KEK Preprint 97-226
November 1997
H

Polarization of $^{5}_{\Lambda}$He produced by the (π^+, K^+) reaction

S. AJIMURA, M. ISHIKAWA, K. IKEDA, T. KISHIMOTO, A. OKUSU,
N. SHINKAI, Y. TANAKA, H. EJIRI, T. NAKANO, T. NAGAE, H. NOUMI,
K. MANABE, M. SEKIMOTO, T. SHIBATA, O. HASHIMOTO, K. MAEDA,
T. TAKAHASHI, T. HASEGAWA, H. BHANG, H. PARK,Y. KIM, M. YOUN,
T. MOTOBA and K. ITONAGA

Submitted to Phys. Rev. Lett.

** From April 1, 1997,* ***High Energy Accelerator Research Organization (KEK)*** *was newly established. The new organization is restructured of three reseach institutes, National Laboratory for High Energy Physics (KEK), Instiues of Nuclear Study (INS), Univ. of Tokyo and Meson Science Laboratory, Faculty of Science, Univ. of Tokyo.*

High Energy Accelerator Research Organization (KEK), 1997

KEK Reports are available from:

Information Resources Division
High Energy Accelerator Research Organization (KEK)
1-1 Oho, Tsukuba-shi
Ibaraki-ken, 305
JAPAN

Phone: 0298-64-5137
Fax: 0298-64-4604
Cable: KEK OHO
E-mail: Library@kekvax.kek.jp (Internet Address)
Internet: http://www.kek.jp

Polarization of $^5_\Lambda$He produced by the (π^+, K^+) reaction

S. Ajimura, M. Ishikawa, K. Ikeda, T. Kishimoto, A. Okusu, N. Shinkai, Y. Tanaka

Department, of Physics, Osaka University, Toyonaka, Osaka, Japan, 560

H. Ejiri, T. Nakano,

Research Center for Nuclear Physics, Osaka University, Suita, Osaka, Japan, 564

T. Nagae, H. Noumi, K. Manabe, M. Sekimoto, T. Shibata

High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305 Japan

O. Hashimoto, K. Maeda, T. Takahashi

Department, of Physics, Tohoku University, Sendai, Miyagi, Japan,

T. Hasegawa

School of Hygienic Science, Kitazato University, Sagamihara, Kanagawa, Japan, 228

H. Bhang, H. Park, Y. Kim and M. Youn

Department of Physics, Souel National University, Souel, Korea

T. Motoba

Laboratory of Physics, Osaka Electro-Commun. University, Neyagawa, Osaka, 572 Japan

K. Itonaga

Laboratory of Physics, Miyazaki Medical College, Miyazaki, 889-16, Japan

(November 19, 1997)

Abstract

We measured the polarization of $^5_\Lambda$He produced by the (π^+, K^+) reaction

by observing the asymmetric emission of its weak decay pions for the first time. The large asymmetry parameter of the mesonic decay, which is unique to $^5_\Lambda$He, made the measurement possible. The observed polarization was quite large and consistent with the theoretical prediction by which the mechanism of the hypernuclear polarization was clarified. The polarization, which was found to be predictable, will open a new field to the spectroscopic study of hypernuclei.

PACS numbers: 21.80.+a, 24.70.+s, 25.80.Hp

The nuclear-spin orientation has been useful for studies of many nuclear properties. The angular distributions of particles emitted by the strong interaction, photons by the electromagnetic interaction and weak decay particles show specific patterns, depending on spins relevant to the transitions. Especially processes caused by the weak interaction could have parity-violating asymmetry with respect to the spin polarization. The angular correlations introduced by the asymmetry have been used not only to study nuclear structures, but also to study fundamental symmetries and their violations. The study of hypernuclei has yet to reach such a stage. Recently the (π^+, K^+) reaction showed remarkable progress to the study of hypernuclei. Deeply bound single-particle levels were clearly seen in the reaction [1,2]. Since the study was mostly for measureing the energy and cross section of the states by magnetic spectrometers, theoretical predictions were frequently vital to assign the spin and parity of the states. The weak decay of hypernuclei gives information about the strangeness-changing weak hadronic interaction in nuclei for which the partial and total decay rates were intensively studied. In a next-generation accelerator that can provide intense meson beams one hopes further to study the properties of hypernuclei for which the production and detection of the spin orientation will be vital. For instance, the production of polarized Λ and its asymmetric weak decay has been used to study the magnetic moment. In the present letter we show that polarized ${}^5_\Lambda$He is really produced with a polarization consistent with the calculation, which in fact demonstrates that we understand the mechanism of hypernuclear polarization.

