The Dual Meissner Effect in Landau Gauge

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The understanding of the color confinement mechanism is an important problem that is yet to be solved. It is believed that the dual Meissner effect is the mechanism[1]. However, the cause of the dual Meissner effect has not yet been clarified. A possible cause is the appearance of magnetic monopoles after projecting $SU(3)$ QCD to an Abelian $U(1)^2$ theory by partial gauge fixing[2]. If such monopoles condense, the dual Meissner effect could explain the color confinement. In fact, an Abelian projection adopting a special gauge called maximally Abelian gauge (MA)[3] leads us to interesting results[4, 5] that support importance of monopoles. However, it has not been clarified how the color confinement is understood in general case in which monopoles do not exist.

Here we show that the dual Meissner effect in an Abelian sense works well even when monopoles do not exist[7]. We perform Monte-Carlo simulations of quenched $SU(2)$ QCD in the Landau gauge where monopoles do not exist and then we measure various correlations.

We define Abelian electric (E^a_{Ai}) and Abelian magnetic fields (B^a_{Ai}) in terms of Abelian plaquettes $\theta^a_{\mu\nu}(s)$ defined with link variables $\theta^a_\mu(s)$:

$$\theta^a_{\mu\nu}(s) \equiv \theta^a_\mu(s) + \theta^a_\nu(s+\hat{\mu}) - \theta^a_\mu(s+\hat{\nu}) - \theta^a_\nu(s), \tag{1}$$

where $\theta^a_\mu(s)$ is given by $U_\mu(s) = \exp(i\theta^a_\mu(s)\sigma^a)$. As a source corresponding to a static quark and antiquark pair, we adopt only non-Abelian Wilson loops in this study.

First we measure the Abelian electric fields as well as the non-Abelian ones. It must be noted that the Abelian electric fields are squeezed also and the Abelian electric fields perpendicular to the $Q\bar{Q}$ axis are found to be negligible. It is, thus, essential to ascertain the reason for the squeezing of the Abelian flux.

It is numerically verified[6] that no DeGrand-Toussaint monopoles[8] are present in the Landau gauge. Hence, the Abelian fields satisfy the simple Abelian Bianchi identity kinematically, as demonstrated below:

$$\vec{\nabla} \times \vec{E}^a_A = \partial_4 \vec{B}^a_A, \qquad \vec{\nabla} \cdot \vec{B}^a_A = 0. \tag{2}$$

In the case of the MA gauge, there exist additional monopole current $(\vec{k}, k_4)$ contributions:

$$\vec{\nabla} \times \vec{E}^{MA} = \partial_4 \vec{B}^{MA} + \vec{k}, \qquad \vec{\nabla} \cdot \vec{B}^{MA} = k_4. \tag{3}$$

Here , $\vec{E}^{MA}$ and $\vec{B}^{MA}$ are defined in terms of plaquette variables $\theta^{MA}_{\mu\nu}(s) \pmod{2\pi}$.

Eq.(2) shows in the Landau gauge that only $\partial_4 \vec{B}_A$, which is regarded as a magnetic displacement current, can play the role of the solenoidal current. It is very interesting to see Fig.1 that demonstrates the occurrence of this phenomenon in the Landau gauge. Note that the solenoidal current is in a direction that squeezes the Coulombic electric field. Let us also see the r dependence shown in Fig.2(left). The components of the magnetic displacement current $\partial_4 B_{Ar}$ and $\partial_4 B_{Az}$ do not vanish; however, they are extremely suppressed. In comparison,

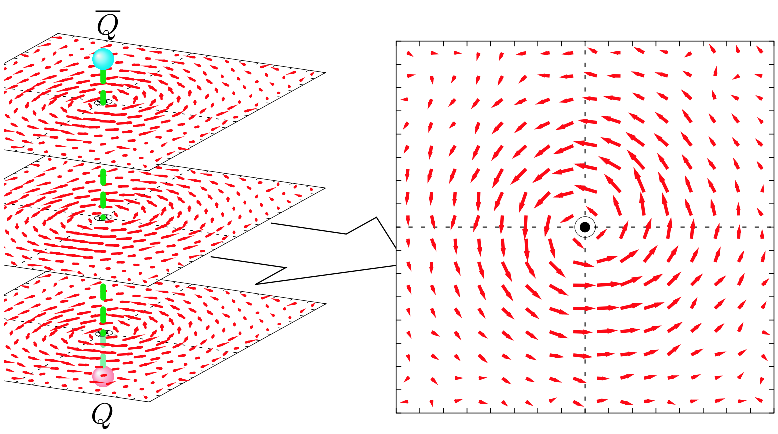

Figure 1: Magnetic displacement currents in Landau gauge as a solenoidal current.

