Screening current and dielectric parameters in dual QCD

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The screening current mechanism and dual Meissner effect in the QCD vacuum have been studied in view of the action for a dual (magnetic) superconductor derivable from the Zwanziger’s two-potential formalism. The flux tube structure emerging as an artifact of screening current in the background of both the monopole and dyon condensation has been investigated. The magneto-statical representation of the flux tube has also been presented with the conditions which are necessary to form a tube. The dielectric parameters of dual QCD vacuum have been calculated and the size of the flux tube resulting from the monopole and dyon condensation is compared.

Keywords: Dyons/monopoles, Screening current, Dual Meissner effect, Flux tube, Dielectric parameters

1 Introduction

The ground state of QCD vacuum with the condensed monopoles¹ has a striking analogy with the conventional superconductivity where the ground state is the condensate of Cooper pairs². Such QCD vacuum as a magnetic superconductor manifests itself in terms of the formation of thin tubes of colour electric flux³. In this formulation, the dual potentials along with the field operators which correspond to the topological objects (viz. monopoles and dyons) are the appropriate variables to describe the large-distance behaviour of QCD vacuum⁴, ⁵. In order to describe the topological (magnetic) charges in the corresponding theories, a field operator similar to a complex scalar field which couples to the dual gauge field in QCD was first proposed by Mandelstam⁶ and ’t Hooft⁷ independently. On the other hand, in view of the techniques of the Abelian gauge fixing⁸ and lattice QCD calculations⁹, it is quite reasonable to pay attention over the dominance of Abelian components¹⁰ in the non-Abelian (Yang-Mills) gauge theories at large-distances where the confinement of the quarks is actually realised¹¹. The physical vacuum with a non-Abelian gauge theory¹² like QCD appears analogous to the ground state of an interacting many body system with vacuum screening currents¹³. The non-perturbative vacuum state¹⁴ with a non-vanishing vacuum expectation value (VEV) of the scalar field vanishes, which is corresponding to the perturbative phase in the usual QCD vacuum¹². Moreover, in the superconducting phase, the vector particles acquire mass through the screening current mechanism and such vector theories are also renormalisable¹⁵.

In the present paper, using an action for magnetic superconductors (i.e. dual QCD) derived from two-potential formalism for Abelian charges and monopoles/dyons¹⁶ as suggested by Zwanziger¹⁷, the role of screening currents in hadronic flux tube formation along with the dielectric parameters of such QCD vacuum has been studied. The dual Meissner effect (DME) and the dielectric parameters are compared for the case of monopole and dyon condensation. The schematic view of DME and the dielectric parameters for both the cases are also presented along with a possible representation of the flux tube in each case.

2 Zwanziger Formalism and Dual QCD: A Brief Overview

The Zwanziger’s formulation of a local field theory deals with two electromagnetic four potentials which interact covariantly with the electric and magnetic currents¹⁷. For the sake of completeness, we will quickly recall the Zwanziger’s approach to construct an Abelian Higgs model¹⁸ (AHM) of QCD.

One can begin with the generalised Maxwell’s equations \( \partial \mu F_{\mu \nu} = J_{\nu} \) and \( \partial \nu F_{\mu \nu} = K_{\mu} \). In these equations, the electric \( (J_{\nu}) \) and magnetic \( (K_{\mu}) \) currents are the
sources of the field strength tensor \((F_\mu)\) and its dual \((F'_\mu)\) respectively. In order to deduce these equations from a classical action, Zwanziger introduced two vector potentials \(A_\mu\) (electric) and \(C_\mu\) (magnetic) with the aim to express the field strength tensors in terms of these potentials. Using an identity for an anti-symmetric tensor and calculating \(NF\) and \(NF'\) along a fixed four vector \(n^\mu\), one can write \(F\) and \(F'\) in terms of the above-mentioned pair of potentials with straightforward calculations\(^\text{17}\). The electric and magnetic currents can also be rewritten easily in terms of these two potentials like the field strength tensors and one can see that the Maxwell’s equations are satisfied with the conserved electric and magnetic currents (i.e. \(\partial J=0\) and \(\partial K=0\)). This elegant dual structure with the conserved currents can further be used, to describe the dual description of QCD vacuum with the Abelian dyons\(^\text{18}\) by assuming a non-trivial vacuum (thus, incorporating spontaneous symmetry breaking in the formulation with the Higgs field).

