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Impurity nuclear physics

Hypernuclear γ spectroscopy and future plans for neutron-rich hypernuclei

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Abstract. Using a germanium-detector array for hypernuclear γ spectroscopy (Hyperball), we measured $B(E2)$ of the ${}^{7}_{\Lambda}$Li hypernucleus and observed a significant shrinkage of the ^{6}Li core induced by a Λ-particle. In this way, nuclear properties can be drastically changed by introducing a Λ-particle, which can be investigated by high-resolution hypernuclear γ spectroscopy. In the future neutron-rich hypernuclei will also be studied, where interesting modifications of nuclear structure by a Λ-particle are expected.

PACS. 21.80.+a Hypernuclei – 23.20.Lv Gamma transitions and level energies

1 Introduction

1.1 Significance and difficulty of hypernuclear γ spectroscopy

Level structures of hypernuclei have been experimentally studied since the '70s mostly by the (K^-, π^-) and later by the (π^+, K^+) reactions. The resolution of hypernuclear level energies, which are measured by analyzing momenta of incident and scattered mesons around 1 GeV/c with magnetic spectrometers, is limited to 1.5 MeV (FWHM) at best. Even with such a limited resolution, the nuclear potential depth for Λ was derived from single-particle orbitals of Λ owing to a selectivity in populations of hypernuclear levels in the (π^+, K^+) reaction [1,2]. However, much better energy resolution is necessary to investigate detailed level structure of hypernuclei, which enables us to approach interesting subjects as follows:

1) *Baryon-baryon interactions*
Level structures of Λ hypernuclei provide us with information on ΛN interactions, in particular, spin-dependent parts (spin-spin, spin-orbit and tensor interactions). $\Lambda\Lambda$ interactions can also be investigated from the structure of double Λ hypernuclei. Such studies will play essential roles in unified understanding of baryon-baryon interactions.
2) *Impurity nuclear physics*
One of the important subject in solid state physics is to study roles of impurities which often drastically change the properties of the matter. Similarly, a Λ-particle added to a nucleus as impurity can change the nuclear properties. It is the main topic of this paper.
3) *Medium effect of baryons*
Since a Λ-particle is free from Pauli effect in a nucleus, it can be a probe to investigate possible modifications of baryon properties in nuclear matter. For example, the measurement of $B(M1)$ in a spin-flip $M1$ transition provides information on the magnetic moment of Λ in a nucleus, which may be changed if a baryon is "swelling" in nuclear matter.

In this article, we discuss the second subject, "impurity nuclear physics". Even a single hyperon added to a nucleus as "impurity" may drastically change the properties of the nucleus, such as size, shape, collective motions, shell /cluster structure, etc. Such effects were not able to be observed before because of limited experimental information on hypernuclear structure. Our result of the shrinkage of ${}^{7}_{\Lambda}$Li, as described in sect. 2, demonstrated that high-resolution hypernuclear γ spectroscopy allows us to open such a new area of nuclear physics to be named as "impurity nuclear physics".

It has thus been a dream of hypernuclear physicists to introduce high-resolution γ-ray spectroscopy with germanium (Ge) detectors and to improve the energy resolution of hypernuclei from a few MeV to a few keV. However, it was almost impossible before because of technical problems due to the huge background inherent in high-energy secondary meson beams; high-energy charged particles from beam halo and scattered beam penetrate a detector and give an energy deposit close to 1 TeV/s (to a detector at 15 cm from the target), which is far beyond the limit of the detector operation.

We recently solved the problem and constructed "Hyperball", a large-acceptance Ge-detector array dedicated to hypernuclear γ-ray spectroscopy. Physics motivation of this project and details of Hyperball are described elsewhere [3].

