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Study of Spin-Dependent ΛN Interactions by Gamma-Ray Spectroscopy of p-Shell Hypernuclei

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1 Introduction

Study of hypernuclear structure is one way to investigate baryon-baryon interactions. By comparing experimental Λ hypernuclear data with their calculated structure, the proprieties of the ΛN interaction models can be verified. The energies of low-lying p-shell hypernuclear levels are described with five parameters of the ΛN effective interaction. They are the spin-averaged central force ($\bar{V}$), the spin-spin force (Δ), the Λ-spin-dependent spin-orbit force (S_Λ), the N-spin-dependent spin-orbit force (S_N) and the tensor force (T). Our purpose is the study of the spin-dependent ΛN interactions through precise measurement of hypernuclear structure. In particular, the present experiment aims at determination of the tensor force strength by the $^{16}O(K^-, \pi^-\gamma)$ reaction and consistency check of all the spin-dependent interactions by the $^{10}B(K^-, \pi^-\gamma)$ reaction.

2 Experiment and Analysis

We performed γ-ray spectroscopy experiment of p-shell hypernuclei with a germanium detector array, Hyperball, at the BNL-AGS D6 beam line (BNL E930 ('01)). The bound states and the excited states of hypernuclei were produced in the (K^-, π^-) reaction with 0.93 GeV/c kaon beam. The D6 beam line included magnetic spectrometers for incident and outgoing particles. Each momentum was reconstructed by the corresponding spectrometer, and the mass and the recoil momentum of hypernuclei were calculated. By gating the mass for particular hypernuclear states, we selected the hypernuclear production events. Hyperball consisted of fourteen germanium detectors, each of which was surrounded by six BGO counters used to reject Compton scattering events and π^0 decay events. All the germanium detectors were energy calibrated up to 7 MeV.

3 Results from the $^{16}O(K^-, \pi^-\gamma)$ reaction

We observed two γ-ray peaks of $^{16}_{\Lambda}O$. They are attributed to the M1 transition from the 6 MeV excited state (1^-) to both of the ground-state doublet members ($1^-, 0^-$) of $^{16}_{\Lambda}O$. We obtained both energies and yield. From their yield ratio, we found the spins of the ground state doublet. We observed three γ-ray peaks when we selected the mass for the p-substitutional state of $^{16}_{\Lambda}O(0^+)$. This state is located above the proton and Λ emission threshold, and no other particle emission channels which subsequently emit γ-ray over 2 MeV are open. Therefore, they are assigned to the γ-rays of ${}^{15}_{\Lambda}$N.

4 Results from the ^{10}B$(K^-, \pi^-\gamma)$ reaction

We searched for a γ-ray peak of the M1 transition between the ground state doublet of ${}^{10}_{\Lambda}$B, by selecting the mass for the bound state region of ${}^{10}_{\Lambda}$B, but no corresponding peak is found. We concluded that the ground-state doublet has a spacing less than 100 keV.

By selecting the mass above the proton emission threshold, we observed two γ-ray peaks of ${}^{9}_{\Lambda}$Be $(\frac{3}{2}^+, \frac{5}{2}^+ \to \frac{1}{2}^+)$. Those γ rays were also observed in the previous experiment. but the spin order of the doublet was not determined. We found those spins from their yield ratio.

By selecting the mass for the s-substitutional state region, we also observed two γ-ray peaks (M1 and E2) of ${}^{7}_{\Lambda}$Li. Those γ rays were also observed in the previous experiment. We also observed a γ-ray peak by taking $\gamma\gamma$ coincidence with the E2 γ-ray peak of ${}^{7}_{\Lambda}$Li. This γ-ray peak is attributed to the M1 transition between the upper spin-doublet states $(\frac{7}{2}^+ \to \frac{5}{2}^+)$ of ${}^{7}_{\Lambda}$Li. This is the first success of $\gamma\gamma$ coincidence for hypernuclei.

5 Discussion

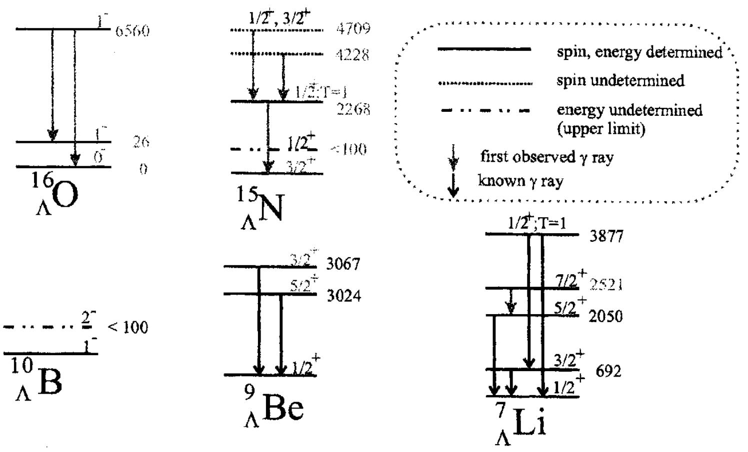

Figure 1: Observed γ-rays and assigned levels.

From the ground-state doublet spacing of ${}^{16}_{\Lambda}$O, we obtained the strength of the tensor force to be $T = 0.03$ MeV. This is the first experimental data on the ΛN tensor force. The strengths predicted by the meson-exchange ΛN interaction models agree with our result. From the three doublet spacings in ${}^{10}_{\Lambda}$B, ${}^{7}_{\Lambda}$Li and ${}^{15}_{\Lambda}$N, we obtained information on the spin-spin force independently. The strength of the spin-spin force was derived to be $\Delta = 0.4$ MeV, which reproduced the Δ value from the previous ${}^{7}_{\Lambda}$Li data. However, the ${}^{10}_{\Lambda}$B data give a value less than 0.3 MeV. From the spin order and the energy spacing of the doublet states of ${}^{9}_{\Lambda}$Be, we obtained the strength of the Λ-spin-dependent spin-orbit force to be $S_\Lambda = -0.01$ MeV. On the other hand, comparing the effective excitation energy of ${}^{7}_{\Lambda}$Li we obtained the strength of the N-spin-dependent spin-orbit force to be $S_N = -0.45$ MeV. The predicted strengths of those spin-orbit forces by the meson-exchange models are $(S_\Lambda, S_N) = (-0.15, -0.25$ MeV$)$ and those by the quark model are $(0.0, -0.4$ MeV$)$. The spin-orbit forces seem to be explained well by the quark model rather than the meson-exchange models.