The Zwanziger’s formulation is somewhat dual to the Ginzburg-Landau (GL) description applicable to the quantum field theories; however a difference to the GL action is that it contains a non-local string term such that it starts from a positive charge and terminates on a negative charge. The partition function for dyons with a Higgs scalar field \(\Phi\) is defined in Euclidian space-time\(^\text{17/20}\) as follows:

\[
Z_D = \int DA_\mu\, DC_\mu\, D\Phi \, \exp \left\{ -S_D[A_\mu, C_\mu, \Phi]\right\} \quad \ldots(1)
\]

where the action \(S_D\) with a correct field-theoretic description of dyons is given as follows:

\[
S_D[A_\mu, C_\mu, \Phi] = S_{zw}[A_\mu, C_\mu] + \int d^4x \left\{ \frac{1}{2} \left( (\partial_\mu - ieA_\mu - ig C_\mu) \Phi \right)^2 - \lambda \left( |\Phi|^2 - \Phi^*_\mu \Phi^\mu \right)^2 \right\} \quad \ldots(2)
\]

where \(e\) and \(g\) denote the electric and magnetic charges respectively and the action \(S_{zw}[A_\mu, C_\mu]\) is given as below\(^\text{18}\):

\[
S_{zw}[A_\mu, C_\mu] = \int d^4x \left\{ \frac{1}{2} \left( n \cdot [\partial \wedge A] \right)^2 + \frac{1}{2} \left( n \cdot [\partial \wedge C] \right)^2 \right\} + \frac{i}{2} \left( n \cdot [\partial \wedge A] \right)^\ast \left( n \cdot [\partial \wedge C] \right) \ldots(3)
\]

The action in Eq. (3) is invariant under a linear transformation of the gauge fields \(A_\mu\) and \(C_\mu\) as \((A_\mu, C_\mu) = R(\delta)(A_\mu, C_\mu)^\top\) where \(T\) denotes the transpose and \(R(\delta)\) is a \(2\times2\) matrix corresponding to well-known \(U(1)\) transformations. Using \(\tan \delta = g/e\), the integration of the usual partition function for dyons given by Eq. (1) over the transformed electric gauge potential then leads to the partition function of the AHM of QCD as given below:

\[
Z_D \propto Z_{AHM} = \int D\tilde{C}_\mu D\Phi \left\{ \exp( -S_{AHM}[\tilde{C}_\mu, \Phi]) \right\} \ldots (4)
\]

where the action \(S_{AHM}\) with the transformed magnetic gauge field \(\tilde{C}_\mu\) in Eq. (4) has the following form:

\[
S_{AHM}[\tilde{C}_\mu, \Phi] = \int d^4x \left\{ \frac{1}{4} \tilde{C}_\mu \tilde{C}^\mu_\nu + \frac{1}{2} |(D_\mu \Phi)|^2 \right\} - \lambda \left( |\Phi|^2 - |\Phi_\mu|^2 \right)^2 \quad \ldots(5)
\]

with \(D_\mu \equiv \partial_\mu - iQ\tilde{C}_\mu\) and \(Q = \sqrt{e^2 + g^2}\). The scalar field \(\Phi\) with electric as well as magnetic charge in the action given in Eq. (5) is dyonic in nature and the gauge field strength tensor \(\tilde{C}_\mu = \partial_\mu \tilde{C}_\nu - \partial_\nu \tilde{C}_\mu\) having its field contents\(^\text{20}\) as \(\tilde{E}\) (colour electric field) and \(\tilde{B}\) (colour magnetic field). The action given in Eq. (5) exactly coincides with the GL-type action and the GL free energy in the broken phase of symmetry for the static case can be approximated as follows:

\[
H_0 = K_g + \frac{1}{2} Q^2 \tilde{F}_\mu \tilde{F}^\mu_\nu \tilde{C}_i^2 + \ldots \quad \ldots(6)
\]

where \(K_g = \tilde{E}^2/2\) is the gluon field energy. We will use the Eqs (5 and 6) for the description of the confining properties of the colour electric sources in view of the colour flux screening and dielectric parameters in dual QCD.

