Lattice Study of Low-lying Nonet Scalar Mesons in Quenched Approximation

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Recent experimental and theoretical evidence for the existence of the σ and the κ [1], indicates that light scalar mesons constitute the nonet state. They cannot be ordinary $q\bar{q}$ mesons as described in the nonrelativistic constituent quark model since in such a quark model, the J^{PC}=0^{++} meson is realized in the $^3P_0$ state, which implies that the mass of the σ and the κ must be as high as $1.2 \sim 1.6$ GeV. Thus, the low-lying scalar mesons below 1 GeV have been a source of various ideas of exotic structures, as mentioned above: they may be four-quark states such as $qq\bar{q}\bar{q}$, or $\pi\pi$ or Kπ molecules.

We present a simulation with weaker couplings on a larger lattice than any other previous simulations although in the quenched level. We perform quenched level simulations on the κ meson so as *to clarify the structure of the mysterious scalar meson rather than to reproduce the experimental value of the mass*; a precise quenched-level simulation should give a rather clear perspective on whether the system can fit with the simple constituent-quark model picture or not.

We perform a quenched QCD calculation using the Wilson fermions, with the plaquette gauge action, on a relatively large lattice ($20^3 \times 24$). The values of the hopping parameter for the u/d quark are $h_{u/d} = 0.1589, 0.1583$ and 0.1574, while $h_s = 0.1566$ and 0.1557 for the s quark. Using these hopping parameters except for $h_s = 0.1557$, CP-PACS collaboration performed a quenched QCD calculation of the light meson spectrum with a larger lattice ($32^3 \times 56$) [2], which we refer to for comparison. The gauge configurations are generated by the heat bath algorithm at $\beta = 5.9$. After 20000 thermalization iterations, we start to calculate the meson propagators. On every 2000 configurations, 80 configurations are used for the ensemble average.

We emply the point-like source and sink for the κ^+ meson

$$\hat{\kappa}(x) \equiv \sum_{c=1}^{3} \sum_{\alpha=1}^{4} \bar{s}_\alpha^c(x) u_\alpha^c(x) \quad , \tag{1}$$

where $u(x)$ and $s(x)$ are the Dirac operators for the u/d and s quarks, and the indices c and α denote the color and Dirac-spinor indices, respectively. The point source and sink in Eq.(1) lead a positive spectral function $\rho(m^2)$ in the correlation function $\langle \hat{\kappa}(t)\hat{\kappa}(0)\rangle = \int dm\rho(m^2)\exp(-mt)$. The result obtained here is thus an upper bound of κ mass, because our result should include excited states.

Our estimated value of the mass of the κ is $\sim$ 1.7 GeV, which is larger than twice the experimental mass $\sim$ 800 MeV. This result was expected on the basis of our experience in calculating the σ meson. The relatively heavy mass of the κ may be at least partly attributed to the absence of the disconnected diagram in the κ propagator; the κ propagator is composed of only a connected diagram. While the disconnected diagram was essential for realizing the low-mass σ, it does not exist for the κ; therefore, the mass of the κ is not made lighter by the disconnected diagram. Indeed, the mass of the valence σ_v described solely with the connected propagator is far larger than the experimental value $\sim$ 500-600 MeV. Our lattice study and the quark model analysis suggest that the simple two-body constituent-quark picture of the κ meson does not agree well with the experimentally observed κ. Note that the quench simulation is a clean theoretical experiment in which a virtual intermediate like $qq\bar{q}\bar{q}$ is highly suppressed. Therefore, if its existence with the reported low mass is experimentally established, the dynamical quarks may play an essential role for making the κ mass so lighter or the κ may contain an unconventional state such as a $qq\bar{q}\bar{q}$ or $K\pi$ molecular state, which are missing in the calculation here.

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References

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