Fluctuations of conserved charges in an interacting hadron gas with magnetic field

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Introduction

Strongly interacting matter under extreme conditions is a vibrant area of research for several decades. Such matter can be created in relativistic heavy-ion collisions. Strong magnetic field is expected to be created in non-central heavy-ion collisions. In this work our purpose is to analyse the effect of magnetic field on the EoS as well as on the conserved charge fluctuations in hot and dense hadronic matter using both Hadron Resonance Gas (HRG) and Excluded Volume Hadron Resonance Gas (EVHRG) models [1].

Model in magnetic field

The pressure of electrically charged particles of non-interacting HRG in the presence of magnetic field can be written as [2]

$$P_c^{\rm id} = \pm \sum_i \sum_{S_z} \sum_{n=0}^{\infty} \frac{eB}{(2\pi)^2} \int dp_z \left(E_{i,c} + T \ln(1 \pm e^{-(E_{i,c}-\mu_i)/T}) \right) \tag{1}$$

where

$$E_{i,c} = \sqrt{p_z^2 + m_i^2 + 2e_i B(n + 1/2 - S_z)} \tag{2}$$

The renormalized field dependent pressure (without pure magnetic field contribution) for spin-1/2 particles is

$$\Delta P^r_{\rm vac}(S = 1/2, B) = \frac{(eB)^2}{2\pi^2} \left(\zeta^{'}(-1, x) + \frac{x}{2}\ln(x) - \frac{x^2}{2}\ln(x) + \frac{x^2}{4} - \frac{\ln(x) + 1}{12} \right) \tag{3}$$

where $x = \frac{m^2}{2eB}$. Similar relation holds for spin-0 and spin-1 particles.

Results

Here we take the sizes of hadrons as prescribed in Ref. [3] i.e. r_π (pion radius) = 0 fm, r_K (kaon radius) = 0.35 fm, r_m (all other meson radii) = 0.3 fm and r_b (baryon radii) = 0.5 fm. We have considered particles with spin upto 1 only.

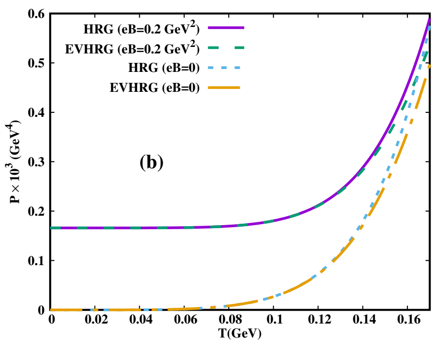

FIG. 1: Total pressure as a function of temperature in presence of magnetic field for $\mu_B = 0$.

The thermal part of the pressure in presence of magnetic field is smaller than that for eB= 0 case. This can be accounted by comparing the dispersion relations in presence of magnetic field (Eq.(2)) and in absence of magnetic field. If $eB \neq 0$ then the effective mass of a spin-0 particle increases but that of spin-1 particle decreases. The efective mass of spin-$\frac{1}{2}$ particles remains almost unchanged in the presence of magnetic field. Since the particles with spin-1 are heavier (lightest spin-1 particle ρ weighs 0.776 GeV which is more than five times heavier than pion), their contribu-

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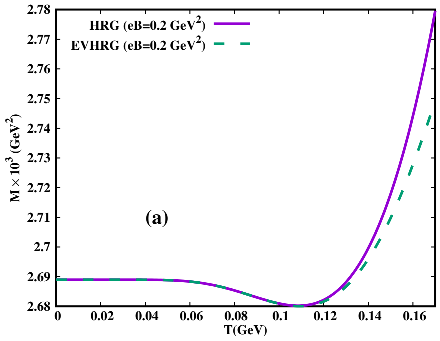

FIG. 2: Total magnetization as a function of temperature for $\mu_B = 0$.

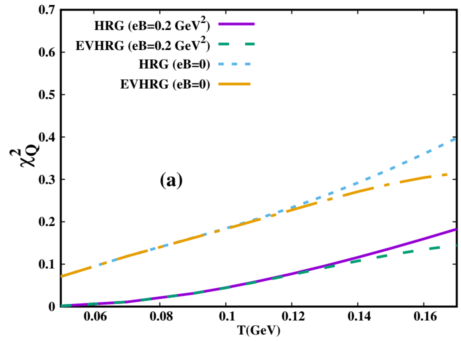

FIG. 4: χ_Q^2 as a function of temperature at μ=0

tions to pressure are much smaller compared to spin-0 particles and show up only at higher temperature. Since pions are dominating particles at low temperature, and since their effective mass increases in presence of magnetic field, the thermal part of the pressure, for HRG model, in presence of magnetic field is smaller than that for without magnetic field.

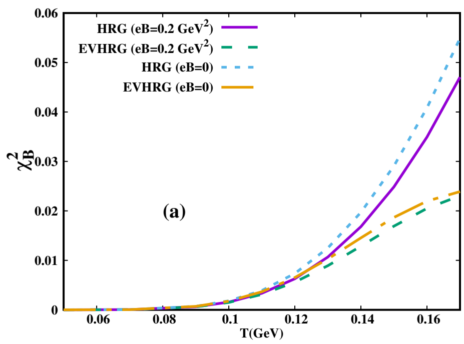

FIG. 3: χ_B^2 as a function of temperature at μ=0

Fig. (2) shows that the magnetization is positive indicating that the hadronic matter is paramagnetic. The thermal part of magnetization is almost zero at very low temperature due to the absence of charged hadrons. Pions, which are the lightest hadronic species, are thermally excited at $T \sim 0.060$ GeV. The thermal part of their magnetization is negative and hence magnetization decreases with increase in temperature. Magnetization starts increasing only when lightest spin-1 particle, ρ-meson, populates the hadronic matter. Thereafter, the magnetization rises rapidly as spin-$\frac{1}{2}$ particles also start to make positive contribution to the magnetization.

Fig. (3) and (4) show that baryon number susceptibility (χ_B^2) and electric charge susceptibility (χ_Q^2) of second order in the presence of magnetic field and in the absence of magnetic field. The effect of magnitic field on electric charge susceptibilities is stronger than that on baryon number susceptibilities since lighter pions are the dominant contributor to χ_Q^2 and protons and neutrons are the dominant contributors to χ_B^2.

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