3 Screening Mechanism and Flux Tube Formation

In order to investigate the screening current and its possible implications on the nature of QCD vacuum, we first analyse the screening current structure of QCD vacuum for the present model. For the very purpose, the field equations corresponding to the action given by Eq. (5) are derived in the form given below:

\[
H_0 = K_g + \frac{1}{2} Q^2 \tilde{F}_\mu \tilde{F}^\mu_\nu \tilde{C}_i^2 + \ldots \quad \ldots(6)
\]

where \(K_g = \tilde{E}^2/2\) is the gluon field energy. We will use the Eqs (5 and 6) for the description of the confining properties of the colour electric sources in view of the colour flux screening and dielectric parameters in dual QCD.
\[ \partial^\nu \tilde{C}_\mu - i \frac{Q}{2} (\Phi^* \partial_\mu \Phi - \Phi \partial_\mu \Phi^*) - Q^2 (\Phi \Phi^*) \tilde{C}_\mu = 0 \] 

\[ D^\mu (D_\mu) \Phi - 4\lambda (|\Phi|^2 - \Phi^2) \Phi = 0 \]  

The field Eqs (7 and 8) govern the dynamics of QCD vacuum in the broken phase of symmetry. It may also be noted that these field Eqs (7 and 8) are identical to the GL-type field equations in conventional superconductivity. Since the macroscopic description of the formulation involves a number of dyons, it is better to specify the mass modes and other crucial parameters in terms of the density of the condensed dyons or monopoles. The scalar field \( \Phi \) would be such that it remains effectively unperturbed by the colour electric field and the density of superconducting dyons or monopoles must be defined by its constant modulus given in terms of \( \Phi_0 \). In the dual QCD vacuum, the parameters specifying the confining mechanism of vacuum are, indeed, closely related to such density profile of dyon or monopole pairs. The vacuum, as the coherent condensate of all such pairs\(^{21}\), may then be normalised to:

\[ n_s(\Phi) = |\Phi|^2 = \Phi_0^2 \]  

The density of condensed dyons given by Eq. (9) cannot possibly be defined like this in the high energy perturbative sector of QCD as the VEV of dyon or monopole field would disappear completely in the ultraviolet region. The density profile along with other confinement parameters in the non-perturbative infrared sector can, therefore, be used for the correct physical explanation of the confining behaviour of QCD vacuum.

Let us consider, the variations in the dyon field such that \( \partial_\mu \Phi = 0 = \partial_\mu \Phi^* \) (as it has a finite value at each space–time point), the field Eq. (7) then takes the following form:

\[ [\partial^\nu, \partial^\nu + m_{v}^2] \tilde{C}_\mu - \partial_\mu (\partial^\nu \tilde{C}_\nu) = 0 \]  

The divergence of Eq. (10) leads to \( \partial^\nu \tilde{C}_\mu = 0 \) (i.e. Lorentz condition). The Eq. (10) appears as the massive vector-type equation and it may be identified with that of the condensed mode of QCD vacuum. The present formulation has two mass (i.e. vector and scalar) modes which are given as follows:

\[ m_v = Q\sqrt{n_s(\Phi)} \; ; \; m_\phi = 2\sqrt{\lambda n_s(\Phi)} \]  

These mass modes appear as in any standard Higgs mechanism\(^{21,22}\) and the massive vector Eq. (10) demonstrates that the QCD vacuum, as a result of symmetry breaking, acquires the properties similar to that of a relativistic superconductor where the quantum fields generate a non-zero VEV. The interaction between the macroscopic field \( \Phi \) and \( \tilde{C}_\mu \) leads to a typical colour flux screening arising because of a screening current due to strong correlation among the dyonic or pure magnetic charges. In passing through, it may be noted that the type of superconducting behaviour of such vacuum is characterised by the GL parameter (\( \kappa \)) defined as \( \kappa = m_\phi / m_v \). The QCD vacuum behaves as type-II superconductor for \( m_\phi > m_v \) while type-I for \( m_\phi < m_v \). However, when the mass scales have equal value i.e. \( Q = 2\sqrt{\lambda} \), the QCD vacuum undergoes a transition from type-II to type-I superconducting state\(^{21}\). The gauge quanta, which propagate in the broken phase of QCD vacuum, then satisfies an equation of the form:

\[ \partial_\mu \partial^\nu \tilde{C}_\mu = J_\mu \]  

where \( J_\mu \) is the screening current that resides in the vacuum and is generated as a result of the dyon condensation of the QCD vacuum. The comparison of Eqs (10 and 12) with Lorentz condition, thus, leads to:

\[ J_\mu = m_v^2 \tilde{C}_\mu \]  

which is a typical screening current condition and in static case, it reduces to the well-known London equation. The setting-up of such condition on screening current in QCD vacuum then makes the confinement of any coloured source inevitable, which is discussed next. The screening current \( J_\mu \) at any given point is directly proportional to \( \tilde{C}_\mu \) at the same point and, therefore, necessarily provides a local relation between them. The colour electric field \( \vec{E} = \nabla \times \vec{C} \) satisfies \( \nabla \times \vec{E} = J_\mu \). Using such considerations, one may immediately deduce the following equation:

