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Λnn bound state with three-body potential

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Abstract. Formalism of the configuration-space Faddeev equations is applied to analyze the bound state problem of ΛNN system. The simulated NSC97f potential for ΛN interaction and semi-realistic NN potentials are used for calculations. We predict a broad Λnn resonance near threshold. A spin dependent three-body ΛNN potential has been proposed to explain experimental evidence for ${}^3_\Lambda n$ bound state. The potential is defined by a Gaussian function of a hyper-radius. It was found that such potential with appropriate spin dependence does not support a bound state of ${}^3_\Lambda n$. A short range form of the potential generates non-physical solutions of the Faddeev equations.

The HypHI Collaboration has recently reported evidence for a bound state of $\Lambda + n + n$ system [1]. However, the bound ${}^3_\Lambda n$ state has not been found under theoretical analysis (see for instance [2]). In the present work we construct a phenomenological three-body ΛNN potential with spin dependence that forms a bound state in the channel $\Lambda + n + n$ (T=1, S=1/2). Such potential does not affect the ground state energy of ${}^3_\Lambda$H hypernucleus fixed by the experimental value of 0.13(5) MeV for the hyperon separation (or binding) energy

Formalism of the configuration-space Faddeev equations was applied for $\Lambda + n + n$ and $\Lambda + n + p$ systems within an s-wave approach. The simulated NSC97f potential [3] for ΛN interaction and MT-I-III semi-realistic NN potential [4] were used for calculations. This model reproduces well the hyperon binding energy for ${}^3_\Lambda$H, with the value of 0.14 MeV (see also Ref. [5]). We have found a broad resonance in the channel $\Lambda + n + n$. The results of the calculations are presented in figure 1a). The method of analytical continuation in the coupling constant is used to calculate the parameters of the resonance [6]. The coupling constant is the coefficient γ which scales triplet component of the ΛN potential. The complex value of the Pade approximant calculated by set of negative energies (circles in figure 1a) for γ=1 gives the energy and width of resonance: $E(\gamma = 1) = E_r - i\frac{\Gamma}{2}$. Our result for the energy of the resonance is 0.2 MeV, that agrees with [7]. Within the presented model, the three-body ΛNN potential is treated as a perturbation of the Hamiltonian. It is defined as one range Gaussian: $V_{3bf}(\rho) = -\delta \exp(-\alpha\rho^2) S(s_\Lambda, s_{NN})$, where ρ is the hyper-radius: $\rho^2 = x^2 + y^2$, with x, y the mass scaled Jacobi coordinates. The function $S(s_\Lambda, s_{NN})$ depends on the spin variables of a hyperon (s_Λ) and NN pair (s_{NN}). Two free parameters δ and α have to be adjusted. We assume the ratio $S(1/2, 1)/S(1/2, 0)$ to be equal 1 or 1/3 [2]. The calculations for α=0.1 fm^{-2} are shown in figure 1b). The three-body ΛNN potential resulted in a bound state of ${}^3_\Lambda n$ generates Λnp over-bound states for S=1/2 and 3/2. The spin dependence, which provides a bound state of ${}^3_\Lambda n$ and keeps the ${}^3_\Lambda$H ground state energy, cannot be considered as realistic. It was found that the short range form (when α>0.1 fm^{-2}) of the potential generates non-physical solutions of the Faddeev equations (see figure 2).

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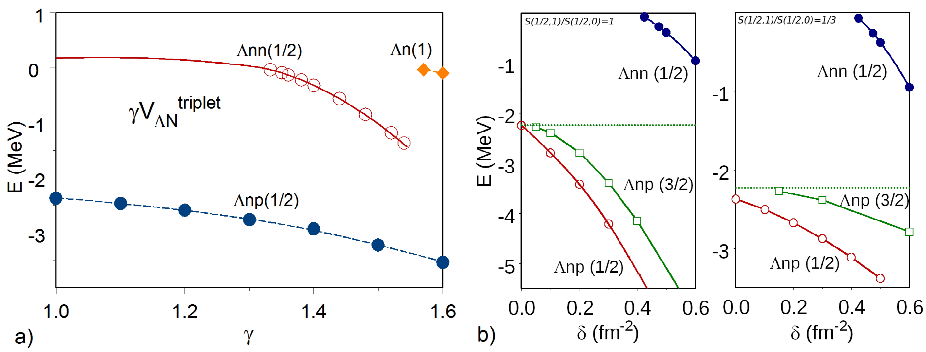

Figure 1. a) Bound state $\Lambda + n + n$ and $\Lambda + n + p$ energies (circles) calculated for different values of γ. The line for Λnn represents the real part of the Pade approximant. The resonance energy corresponds to the value of the approximant for γ=1. The three-body potential is not taken into account. The energy is measured from the $\Lambda+n+n$ threshold. b) $\Lambda+n+n$ and $\Lambda+n+p$ energies (solid and open circles) calculated for different values of δ (α=0.1 fm^{-2}). The δ parameter is scaled by the value $\hbar^2/m$, m is mass of nucleon. (Left) $S(1/2,1)/S(1/2,0)$=1, (Right) $S(1/2,1)/S(1/2,0)$=1/3.

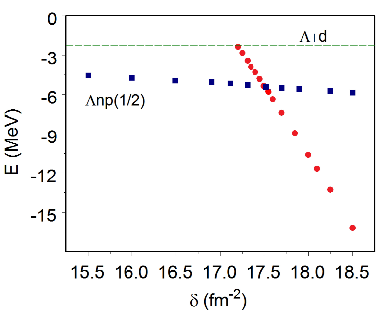

Figure 2. Bound state $\Lambda + n + p$ energies calculated for different values of the δ parameter of the three body potential (α=0.9 fm^{-2}). The squares (circles) correspond to physical (non-physical) solution of the Faddeev equations. $\Lambda + d$ threshold is shown by horizontal dashed line.

We have found a broad Λnn resonance near threshold with the energy of 0.2 MeV and the width of 2 MeV. It is not possible to construct a three-body potential for both Λnn and Λnp systems with reasonable spin dependence under the condition of existence of a ${}^{3}_{\Lambda}n$ bound state. The fact of the appearance of non-physical solutions reflects the known problem of implementation of three-body force into the Faddeev equation formalism.

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