Field Decomposition Formulation for QCD and Thermodynamics of Quark Gluon Plasma

Garima Punetha* and H. C. Chandola
Center of Advanced Study, Department of Physics,
D.S.B. Campus, Kumaun University Nainital-263001 INDIA

Introduction

The investigation of the properties of the QGP at nonzero temperature and baryon chemical potential is one of the main challenge of QCD and has been intensively studied theoretically[1, 2]. The present paper mainly deals with the investigation of thermodynamic properties of QGP using field decomposition formulation based on magnetic symmetry in the framework of temperature dependent bag model.

QCD using field decomposition and thermodynamics of QGP

The gauge independent field decomposition formulation[3–5] based on magnetic symmetry provides a gauge invariant investigation and the topological ground of confinement for which the Lagrangian in quenched approximation is expressed in the following form,

$$\pounds_d^{(m)} = -\frac{1}{4}B_{\mu\nu}^{(d)^2} + \left|\left[\partial_\mu + i\frac{4\pi}{g}B_\mu\right]\phi\right|^2 - V(\phi^*\phi), \quad (1)$$

where $V(\phi^*\phi)$ is the effective potential responsible for the dynamical breaking of magnetic symmetry. Investigating the confining phase of QCD and utilizing the asymptotic solutions of the associated fields[4, 5], the energy per unit length of the resulting flux tube configuration is given as,

$$k = 2\pi\int_0^\infty \rho d\rho\left[\frac{n^2g^2}{32\pi^2\rho^2}\left(\frac{dF}{d\rho}\right)^2 + \frac{n^2}{\rho^2}F^2(\rho)\chi^2(\rho)\right.$$

$$\left. + \left(\frac{d\chi}{d\rho}\right)^2 + \frac{48\pi^2}{g^4}\lambda(\phi^*\phi - \phi_0^2)^2\right] = \gamma\phi_0^2. \quad (2)$$

where $F(\rho) \stackrel{\rho\to\infty}{\longrightarrow} C\sqrt{\rho}exp\left(-m_B\rho\right)$. The estimate of the various values of the confinement parameters generated after the dynamical breaking of magnetic symmetry is summarized in Table 1[3]. These estimates for zero temperature may now be utilized for analyzing the thermal response and phase structure of QCD under unusual thermal/density conditions. Using the grand canonical partition function $Z = Tr\left[\exp\left(-\frac{1}{T}(\hat{H} - \mu\hat{N})\right)\right]$, all standard thermodynamical parameters can be derived and given in the following form, $P = T\left(\frac{\partial lnZ}{\partial V}\right)_T, \epsilon = \left(\frac{T^2}{V}\right)\left(\frac{\partial \ln Z}{\partial T}\right)_V, C_V = \left(\frac{\partial\epsilon}{\partial T}\right)_V, c_s^2 = \frac{dP}{d\epsilon} = \epsilon\frac{d(P/\epsilon)}{d\epsilon} + \frac{P}{\epsilon} = \frac{s(T)}{C_V(T)}$. Constructing the hadronic bag[6] using the confining part of the flux tube energy in dual QCD formulation[5] leads to the bag pressure(bag parameter) depending on vector glueball mass of the magnetically condensed QCD vacuum given by,

$$B^{1/4}(T) = \left(\frac{12}{\pi^2}\right)^{1/4}\frac{m_B^{(T)}}{8}, \quad (3)$$

TABLE I: The masses of vector (m_B) and scalar (m_ϕ) glueballs as a functions of α_s using quadratic potential.

