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A- Σ COUPLING AND CORE EXCITATION EFFECTS IN THE LIGHT HYPERNUCLEI*

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Λ - Σ COUPLING AND CORE EXCITATION EFFECTS

IN THE LIGHT HYPERNUCLEI *

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We have recently reported¹ an investigation of the effects on the binding energies of ${}^4_{\Lambda}\text{H}$, ${}^4_{\Lambda}\text{He}$, and ${}^5_{\Lambda}\text{He}$ produced by the Λ - Σ coupling.² The conclusions drawn were: 1) the Λ - Σ coupling produces a significant effect on the binding energies of ${}^4_{\Lambda}\text{H}$ and ${}^4_{\Lambda}\text{He}$ under the assumption that Λ - Σ coupling is suppressed in the ${}^5_{\Lambda}\text{He}$ system (since a core excitation of ${}^4\text{He}$ to a T=1 state is required in order to couple with the Σ isotriplet); 2) the difference in the Λ -separation energy for each member of the ${}^4_{\Lambda}\text{H}$ - ${}^4_{\Lambda}\text{He}$ isodoublet results from the admixture of the Σ state, being in part due to Coulomb effects and in part due to the mass splitting within the Σ triplet.

No explicit calculations were reported in which we included the effects of the core excitations in ${}^4\text{He}$. We wish to report new results in which we allow for the T=1 excitation of ${}^4\text{He}$ and which confirm that in fact the Λ - Σ coupling is strongly suppressed in ${}^5_{\Lambda}\text{He}$. We also will discuss the consequences of this for the Λ -separation energy splitting in the ${}^4_{\Lambda}\text{H}$ - ${}^4_{\Lambda}\text{He}$ system.)

One must note that the observed T=1 states in ${}^4\text{He}$ all have odd parity. Since ${}^5_{\Lambda}\text{He}$ has a T=0, $J^{\pi}=1/2^{+}$ ground state, an admixture of the T=1 Σ coupled with the observed T=1 resonant states must have odd relative L (1,3,5...). The combination of exclusion of the Σ from the region of the origin by the centrifugal barrier and concentration of the Σ near the origin due to its large excitation energy ($m_{\Sigma}-m_{\Lambda} \approx 78$ MeV) tends to make these odd parity states relatively unimportant --- certainly less important than any T=1, J=0 resonance, if one existed. Therefore, we hypothesize the existence of such a T=1, $J^{\pi}=0^{+}$ excited state in ${}^4\text{He}$ and include the effects of the Σ coupled to this T=1 state.

As in our previous calculation we use the Dalitz-Downs³ model for both ${}^4_{\Lambda}\text{H}$ - ${}^4_{\Lambda}\text{He}$ and ${}^5_{\Lambda}\text{He}$. In this model the hypernucleus is assumed to be a two-body system composed of the hyperon interacting with the nuclear core in a relative s-state. Within the model the equations to be solved for the relative wave function (a two component wave function composed of ϕ_{Λ} , the amplitude for the dominant Λ component, and ϕ_{Σ} , the amplitude for the Σ admixture;

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$\langle \phi_\Lambda | \phi_\Lambda \rangle + \langle \phi_\Sigma | \phi_\Sigma \rangle = 1$ are:

$$\begin{aligned} -\frac{\hbar^2}{2\mu_\Lambda} \frac{d^2}{dr^2} \phi_\Lambda(r) + V_\Lambda(r)\phi_\Lambda(r) + V_{\Lambda\Sigma}(r)\phi_\Sigma(r) &= E\phi_\Lambda(r) \\ \frac{\hbar^2}{2\mu_\Sigma} \frac{d^2}{dr^2} \phi_\Sigma(r) + V_\Sigma(r)\phi_\Sigma(r) + V_{\Lambda\Sigma}(r)\phi_\Lambda(r) &= (E - \Delta m)\phi_\Sigma(r) \end{aligned} \quad (1)$$

In these equations Δm represents the excitation energy of the virtual Σ state (the Λ - Σ mass difference) plus any core excitation energy of the nuclear state in the case of ${}^5_\Lambda\text{He}$. The potentials $V_\Lambda(r)$ and $V_\Sigma(r)$, which describe the interactions of the Λ and Σ with the nucleus, are given by

$$\begin{aligned} V_\Lambda(r) &= \int d^3r' \rho(r') V_{\Lambda N}(\vec{r}-\vec{r}') \\ V_\Sigma(r) &= \int d^3r' \rho(r') V_{\Sigma N}(\vec{r}-\vec{r}') \end{aligned} \quad (2)$$

where $V_{\Lambda N}$ and $V_{\Sigma N}$ are the basic Λ -N and Σ -N interactions, $\rho(r')$ is the nuclear mass density of the core state. The $V_{\Lambda\Sigma}$ represents the Λ - Σ coupling

$$V_{\Lambda\Sigma}(r) = \int d^3r' \rho_t(r') V_{\Lambda\Sigma N}(\vec{r}-\vec{r}') \quad (3)$$

where $V_{\Lambda\Sigma N}$ represents the Λ - Σ transition coupling at $\vec{r}$ in the presence of a nucleon at $\vec{r}'$ and $\rho_t(r')$ is the transition mass density. We assume a Gaussian mass density for all states. We use Gaussian potentials of the form

$$V(\vec{r}-\vec{r}') = V_0 \exp(-(\vec{r}-\vec{r}')^2/b^2), \quad (4)$$

where $b = 1.05$ f corresponding to a 2π mass exchange.