Λ hypernuclei have two types of hadronic decay modes. One is mesonic decay (M-decay) and the other is nonmesonic decay (NM-decay). M-decay is a process where free Λ decay ($\Lambda \rightarrow p + \pi^-$, $n + \pi^0$) takes place in a nucleus. The Λ has an asymmetry parameter ($\alpha_\Lambda = 0.642 \pm 0.013$) [3] for $p\pi^-$ decay due to interference of the s- and p- wave amplitudes. M-decay may also have the finite asymmetry parameter which can be calculated reliably [4]. Hypernuclei, that have a large asymmetry parameter and large branching ratio of the M-decay, are useful though one can find only few of them [4]. ${}^5_\Lambda$He is the such a rare case.

NM-decay is a process by which a Λ and a nucleon in a nucleus have the weak interaction,

making two nucleons in the final state. It may have a parity-violating asymmetry parameter [5] which is poorly predicted, since NM-decay is not yet well understood. A study of the asymmetry parameter clarifies the mechanism of NM-decay. If it turns out to be large, there will be many practical uses, since NM-decay becomes dominant for hypernuclei heavier than A$\sim$7.

Recently, polarized ${}^{12}_\Lambda$C hypernuclei were produced by the ^{12}C(π^+, K^+) reaction, and its asymmetric NM-decay was observed [6]. The asymmetry parameter was found to be quite large (-1.0 ± 0.4), although the statistics was limited and its polarization had to be calculated, since the M-decay of ${}^{12}_\Lambda$C was practically of no use. The polarization of Λ produced by the quasifree process [7] was measured and found to be consistent with that calculated for the $n(\pi, K^+)\Lambda$ reaction with a minor correction due to the binding effect of a neutron [8]. One can accept that the hypernuclear polarization is calculable, though one desires experimental evidence.

A study of ${}^5_\Lambda$He by the (π^+, K^+) reaction was carried out to make up for the shortcomings of the ${}^{12}_\Lambda$C study. The purpose of the experiment is to obtain: (1) the polarization of ${}^5_\Lambda$He by observing the M-decay, (2) the branching ratio in order to clarify the isospin structure of the M- and NM-decays and (3) the asymmetry parameter of NM-decay. In this letter we present the results of (1) the polarization of ${}^5_\Lambda$He. The results of subjects 2 and 3 will appear in the future publications. It has to be noted that the M-decay of ${}^5_\Lambda$He has a large asymmetry parameter (almost equal to that of free Λ with little theoretical ambiguity [9]) and a large branching ratio [10]. They made the polarization measurable, which was essential for the present experiment.

The experiment (PS-E278) was carried out at the K6 beam line of KEK-PS. The ^{6}Li$(\pi^+, K^+p){}^5_\Lambda$He reaction at P_π=1.05 GeV/c was used to produce polarized ${}^5_\Lambda$He. The π^+ beam intensity was typically $\sim 3 \times 10^6$/spill, where a spill consisted of 1.7 seconds of continuous beam every 4.0 seconds. The beam-line spectrometer measured the incident pion momentum. The momentum of outgoing kaons was measured by the SKS spectrometer, which has a good energy resolution (2 MeV FWHM) and a large acceptance ($\sim 100msr$)

[11]. The large solid angle makes the simultaneous measurement of positive and negative scattering angles possible, which is essential to remove any spurious error in the asymmetry measurement. The target was 95% enriched metal ^{6}Li with a size of $2 \times 5 \times 6$ cm^3. A differential-type lucite Čerenkov counter located just behind the target was sensitive only to pions, and was effective to reduce the trigger rate. The data-taking rate was kept tolerable for the target, which was $2 \sim 3$ times thicker than usual. Scattered kaons were clearly identified with negligible background from the mass spectrum obtained by combining time-of-flight (TOF).

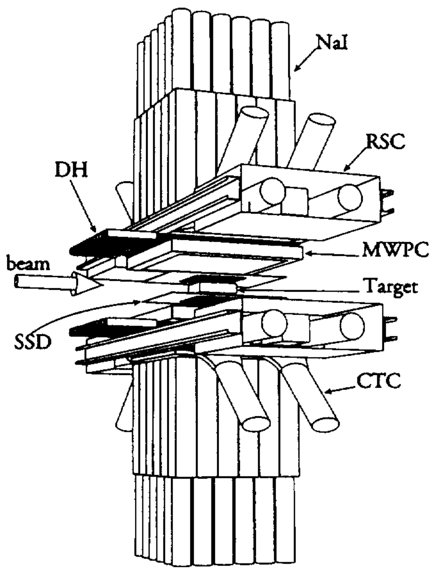

Figure 1

Perspective view of the decay counter system.

