Research Group for Advanced Theoretical Physics

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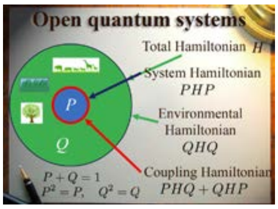
The Advanced Theoretical Physics (ATP) Group conducts the research of fundamental sciences related to atomic energy. Our missions are to support experimental researches in JAEA and to explore interdisciplinary researches with new ideas. We also form a platform to exchange new ideas, to stimulate international collaborations and to train young researchers. Core members interests cover theoretical physics on hadrons and nuclei, the strongly interacting systems. In addition, condensed matter physicists working on spintronics join the ATP.

As activities of Japanese Fiscal Year 2020, we would like to report two items, the international workshop as a REIMEI project and a collaboration among members of the group.

Workshop on "Physics of heavy-quark and exotic hadrons 2021" (Co-organized by KEK and JAEA)

The entitled international workshop was held on 15-17 February, 2021 as a Reimei project activity. There were 121 participants of 66 Japanese and 55 foreigners altogether from 16 countries. The workshop started with the invited lecture of three hours by Prof. Hatano who is the PI of the Reimei project about “Resonant states of open quantum systems” (Fig. 1). Other invited talks from various fields were also presented including nuclear and hadron physics. One hour was given to each talk, aiming at intensive discussions. Different approaches to resonance physics were discussed which gave useful suggestions to the current works of participants.



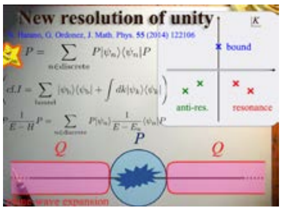


Fig.1: Snapshots showing typical contents of the discussions from the lecture slide of Prof. Hatano.

Stable double-heavy tetraquarks

This work was performed as a collaboration in part among the theory group members (Philipp Gubler, HIYAMA Emiko, HOSAKA Atsushi and OKA Makoto), and the results were published in Physics Letters [1].

One of long-standing questions in hadron physics is whether stable exotic hadrons exist or not. If so, the relevant questions are what structure, what property, and how best measured. The answers to them have been conjectured; double heavy quarks stabilize four and five quark systems. Consequently, double heavy tetraquarks and pentaquarks were predicted [2]. The basic principle is the strong color-Coulomb attractive interaction between the heavy quarks and the location of the threshold of two or more particles which exotic states decay to. A well-known feature of the Coulomb force helps to stabilize the system; the binding energy becomes larger for heavier particles, $E_B \sim \alpha^2\mu/n^2$ (n: principal quantum number), where α is the fine structure constant of the strong interaction that is of order 0.5, and $\mu$the reduced mass of the two heavy quarks.

For this problem, we have studied the double heavy tetraquark systems such as bbq^*q^* (b: bottom quark, q^* = anti u or d quark) in the quark model. The four-body systems were analyzed in the full four-body calculations to find stable states for various quark flavor contents. The results are summarized in Fig. 2 below. One conclusive result is that there should exist a deeply bound state of isospin I = 0 and spin-parity J^P =1$^+$ with a binding energy nearly 200 MeV, which confirms the previous conjecture [2]. In addition to the masses, we have also studied the density distributions of the obtained states to examine the internal structure. It is interesting to observe that two very different structures were found for the deeply bound state and the shallow one with 4 MeV binding energy. The former has a compact three-body like structure with strongly bound heavy diquark (bb) and q^*q^* moving around it, while the latter forms a molecular like structure of (bq^*)-(bq^*). These results answer the question of what structure and what property. We have also discussed possible decays of these states including weak and radiative decays to answer how best measured in terms of weak and electromagnetic processes.

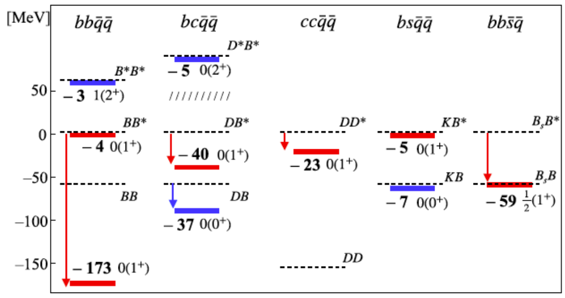


Fig.2 Bound tetraquarks with their energies $-E_B$ (MeV) measured from the thresholds for various flavor contents. The labels beside each bar indicate isospin and spin-parity quantum numbers $I(J^P)$. The hatch pattern in the bcq^*q^* sector indicates that the distance between the DB^*-D^*B^* thresholds does not reflect the actual scale.

References

[1] Q. Meng, E. Hiyama, A. Hosaka, M. Oka, P. Gubler, K.U.Can, T.T.Takahashi, H.S.Zong, Phys.Lett.B 814 (2021) 136095, doi: 10.1016/j.physletb.2021.136095.
[2] M. Karliner, J.L. Rosner, Phys. Rev. Lett. 119(20) (2017) 202001,doi:10.1103/PhysRevLett.119.202001. Also in Nature 551 (2017) 89. doi: 10.1038/nature24289.