1.2 Hyperball

Hyperball consists of fourteen sets of coaxial N-type Ge-detectors equipped with fast electronics including low-gain transistor-reset preamplifiers and fast shaping amplifiers with gated intergrators. The photo-peak efficiency for the Ge-detectors is 2.5% in total at 1 MeV. BGO counters were installed around each Ge-detector for the purpose of not only Compton suppression but rejection of high-energy photons from π^0 which is the most serious background in hypernuclear experiments. The performances of each Ge-detector such as gain drift, resolution, electronics dead time, etc., are monitored through the whole beam time using triggered γ-rays from a ^{60}Co source embedded in a plastic scintillator and installed behind each Ge-detector.

2 Recent experimental results —$^7_\Lambda$Li and $^9_\Lambda$Be

2.1 Spectrum and level scheme of $^7_\Lambda$Li

The first experiment with Hyperball (KEK E419) was performed in 1998 at the 12 GeV Proton Synchrotron at the High-Energy Accelerator Research Organization (KEK). More details on this experiment are found in refs. [4,5].

Bound states of $^7_\Lambda$Li were produced by the ^{7}Li(π^+, K^+) reaction employing the K6 beam line and the Superconducting Kaon Spectrometer (SKS), and γ-rays were measured in coincidence with Hyperball. In this experiment we succeeded in observing well-identified hypernuclear γ transitions using Ge-detectors for the first time.

As shown in fig. 1, each π^+-particle at 1.04 GeV/c was momentum-analyzed by the K6 beam line spectrometer and injected to a 20 cm thick ^{7}Li target, and the outgoing K^+ was analyzed and identified by SKS. Hyperball was installed around the target. The data was taken for 25 days with a beam intensity of $2 \times 10^6 \pi^+$/pulse (0.7 s duration). The energy resolution of the Ge-detectors was 3 keV FWHM and the electronics dead time was 46%.

Figure 2 is the γ-ray spectrum when the bound-state region of $^7_\Lambda$Li is selected. We observed four γ-ray peaks at 691.7±0.6±1.0 keV, 2050.4±0.4±0.7 keV, 3186±4±6 keV, and 3877 ± 5 ± 7 keV. The 692 keV peak is uniquely assigned as the spin-flip $M1(\frac{3}{2}^+ \to \frac{1}{2}^+)$ transition, and the 2050 keV peak as the $E2(\frac{5}{2}^+ \to \frac{1}{2}^+)$ transition. The shapes of these peaks are consistent with Doppler broadening estimated from the expected lifetimes of those states. The 692 keV peak becomes sharp after event-by-event Doppler-shift correction as shown in the left inset of fig. 2 (left). The peaks at 3186 keV and 3877 keV, which were observed in the Doppler-shift corrected spectrum fig. 2 (top-right), are assigned as the $M1$ transitions from the $\frac{1}{2}^+(T = 1)$ state to the ground-state doublet $(\frac{1}{2}^+, \frac{3}{2}^+)$. We have thus established the level scheme of $^7_\Lambda$Li as shown in fig. 3.

Since the energy spacing of the ground-state doublet $(\frac{3}{2}^+, \frac{1}{2}^+)$ is determined almost only by the ΛN spin-spin interaction, the observed $M1$ energy unambiguously gives the strength of the spin-spin term in the effective ΛN interaction [4].

