Effective $\bar{K}N$ Interaction and K^-pp System in Chiral SU(3) Dynamics ◇

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The study of $\bar{K}$-nuclear systems attracts considerable interest in nuclear and hadron physics. The analysis based on a phenomenological $\bar{K}N$ interaction [1,2] suggested that the $\bar{K}$-nuclear systems would be deeply bound and have very special properties. On the other hand, $\bar{K}N$ scattering has been well described by the coupled-channel approach based on chiral SU(3) symmetry [3,4]. It is therefore of interest to investigate $\bar{K}$-nuclear systems theoretically with systematic constraints from chiral SU(3) dynamics.

We construct an effective $\bar{K}N$ potential in coordinate space based on chiral SU(3) dynamics [5]. This procedure involves two steps:

1. transforming the coupled-channel dynamics into a single channel effective $\bar{K}N$ interaction, and
2. translating this effective interaction into an "equivalent", energy-dependent, local potential.

Step 1 is exact within the chiral coupled-channel approach, whereas step 2 involves approximations.

In performing step 1 we systematically investigate how the dynamics of the $\pi\Sigma$ channel influences the effective $\bar{K}N$ interaction. It turns out that the $\pi\Sigma$ interaction generates a broad resonance whereas the $\bar{K}N$ interaction produces a weakly bound state. This eventually causes the two-pole structure of the $\Lambda(1405)$. The attractive forces in the $\bar{K}N$ and $\pi\Sigma$ coupled channels cooperate to form the $\Lambda(1405)$ as a $\bar{K}N$ quasibound state embedded in the resonating $\pi\Sigma$ continuum.

As a consequence of the two-pole structure and the strong $\pi\Sigma$ attractive interaction, the resonance structure observed in the $\bar{K}N$ channel is located at $\sqrt{s} \simeq 1420$ MeV. This value should be used to adjust the strength of the $\bar{K}N$ potential, and the energy is shifted upward from the PDG value of $\Lambda(1405)$ which was deduced from the maximum of the $\pi\Sigma$ mass spectrum.

We study several versions of chiral SU(3) dynamical models to estimate theoretical uncertainties. The effects of the higher order terms of the chiral expansion in the interaction kernel are also examined. The occurrence of the quasibound state at $\sqrt{s} \simeq 1420$ MeV turns out to be model independent, irrespective of the wide spread in the locations of the second pole of the $\Lambda(1405)$. This implies that the $\bar{K}N$ binding energy associated with the $\Lambda(1405)$ is actually not 27 MeV but only 12 MeV, indicating significantly less attraction in the effective $\bar{K}N$ interaction than previously anticipated on purely phenomenological grounds.

In step 2, we construct an equivalent local potential, with a Gaussian coordinate space form factor reflecting finite range effects. The range parameter is adjusted so as to reproduce the position of the $\bar{K}N$ quasibound state and found to be somewhat smaller than that expected from a vector meson exchange picture. In any case, a local parametrization of the $\bar{K}N$ effective interaction works only with an adjustment of its energy dependence. This extra energy dependence considerably reduces the attractive strength of the potential in the subthreshold region as compared to naive expectations.

We apply the potentials so obtained to the K^-pp prototype system in Ref. [6]. We utilize the realistic Av18 potential for the NN interaction, and perform a variational calculation of the K^-pp wavefunction with $J^\pi = 0^-$ and $(T, T_3) = (1/2, 1/2)$. The energy dependence of the $\bar{K}N$ potential is taken into account self-consistently. Theoretical uncertainties have been considered. The resulting binding energy of the K^-pp system is

$$B(K^-pp) \;=\; 19 \,\pm\, 3\,\text{MeV}, \tag{1}$$

with the mesonic decay width ($\bar{K}NN \to \pi YN$) in the range 40 to 70 MeV, estimated perturbatively from the imaginary part of the $\bar{K}N$ potential. By examining the wavefunction, we confirmed that the $I = 0$ $\bar{K}N$ component in the ppK^- cluster is similar in structure to the $\Lambda(1405)$, interpreted as an $I = 0$ $\bar{K}N$ quasibound state.

The overall picture presented here, constrained by chiral SU(3) dynamics, differs strongly from previous purely phenomenological approaches [2]. The main point in the present analysis is the appreciation of the strong $\pi\Sigma$ interaction required by chiral symmetry. The resulting effective potential is significantly less attractive in the energy range relevant to the discussion of deeply bound antikaon-nuclear clusters. The ppK^- system emerging from the present calculation is quite weakly bound in comparison with the previous study using a purely phenomenological potential [2].

References

[1] Y. Akaishi and T. Yamazaki, Phys. Rev. C **65** (2002) 044005.
[2] T. Yamazaki and Y. Akaishi, Phys. Rev. C **76** (2007) 045201 .
[3] N. Kaiser, P. B. Siegel, and W. Weise, Nucl. Phys. **A594** (1995) 325.
[4] E. Oset and A. Ramos, Nucl. Phys. **A635** (1998) 99.
[5] T. Hyodo and W. Weise, Phys. Rev. C **77** (2008) 035204.
[6] A. Doté, T. Hyodo and W. Weise, arXiv:0802.0238 [nucl-th], Nucl. Phys. A, in press.

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