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$\Xi^{12}C(0^+)$ and $\Xi^{16}O$ Potentials Derived from the SU_6 Quark-Model Baryon-Baryon Interaction*

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There exists a renewed interest in interactions between hyperons and nuclei, since rich experimental data are expected to emerge from the strangeness experiments at J-PARC. In particular, our understanding on interactions between the octet-baryons ($B_8 = N,\ \Lambda,\ \Sigma$ and Ξ) and light nuclei will be significantly improved by observing possible bound states and resonances of light hypernuclei. These interactions are also important as basic constructing blocks of heavier hypernuclei through sophisticated microscopic calculations of many-cluster systems. Needless to say, these hypernucleus data afford invaluable source of information for underlying baryon-baryon interactions, since the direct scattering data for the hyperon-nucleon (YN) interaction are still scarce and none exists for the hyperon-hyperon (YY) interaction. It is therefore important to apply models for the baryon-baryon interaction to finite nuclei, and to clarify characteristics of the interaction and its implications to hypernuclear physics.

We have developed a quark-model (QM) baryon-baryon interaction for the octet-baryons [1], which reproduces all the two-nucleon data and the low-energy YN scattering data. It is formulated in the $(3q)$-$(3q)$ resonating-group method (RGM), using the spin-flavor SU_6 QM wave functions. A colored version of the one-gluon exchange Fermi-Breit interaction is fully incorporated with the flavor symmetry breaking, and effective meson-exchange potentials are introduced between quarks. The early version, the model FSS [2] includes only the scalar (S) and pseudoscalar (PS) meson exchange potentials, while the renovated version fss2 [3,4] introduces also the vector (V) meson exchange potentials and the momentum-dependent Bryan-Scott terms for the S and V mesons. One of the important differences between FSS and fss2 is that the former describes the LS forces only by the Fermi-Breit interaction, while the latter also contains the ordinary LS component originating from the S-meson exchange.

As an important application of our QM baryon-baryon interactions, we have carried out Faddeev calculations for the triton and the hypertriton in Ref. [5], in the most reliable framework of using the energy-independent renormalized RGM kernels [6]. The triton binding energy, predicted by fss2, is very close to the ex-

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perimental value with about 350 keV less bound, and the Λ separation energy of the hypertriton is 262 keV vs. the experimental value, 130 ± 50 keV. In the hypertriton calculation, the detailed information is obtained for the central force of the ΛN interaction, since this system is S-wave dominant.

For the p-shell Λ-hypernuclei, some kinds of models inevitably need to be assumed so far, to connect properties of the Λ-hypernuclei and the underlying YN interactions. In our previous publications, we have studied $B_8\alpha$ [7,8] and $B_8(3N)$ potentials [9] based on the G-matrix calculations of our QM hyperon-baryon interaction within the framework of the lowest-order Brueckner theory. Here, $(3N)$ stands for the triton or ^{3}He, and rigid translational-invariant harmonic-oscillator (h.o.) shell-model wave functions are assumed with the size parameters $\nu = 0.257$ fm^{-2} for α and and 0.18 fm^{-2} for the $(3N)$ cluster. In these calculations, we have developed a new method to derive direct and knock-on terms of the interaction Born kernel from the YN G-matrices with explicit treatments of the nonlocality and the center-of-mass (c.m.) motion between the hyperon and the α cluster. This framework makes it possible to take into account the short-range correlations and other correlations related to the channel-coupling effect of baryon channels, which is a new feature of the YN and YY interactions. For example, a strong ΛN-ΣN coupling is caused by the strong tensor component of the one-pion exchange, and the very small single-particle (s.p.) spin-orbit force of the Λ hyperon is explained by a strong cancellation of the ordinary LS and the antisymmetric LS ($LS^{(-)}$) forces generated from the rich structure of the LS components of the Fermi-Breit interaction. [10] The G-matrix calculations are carried

