Effect of repulsive interactions in Hadron Resonance Gas model

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Introduction

Hadron Resonance Gas (HRG) model has been quite sucessful in describing the hadron multiplicity ratios produced in ultra relativistic heavy ion collision experiments. HRG model is a low temperature statistical thermal model which is used to describe the hadronic state of strongly interacting matter and is based on the Dashen, Ma, Bernstein theorem [1]. It is based on the relativistic virial expansion and S-matrix formulation. This model takes into account the attractive interactions among stable hadrons by considering the unstable resonances as stable particles. However, there are indications that repulsive interactions among the particles are also important to describe the lattice data for some of the thermodynamic quantities and susceptibilities of conserved charges. One way of incorporating short-range repulsive interactions is to use the mean-field approach and this model is named as HRG mean-field (HRGMF) model. In this work, we investigate the effect of mean-field repulsive interaction on specific heat (C_V), isothermal compressibility (κ_T) and speed of sound squared (C_s).

Model

The thermodynamic quantities in HRG model can be derived from the grand canonical partition function.

$$\ln \mathcal{Z}_i^{id} = \pm \frac{V g_i}{2\pi^2} \int_0^\infty p^2 \, dp \times \ln\{1 \pm exp[-(E_i - \mu_i)/T]\} \quad (1)$$

In the HRGMF model, the repulsive interaction is incorporated by shifting the single particle energies by a density dependent term [3, 4]:

$$\varepsilon_a = \sqrt{p^2 + m_a^2} + U(n) = E_a + U(n) \quad (2)$$

We assume different repulsive interaction parameter for baryons and mesons. For baryons (antibaryons):

$$U(n_{B\{\bar{B}\}}) = K_B n_{B\{\bar{B}\}} \quad (3)$$

and for mesons

$$U(n_M) = K_M n_M \quad (4)$$

The total hadron number density is

$$n(T, \mu) = \sum_a n_a = n_B + n_{\bar{B}} + n_M \quad (5)$$

where the number density of a-th hadronic speciesis given by n_a.

$$n_B = \sum_{a \in B} \int d\Gamma_a \, \frac{1}{e^{\frac{(E_a - \mu_{\text{eff},B})}{T}} + 1} \quad (6)$$

where $\mu_{\text{eff},B} = c_i \mu_i - K_B n_B$ and $c_i = (B_i, Q_i, S_i), \mu_i = (\mu_B, \mu_Q, \mu_S)$ and $d\Gamma_a \equiv \frac{g_a d^3p}{(2\pi)^3}$. The sum is over all the baryons. Similar equations hold for antibaryons and mesons.

Results

We keep K_B fixed at 0.45 GeV·fm^3 and take three representative values of K_M. The

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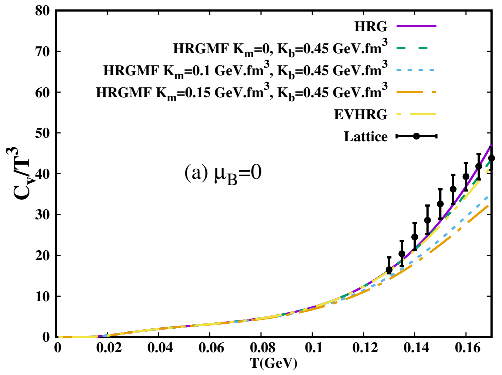
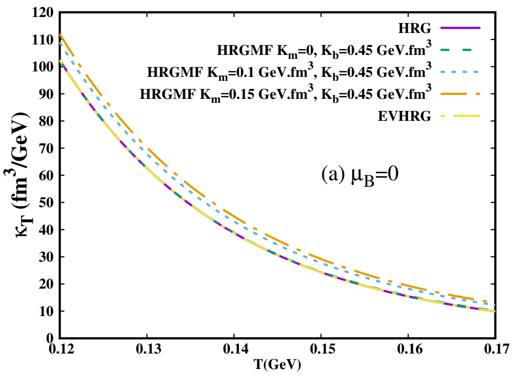
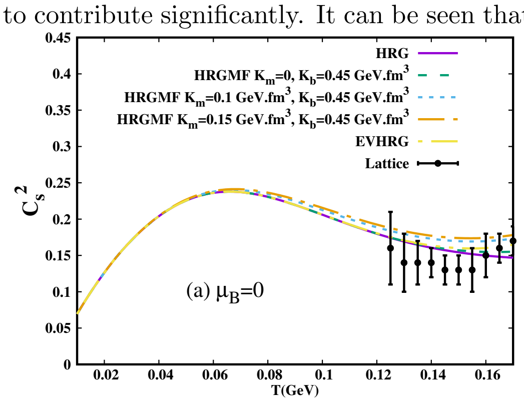




scaled specific heat becomes smaller as the repulsive mean-field parameter K_M is increased. This is because with the increase of repulsive mean-field interaction, the number density of particles is reduced. The isothermal compressibility (κ_T) deacreases with the increase of temperatures as the system becomes populated with more particles and it becomes harder to compress the system. When the repulsive interactions are turned on, the pressure of the system is smaller. Hence the κ_T increases with the increase of K_M. The speed of sound, at low temperatures, increases when the temperature is increased as more and more hadrons populate the system. At medium range of temperatures, it begins to decrease with the increase of temperatures because, at this region, the increase in energy density lags behind the increase in pressure. At higher temperatures, the speed of sound begins to increase again as heavier hadrons start to contribute significantly. It can be seen that



the model with repulsive interactions performs better in describing the minima in C_s^2. At high temperatures, speed of sound increases with the introduction of repulsive interactions.

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