Decay particles from the $^5_\Lambda$He were measured by the decay-counter system shown in figure 1. Two sets of detector systems were placed below and above the target. Each detector system consisted of a Si micro-strip detector (SSD), a multiwire proportional chamber (MWPC), a plastic scintillator hodoscope (DH), a range shower counter (RSC), and 36 NaI detectors. Each NaI detector had a dimensions of $6.5 \times 6.5 \times 30$ cm^3, which gives a clue to the size of the detector system. The SSD with a thickness of 0.5 mm covers a 62×62 mm^2 area with 1 mm pitch. The MWPC has three layers that cover a 192×192 mm^2 area with a 2 mm pitch. The tracks of the charged particles were identified by the SSD, MWPC and the DH. A range shower counter (RSC), consisting of 32 layers of thin (0.2 mm) lead and 1 mm plastic sheets [12], worked as a range counter for protons below 100 MeV and charged pions below 40 MeV and as a gamma-ray shower counter. Charged particles that punched though the RSC were identified by a plastic scintillator (CTC). The whole system covered 32.5% of the total solid angles for charged particles.

Pions and protons from $^5_\Lambda$He decay were identified by dE/dX information given by SSD and the total energy. The detector was sensitive to 10 to 50 MeV pions, which was appropriate to the present study, since the decay pion peaked at around 32 MeV. The particle identification (PI) spectrum is shown in figure 2 for the decay particles from $^5_\Lambda$He. The broad peak on the left is due to pions, and the sharp peak on the right is due to protons. The left side of the dashed line in the spectrum is taken to be the pion window. In order to derive the pion asymmetry, contamination of protons in the pion region was evaluated. The Landau-tail in the dE/dX spectrum tends to be pions which leak into the proton region, although little contamination of protons is expected in the pion region. Actually, the contamination was found to be negligible.

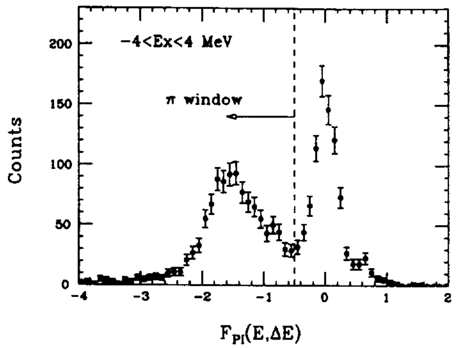

Figure 2

PI spectrum of decay particles gated by the ground-state region of ${}^{6}_{\Lambda}$Li.

The excitation-energy spectra of the ^{6}Li(π^{+}, K^{+}) reaction are shown in figure 3. The ground state is clearly seen in both the inclusive and pion-gated spectra. The peak was hardly seen in the previous experiment, where the ${}^{6}_{\Lambda}$Li was studied based on the (K^{-}, π^{-}) reaction. The ground state is 4 MeV, bound from the Λ emission threshold, above which the production of the Λ by the quasifree process is expected. Experimentally we define the ground-state region to be at Ex= $-4 \sim 4$.

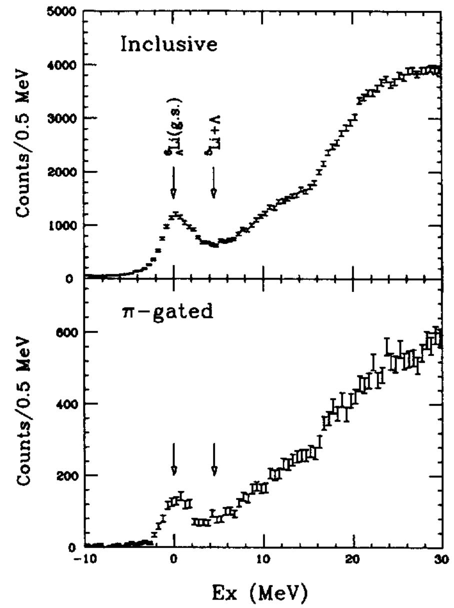

Figure 3

Excitation-energy spectra of the ^{6}Li(π^{+}, K^{+}) reaction. The upper plot is the inclusive spectrum, and lower plot is the pion gated spectrum.

