Implications of DMHD in Color Flux Tube Dynamics of QCD

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It has been widely believed that the non-perturbative features of QCD vacuum particularly the color confinement [1]-[3] can be realized in terms of the color flux-tube structure of dual QCD which has also played a significant impetus in exploring the peculier properties like Quark-Gloun Plasma associated with QCD at high temperature and density which is still not clear and understandable. These investigations has also been revitalized by ultrarelativistic heavy-ion collisions at RHIC and LHC. One of the exiting outcome stemming from the analysis of RHIC resultsis that the QGP [3] in the viscinity of critical temperature (T_c) exhibit itself as a strongly coupled fluid (sQGP). Many studies in this direction related this peculier feature to the dual scenario of QCD where quarks and gluons are confined within the hadronic boundaries by means of color flux-tubes. This implies that the confining domain of QCD vacuum is magnetically dominated while the high temperature regime is dominated by color electric objects. Thus it seems to be an intimate connection of the stability of color flux-tubes with the strongly coupled behavior of QGP near T_c, where magnetic coupling become intense, and corresponding state is characterised as dual magnetic plasma dominated by color magnetic monopoles. The experimentally observed structures cone and ridge in heavy-ion collisions in a dual magnetized medium may have zero expansion velocity, that indicates the existence of stablized flux-tubes near T_c. In the present study using the DMHD fpormulation we have investigated the evolution of color flux tubes and the stability of such flux-tubes in dual magnetized phase by evaluating their life time in the near infrared sector of QCD.

In RHIC, the formation of glasma and its subsequent decay into QGP suggest the existence of dual corona in QGP where color electric field coexist with the plasma. In the dual magnetic plasma phase, the uncondensed monopole be able to create a coil and form a solenoidal currents, which induce a color-electric field and form a stablized flux-tube. The diffusion of this color electric field in the dual magnetized medium thus provides the flux-tube evolution in terms of its half-life in the presence of dissipative effects which brings into the system by allowing the conductivity to be finite due to the presence of colored fields. The dual magnetic plasma consists of four main components, viz monopole, antimonopole, quarks and gluons. The monopoles and antimonopoles which are gauge equivalent flow oppositly and produce the solenoidal current around the color flux-tube. The medium thus produced has an overall zero magnetic charge, so that their density becomes $n_+ = n_- = \frac{n_m}{2}$. The electrical objects, quarks and gluons, have densities n_q and n_g respectively. For the dual magnetized phase in the viscinity of T_c-region, the total scattering rate for the positively charged colored monopole may then be expressed as,

$$\nu_+ = \nu_{+-} + \nu_{+g} + \nu_{+q} \tag{1}$$

where, we have ignored intra collision as it cannot change the total momentum of the particular object and do not make any significant contribution in the respective current. The +- cross section is the transport

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cross section arising due to dual Coulomb force obtained using the Dirac quantization condition and the density $n_e \rightarrow n_-$ [4]. Thus, by symmetry, the total collision rate is then $\nu_{total} = \nu_+$. Keeping in view of above discussion to dual magnetized phase, the total collision rate and the conductivity of the medium in the present dual QCD scenario may then be expressed as,

$$\nu_{tot} = 4T_c\left[\sqrt{\left(\frac{49\alpha_s^4}{m_\phi}+1\right)}\right],\ \sigma_m = \frac{3.75\alpha_s}{m_\phi \nu_{tot}}T_c^3 \quad (2)$$

The energy per unit length k_m diffused during the dual magnetised phase is then given by,

$$k_m(t) = 2\pi\int_0^\infty r_{ft}dr_{ft}\left[\frac{E_m^2(r_{ft},t)}{8\pi}+K(r_{ft},t)\right], \quad (3)$$

which may then scales as,

$$\frac{k_m(\tau_m)}{k(0)} = \frac{a_0^2}{a_0^2+4\eta_m\tau_m} \quad (4)$$

For $\alpha_s = 0.96$, we estimate $a_0 = 0.2fm$ that leads the mean square flux-tube radius for large coupling domain as 27.04 fm. Thus, to gain analyse more about the time evolution of color flux-tube in large hadronic domain, let us calculate the half-life $t_{1/2}$ of the associated field at the origin. At the origin at t=0, we have $E_m = E_{m0}$. So by definition,

$$E_m(0,t_{1/2}) = \frac{E_m}{2} = \frac{E_{m0}a_0^2}{(a_0^2+4\eta_m t_{1/2})}, \quad (5)$$

which then leads the half-life of the color flux-tube in the following form,

$$t_{1/2} = \frac{1}{4}\frac{a_0^2}{\eta_m} = \pi\sigma_m a_0^2 = 6.7\times10^{-3}fm. \quad (6)$$

Similarly, for other couplings $\alpha_s = 0.12$, 0.24 and 0.48, the flux-tube life time comes out to be $2.3\times10^{-4}fm$, $1.5\times10^{-4}fm$ and $6.7\times10^{-3}fm$ respectively.

Using the dual description of MHD, computation of the value of the constant η_m (which contains the contribution from conductivity of dual plasma) using a picture of monopole-monopole and monopole-gluon rescattering leads that the semi-classical approach indicates very strong dissipative effects that are way too strong for the flux tubes to survive or decay very quickly in the few fm/c time frame in the magnetic phase. Hence, it indicates that a classical approach to the flux tube dissipation appear to have its own limitations and agreed with the results obtained by [4]. As a matter of fact, unlike flux tubes usually considered in magnetohydrodynamics (e.g., in solar plasmas), the QCD flux tubes under consideration are microscopically small in size and not larger than the quasiparticle Compton wavelength possibly sourcing the contradiction. It further indicates towards using the quantum-mechanical description of DMHD. Quantum effects in the monopole motion may then provide two supercurrents which propagate through each other without any dissipation which may therefore, be helpful to eliminate the inconsistencies in the semi-classical treatment of DMHD and explore new avenues in this direction.

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