\[ \nabla^2 \vec{E} - \nabla \left( \nabla \cdot \vec{E} \right) - m_v^2 \vec{E} = 0 \]  

where \( \vec{E} \) is the colour electric field.
The screening current also satisfies an equation exactly similar to given in Eq. (14) which can be visualized by just replacing \( \mathbf{\tilde{E}} \) by \( \mathbf{J}_s \) in Eq. (14). If we consider, \( \mathbf{\tilde{E}}=\{0,0,E_z(x)\} \) which also satisfy \( \nabla \cdot \mathbf{\tilde{E}}=0 \), the Eq. (14) reduces to the following simple second order differential equation (or Helmholtz equation in dual QCD),

\[
     k \{ \partial_z^2 E_z(x) - m_v^2 E_z(x) \} = 0 \quad \ldots (15)
\]

where \( k \) is unit vector along \( z \)-direction. Eq. (15) has the following general solution:

\[
     E_z(x) = D_1 \exp (-m_v x) + D_2 \exp (m_v x) = 0 \quad \ldots (16)
\]

where \( D_1 \) and \( D_2 \) are integration constants. Since \( E_z(0)=E_0 \) at \( x=0 \) and it cannot increase to infinity far from \( x \), the integration constants are given as \( D_1=E_0 \) and \( D_2=0 \). Eq. (16), itself, guarantees that the colour electric field penetrates the vacuum up to a finite depth \( 1/m_v \). The penetration depth acts as an important parameter and it is one of the characteristic features of the broken phase of symmetry in dual QCD. The screening current in terms of the vector mass mode effectively screens out the colour electric flux and confirms the onset of the DME in QCD. Such dyonic screening leading to DME may also be thought of as fundamental as that of a displacement current in the quantum electrodynamics (QED) with a definite local relationship with \( \mathbf{\tilde{C}} \) around a given point. For the case when \( e=0 \), the dyonic vector mass mode given in Eq. (11) reduces to the pure magnetic counterpart (i.e. monopole case) with the mass of dual gauge field given by \( m_g = g \sqrt{n_0(\Phi)} \). The dyonic vector mass mode is therefore always greater than its pure magnetic counterpart at a constant density (i.e. the number of monopoles or dyons remain the same in the condensed mode). A comparative view of both the cases is shown in Fig. 1 in terms of a dimensionless quantity \( \gamma=Q/g \). The cases with \( \gamma=1 \) (\( e=0 \)) and \( \gamma > 1 \) (\( e\neq0 \)) are corresponding to monopole and dyon condensation, respectively. In case of dyon condensation, the decay of the colour flux is always faster than that of the monopole condensation as \( m_v^2 > m_g^2 \). We can consider the maximum radius of the flux tube as the inverse of the vector mass mode \( ^{11} \) and since the vector mass mode for the monopole case is less heavier than that of the dyon case, the radius for the flux tube for the latter would be smaller

\[
    \nabla P = \mathbf{J}_s \times \mathbf{\tilde{E}} \quad \ldots (17)
\]

where \( P \) is analogous to the scalar pressure which is constant everywhere inside the condensate. The scalar pressure \( P \) can be identified in terms of a colour force...
\( \mathbf{E} \times \mathbf{J} \), per unit area (i.e. the negative gradient of pressure) of the flux tube. The static condition for pressure balance may, further, be expressed as follows:

\[
V(P+2K_\pi-(\mathbf{E} \cdot V)\mathbf{E}) = 0 \quad \text{(18)}
\]

Eq. (18) is necessary to maintain the equilibrium of the condensate and the colour force would prevent the motion of the flux lines in the transverse direction. For the simplest equilibrium configuration, the flux lines are a set of parallel lines in the form of a flux tube with:

\[
(\mathbf{E} \cdot V)\mathbf{E} = 0 = (V \cdot \mathbf{E})\mathbf{E} \quad \text{(19)}
\]

and, thus, leads to the conservation of the scalar quantity \( P+2K_\pi \). However, in the absence of the pressure exerted by the gluon fields, the flux lines of the tube may begin to move in the direction perpendicular to the screening current and colour electric field. In fact, the colour electric flux and the screening current lie nearly in surface of the constant confining pressure and both are normal to the \( \nabla P \) i.e.,

\[
\mathbf{E} \cdot \nabla P = (\mathbf{E} \cdot \nabla)\mathbf{E} = 0 \quad \text{(20)}
\]