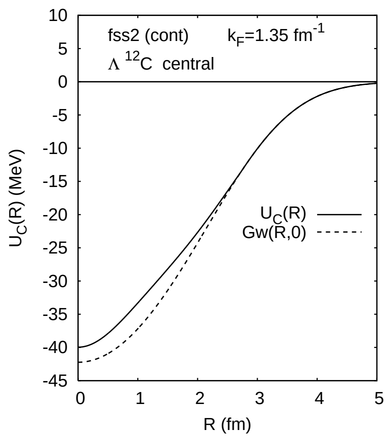

Fig.1. The zero-momentum Wigner transform (dashed curve) and the solution of the transcendental equation (solid curve) for the bound-state energy $E_B = -13.51$ MeV, obtained from the Wigner transform of $\Lambda^{12}C(0^+)$ Born kernel. The model is fss2 and $k_F = 1.35$ fm^{-1} is used.

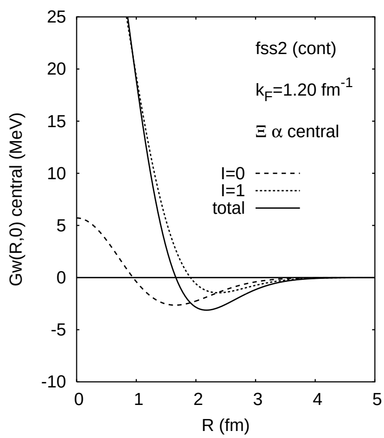

Fig.2. The central components of the zero-momentum Wigner transform for the $\Xi\alpha$ Born kernel. The contributions from the $I = 0$ and $I = 1$ components are separately shown. The model is fss2 and $k_F = 1.20$ fm^{-1} is used. The energy-independent QM RGM kernel is used.

out by assuming a constant Fermi momentum k_F, which is a parameter in the present framework. As in the Faddeev calculations of the triton and hypertriton, the energy-independent QM baryon-baryon interaction is used for the G-matrix calculation.

We extend this method to the B_8 $^{12}C(0^+)$ and B_8 ^{16}O systems, assuming the h.o. shell-model wave functions with $\nu = 0.20$ fm^{-2} for ^{12}C and 0.16 fm^{-2} for ^{16}O. Our main interest is to find new features appearing in the core nuclei involving the p-shell orbits. For the G-matrix calculation, we use $k_F = 1.35$ fm^{-1}, which corresponds to the normal saturation density.

As an example of Λ-core potentials, we show in Fig. 1 the $\Lambda^{12}C(0^+)$ potential for the $^{13}_{\Lambda}C$ ground state, calculated from the model fss2. Since the $\Lambda^{12}C(0^+)$ Born kernel, derived from the ΛN G-matrix folding is nonlocal, we have calculated the Wigner transform in the WKB-RGM approach [11]. The effective local potential is then obtained by solving the transcendental equation for the Wigner transform. Figure 1 also shows the zero-momentum Wigner transform with the dashed curve, which is already a good approximation to the effective local potential (solid curve). This potential predicts the bound-state energy $E_B = -13.51$ MeV, which is used for the input of the transcendental equation. We compare in Table 1 our QM predictions for the bound-state energies of light Λ hypernuclei with available experimental data. The bound-state energies are calculated by solving the Lippmann-Schwinger equations for the Λ-core Born kernels. The result for the hypertriton is taken from the Faddeev calculations in Ref. [5]. We find that the present G-matrix approach can give reasonable results for the Λ s.p. potentials in light nuclei, if an appropriate Fermi momentum for each system is chosen.