α_s	γ	$\phi_0(GeV)$	$m_B(GeV)$	$m_\phi(GeV)$	$\kappa_{QCD}^{(d)}$
0.22	7.891	0.149	1.51	2.22	1.5
0.47	6.28	0.167	1.21	1.22	1
0.96	5.40	0.181	0.929	0.655	.7

*Electronic address: garimapunetha@gmail.com

where, $m_B^{(T)}$ is the temperature dependent vector glueball mass derived using path-integral formalism alongwith the mean-field approach[7] given by the following expression,

$$m_B^{(T)} = \left[m_B^{(0)^2} - \left(8\pi^2 + 2\pi\alpha_s \right) \frac{T^2}{3} \right]^{\frac{1}{2}}, \quad (4)$$

with $m_B^{(0)}$ as the vector glueball mass at $T = 0$. With the construction of a suitable partition function for QGP, the calculation of pressure for hadron and QGP phases alongwith the Gibbs criteria leads to the critical temperature given by expression,

$$T_{c(\pi)} = \left(\frac{90}{17\pi^2} \right)^{1/4} B(T)^{1/4} \approx 0.856 B(T)^{1/4}, \quad (5)$$

above which the hadronic system evolves into a system of quarks and gluons.

The Results of the QGP calculations

Following Gibbs criteria of phase transition the critical transition temperatures of $0.140 GeV$, $0.116 GeV$ and latent heat $\Delta\epsilon$ of $0.37 GeV/fm^3$, $0.17 GeV/fm^3$ are obtained for two different coupling $\alpha_s = 0.22$ and $\alpha_s = 0.47$ respectively. The variation of specific heat (C_V) and speed of sound (c_s^2) with temperature has been shown in figure 1. C_V which is a measure of energy fluctuations in the system tend to rise sharply near a phase transition and exhibits a small upward cusp at T_c. At the critical temperature, the evolution of c_s^2 has been observed which corresponds to a transition from hadron gas to QGP phase and reaches a conformal value of 1/3 at high temperature. Furthermore, in figure 2 the coordinates for the existence of a QCD critical end point (CEP) are shown to be $(T_E, \mu_E) = (0.140, 0.019) GeV$ for $\alpha_s = 0.22$. Using such thermal bag reduces the values of critical parameters in comparision to temperature independent hadronic bag so that the expected first order phase transition turns into a rapid crossover.

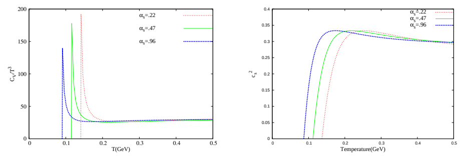

FIG. 1: The variation of normalized specific heat and speed of sound with temperature in the infrared sector of QCD for $\alpha_s = 0.22$ and $\alpha_s = 0.47$.

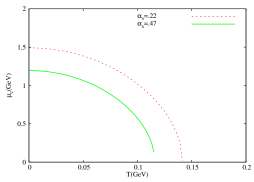

FIG. 2: The variation of chemical potential with temperature in the infrared sector of QCD for $\alpha_s = 0.22$ and $\alpha_s = 0.47$.

Acknowledgments

The author (HCC) is thankful to the University Grants Commission, New Delhi for the financial support project no. $41/840/2012(SR)$ during the course of the study.

References

[1] E. Shuryak, *Prog. Part. Nucl. Phys.* **62**, 48 (2009).

[2] B.Müller, J. Schukraft and B. Wyslouch, *Ann. Rev. Nucl. Part. Sci.* **62**, 361 (2012).

[3] Y. M. Cho, *Phys. Rev.* **D 21**, 1080 (1980), ibid **D 23**, 2415 (1981), Y. M. Cho, F. H. Cho and J. H. Yoon, *Phys. Rev.* **D 87**, 085025 (2013).

[4] H. C. Pandey, H. C. Chandola, *Phys. Lett.* **B 476**, 193 (2000).

[5] H. C. Chandola, D. Yadav, H. C. Pandey, H. Dehnen, *Int. J. Mod. Phys.* **A 20**, 2743 (2005).

[6] A. Chodos, R. L. Jaffe, K. Johnson, C. B. Thorn and V. F. Weisskopf, *Phys. Rev.* **D9**, 3471 (1974).

[7] H. C. Chandola, D. Yadav, *Nucl. Phys.* **A829**, 151 (2009).