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Three ways to decipher the nature of hadronic molecules (Part 3)

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In the past two decades, a plethora of hadronic states beyond the conventional quark model of qqbar mesons and qqq baryons have been observed experimentally, which motivated extensive studies to understand their nature and the non-perturbative strong interaction. Since most of these exotic states are located near the mass thresholds of pairs of conventional hadrons, the prevailing picture is that they are primarily hadronic molecules. In principle, one can verify the molecular nature of these states by thoroughly comparing their masses, decay widths, and production rates in a particular picture with experimental data. However, this is difficult or impossible. First, quantum mechanics allows for mixing configurations permitted by symmetries and quantum numbers. Second, data are relatively scarce because of their small production rates and the many difficulties in the experimental measurements. As a result, other alternatives need to be explored. In these three lectures, I introduce three approaches that can help disentangle the nature of the many exotic hadrons discovered.

In the first approach, based on the molecular interpretations for some exotic states, we study the likely existence of multiplets of hadronic molecules related by various symmetries, such as isospin symmetry, SU(3)-flavor symmetry, heavy quark spin/flavor symmetry, and heavy antiquark diquark symmetry, which are known to be approximately satisfied and can be employed to relate the underlying hadron–hadron interactions responsible for the formation of hadronic molecules. The masses of these multiplets of hadronic molecules can then be obtained by solving the Lippmann–Schwinger equation. Their decay and production patterns are also related. As a result, experimental discoveries of such multiplets and confirmations of the predicted patterns will be invaluable to understanding the nature of these hadronic molecular states.

In the second approach, starting from some hadronic molecular candidates, one can derive the underlying hadron–hadron interactions. With these interactions, one can study related three-body systems and check whether three-body bound states/resonances exist. The existence of such three-body molecules can directly verify the molecular nature of exotic hadrons of interest.

In the third approach, one can turn to the femtoscopy technique to derive the hadron–hadron interactions, hence inaccessible. This technique provided an unprecedented opportunity to understand the interactions between unstable hadrons. Although the past focus was mainly on the light quark sector, we have seen increasing theoretical activities in the heavy quark sector in recent years. We review relevant studies and point out future directions where more effort is needed.

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