Scalar-quark systems in SU(3)$_c$ quenched lattice QCD

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First study of the exotic systems of scalar-quarks $\phi(\phi^\dagger)$ is performed with $SU(3)_c$ lattice QCD with $\beta = 5.7$ corresponding to lattice spacing $a \simeq (1.1\text{GeV})^{-1}$ in quenched approximation, where the scalar-quark loop is neglected [1]. One of the motivations is to clarify the mass generation of scalar colored particles. The origin of the constituent-quark mass for light quarks in QCD is considered as spontaneous breaking of chiral symmetry [2]. On the other hand, the system of scalar particles does not have chiral symmetry. Therefore, the mechanism of the mass generation of scalar particles is expected to be different from that of the massless fermions such as chiral quarks. For the study of the mechanism, we investigate "scalar-quark hadrons", i.e., the bound states of scalar-quarks ϕ. We also investigate the bound states of scalar-quarks ϕ and quarks ψ, which we name "chimera hadrons". The study is also motivated by the diquark picture in hadron physics. Diquark is important degrees of freedom for hadron physics in some aspects [3, 4]. However, the nature of a diquark as a real object, its size and mass for example, is not well understood. The scalar-quark in our study can be regarded as the point-like color $\bar{\mathbf{3}}$ diquark ($J = 0$). Therefore, the study of scalar-quark systems may clarify the nature of point-like diquarks.

First, we study scalar-quark hadrons, namely scalar-quark meson $\phi^\dagger\phi$ and scalar-quark baryon $\phi\phi\phi$ in $J = 0$ channel. As a result, the scalar-quark meson mass $M_{\phi^\dagger\phi}$ is found to be 3.0GeV at the bare scalar-quark mass $m_\phi = 0$, and the scalar-quark baryon mass $M_{\phi\phi\phi}$ is about 4.7GeV at $m_\phi = 0$. From the results, we find the constituent scalar-quark picture, i.e., $M_{\phi^\dagger\phi} \simeq 2M_\phi$ and $M_{\phi\phi\phi} \simeq 3M_\phi$, where $M_\phi \simeq 1.5\text{GeV}$ is the constituent scalar-quark mass at $m_\phi = 0$. The constituent scalar-quark mass is very large compared to the constituent quark mass $M_\psi \simeq 400\text{MeV}$ at the bare quark mass $m_\psi = 0$. Next, we study the bound states of quarks ψ and scalar-quarks ϕ, i.e., $\phi^\dagger\psi$ (chimera meson), $\psi\psi\phi$ and $\phi\phi\psi$ (chimera baryons) in $J = 0$ channel. We find the chimera-meson mass $M_{\phi^\dagger\psi} = 1.9\text{GeV}$, chimera-baryon masses $M_{\psi\psi\phi} = 2.3\text{GeV}$ and $M_{\phi\phi\psi} = 3.6\text{GeV}$ at $m_\psi = 0$ and $m_\phi = 0$. These bound states have large masses compared to the ordinary ground-state mesons or baryons, and we find the constituent scalar-quark and quark picture with the large constituent scalar-quark mass M_ϕ around 1.5GeV at the cutoff scale $a^{-1} \sim 1\text{GeV}$.

As well as the large dynamically generated mass of scalar-quarks, glueball mass about 1.5GeV [5] and the 400MeV difference between current and constituent mass of charm quark are examples of dynamically generated mass without chiral symmetry breaking. From these evidences, we conjecture that *all colored particles (scalar, spinor, vector) generally acquire a large effective mass due to dressed gluon effects*, as shown in Fig.1. Also, the large quantum correction in the scalar-quark systems indicates that the simple modeling which treats the diquark as a local scalar field at the scale of $a^{-1} \sim 1\text{GeV}$ in QCD is rather dangerous.

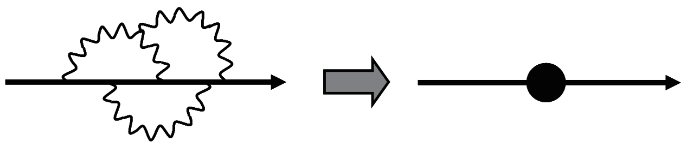

Figure 1: Figure for dynamical mass generation of colored particles. The arrow denotes colored particles (scalar, spinor, vector) and the wavy lines denote gluons. Even without chiral symmetry breaking, colored particles generally acquire a large effective mass due to dressed gluons.

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References

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