The asymmetry (A) was obtained from the experimental coincidence yields as

$$\sqrt{\left(\frac{N^{\uparrow}(+\theta)N^{\downarrow}(-\theta)}{N^{\downarrow}(+\theta)N^{\uparrow}(-\theta)}\right)} = \frac{1+A}{1-A}. \tag{0.1}$$

Here, $N^{\uparrow}(+\theta)$ stands for number of counts in the up decay counter system when kaons are detected by the SKS spectrometer at $\theta = dx/dz$, where x is positive. Here, the z and y directions are the beam direction and the upward direction, respectively and the x direction is given by the right-handed coordinate system, accordingly. First-order systematic errors related to the normalization of the beam intensity, the fluctuation of the beam intensity, the asymmetry of the solid angle and the misalignment of the beam center all cancel in this ratio. In order to determine any spurious instrumental asymmetry, the $(\pi^+, \pi^+ X)$ reaction was measured simultaneously with the (π^+, K^+) reaction, since no up-down asymmetry is expected in the former reaction because no parity violating weak interaction is involved.

The observed asymmetry (A^π) is related to the polarization (P) by

$$A^\pi = P\alpha^\pi\varepsilon. \tag{0.2}$$

Here, α^π stands for the asymmetry parameter of the ${}^5_\Lambda$He M-decay, and ε is the reduction factor of the asymmetry due to the finite solid angle of the detector, which was estimated by a Monte-Carlo simulation (GEANT). The α^π was taken to be equal to that of free Λ decay. The value is sufficiently accurate for the present study [9]. The observed polarization is given in table 1. The instrumental asymmetry was less than 3%. The errors are dominantly from statistics.

reaction		$\theta = 2 \sim 7^o$	$\theta = 7 \sim 15^o$
$(\pi^+, \pi^+ X)$	asymmetry	-0.001 ± 0.014	-0.014 ± 0.013
	P	< 0.03	< 0.03
(π^+, K^+)	asymmetry	-0.113 ± 0.044	-0.197 ± 0.054
	P	0.214 ± 0.084	0.375 ± 0.103
	$P_{cal}(2)$	0.181	0.368
	$P_{cal}(4)$	0.123	0.250

Table 1

Observed asymmetry and polarization obtained by equation 2. See the text for the predicted values.

The ${}^6_\Lambda$Li ground state produced by the (π^+, K^+) reaction lies 0.9 MeV above the proton emission threshold and 4 MeV bound for the Λ [10]. The states around the ${}^6_\Lambda$Li ground-state region exclusively produce ${}^5_\Lambda$He by emitting a proton. In order to calculate the polarization

of ${}^5_\Lambda$He, first the polarization of the ${}^6_\Lambda$Li states was calculated, and then depolarization due to the proton emission to make ${}^5_\Lambda$He was estimated.

The cross section and polarization have been calculated for the ^{6}Li(π^+, K^+) reaction at 1.05 GeV/c [13]. The DWIA calculation employed the polarization of the elementary (π^+, K^+) reaction, the initial nuclear and final hypernuclear wave functions and the distortion of meson waves due to the meson nucleus interaction. The ${}^6_\Lambda$Li ground state is a doublet of 1^- and 2^- with a configuration of $(p_{3/2})^{-1}_n(s_{1/2})_\Lambda$. The calculated polarization is shown in table 2 for three typical scattering angles [13]. The 2^- state has the largest cross section among the states in the ground-state region. The state emits a proton with a uniquely $p_{3/2}$ partial wave. No depolarization takes place for such a stretched transition [14]. The polarization of the 1^- state is opposite to that of the 2^- state. This is due to the fact that the spin polarization of Λ is in the same direction for both states, and that the coupling is parallel for the 2^- state and anti-parallel for the 1^- state. Since the partial wave of the proton is still $p_{3/2}$, the proton emission flips the ${}^5_\Lambda$He polarization while keeping the Λ polarization the same.

Next the excited states in the ground-state region are the 1^-_2 and 0^-_1 with the configuration of $(p_{1/2})^{-1}_n(s_{1/2})_\Lambda$. Here, the states are predicted to be ~6 MeV, though they could appear at around 4 MeV [13], depending on the models employed. The partial wave of the decaying proton is now $p_{1/2}$. Since the states gives almost no polarization the contribution grately reduces the ${}^5_\Lambda$He polarization. $P_{cal}(2)$ in table 1 is the calculated polarization for only the ground-state doublet, and $P_{cal}(4)$ is that for four states. It is reasonable that the observed polarization is consistent with $P_{cal}(2)$ since the ground-state region has at most half the contribution from the 1^-_2 and 0^-_1 states.

