Flux-tube structure of dual QCD and thermal field dynamics

Deependra Singh Rawat[1],* H.C.Chandola[1], Dinesh Yadav[1], and H.C. Pandey[1]
[1] *Department of Physics, Kumaun University, Nainital, 263001, INDIA*
[2] *Birla Institute of Applied Sciences, Bhimtal, 263136, INDIA.*

Quantum Chromodynamics (QCD) provides the most successful description of the particles subjected to the strong interaction [1]-[2]. It reflects the underlying stucture of hadrons in terms of quarks and gluons. However, the quark have never been found in isolation yet despite of extensive searches that leads to the belive that there must exist a mechanism which confines the quarks into the color singlet state of hadrons. This commonly attributed confinement problem of color isocharges in QCD attracts a great deal of interest which is plagued by the lack of precise understanding in a fundamental way. Recently the color confinement has been discussed by utilizing the magnetic symmetry [3],[4]-[5] based dual QCD formulation as an effective theory of the non-perturbative QCD alonwith and extended to discuss the collective behavior of hadronic matter at finite temperature and densities [4]-[5]. In the present study we have put forward a brief description of the flux-tube configuration to explain color confining nature of dual QCD vacuum at zero temperature and its stablity issues has been discussed.

The underlying mechanism of color confinement for the color gauge group SU(2) can be studied by using the magnetic symmetry based dual QCD formulation for which the gauge independent Lagrangian in quenched approximation (in the absence of all the color electric objects) may be written as,

$$\mathcal{L}_m^{(d)} = -\frac{1}{4}B_{\mu\nu}^2 + |[\partial_\mu + i\frac{4\pi}{g}B_\mu^{(d)}]\phi|^2 - 3\lambda\alpha_s^{-2}(\phi^*\phi - \phi_0^2)^2 \tag{1}$$

The quadratic effective potential is appropriate for inducing the dynamical breaking of magnetic symmetry that forces the magnetic condensation resulting in dual Meisner effect with the QCD vacuum in a state of magnetic supercondutor which, with the formation of flux tubes confine the color isocharges. The above Lagrangian governs the nature of magnetically condensed vacuum and its associated flux tube structure in tems of the associated field equations $\mathcal{D}^\mu\mathcal{D}_\mu\phi + 6\lambda\alpha_s^{-2}(\phi^*\phi - \phi_0^2)\phi = 0$ and $B'^{\nu}_{\mu\nu} - i\frac{4\pi}{g}(\phi^* \overleftrightarrow{\partial}_\mu \phi) - 8\pi\alpha_s^{-1}B_\mu^{(d)}\phi\phi^* = 0$. The close resembalance of these field equations with the Neilsen and Olesen [6] vortex like solutions leads to the possibility of the existence of the monopole pairs inside the superconducting vacuum in the form of thin flux tubes that may be responsible for the confinement of any colored fluxes. The formation of color electric-flux tubes and the confinement of color charges can be visualized more effectively on the energetic grounds that may lead to the critical radius and critical density of phase transition [5] inside the hadronic sphere as $R_c = \left(\frac{8}{3}\pi n^2\alpha_s\right)^{\frac{1}{4}} m_B^{-1}$ and $d_c = \frac{1}{2\pi R_c^2} = \left(\frac{32}{3}\pi^3 n^2\alpha_s\right)^{-\frac{1}{2}} m_B^2$. For the optimal value of (α_s) in infrared sector of QCD as $\alpha_s \equiv 0.12$ with the glueball masses $m_B = 2.102GeV$ and $m_\phi = 4.205GeV$, lead to, $R_c = 0.094\ fm\ and\ d_c = 18.003\ fm^{-2}$. In this case, for below 0.094 fm, the quarks and gluons appear as free states and the system stands near the boundary of the perturbative phase. The flux tube density in this sector increases sharply and with sufficiently dense flux tube system, the flux tube annihilation may takes place which then leads to the generation of dynamical quarks and gluons. The gluon self-interactions are then expected to play a major role in the thermalization of QCD system and create an intermediatery

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*Electronic address: dsrawatphysics@kunainital.ac.in state of quark-gluon plasma (QGP).

The thermal evolution of the multi-flux tube based dual QCD vacuum may further analysed by using path-integral formalism alongwith the mean-field approach [4] where the associated thermodynamical potential leads to thermal counterpart of the vector mass mode of the magnetically condensed QCD vacuum in terms of the critical temperature as $m_B^{(T)} = (8\pi\alpha_s^{-1})^{1/2}\phi_0\sqrt{1-(\frac{T}{T_c})^2}$ where $T_c = 2\phi_0\sqrt{3/(4\pi\alpha_s+1)}$. With these considerations for the multi-flux tube system on the S^2- sphere with the periodic distribution of flux tubes over the sphere of radius R, the color electric field under varying thermal conditions is obtained as [5], $E_m^{(T)}(\theta) = \tilde{E}_m^{(T)} exp(-Rm_B^{(T)} sin\theta)$

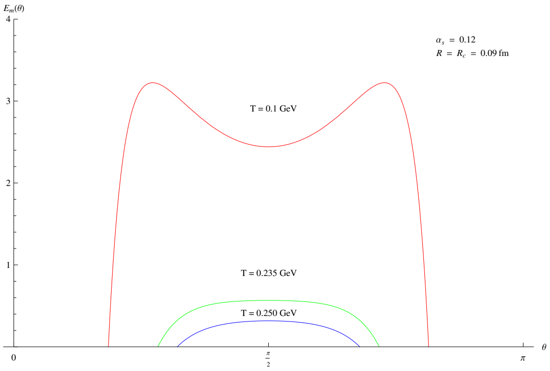

FIG. 1: Profiles of color electric field $E_m(\theta)$ for different T at $\alpha_s = 0.12$

The thermal evolution of the above color electric field for the optimal value of strong coupling constant i.e. $\alpha_s = 0.12$ as depicted demonstrate a partially uniform distribution of color electric field around the critical temperature of 0.235 GeV. However, at this temperature, the deviation of color electric from the complete uniform distribution is an indication of the appearence of thermal monopoles contributing to the stability of multi-flux tube system before transiting to the weakly coupled QGP or completely deconfined phase. The weakining of color electric field around critical temperature may subsequently set up the plasma oscillation in the flux tube system. In the present multi-flux tube system, since the magnetic glueball mass (m_B), that determines the magnitude of dual Meissner effect, is much greater than the plasma frequency obtained for type-II superconductor [7] such plasma oscillations though may lead to the breaking of flux-tubes in magnetically condensed QCD vacuum but not eventually radiative flux system therby maintaining the stability of flux-tube system around critical point of phase transition. The existence of stable flux tube system in thermal domain also, is a noble feature of present dual QCD formulation and may be used to deal with the dynamical problem of QCD phase transitions.

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