we present the case of the MA gauge in Fig.2(right). Here, $\partial_4 B_{A\phi}$ is found to be numerically negligible as already expected from the literatures[9, 10]. Instead monopole currents are found to circulate[10, 11]. In this case, k_r is non-vanishing, although it is also suppressed in comparison with k_ϕ. k_z is almost zero. The authors believe that the non-vanishing of the radial and z components of $\partial_4 \vec{B}$ in the Landau gauge and k_r in the MA gauge is due to lattice artifacts and the small size of the Wilson loop used here. It is interesting that the shapes of $\partial_4 B_{A\phi}$ in the Landau gauge and k_ϕ in the MA gauge appear to be similar even though the strengths are different. These shapes have a peak at almost the same distance 0.2[fm] and almost vanish at approximately 0.7[fm].

We do not yet understand what causes the magnetic displacement current. A mean-field calculation suggests that the dual Meissner effect through the mass generation of the Abelian electric field is related to a gluon condensate $\langle A_\mu^a A_\mu^a \rangle \neq 0$ of mass dimension 2[7]. So the dimension 2 gluon condensate may be important. It is under investigation.

The numerical simulations have been done on NEC SX-5 at RCNP and NEC SX-7 at RIKEN.

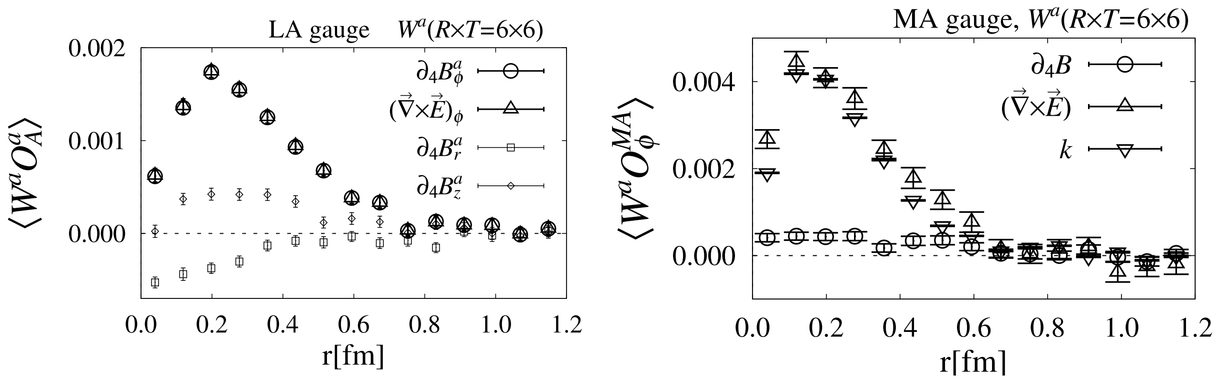

Figure 2: (Left) Curl of Abelian electric fields and magnetic displacement currents around a static quark pair in Landau gauge. (Right) Curl of Abelian electric fields, monopole currents, and magnetic displacement currents around a static quark pair in MA gauge.

References

[1] G. 't Hooft (1976) , S. Mandelstam , Phys. Rept. **23C**, 245 (1976).

[2] G. 't Hooft, Nucl. Phys. **B190**, 455 (1981).

[3] T. Suzuki, Prog. Theor. Phys. **69**, 1827(1983). A.S. Kronfeld, et al. , Phys. Lett. **B198**, 516 (1987); A.S. Kronfeld, et al. , Nucl. Phys. **B293**, 461 (1987).

[4] T. Suzuki and I. Yotsuyanagi, Phys. Rev. **D42**, R4257 (1990).

[5] T. Suzuki, Nucl. Phys. Proc. Suppl. **30**, 176 (1993); M.N. Chernodub and M.I. Polikarpov, (1997).

[6] T. Suzuki et al., "The dual Meissner effect in SU(2) Landau gauge", hep-lat/0410039.

[7] T.Suzuki et al., Phys. Rev. Lett. **94**, 132001 (2005).

[8] T.A. DeGrand and D. Toussaint, Phys. Rev. **D22**, 2478 (1980).

[9] P. Cea and L. Cosmai, Phys. Rev. **D52**, 5152 (1995).

[10] G.S. Bali, V. Bornyakov, M. Muller-Preussker and K. Schilling, Phys. Rev. **D54**, 2863 (1996).

[11] Y. Koma, M. Koma, E.-M. Ilgenfritz, T. Suzuki, and M.I. Polikarpov, Phys. Rev. **D68**, 094018 (2003).

[12] V. Singh D.A. Browne, and R.W. Haymaker, Phys. Lett. **B306**, 115 (1993).