Moreover, in order to check the quantisation of the colour electric flux which constricts as flux tubes \( 24 \), let us consider the Nielsen-Olesen type ansatz \( 25 \) for the dual gauge and dyon field in the cylindrically symmetric coordinate system as \( \tilde{\mathbf{C}} = \tilde{C}(r) \hat{e}_0 \) and \( \Phi = \zeta(r) \exp(i\phi) \) with \( \phi = n\theta \) where \( n = 0, \pm 1, \pm 2, \pm 3, \ldots \) The quantisation of colour electric flux may then be understood in terms of the kinetic energy part corresponding to the scalar field i.e. \( |D_\mu \Phi|^2 \) as given in action in Eq. (5). The minimisation of such kinetic energy leads to the quantisation of the colour electric flux which can be visualised by considering the line integral \( \oint \tilde{\mathbf{C}} \cdot d\mathbf{l} \) around the circle \( S^1 \) at infinity. Using the Stokes theorem, the total colour electric flux enclosed, is then given in the following form:

\[
\Psi_\pi = \oint (\nabla \times \tilde{\mathbf{C}}) \cdot d\mathbf{S} = \int \mathbf{E} \cdot d\mathbf{S} = n \Psi_0 \quad \text{(21)}
\]

where \( \Psi_0 = 2\pi / Q \) which shows that the electric flux is quantised in terms of the dyonic charge.

### 4 Dielectric Parameters and Confinement

The bulk QCD magnetic properties of such vacuum as a dielectric medium \( 26 \) have been investigated. The vacuum polarisation and dielectric constant are inherently connected through the polarisation tensor. In order to translate the field \( \Phi \) to a minimum energy position with its parameterisation as \( \Phi = (\Phi_0+\chi+i\eta) \), the kinetic and potential energy terms in the action in Eq. (5) are modified as follows:

\[
\begin{align*}
|D_\mu \Phi|^2 &= (\partial_\mu \chi)^2 + (\partial_\mu \eta)^2 + Q^2 \Phi_0^2 \tilde{C}_\mu \tilde{C}^\mu \\
&\quad - Q \Phi_0 \tilde{C}_\mu \partial^\mu \eta + \cdots \quad \text{(22)}
\end{align*}
\]

\[
\begin{align*}
\lambda (|\Phi|^2 - \Phi_0^2)^2 &= \lambda (\chi^2 + \eta^2)^2 \\
&\quad + 4\lambda (\chi^2 + \eta^2) \chi \Phi_0 + 4\lambda \Phi_0^2 \chi^2 \\
&\quad \text{ (23)}
\end{align*}
\]

where in Eq. (22), the remaining part is for the interaction terms which contain at least three fields (i.e. cubic and quartic in nature). However, the last (quadratic) term \( \tilde{C}_\mu \partial^\mu \eta \) on the right-hand side of Eq. (22) implies that one can have Feynmann diagrams in which the dual gluon field changes to \( \eta \) without interacting any other particle. The action given by Eq. (22) can now be expanded about vacuum, which gives to its following linearly approximated London form \( 27 \):

\[
S_{\text{AHM}}[\tilde{C}_\mu, \Phi] = \int d^4x \left\{ -\frac{1}{4} \tilde{C}_{\mu
u} \tilde{C}_{\nu\rho} + \frac{1}{2} (\partial_\mu \chi)^2 \\
&\quad + \frac{1}{2} (\partial_\mu \eta)^2 + \frac{1}{2} Q^2 \Phi_0^2 \tilde{C}_\mu \tilde{C}^\mu + 4\lambda \Phi_0^2 \chi^2 + \cdots \right\} \quad \text{(24)}
\]