Pions are from the Λ produced by the quasifree process from the region above 4 MeV. The asymmetry of the region (4 <Ex< 12MeV) turned out to show a similar asymmetry as the ground state. The leakage of pions from the region doesn't affect the observed polarization of ${}^5_\Lambda$He. The large asymmetry of ${}^5_\Lambda$He reflects the fact that the dominant state (2^-_1) keeps the maximum polarization of Λ produced by the elementary process in proton emission.

State($^6_\Lambda$Li)		$\theta = 6^o$	$\theta = 12^o$	$\theta = 18^o$
1^-_{gs}	$\frac{d\sigma}{d\Omega}[\mu b/sr]$	0.78	0.64	0.34
	P($^6_\Lambda$Li)	-0.443	-0.586	-0.570
	P($^5_\Lambda$He)	0.222	0.293	0.285
2^-_1	$\frac{d\sigma}{d\Omega}[\mu b/sr]$	6.90	4.19	1.64
(0.42 MeV)	P($^6_\Lambda$Li)	0.249	0.441	0.568
	P($^5_\Lambda$He)	0.249	0.441	0.568
1^-_2	$\frac{d\sigma}{d\Omega}[\mu b/sr]$	0.97	0.81	0.44
(6.12 MeV)	P($^6_\Lambda$Li)	0.127	0.163	0.154
	P($^5_\Lambda$He)	0.127	0.163	0.154
0^-_1	$\frac{d\sigma}{d\Omega}[\mu b/sr]$	3.43	1.92	0.68
(6.18 MeV)	P($^6_\Lambda$Li)	0.0	0.0	0.0
	P($^5_\Lambda$He)	0.0	0.0	0.0

Table 2

Predicted cross section and polarization of low-lying $^6_\Lambda$Li hypernuclear states shown for three typical scattering angles. The 1^-_{gs} and 2^-_1 states have mostly the $(p_{3/2})_p(s_{1/2})_\Lambda$ configuration. The 1^-_2 and 0^-_1 states are mostly the $(p_{1/2})_p(s_{1/2})_\Lambda$ configuration.

We demonstrated that the polarized $^5_\Lambda$He hypernucleus were really produced by the (π^+, K^+) reaction. The large asymmetry parameter and the large branching ratio of the $^5_\Lambda$He M-decay was essential for the polarization measurement. The observed polarization is consistent with the DWIA calculation, which includes the polarization in the elementary reaction and the depolarization due to proton emission. The present study demonstrates that the theoretical model describes the polarization mechanism. Thus, the calculated polarization can be used even when a direct measurement is practically impossible due to the small branching ratio and small asymmetry parameter of the M-decay. However, it is usually the case for many hypernuclei.

We are grateful to professors K. Nakai, T. Ohshima, K. Nakamura, J. Chiba and T. K. Ohska for supports to carry out the experiment. We thank professor M. Kihara for arranging continuous operation of the accelerator and cryogenic group of KEK for the help when we had quenching of the SKS.

REFERENCES

[1] P. H. Pile *et al.*, Phys. Rev. Lett. 66 (1991) 2585

[2] T. Hasegawa *et al.*, Phys. Rev. Lett. 74 (1995) 224

[3] Review of Particle Physics, PDG, Phys. Rev. D54, 1(1996)

[4] T. Motoba K. Itonaga and H. Bandō, Nucl. Phys. A849 (1988) 683

[5] T. Kishimoto, KEK 83-6 (1983) 51, unpublished

[6] S. Ajimura et al., Phys. Lett. B282 (1992) 293

[7] S. Ajimura et al., Phys. Rev. Lett. 68 (1992) 2137

[8] T. Kishimoto and S. Ajimura, Prog. Theo. Phys., 89 (1993) 1021

[9] T. Kishimoto, T. Motoba and K. Itonaga, contributed paper to the PANIC (1993)

[10] J. J. Syzmanski, et al., Phys. Rev. C 43 (1991) 849

[11] T. Fukuda et al., Nucl. Inst. Meth. A 361 (1995) 485

[12] T. Kishimoto, et. al, INS annual report 1993

[13] T. Motoba and K. Itonaga, Nucl. Phys. A577 (1994) 293c; T. Motoba, K. Itonaga and T. Kishimoto, paper in preparation

[14] H. Ejiri, T. Kishimoto and H. Noumi, Phys. Lett. B225 (1989) 35