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Structure of exotic hadrons by the weak-binding relation with finite range correction

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Because the $\Lambda(1405)$ cannot be explained by the qqq picture in the constituent quark model, it is expected to have an internal structure of, for instance, the $\bar{K}N$ molecular state. In recent experiments, many candidates for exotic hadrons have been discovered in the heavy quark sector such as XYZ mesons, for which hadronic molecular states and tetraquark states are proposed. While intensive studies are performed to clarify the nature of those candidates, here we aim at discussing them from the viewpoint of the hadronic molecules.

To analyze the internal structure of the candidates for exotic hadrons, the weak-binding relation was developed as a model-independent approach [1,2]. It is the relation between observables and the compositeness which is the fraction of the hadronic molecular component of hadrons. In Ref. [2], the internal structure of $\Lambda(1405)$ is found to be dominated by the $\bar{K}N$ molecular state by using the weak-binding relation. However, the previous works did not take into account the effect of the effective range. To apply the weak-binding relation to systems with a large effective range, we need to consider a range correction to the weak-binding relation.

In this talk, we show that the weak-binding relation cannot be applied to the system with a large effective range [3]. As the range correction to the weak-binding relation, we modify the correction terms which arise from the higher order terms of the expansion. We perform the numerical calculations to check whether the modification of the weak-binding relation works or not [4]. For the calculation, we consider the effective field theory where the exact value of the compositeness is known by definition, the scattering length and effective range are independently controllable by varying the model parameters. By comparing with the compositeness from the weak-binding relation, we search for the applicable parameter regions. We find the parameter region where only the improved weak-binding relation can be applied, so the modification of correction terms of the relation works well. We apply the improved weak-binding relation to the actual hadrons, hypernuclei, and atomic systems (deuteron, $X(3872)$, $N\Omega$, $\Omega\Omega$ dibaryon, ${}^{3}_{\Lambda}$H, ^{4}He dimer), and estimate the compositeness to discuss their internal structures [5]. We show that all states are dominated by the composite components. From the results of the $X(3872)$ and the $N\Omega$ dibaryon, we find that the range correction is need to estimate the compositeness of physical states.

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