Energy spectrum of $^{15}_{\Xi}$C and the ΞN two-body interaction†

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Studying the interaction of the strangeness $S = -2$ sector is important in hypernuclear physics for a unified understanding of baryon-baryon interaction. To this end, it is crucial to study the structure of double-strangeness hypernuclei, such as double-Λ and Ξ hypernuclei.

In this work, we focused on new experimental data, IRRAWADDY event,[1)] of a $^{15}_{\Xi}$C nucleus observed at $B_\Xi = 6.27 \pm 0.27$ MeV. We estimate the strengths of the $N\Xi$ interaction and give a consistent interpretation for all the events[1–4)] of the Ξ hypernucleus including IRRAWADDY. In addition to our previous work based on the relativistic mean-field (RMF) model,[5)] we introduce an $N\Xi$ residual interaction and infer that KINKA ($B_\Xi = 8.00 \pm 0.77$ or 4.96 ± 0.77 MeV) and IRRAWADDY events[1)] are the ground-state spin doublet with the Ξ particle in the s orbit and that IBUKI ($B_\Xi = 1.27 \pm 0.21$ MeV) and KISO ($B_\Xi = 3.87 \pm 0.21$ or 1.03 ± 0.18 MeV) events[2,4)] are members of the excited-state multiplets with the Ξ particle in the p orbits.

To describe the $^{15}_{\Xi}$C nucleus and estimate its energy spectrum, we employ an RMF model and spin-isospin dependent residual interaction. Within the RMF model, we adopt the PK1 parameter set[6)] for the nucleon-meson couplings, while the coupling constants in the hyperon sector are fitted to roughly reproduce the observed spectrum. Moreover, the effect of the residual interaction is estimated by first-order perturbation theory with the RMF wave functions taken as the unperturbed states. The ^{14}N subsystem of the $^{15}_{\Xi}$C nucleus is described as the $p_{1/2}$ neutron and proton coupled to spin-parity $J^{\pi_{np}}_{np} = 1^+$ and isospin $T_{np} = 0$ on top of the inert ^{12}C core. The Ξ particle is then coupled to the nucleon pair to make the total quantum number $J^\pi T$, where J^π is the total spin-parity of the system, and $T = 1/2$ in the case of $^{15}_{\Xi}$C.

We consider a residual interaction acting on s and p waves. The s-wave interaction is given by

$$V_{N\Xi} = \sum_{i\in\text{nucleons}} (v_\sigma \boldsymbol{\Sigma}_i \cdot \boldsymbol{\Sigma}_\Xi + v_\tau \vec{\tau}_i \cdot \vec{\tau}_\Xi + v_{\sigma\tau} \boldsymbol{\Sigma}_i \cdot \boldsymbol{\Sigma}_\Xi \vec{\tau}_i \cdot \vec{\tau}_\Xi)\delta(\mathbf{r}_i - \mathbf{r}_\Xi), \quad (1)$$

where $\boldsymbol{\Sigma}$ is the spin operator acting on a Dirac spinor and $\vec{\tau}$ are the isospin operators. The strength parameters of $V_{N\Xi}$ are fixed based on the HAL QCD ΞN potential.[7)] We further introduce a p-wave spin-dependent interaction given by

$$V^p_{N\Xi} = \sum_{i\in\text{nucleons}} v^p_\sigma \boldsymbol{\Sigma}_i \cdot \boldsymbol{\Sigma}_\Xi \overleftarrow{\nabla} \cdot \delta(\mathbf{r}_i - \mathbf{r}_\Xi) \overrightarrow{\nabla}, \quad (2)$$

where v^p_σ is a parameter to be optimized by the measured energies of IRRAWADDY and KINKA events.

Fig. 1(a) shows the energy spectrum of $^{15}_{\Xi}$C as a function of v^p_σ, which is obtained by assuming that the IRRAWADDY event is the ground state of $^{15}_{\Xi}$C. It is seen that $v^p_\sigma \sim -150$ MeV.fm^5 and $\sim$100 MeV.fm^5 give spectra consistent with all the experimental data. Fig. 1(b) shows the energy spectrum obtained by assuming that the lower candidate of the KINKA event is the ground state. In this case, $v^p_\sigma \sim -150$ MeV.fm^5 and $\sim$125 MeV.fm^5 give results consistent with the data.

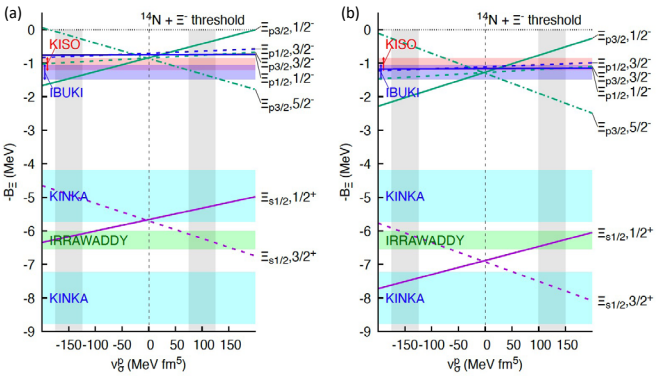

Fig. 1. Estimated energy spectrum of $^{15}_{\Xi}$C nucleus as a function of the p-wave spin-spin interaction strength v^p_σ. The energies of the levels labeled by the orbital occupied by the Ξ^- particle, Ξ_{lj}, and the total spin parity, J^π, are represented by lines. The experimental data of B_{Ξ^-} are shown by color bands.

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