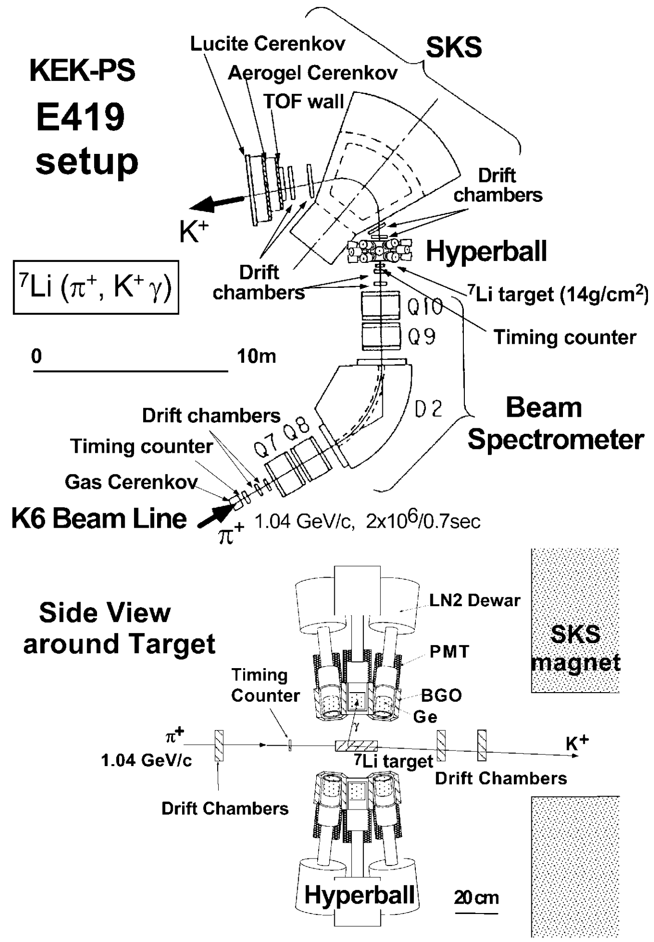

Fig. 1. Setup of KEK E419 with the K6 beam line and SKS. Hyperball was installed around the target (see text).

2.2 B(E2) and shrinkage of the hypernuclear size

As for the $E2(\frac{5}{2}^+ \to \frac{1}{2}^+)$ transition at 2050 keV, which was previously observed at BNL with NaI counters [6], we have measured the lifetime of the $\frac{5}{2}^+$ state with Doppler shift attenuation method (DSAM) by taking advantage of our high resolution [5] and then obtained the $E2$ reduced transition probability, $B(E2)$. A large momentum transfer ($\sim$ 400 MeV/c) of the (π^+, K^+) reaction is essential in this measurement. The stopping time of the recoiling $^7_\Lambda$Li hypernucleus ($\sim$ 10 ps) is of the same order as the expected lifetime of the $\frac{5}{2}^+$ state, which allows accurate determination of the lifetime from the shape of the partly broadened peak. A simulation was carried out to calculate the peak shapes assuming various lifetimes, and they were fitted to the measured spectrum. The lifetime was obtained to be $5.8^{+0.9}_{-0.7} \pm 0.7$ ps so as to give the minimum fitting chi square. Figure 4 shows the peak shape together with the spectrum for the optimum lifetime. $B(E2)$ was then derived to be $3.6 \pm 0.5^{+0.5}_{-0.4}$ e^2fm^4. It is the first measurement of a reduced transition probability in a hypernucleus.