The Σ-core and Ξ-core interactions are generally repulsive, except for a special case like $^{4}_{\Sigma}He$. The origin of the repulsion in the Σ-core potential is the quark-Pauli effect which appears in the isospin $I = 3/2$ ^3S state for the most compact SU_3 (30) configuration. On the other hand, the isospin $I = 0$ channel of the ΞN interaction, the $^1S_0$ H-particle channel in particular, is attractive owing to the color-

Table 1. Comparison of the ground-state energies of some light Λ hypernuclei between the QM predictions and the experiment. The energies are measured from the Λ separation threshold. The unit is in MeV. The listed Fermi momenta k_F are used for the G-matrix calculations except for the hypertriton $^3_{\Lambda}H$.

System	k_F (fm^{-1})	fss2	FSS	exp't [12]
$^3_{\Lambda}H$	Faddeev [5]	−0.262	−0.790	-0.13 ± 0.05
$^4_{\Lambda}H(0^+)$	1.07	−1.55	−2.29	-2.04 ± 0.04
$^4_{\Lambda}He(0^+)$				-2.39 ± 0.03
$^4_{\Lambda}H(1^+)$	1.07	−0.97	−0.32	-0.99 ± 0.04
$^4_{\Lambda}He(1^+)$				-1.24 ± 0.05
$^5_{\Lambda}He$	1.20	−3.43	−2.41	-3.12 ± 0.02
$^{13}_{\Lambda}C$	1.35	−13.90	−11.31	-11.69 ± 0.12
$^{17}_{\Lambda}O$	1.35	−16.04	−13.37	

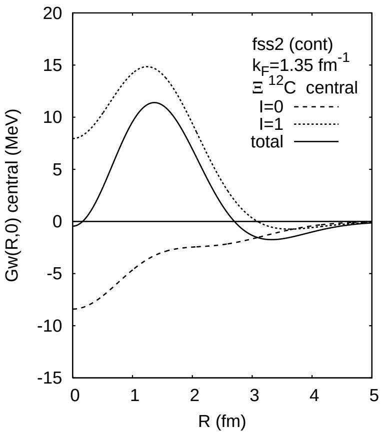

Fig.3. The same as Fig 2, but for the $\Xi^{12}C(0^+)$ Born kernel. The model is fss2 and $k_F = 1.35$ fm^{-1} is used for the G-matrix calculation.

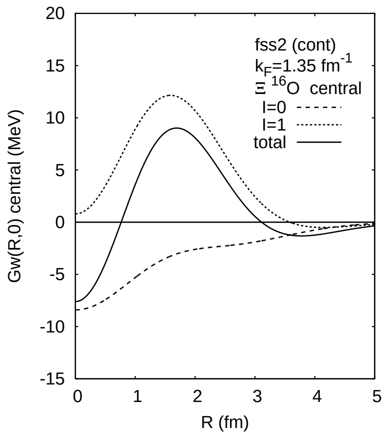

Fig.4. The same as Fig. 3, but for the $\Xi^{16}O$ zero-momentum Wigner transform.

magnetic term of the Fermi-Breit interaction. The $I = 1$ ΞN interaction is repulsive, but involves a strong channel-coupling effect with the $\Sigma\Lambda$ channel. Since the extension of the Wigner transform to the negative q^2 is not easy numerically, we only discuss the zero-momentum Wigner transform, $G^C_W(R, 0)$, which we call the "B_8-core potential" in the following. The $\Xi^{12}C(0^+)$ and $\Xi^{16}O$ potentials, obtained as the zero-momentum Wigner transform of the folding kernels for the G-matrix interaction with the Fermi momentum $k_F = 1.35$ fm^{-1}, are illustrated in Figs. 3 and 4 for fss2. We find a weak attraction in the surface area around $R \sim 3$ - 4 fm, which is a common feature to the previous $\Xi\alpha$ potential shown in Fig. 2. The present potentials, however, also possess an attractive pocket in the short-range region with $R \leq 1.2$ fm, which originates from the strong attraction in the isospin $I = 0$ component. This feature is clearly related to the p-orbit of the core nuclei. Such a structure of the nuclear potentials should appreciably influence on the Coulombic bound states for the Ξ^- atoms.

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