Flux tube interaction and QGP formation process

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Abstract

In order to study the underlying mechanisms associated with the non-perturbative confining features and phase structure of QCD, a dual color gauge theory based on magnetic symmetry leading to the multi-flux tube structure of QCD, has been analyzed and the interaction energy between flux tubes has been calculated. The flux tube interaction has been shown to play an important role in the pre-equilibrium QCD system and leads to the annihilation of flux tubes depending on their color charge.

Quantum Chromodynamics as a fundamental descriptiopn of strong interaction, explains the binding of three almost massless color isocharges into a much heavier nucleons and thus most of the mass of the visible universe.Though QCD has proved to be very successful in explaining the features associated with its high energy sector, it is still challenging to explore its low energy features among which color confinement is the major challenging issue for many years. There are various non perturbative models have been proposed in this direction among which magnetic symmetry based dual QCD [1]-[3] has been used here as a viable theory to explain the confining features of quarks inside the hadronic bag. In such a dual gauge theory of strongly interacting particles, the flux tube solutions [4] appear as a topological excitation with the appearence of vector and scalar glueballs in the magnetically dominated regime of QCD vacuum. This novel picture of dual QCD vacuum is expected to systematically explore the complex phase structure of QCD with the possibility of the formation of QGP[5, 6] as a state of nuclear matter under the extreme conditions of temperature and density [7, 8].In view of these facts, in the present article we have investigated the interaction among various kind of flux tubes in the QCD system.

In a (4+n)-dimensional metric manifold (g_{AB}), magnetic symmetry [9, 10] based field decomposition formulation provides a gauge invariant investigation and topological features to the color confinement for which the Lagrangian with built-in dual structure in quenched approximation may be expressed as [1]-[3],

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

$$-3\lambda\alpha_s^{-2}(\phi^*\phi - \phi_0^2)^2 \quad (1)$$

ϕ being the complex scalar monopole field and $\alpha_s = g^2/4\pi$.The quadratic effective potential introduced here for inducing the dynamical breaking of magnetic symmetry which, in turn, leads to the monopole condensation resulting in the QCD confinement through dual Meissner effect. The associated flux structure of dual QCD vacuum then leads to the static quark potential[2] given by,

$$V(r) = -\frac{\mathbf{Q^2}}{4\pi}\frac{exp(-m_B r)}{r} + \frac{Q^2 m_B^2}{8\pi} r ln(1+\kappa^2) \quad (2)$$

where, $\kappa = m_\phi/m_B$. The $m_B (= (8\pi\alpha_s^{-1})^{\frac{1}{2}}\phi_0)$ and m_ϕ are respectively the characteristic mass scales of the vector and scalar mode of the magnetically condensed QCD vacuum.

We now apply the magnetic symmetry based

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dual QCD approach to the quark-gluon plasma (QGP) formation process in ultrarelativistic heavy ion collisions where many color flux-tubes are formed just after the collision as a result of the flux tube interaction. The said formulation describes well the flux tube structure which is very much important in the initial stage immediate after the heavy ion collisions. There would be the overlapping of several flux tubes in the central zone where the energy of the collision is high enough and therefore the interaction between the flux tubes plays a vital role. In the QCD system the quark color charges (Q_i and $\bar{Q}_i$, i=1,2) are, in fact, capped by the flux tube at its ends. For optimal values of strong coupling ($\alpha_s \simeq 0.22$), the magnetically condensed vacuum forms type-II superconducting phase with a large number of flux tubes[1]. We then study the interaction between the two color flux tubes at distance 'ρ' from each other and idealize the system as two sufficiently long flux tubes by neglecting the effect of their ends. For $\rho \gg m_\phi^{-1}$, the interaction energy per unit length between the flux tubes comes out to be

$$\varepsilon_{int} \simeq (\mathbf{Q_1}.\mathbf{Q_2})\phi^{-1}E_m(\rho) \qquad (3)$$

Where

$$E_m(\rho) = \frac{\phi C}{4\pi\rho^{3/2}}(2m_B\rho - 1)exp(-m_B\rho)$$

. In SU(2) QCD, flux tubes with opposite flux direction (e.g. $R - \bar{R}$ and $\bar{R} - R$), we have $\mathbf{Q_1} = -\mathbf{Q_2}$, i.e. $\mathbf{Q_1}\dot{\mathbf{Q_2}} = -e^2/4$, so that these flux tubes get attracted towards each other and would be annihilated into dynamical gluons. On the basis of the above calculation, we may deal an interesting scenario on the QGP formation via the annihilation of the color flux tubes. When the flux tubes are sufficiently dense in the central region just after the relativistic heavy-ion collisions, the flux tubes annihilation may occur. During the interaction process lots of dynamical quarks and gluons would be created and the energy of the flux tubes turns into that of the kinetic motion of quarks and gluons. The thermalization is achieved through the stochastic collisions between quarks and gluons, and finally the hot QGP would be created. In more realistic case, both the quark-pair creation and the flux-tube annihilation would take place at the same time. For instance, the flux tube breaking [11] would occur before the flux tube annihilation for the dilute flux tube system. On the contrary, in case of the extremely high energy collisions, there would be lots of flux tubes overlapping in the central region between heavy ions, and therefore the flux tube interaction should play the dominant role in the QGP formation process. For SU(3) case the interaction between different color flux tubes leads their unification into a single flux tube. In both the cases magnetic symmetry based dual QCD provides and effective method for the dynamics of color-electric flux tubes in the QGP formation.

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