It shows a particle spectrum with massive scalar (\( \chi \)) and vector (\( \tilde{C}_\mu \)) fields accompanied by a mass-less scalar (\( \eta \)) field as described in Eq. (24). The dual gauge field in fact interacts with the medium through a mass-less and constant scalar field. The appearance of the \( \eta \) field is actually spurious (unphysical) and can be gauged (or eliminated) away with a suitable choice of gauge in a way same as in the Higgs mechanism. This can also be understood as a consequence of well-known Goldstone theorem. In order to have the bulk magnetic properties of such QCD vacuum, the magnetic polarisation tensor \( 27,28 \) can be calculated in the following form:

\[
\tilde{\Pi}_{\mu\nu}(p) = (p_\mu p_\nu - p^2 g_{\mu\nu}) \tilde{\Pi}(p^2, \Phi_0) \quad \text{(25)}
\]
where the polarisation function is given as 
\[ \Pi(p^2, \Phi_0) = -m_e^2 / p^2 \]
which can be calculated by using the Feynman rules, and the Eq. (25) remains valid for all values of momentum \( p \). The polarisation tensor is related to the dual gluon propagator as follows:

\[ \tilde{D}_{\mu\nu}(p) = \frac{\tilde{D}_{\mu\nu}^0}{1 + \Pi(p^2, \Phi_0)} \quad \ldots (26) \]

where \( \tilde{D}_{\mu\nu}^0 \) is the bare gluon propagator as given below:

\[ \tilde{D}_{\mu\nu}^0 = \frac{1}{p^2} \left( -g_{\mu\nu} + \frac{p_{\mu}p_{\nu}}{p^2} \right) \quad \ldots (27) \]

Using the polarisation function, the magnetic permeability (which would be basically defined through the bare and full dual gluon propagators) may then be given as:

\[ \mu(p^2, \Phi_0) = 1 + \tilde{\Pi}_{\mu\nu}(p) = 1 - p^2 m_e^2 \quad \ldots (28) \]

In view of the relativistic invariance (i.e. the QCD vacuum should behave same in all the Lorentz frames), the dielectric parameter may then immediately be defined as \( \varepsilon(p^2, \Phi_0) = \{ \mu(p^2, \Phi_0) \}^{-1} \). The relativistic invariance (i.e. \( \varepsilon \mu = 1 \) in natural system of units) indeed translates the magnetic response of the present theory into the electric one without any loss of generality. The dielectric constant of superconducting QCD vacuum vanishes with the vanishing momenta and consequently the magnetic permeability rises to infinity, which indicates that the QCD vacuum behaves as a perfect dielectric medium. However, at a fixed momentum, the dielectric constant for the case of dyonically condensed QCD vacuum is greater than that of the pure magnetically condensed mode. Since the dielectric constant may be considered as a measure of the extent to which it concentrates the colour flux lines, so a much finer flux tube would emerge for the dyonically condensed QCD vacuum where the dielectric constant is always greater than the case of monopole condensation. The schematic view of the dielectric parameters for the dyon condensation is also shown in Fig. 2. We have plotted the dielectric parameters with respect to \( (m_e / p)^2 \) which acquire a unique value at a particular momentum. The higher value of the dielectric constant for the case of dyon condensation may, therefore, be inherently connected to the fast decay rate of the colour electric field as evident from Fig. 1. In a nutshell, by combining these three points: the radius of the flux tube, the number of flux lines passing through an area and the definition of the dielectric parameter, a slightly thin flux tube structure can be inferred schematically as shown in Fig. 3 for the case of dyon condensation where the number of flux lines are more but constricted in a less space. Detailed investigations are further needed to have a more transparent picture of such flux tubes in view of the fluctuating dyonic charge\(^{18,20}\).

5 Conclusions and Open Issues

The dyon condensation, thus, provides an illuminating alternative way to explain the colour confinement through DME which arise as a consequence of the screening current in vacuum and is equally capable in describing the superconducting QCD vacuum as the monopole condensation. The presence of the magnetic and dyonic charges in QCD imparts the dielectric nature to it due to their vacuum polarisation. It is shown that with the vanishing momenta for which the magnetic permeability rises to infinity indicates that the QCD vacuum behave as a perfect dielectric medium which is irrespective of the
type of condensate therein vacuum. A schematic view of DME is shown in Fig. 1 for both the cases, however a qualitative view of the dielectric parameters at different couplings is also shown in Fig. 2. The higher value of dielectric constant at fixed momenta and density of dyons causes a flux tube with smaller radius in comparison to the case of monopole condensation. In the present study, we have also succeeded to establish a comparison (however, phenomenologically) between the flux tube structures (see Fig. 3) for the monopole and dyon condensation case from the view point of the DME as an onset of screening currents and the dielectric parameters. Further, it is worth mentioning that there is no consensus on the mechanism which is really responsible for the vanishing of the colour dielectric function of a colour confining medium, and the problem needs more investigations. Though, there are some convincing arguments in favour of the magnetic confinement. Moreover, a sensible GL-type model of confinement is also needed where the baryons can be included in the medium.

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