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Statistical Thermodynamics within the Hadron resonance gas (HRG) model including magnetic fields at the CBM Experiment

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In this paper, statistical thermodynamic quantities such as pressure density (P/T^4), energy density (ϵ/T^4), and trace anomaly $(\epsilon - 3P)/T^4$, are calculated using the HRG model in the presence of finite magnetic field eB effect. The mentioned thermodynamics have been calculated at both vanishing and finite 170, 340, and 425 baryon chemical potential μ_b where the values of eB are taken to be 1, 1.2, and 1.5. The obtained results are compared with the recent lattice QCD data over temperatures ranging from 130 MeV to 200 MeV at the mentioned values of eB. For balance temperatures up to the chiral phase transition's vicinity temperature $\simeq$ 160 MeV, a decent fitting between the model and the lattice data is observed for different values of eB and μ_b especially at $(\mu_b, eB) = (1.2, 170)$, $(1.2, 340)$, and $(1.2, 425)$, where eB is expressed in GeV^2 and μ_b in MeV. For $\mu_b = 0$ and 170 MeV, the ideal HRG model seems to offer the best fit. The effect of magnetic field seems to be more applicable at non-vanishing chemical potentials, especially within the range $\mu_b \in [170, 340]$ MeV. Further investigation shall be made for a better description of the lattic QCD data.

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1. Introduction

The gauge field theory of quantum chromodynamics (QCD) describes the strong interactions of coloured quarks and gluons and their colourless bound states. The study of strongly interacting matter under severe temperature T and baryon chemical potential μ_b has sparked a spectacular global theoretical and experimental effort.

The EoS at vanishing chemical potentials does already provide important input into the modeling of the hydrodynamic evolution of hot and dense matter created in heavy-ion collisions such as the beam energy scan (BES) at RHIC [1] and in future experiments at future facilities like FAIR at GSI and NICA at JINR [2]. In this paper, we have used HRG model with finite magnetic field effect to obtain better results consistent with that obtained from the recent lattice (QCD) theory at both vanishing and finite μ_b.

2. The Used Approach

In a grand canonical ensemble, the partition function reads [3],

$$Z(T,V,\mu) = \mathrm{Tr}\left[\exp\left(\frac{\mu N - H}{T}\right)\right], \tag{1}$$

where H is the Hamiltonian containing all relevant degrees of freedom and N is the number of particles in the statistical ensemble. Eq. (1) would be expressed as a sum overall hadron resonances as follows,

$$\ln Z(T,V,\mu) = \sum_i \ln Z_i(T,V,\mu) = V \sum_i \frac{g_i}{2\pi^2} \int_0^\infty \pm p^2 dp \ln\left[1 \pm_. \exp\left(\frac{\mu - \varepsilon_i}{T}\right)\right], \tag{2}$$

where $\pm$ stands for fermions and bosons, respectively. μ_i represents the chemical potential. ϵ_i is the dispersion relation and it is defined as,

$$\epsilon_i = \sqrt{P^2 + m_i^2}. \tag{3}$$

All the considered thermodynamic quantities can be derived from Eq. (2) In case of applying magnetic field effects, Eq. (3) will be modified depending on Landau quantization suggestions [4, 5] as the following

$$\epsilon_i = \sqrt{P^2 + \{2l - 1 - 2s\}|e_i|B + m_i^2}. \tag{4}$$

with s = -s_i 0, 1, 2, . . . s_i and l = 0, 1, 2,.... being the spin and orbital quantum numbers, respectively, and e_i is the electrical charge of the i-th hadron.

3. Results and Discussion

We have compared the obtained results of the calculated thermodynamics using the HRG model based on magnetic field effect with the corresponding lattice thermodynamics data [6–8] in at temperature range $T \in [130, 200]$ MeV. Figs. (1 - 4) show the temperature dependence of the normalized pressure (P/T^4), the normalized energy density (ϵ/T^4), and trace anomaly $(\epsilon - 3p)/T^4$ (dashed curves) for the ideal HRG model, eB = 1.0, 1.2, and 1.4 GeV^2, respectively. The best fit occurs at eB = zero and 1.2 GeV^2. It is quite obvious that the model fits the lattice data better compared to the corresponding vanishing chemical potential case(s) [9, 10].

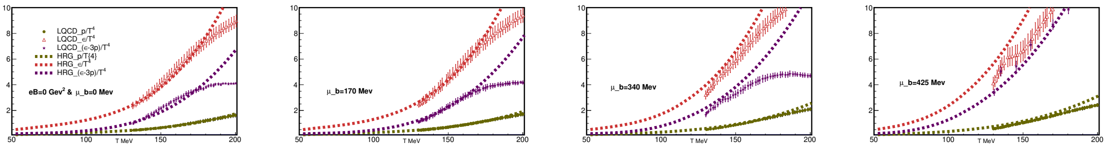

Figure 1: depicts the temperature dependence of the pressure density (P/T^4) , energy density (ϵ/T^4), and trace anomaly $(\epsilon - 3p)/T^4$(dashed curves) calculated using the ideal HRG model.

