Bound States of (Anti) Scalar-Quarks in $SU(3)_c$ Lattice QCD

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We perform the first study of the exotic systems of scalar-quarks ϕ ($\phi^\dagger$) in $SU(3)_c$ lattice QCD at β =5.75 in quenched approximation, where the scalar-quark loop is neglected. One of the motivations is to clarify the mass generation of scalar colored particles. The origin of the constituent-quark mass in QCD is considered as spontaneous breaking of chiral symmetry. 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 nontrivial compared with the massless Fermi particles such as chiral quarks. For the investigation of the mechanism, it is the suitable way to study scalar QCD which includes scalar-quarks instead of quarks, and compare it with ordinary QCD.

First, we study the scalar-quark meson $\phi^\dagger\phi$ of scalar-quark ϕ and anti scalar-quark $\phi^\dagger$ in J=0 channel. As a result, the mass of the bound state $M_{\phi^\dagger\phi}$ is found to be 3.0GeV with the bare scalar-quark mass m_ϕ= 0MeV. Therefore, the constituent mass of the scalar-quark is about 1.5GeV with m_ϕ=0MeV, which is very large compared to the constituent quark mass with the bare quark mass m_Ψ=0MeV.

Second, we study the bound states of quarks Ψ and scalar-quarks ϕ, i.e., $\phi^\dagger\Psi$ (chimera meson), $\phi\Psi\Psi$, $\phi\phi\Psi$ (chimera baryon) and $\phi\phi\phi$ (scalar-quark baryon) in J=0 channel. We find $M_{\phi^\dagger\Psi}$ =2.0GeV, $M_{\phi\Psi\Psi}$=2.5GeV, $M_{\phi\phi\Psi}$= 3.8GeV and $M_{\phi\phi\phi}$=4.9GeV with m_Ψ =100MeV and m_ϕ=120MeV. These bound states have large masses compared to the ordinary light mesons or baryons, and again we find the large constituent mass of the scalar-quark around 1.5GeV.

Finally, we investigate the quark-mass dependence of the chimera hadrons, and find that the m_Ψ-dependence $M_{\phi^\dagger\Psi}(m_\Psi)$ is almost the same as $M_{\phi\phi\Psi}(m_\Psi)$ apart from a constant. This indicates the similar structure of $\phi^\dagger\Psi$ and $\phi\phi\Psi$ in terms of the quark Ψ. Due to the large constituent mass of the scalar-quark, $\phi^\dagger$ in $\phi^\dagger\Psi$ and $\phi\phi$ in $\phi\phi\Psi$ are localized at the centers of the systems and the wave functions of Ψ are spread around $\phi^\dagger$ and $\phi\phi$. Namely, the two systems are considered to have "atomic structure" of a light quark Ψ spread around heavy scalar-quark(s).