Length (Mass) Scales in Finite Temperature Dual QCD

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Introduction

The quantum chromodynamics (QCD) vacuum with condensed monopoles/dyons (i.e., a dual Ginzburg-Landau (DGL) type model of QCD or dual QCD) has been quite successful to describe the large-distance behavior of QCD vacuum [1–4]. Nair and Rosenzweig have shown the bag and string models of hadrons are analogous to the type I and type II superconductors respectively in the framework of DGL model of QCD [5]. The Ginzburg-Landau (GL) parameter κ is used to characterize the type I and the type II superconductors in such models.

Our aim is to develop a model of dual QCD to see the changes in its various properties with the temperature especially in terms of its superconducting behavior.

In this paper, we have considered the temperature dependent DGL parameter and analysed the type-I and type-II superconducting phases of dual QCD. For this purpose, we use the effective potential at finite temperature [6–8] to describe the thermal effects of the model by investigating the field masses (or length scales) at finite temperature.

Length Scales in Dual QCD

We use the DGL model of QCD having the field–theoretic description of dyons with the following Lagrangian [9],

$$\mathcal{L} = -\frac{1}{4}(\partial_\mu \tilde{A}_\nu - \partial_\nu \tilde{A}_\mu)^2 + \frac{1}{2}|D_\mu \phi|^2 - V(\phi), \quad (1)$$

here $D_\mu = \partial_\mu + i\,Q\tilde{A}_\mu$ and $Q = \sqrt{e^2+g^2}$ with e and g as electric and magnetic charge respectively. $V(\phi) = \lambda(\phi\phi^* - v^2)^2$ with $\phi = \phi_1 + i\phi_2$.

On following the standard method in the broken mode of symmetry, Eq.(1) gives rise to two mass modes (i.e., the mass of the scalar and gauge fields as $m_\phi = 2\sqrt{\lambda}\phi_o$ and $m_{\tilde{A}} = Q\phi_o$ respectively). As such the QCD vacuum acquires the properties similar to that of a relativistic superconductor due to the breakdown of symmetry and leads to a dual Meissner effect (DME). The length scale $\xi_L = {m_\phi}^{-1}$ characterises the distance over which superconductivity remains established while the length scale $\lambda_L = m_{\tilde{A}}^{-1}$ denotes the London penetration depth or how sharply the electric field die off in the dual superconductor.

Now we define the GL parameter as $\kappa = \lambda_L/\xi_L$. In type I superconductor the vortices attract while in type II superconductors the vortices repel each other[5]. For $\kappa > 1$, superconductivity remains established so hadronic properties are well explained by the string model while for $\kappa < 1$ the vortices become free because of death of electric field before the establishment of dual superconductivity so the hadrons are well explained by the bag model. In other words, for $\kappa > 1$ the QCD vacuum will behave like the type II dual superconductor and for $\kappa < 1$the QCD vacuum will behave like the type I dual superconductor.

To see the temperature dependent effects, we consider the temperature dependent expressions of λ [10] and Q [11] as $\lambda(T) = \lambda_o(1 - aT/T_c)$, where $a = 0.88$ from quenched lattice calculation [12] and T_c is the critical temperature for phase transition and $Q^2(T) = 4\pi/[9ln(\frac{T}{0.1254T_c})^2]$ (for three quark flavors). Since the field masses should be positive quantities and imposing this condition to the temperature dependent expressions of λ and Q one obtains $0.1254T_c < T < 1.136T_c$.

It is worth noting that this temperature range actually depends upon the empirical

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parameter a. Further, we have considered $\lambda_o = 1$, and $\phi_o = 1$ for the numeric estimation of the mass of the fields.

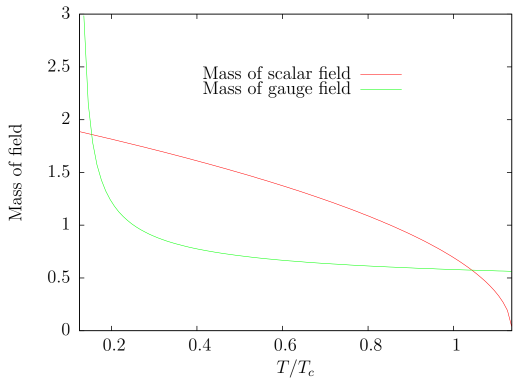

FIG. 1: Mass of fields as a function of temperature (scaled with T_c).

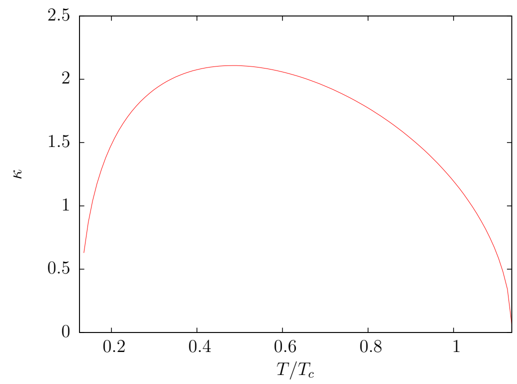

FIG. 2: The GL parameter (κ) as a function of temperature (scaled with T_c).

Results and Conclusions

In Fig.1, the scalar field mass and the gauge field mass are plotted as a function of scaled temperature (*wrt*, T_c). It is evident from the Fig.1 that the mass of gauge field decreases much rapidly than the scalar field mass at low temperature and this trend is reversed at high temperature. The comparative behavior of the mass scales is shown in Fig.2. It is clear from Fig.2 that the GL parameter κ is less than 1 at low and high temperature (near T_c). Therefore the QCD vacuum shows type I superconductor behavior in these regions. However in the intermediate temperature region, the GL parameter κ is greater than 1 and it therefore behaves like the type II superconductor in this region. The similarity in the superconducting behavior of dual QCD vacuum at the extreme ends of the temperature scale in view of the evolution of GL parameter κ needs careful attention.

We intend to develop this model more rigorously for the complete range of the temperature in near future.

Acknowledgments

We are grateful to the people of India for their generous support for research.

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