-equilibrium system which dissipates energy and produces entropy, which is measured by the degree of non-extensivity, q. Thus, it is called as q-non-equilibrium, which is related to the response of the system to gradients of different thermodynamical intensive quantities. This system does not relax to a Boltzmann-Gibbs equilibrium but to a local q-equilibrium. We study the transport coefficients such as shear and bulk viscosities, electrical (σ_{el}) and thermal (κ) conductivities and isothermal compressibility using the relativistic non-extensive Boltzmann transport equation (NBTE) for hadron gas, where we employ the relaxation time approximation for the collision integral. Also, we calculate the ratio of the two conductivities to examine the validity of Wiedemann-Franz law which was originally proposed for free electron metals. In Boltzmann's approximation, the thermodynamically consistent Tsallis distribution is given as,

$$f_a^0 = \frac{1}{\left[1+(q-1)\Big(\frac{p^\mu u_\mu - \mu}{T}\Big)\right]^{\frac{q}{q-1}}}, \quad (1)$$

where p^μ is the momentum four vector and $u_\mu = (1,\ \mathbf{0})$ is the fluid four velocity in the local rest frame. q is the non-extensive parameter, which signifies how far the system is away from thermodynamic equilibrium. T and $\mu = B\mu_B + s\mu_s$ are temperature and chemical potential, respectively. Here we consider only the baryochemical potential, μ_B, ignoring the strangeness chemical potential.

For the detailed derivation of different transport properties using BTE in non-extensive statistics (Eq. 1), the readers are suggested to follow Refs. [1, 2].

Results and discussion

In Fig. 1, we have shown our results for electrical conductivity along with results obtained using other approaches such as lattice QCD, super Yang-Mills plasma, kinetic theory and parton hadron string dynamics (PHSD). For this, we have taken $q = 1.0001$ so that it approximates the equilibrium scenario since results obtained in other approaches assume equilibrium distribution function and we have considered three different baryon chemical potentials, μ_B. We see that σ_{el} decreases with μ_B. We can see that the values we obtained are slightly less compared to the values obtained in PHSD and significantly higher compared to the estimations done using kinetic theory for $\mu_B = 0$.

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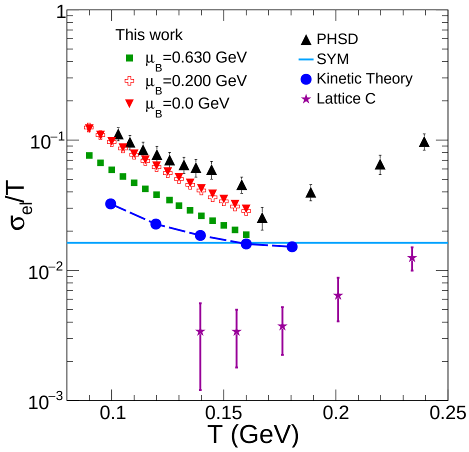

FIG. 1: (Color online) σ_{el}/T vs T for different baryochemical potentials, μ_B with $q \sim 1$ are compared with the results from other theoretical models [2].

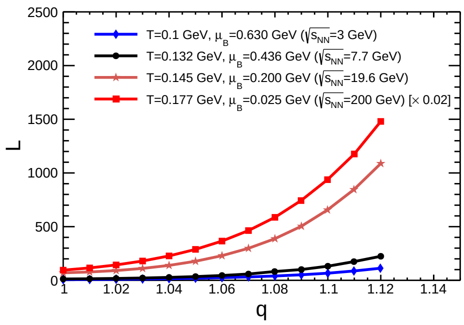

FIG. 2: (Color online) Lorenz number as a function of the non-extensive parameter, q [2].

Fig. 2 shows the variation of the Lorenz number (L) with the Tsallis non-extensive parameter q. The temperature corresponding to each μ_B in the plot indicates the chemical freeze-out temperatures at the mentioned centre-of-mass energies. We observe that L increases slowly with q for lower values of q and then increases rapidly for all μ_B. This behaviour is due to much sharper increase in κ with q compared to σ_{el}. We would emphasise here that, we are considering only the freeze-out temperatures. Had we considered a much lower temperature, we would have observed exactly opposite behaviour of L with q as κ tends to decrease with increasing q at lower temperature. However, the qualitative behaviour of σ_{el} with q remains the same for any temperature. At very high μ_B, the Lorenz number is very small at small q as κ falls dramatically with μ_B whereas σ_{el} remains relatively unchanged.

The reported results here are a glimpse of complete set of results on transport properties. In the conference presentation, more detailed results along with the results on validity of Widemann-Franz law in hadron gas system from Refs. [1, 2] will be presented.

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References

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