# Resonance on essential kaonic nuclear systems

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In strangeness nuclear physics and hadron physics, nuclear systems with anti-kaons (kaonic nuclei, $\bar{K}$ nuclei) have been one of hot issues, because of their expected exotic nature. An anti-kaon ($\bar{K}$ meson = $K^-$ and $\bar{K}^0$) is a pseudo-scalar meson involving a strange quark, and the attraction between an anti-kaon and a nucleon is considered to be so attractive that they can form a quasi-bound state which corresponds to a hyperon resonance $\Lambda(1405)$ existing at 27 MeV below the $\bar{K}N$ threshold. Due to such a strong $\bar{K}N$ attraction, an anti-kaon pulls nucleons close to itself when an anti-kaon is put into a nucleus. The anti-kaon behaves as if it were a seed of attraction, and is expected to form a dense state in a nucleus against the well-known nuclear incompressibility. Actually, an early study reported that in light kaonic nuclei could be dense and their density could amount to $2 \sim 4\rho_0$, where $\rho_0$ means a normal nuclear density, 0.16 fm$^{-3}$ [1].

To clarify the exotic nature of kaonic nuclei, many theorists and experimentalists have eagerly investigated essential two systems: an excited hyperon $\Lambda(1405)$ which is a two-body $\bar{K}N$ quasi-bound system, and a three-body "$K^-pp$" system (composing two protons and a $K^-$ meson, naively) which would be a prototype of kaonic nuclei. From theoretical point of view, the treatment of 1. coupled-channel problem and 2. resonance is important to investigate these systems, since the $\bar{K}N$ pair couples strongly to $\pi Y$ pair and these systems are not purely a bound state but a resonance. ($Y$ means hyperons of $\Lambda$ and $\Sigma$.) For instance, $\Lambda(1405)$ is certainly located energetically below $\bar{K}N$ threshold, but is above the $\pi\Sigma$ threshold and decays to the $\pi\Sigma$. In other words, $\Lambda(1405)$ is a so-called Feshbach resonance.

By the way, the complex scaling method is known to be a powerful tool to study resonances in the ordinary nuclear physics, because of great success in studies of resonant states of stable/unstable nuclei. Therefore, in our study of kaonic nuclei, we employ a coupled-channel complex scaling method (ccCSM) which can deal with the above-mentioned two ingredients simultaneously. In the present talk, I will introduce interests of kaonic nuclei from the viewpoint of physics, and report our comprehensive studies of $\Lambda(1405)$ and "$K^-pp$" with the ccCSM, based on our recent papers [2-4]. In addition, I would like to mention to the experiments on these systems performed and on-going at J-PARC.

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