Candidates of hadronic molecules and compositeness

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Clarifying the internal structure of hadrons is one of the most important topics in hadron physics and strong interaction [1], from the viewpoint of the effective degrees of freedom to describe each hadron. Actually, while we naïvely expect that ordinary hadrons can be described by three quarks (qqq) for baryons and by a quark–antiquark pair ($q\bar{q}$) for mesons in the constituent quark models, there should exist exotic hadrons, which cannot be classified into the qqq or $q\bar{q}$ configuration.

In this study, we mainly consider hadronic molecules, which are composed of two (or more) hadrons themselves, and investigate the structure of candidates of hadronic molecules with compositeness [2, 3]. Here compositeness is defined as the norm of the two-body wave function for hadrons. Since the total wave function should be normalized to be unity, one can discuss the composite fraction of the hadronic molecule candidates by comparing the compositeness with unity.

In Refs. [2, 3] we have established theoretical framework of the compositeness. In particular, we have established a way to extract the two-body wave function and compositeness from the resonance pole position in the scattering amplitude and its residue for arbitrary interaction. Then, we have evaluated the compositeness of hadronic resonances from the hadron–hadron scattering amplitude in the chiral unitary approach. As a consequence, we have found that $\Lambda(1405)$ and $f_0(980)$ are dominated by the $\bar{K}N$ and $K\bar{K}$ composite states, respectively. In addition, we have found that $\Delta(1232)$ resonance has non-negligible πN component, while the πN, ηN, $K\Lambda$, and $K\Sigma$ components are negligible for $N(1535)$ and $N(1650)$.

The compositeness has been applied to $a_0(980)$ and $f_0(980)$, and we proposed a method to restrict the value of the $K\bar{K}$ compositeness for $a_0(980)$ and $f_0(980)$ via the $a_0(980)$-$f_0(980)$ mixing [4]. As a result, the experimental value of the $a_0(980)$-$f_0(980)$ mixing intensity implies that $a_0(980)$ and $f_0(980)$ cannot be simultaneously $K\bar{K}$ molecular states.

In Ref. [5] we have shown that the $\Xi(1690)$ resonance can be dynamically generated in the s-wave $\bar{K}\Sigma$-$\bar{K}\Lambda$-$\pi\Xi$-$\eta\Xi$ coupled-channels chiral unitary approach. In our model, the $\Xi(1690)$ resonance appears near the $\bar{K}\Sigma$ threshold as a $\bar{K}\Sigma$ molecular state and the experimental data are reproduced well. We have discussed properties of the dynamically generated $\Xi(1690)$ in Ref. [5].

Related to the hadron–hadron scattering amplitude and compositeness, we have discussed a method to observe the hadron–hadron scattering in the semi-leptonic decay of heavy hadrons [6, 7]. This decay provides us with an ideal condition for the hadron–hadron scattering because the final state is a pair of leptons and hadrons. In particular, the experimental value of the branching ratio for the $D_s^+ \to f_0(980) l^+ \nu$ and $f_0(500) l^+ \nu$ decays strongly indicates that the $f_0(980)$ has a substantial fraction of the strange quarks while the $f_0(500)$ has a negligible strange quark component [7].

Finally, we have discussed a method to specify directly the number of the constituents by considering a constituent-counting rule suggested by perturbative QCD, which emerges as a scaling behavior of cross sections in hard exclusive reactions with large scattering angles. In Ref. [9] we have applied this constituent-counting rule to the CLAS data on the photoproduction cross section of $\Lambda(1405)$, and we find that the current CLAS data are not enough to conclude the numbers of its constituents.

References

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