$K^-\alpha$ scattering length, the problem of K^--helium bound states and the reaction $dd \to \alpha K^+ K^-$

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Exotic few-body nuclear systems with a $\bar{K}$-meson as a constituent have been studied by Akaishi and Yamazaki [1]. They proposed a phenomenological $\bar{K}N$ potential model, which reproduces K^-p and K^-n scattering lengths from Ref. [2], kaonic-hydrogen atom data, and properties (mass and width) of the $\Lambda(1405)$ resonance. The $\bar{K}N$ interaction in this model is characterized by a strong attraction in the $I=0$ channel, which causes the few-body systems to form dense nuclear objects. As a result, the nuclear ground states of a K^- in (pp), ^{3}He, ^{4}He and ^{8}Be were predicted to be discrete states with binding energies of 48, 108, 86 and 113 MeV and widths 61, 20, 34 and 38 MeV, respectively. Recently a strange tribaryon $S^0(3115)$ with a width of less than 21 MeV/c^2 has been found in the ^{4}He(stopped K^-, p) reaction [3]. This state may be interpreted as a candidate of a neutral deeply bound state $(\bar{K}NNN)^{Z=0}$ with $I=1, I_z=-1$. However, the $S^0(3115)$ is about 100 MeV lighter than the predicted state for which $Z=2$, $I_z=+1$ is expected. Therefore, further searches for bound kaonic nuclear states as well as new data on the interactions of $\bar{K}$ mesons with lightest nuclei are needed.

Up to now the s-wave $K^-\alpha$ scattering length $A(K^-\alpha)$ has not been measured and theoretical calculations of this quantity are not available. Here we present first calculations of $A(K^-\alpha)$ within the Multiple Scattering Approach (MSA). To calculate the s-wave $K^-\alpha$ scattering length as well as the FSI enhancement factor we use the Foldy–Brueckner adiabatic approach based on the multiple scattering (MS) formalism (see Ref. [4]). This method has already been used for the calculation of the enhancement factor for, *e.g.*, the reactions $pd \to {}^3\mathrm{He}\eta$ [5], and $pn \to d\eta$ [6] and $pp \to d\bar{K}^0K^+$ [7].

The calculations of $A(K^-\alpha)$ have been performed for four sets of parameters for the $\bar{K}N$ scattering length taken from Table I of Ref. [8]: K-matrix fit (Set 1), separable fit (Set 2), constant scattering length fit (CSL) from Dalitz–Deloff (Set 3) and CSL fit from Conboy (Set 4). The results of our calculations are presented in the right column of Table 1. They are very similar for Sets 1–3 giving the real (imaginary) parts of $A(K^-\alpha)$ in the range $-1.8\ldots-1.9$ fm ($0.9\ldots0.98$ fm). The results for Set 4 are different: Re $A(K^-\alpha) = -2.24$ fm and Im $A(K^-\alpha)$=1.58 fm.

	$a_0(\bar{K}N)$[fm]	$a_1(\bar{K}N)$[fm]	$A(K^-\alpha)$[fm]
Set 1	$-1.59+i0.76$	$0.26+i0.57$	$-1.80+i0.90$
Set 2	$-1.61+i0.75$	$0.32+i0.70$	$-1.87+i0.95$
Set 3	$-1.57+i0.78$	$0.32+i0.75$	$-1.90+i0.98$
Set 4	$-1.03+i0.95$	$0.94+i0.72$	$-2.24+i1.58$

Table 1: Different sets of the $\bar{K}N$ scattering lengths $a_I(\bar{K}N)$ ($I=0,1$) taken from Ref. [8] to calculate the scattering length $A(K^-\alpha)$ (right column).

Unitarizing the constant scattering length approach we can reconstruct the $\bar{K}\alpha$ amplitude in the zero range approximation

$$f_{\bar{K}\alpha}(q) = \left((A_{\bar{K}\alpha})^{-1} - ik\right)^{-1}, \tag{1}$$

where $k = k_{\bar{K}\alpha}$ is the relative momentum of the $K^-\alpha$ system. The denominator of the amplitude has a zero at a complex energy

$$E^* = E_R - \frac{1}{2}i\Gamma_R = \frac{k^2}{2\mu}, \tag{2}$$

where E_R and Γ_R are the binding energy and width of a $K^-\alpha$ resonance. For Set 1 and Set 4 we found $E^* = (-6.7-\frac{1}{2}i18)$ MeV and $E^* = (-2.1-\frac{1}{2}i11.4)$ MeV, respectively. Note that assuming a strongly attractive phenomenological $\bar{K}N$ potential Akaishi and Yamazaki [1] found a deeply bound $\bar{K}\alpha$ state: $E^* = (-86-\frac{1}{2}i34)$ MeV. Having a very similar $\bar{K}N$ scattering length (as given by Set 1) our approach predicts a loosely bound state. It is not clear whether medium effects might be so strong that they drastically change the $\bar{K}\alpha$ scattering length predicted by the multiple scattering approach with the vacuum value of the $\bar{K}N$ scattering amplitude. In any case it is very importnat to measure the s-wave $\bar{K}\alpha$ scattering length. Note that in the limit of small absorption, *i.e.* when the imaginary part of $A_{\bar{K}\alpha}$ goes to zero, the real part of the scattering length should be much larger for the case of a loosely bound state as compared to the case of a deeply bound state. Such a situation is supported by the calculations within the zero range approximation (ZRA) (even in the presence of absorption) where in the case of a deeply bound state we find: $A(\bar{K}\alpha) = -0.07 + i0.72$ fm. We expect that the ZRA can be applied for the description of the amplitude which is generated by the short range potential used in Ref.[1].

The reaction

$$dd \to \alpha K^- K^+ \tag{3}$$

provides an interesting tool to study $I=0$ resonances in the K^-K^+ sector . At the same time near threshold it is sensitive to the to $K^-\alpha$ final state interaction.We analyzed the $K^-\alpha$ FSI effect in the reaction $dd \to \alpha K^+K^-$ and found that the measurement of the $K^-\alpha$ mass distribution in the reaction $dd \to \alpha K^+K^-$ near threshold may provide a new possibility to determine the s-wave $K^-\alpha$ scattering length.

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