In our previous calculations we assumed the ${}^4_\Lambda\text{He}$ transition mass density $\rho_t(r')$ to be zero. In ${}^5_\Lambda\text{He}$ then only the $V_{\Lambda N}$ potential contributed and the depth was chosen to reproduce the ${}^5_\Lambda\text{He}$ Λ -separation energy $E_\Lambda({}^5_\Lambda\text{He})$. The $V_{\Sigma N}$ and $V_{\Lambda\Sigma N}$ depths were then determined to give the observed $E_\Lambda({}^4_\Lambda\text{He})$. These results are indicated in the first two lines of the tables below.

In our present calculations we assume the $T=1$ state of ${}^4_\Lambda\text{He}$ to be either a one or two particle excitation of the 2S harmonic oscillator type. The $\rho_t(r')$ is the overlap of a 1S and a 2S state. The well depths $V_{\Lambda N}$ and $V_{\Lambda\Sigma N}$ were then determined to produce the correct $E_\Lambda({}^5_\Lambda\text{He})$ and $E_\Lambda({}^4_\Lambda\text{He})$. We assumed a $2\hbar\omega$ excitation of approximately 40 MeV for the $T=1$ ${}^4_\Lambda\text{He}$ state. The results of the calculation were not sensitive to that choice. They are presented in the 3rd line of each table.

Binding Energy Table						
	$V_{\Lambda N}$	$V_{\Lambda \Sigma N}$	$V_{\Sigma N}$	$E_{\Lambda}({}^5_{\Lambda}\text{He})$	$E_{\Lambda}({}^4_{\Lambda}\text{H})$	ΔB_{Λ}
1.	38.2	--	--	3.08	--	--
2.	38.2	30.0	29.0	--	2.02	.15
3.	38.0	30.1	29.0	3.09	2.01	.15
1.	38.2	--		3.08	--	--
2.	38.2	25.0	48.0	--	2.01	.21
3.	37.9	25.3	48.0	3.09	2.02	.21
1.	38.2	--		3.08	--	--
2.	38.2	20.0	64.0	--	2.00	.30
3.	37.2	20.4	64.0	3.07	2.02	.31

We wish to emphasize two points from these tables. First, the inclusion of the Λ - Σ coupling in ${}^5_{\Lambda}\text{He}$ has no appreciable effect. The potential well depths change only slightly from the values determined when the coupling was not included. (Doubling the coupling strength does not change this conclusion.) The strong Σ suppression arises because of the cancellations that occur when averaging $V_{\Lambda \Sigma N}(\vec{r}-\vec{r}')$ over $\rho_t(r')$ and because only one or two nucleons can take part in the interaction when the core state is excited.

Second, the tables exhibit the calculated energy splitting of the isodoublet $\Delta B_{\Lambda} = E_{\Lambda}({}^4_{\Lambda}\text{He}) - E_{\Lambda}({}^4_{\Lambda}\text{H})$, which is to be compared with the measured value of approximately 0.29 MeV. The splitting results from two effects: 1) the mass differences within the Σ isotriplet, which in effect replace Δm in ${}^4_{\Lambda}\text{H}$ by 80.1 MeV and in ${}^4_{\Lambda}\text{He}$ by 74.8 MeV; 2) Coulomb energy differences which can be written

$$\Delta B_C = -\frac{4}{3} P_{\Sigma} E_C({}^3\text{He}) + \frac{4}{3} e^2 \int \frac{d^3 r d^3 r'}{4\pi r^2} \frac{\phi_{\Sigma}^2(r')}{|\vec{r}-\vec{r}'|} \rho_C(r') \quad (5)$$

where P_{Σ} is the Σ probability, $E_C({}^3\text{He})$ is the Coulomb energy ${}^3\text{He}$, and $\rho_C(r')$ is the ${}^3\text{H}-{}^3\text{He}$ isoscalar charge density normalized to 3. With the potential parameters quoted the results agree quite well with the experimental value for ΔB_{Λ} . Discussions with A. Bodmer and A. Kerman is gratefully acknowledged.

References

1. B. F. Gibson, A. Goldberg, M. S. Weiss, Phys. Rev. (to be published)
2. A. R. Bodmer, Phys. Rev. 141 (1966) 1387.
3. R. H. Dalitz and B. W. Downs, Phys. Rev. 111 (1958) 967.