Scalar Glueball as the "Flux-Tube Ring" in the DGL Theory

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The existence of glueball states is naively expected in terms of the gluon self-coupling in quantum chromodynamics (QCD). Recent progress of lattice QCD simulations predicts the masses of glueballs $M(0^{++}) = 1.50 \sim 1.75$ GeV, $M(2^{++}) = 2.15 \sim 2.45$ GeV [1]. Experimentally, there are some candidates; $f_0(1500)$ and $f_0(1710)$ for the scalar glueball, $f_J(2220)$ (J=2 or 4), $f_2(2300)$ and $f_2(2340)$ for the tensor glueball[2]. However, the abundance of $q\bar{q}$ meson states in the $1 \sim 3$ GeV region and the possibility of the quarkonium-glueball mixing states still make it difficult to identify the glueball states[1]. At present, no glueball state has been firmly discovered yet. More studies for the glueballs from many directions, of course based on QCD, are necessary to specify the glueball states.

For this purpose, we use the dual Ginzburg-Landau (DGL) theory, which is an effective theory of the nonperturbative QCD[3]. The DGL theory describes the QCD-vacuum as the dual superconductor, which is numerically supported by the recent studies of lattice QCD in the maximally abelian (MA) gauge[4]. The DGL theory has the vortex-type solution as the hadronic flux-tube like the Abrikosov vortex in the Ginzburg-Landau (GL) theory for ordinary superconductivity. The flux-tube not only explains the color confinement but also provides intuitive pictures of the hadrons in terms of the string-like structure of the color-electric flux. The hadrons including the valence quarks topologically correspond to the open flux-tube excitation with terminals. While the glueball, considered as an object without valence quarks, can be regarded as the "flux-tube ring" intuitively[5]. Therefore, the flux-tube ring solution in the DGL theory may enable us to understand the glueball properties.

We consider the simplest ring solution that the ends of the flux-tube meet each other to form a circle as shown in Fig.1. In order to simplify the system, we idealize the flux-tube ring as the relativistic closed string with the proper string tension which characterizes the flux-tube. Then, the ring can be easily described by the Nambu-Goto action. Parametrizing the closed string as a circle with the radius R, we obtain the hamiltonian

$$H(P_R, R) = \sqrt{P_R^2 + \{2\pi R \sigma_{\rm eff}(R)\}^2}, \tag{1}$$

where P_R is the canonical conjugate momentum of the coordinate R and $\sigma_{\rm eff}(R)$ the string tension of the flux-tube composing the ring. Here, $\sigma_{\rm eff}(R)$, which we call the "effective string tension", is calculated in terms of the flux-tube ring solution in the DGL theory with the relation $E(R) = 2\pi R \sigma_{\rm eff}(R)$, where $E(R)$ denotes the static energy of the flux-tube ring. Since the flux-tube has finite thickness, the effective string tension can be varied as the ring radius is reduced, which characterizes the difference between the flux-tube and the string. The parameters are fixed as g=2.9, λ=66 and v=0.098 GeV, which are chosen so as to reproduce the dual gauge mass m_B=0.5 GeV, the monopole mass m_χ=1.6 GeV and the string tension of the straight flux-tube σ=1.0 GeV/fm. Inserting the effective string tension into the hamiltonian (1), we analyze the Schrödinger equation

$$H(P_R, R)^2 \Phi(R) = M^2 \Phi(R), \tag{2}$$

with the boundary condition $\Phi(R{=}0) = \Phi(R{=}\infty) = 0$. The ground state is found to have the eigenvalue M_G=1.6 GeV, which is considered as the lowest glueball mass. The size of the

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ring is also estimated as R=0.25 fm. It is interesting to note that the mass spectrum M_G is almost consistent with the scalar glueball mass that the lattice QCD predicts for the lowest state[1].

To summarize, we would like to mention that our main idea is the description of the flux-tube ring solution in the DGL theory as the relativistic closed string with the effective string tension, which enables us to write the hamiltonian of the flux-tube ring using the NG action and discuss the mass spectrum and the wave function of the glueball state. The boundary condition $\Phi(R{=}0){=}0$ dictates the ring structure of the color-electric flux to the wave function. Although the ring has not yet been assigned the definite quantum numbers using the angular momentum projection method, we naively consider that the ring has the scalar quantum number 0^{++} for the lowest state. One may find that the monopole mass m_χ=1.6 GeV is very similar to the glueball mass M_G. The monopole field denotes a complex scalar field and its origin is the off-diagonal gluon field in the MA-gauge in QCD. Thus, the monopole field would also present the scalar gluonic excitation such as the scalar glueball. We are now investigating the scalar glueball in terms of the monopole field in the DGL theory and some results are presented in [6].

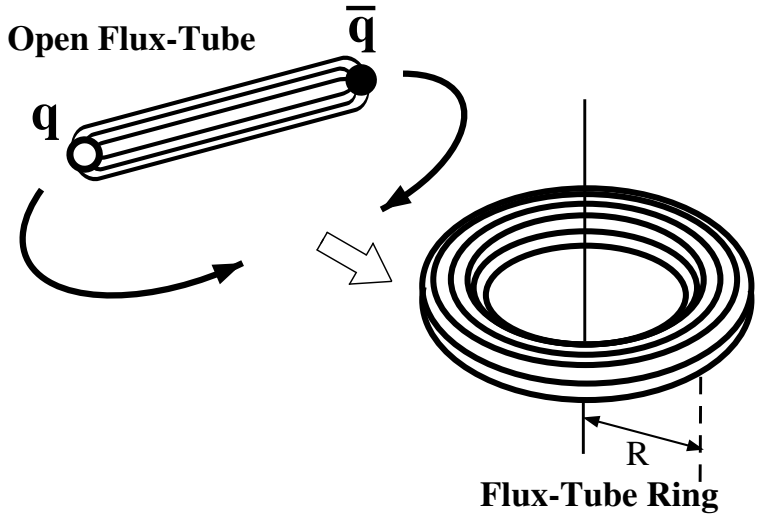

Fig.1: The flux-tube ring system with the ring radius R.

References

[1] N. A. Törnqvist, "*Summary of Gluonium95 and Hadron95 Conferences*" HU-SEFT-R-1996-16a, hep-ph/9510256, and references therein.

[2] C. Caso et al. Particle Data Group, Euro. Phys. J. **C3**, 1 (1998).

[3] H. Suganuma, S. Sasaki and H. Toki, *Nucl. Phys.* B **435**, 207 (1995).

[4] A. Tanaka and H. Suganuma, Proc. of Int. Symp. on "*Innovative Computational Methods in Nuclear Many-Body Problems (INNOCOM 97)*", Osaka, Nov. 1997, (World Scientific) p.281. ; hep-lat/9901022.; K. Amemiya and H. Suganuma, p.284.; hep-lat/9811035.

[5] Y. Koma, H. Suganuma and H. Toki, Proc. of Int. Symp. on "*INNOCOM97*", Osaka, Nov. 1997, (World Scientific) p.315 ; hep-ph/9902441.

[6] Y. Koma, H. Suganuma and H. Toki, Annual Report 1998, "*Scalar Glueball as the Color-Singlet Monopole in the DGL theory*"