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The 0^+-1^+ A=4 Λ-Hypernuclei Binding Energy Difference in an Exact Equation, Separable Potential Calculation

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The A=4 Λ-hypernuclei are the only known baryonic systems with A<6 which exhibit a particle-stable excited state. Therefore, the binding-energy systematics offer a unique opportunity to test our ability to model the low-energy properties of the hyperon-nucleon (YN) force. We have previously observed[1] that the charge symmetry breaking exhibited by the 0^+ ground-state Λ-separation energies for this isodoublet appears to be consistent with that reflected in the low-energy ΛN scattering parameters of the Nijmegen[2] meson theoretic YN potential model D, only if one utilizes exact four-body equations from a complete four-body theory. We wish to point out here that the 0^+-1^+ binding energy difference in this system is sensitive to ΛN⟷ΣN conversion.

Measurement of the M1 γ-deexcitation energies in the A=4 hypernuclear system has yielded[3]

$$E_\gamma({}^4_\Lambda H) = 1.04 \pm .04 \text{ MeV} \qquad \text{and} \qquad E_\gamma({}^4_\Lambda He) = 1.15 \pm .04 \text{ MeV}.$$

Theorists' ability to model bound-state systems is much more highly developed than it is for the continuum. Furthermore, the experimental precision possible in such measurements is normally much higher than one can achieve in scattering experiments. Does the average value of ΔE = 1.1 MeV from this spin-flip transition reflect the simple spin-dependence of the observed ΛN scattering lengths and effective ranges?

We have explored this question using i) exact four-body equations which are equivalent to those of Yakubovsky in their separable potential formulation[4] and ii) YN separable potentials[5] whose parameters were determined from the low-energy scattering properties of the Nijmegen model F.[6] We solve the coupled, two-variable integral equations numerically without resort to separable expansion of the three-body kernels. When we represent the ΛN interaction in terms of one-channel central potentials fitted to ΛN scattering data and assume that the interaction is unaltered when the ΛN pair is embedded in the nuclear medium (i.e., when it binds to a nuclear core), then we find that the A=4 1^+ state is more bound than the 0^+ state.[7] That is, we find that the ground state and excited state are inversely ordered in comparison with experiment. If we instead model the ΛN↔ΣN conversion as a coupling of the Λ-Σ system to a spatially symmetric T=1/2, $J^\pi=1/2^+$ trinucleon core, then we find a suppression of the off-diagonal (ΛN↔ΣN) potential which reduces the binding in the 0^+ state more than in the 1^+ state. We obtain a model value for the $1^+\to0^+$ transition energy of $E_\gamma \approx 1.4$ MeV. That is, E_γ then has the right sign and correct magnitude. We conclude that the 1^+-0^+ binding energy difference in the A=4 hypernuclei reflects the spin-dependence of the YN interaction in a complex manner that cannot be simply represented by one-body equation (e.g. mean field) approximations to few-body systems.

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