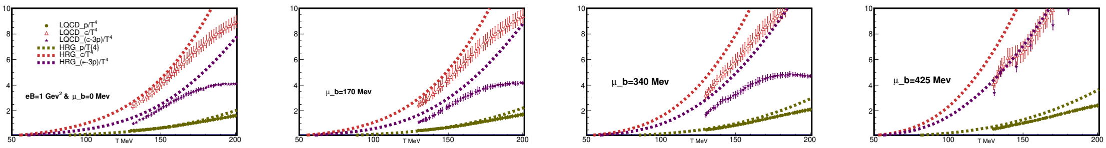

Figure 2: Same as Fig. (1) but at $eB = 1.$ GeV^2

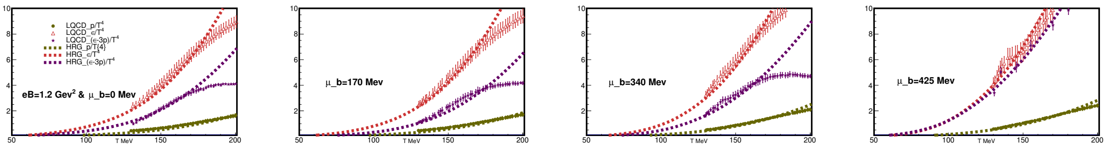

Figure 3: Same as Fig. (2) but at $eB = 1.2$ GeV^2

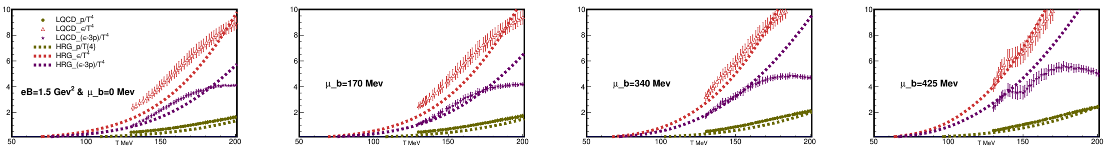

Figure 4: Same as Fig. (3) but at $eB = 1.5$ GeV^2

4. Conclusions

In this work, the obtained data do not seem to satisfactorily mimic the corresponding lattice data over this temperature interval, $T \in [130, 200]$ MeV. The best fit occurs in the vicinity of of $T \in [140, 170]$ MeV for $\mu_b = 170$ MeV at zero and 1.2 GeV^2 magnetic field, respectively. Another remarkable matching between our model data with the corresponding lattice data occurs for $\mu_b = 340$ MeV, at 1.2 GeV^2 magnetic field for temperatures T $\leq$ 170 MeV. At $T \in [130, 160]$ MeV, the results show reasonable match with the corresponding lattice data for different magnetic field values except for $\mu_b = 425$ MeV where no good fitting is observed for any magnetic field value expect at 1.2 GeV^2.

References

[1] J. Engels, F. Karsch, H. Satz, and I. Montvay, *High temperature SU (2) gluon matter of the lattice*, Phys. Lett. B B 101 (1981) 1.

[2] T. Banks and A. Ukawa, *EM Lifshitz Statistical Physics*, C. of Theor. Phys B 5 (1980) 396-400.

[3] A. Bazavov et al., *Chiral and deconfinement aspects of the QCD transition*, Phys. Review D B 85 (2012) 5.

[4] A. Tawfik, and D. Toublan, *Quark-antiquark condensates in the hadronic phase*, Phys. Lett. B B 623 (2005) 48-54.

[5] A. Tawfik, and E. Abbas, *Thermal description of particle production in Au-Au collisions at RHIC energies (STAR)*, Phys. of Part. and NAc. Lett. B 12 (2015) 4.

[6] R. V. Gavai and S. Gupta, *Quark number susceptibilities, strangeness, and dynamical confinement*, Phys. Review D. B 64 (2001) 7.

[7] C. Allton et al., *QCD thermal phase transition in the presence of a small chemical potential*, Phys. Review D. B 66 (2002) 7.

[8] S. Ejiri, F. Karsch, E. Laermann, and C. Schmidt, *Isentropic equation of state of 2-flavor QCD*, Phys. Review D. B 73 (2006) 5.

[9] S. Borsanyi et al., *QCD equation of state at nonzero chemical potential: continuum results with physical quark masses* , H. E. Phys. B 2012 (2012) 8.

[10] M. D'Elia, G. Gagliardi, and F. Sanfilippo, *Higher order quark number fluctuations via imaginary chemical potentials in N f= 2+ 1 QCD*, PPhys. Review D. B 95 (2017) 9.