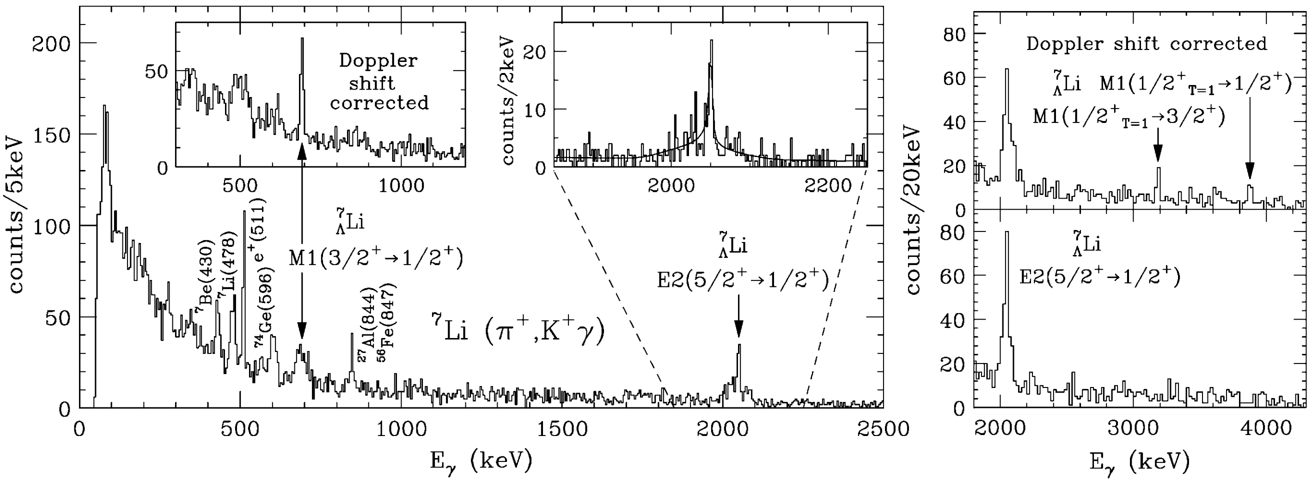

Fig. 2. γ-ray spectrum of $^{7}_{\Lambda}$Li measured with Hyperball. Four hypernuclear transitions, $M1(\frac{3}{2}^+ \to \frac{1}{2}^+)$, $E2(\frac{5}{2}^+ \to \frac{1}{2}^+)$, $M1(\frac{1}{2}^+(T=1) \to \frac{3}{2}^+)$, and $M1(\frac{1}{2}^+(T=1) \to \frac{1}{2}^+)$, were observed.

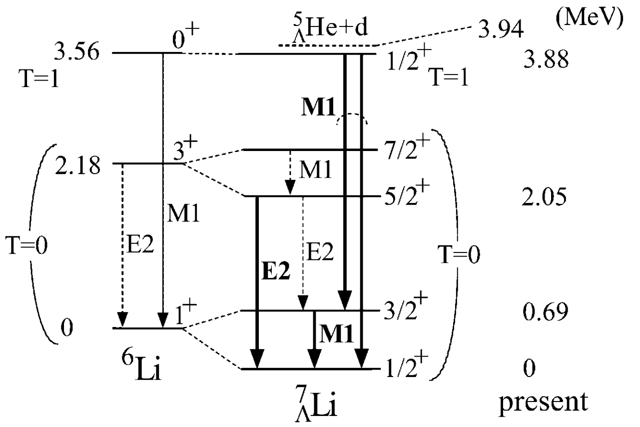

Fig. 3. Level scheme of $^{7}_{\Lambda}$Li established by the E419 experiment, shown together with the level scheme of the core nucleus ^{6}Li. Observed transitions are shown in thick arrows.

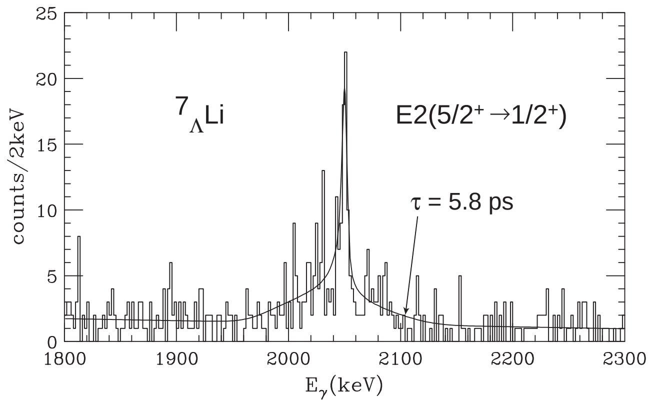

Fig. 4. γ-ray spectrum of $E2(\frac{5}{2}^+ \to \frac{1}{2}^+)$ transition in $^{7}_{\Lambda}$Li. The peak shape was fitted to a simulated one with a parameter of the lifetime of $\frac{5}{2}^+$ as shown in a solid line.

The measured $B(E2)$ is only 1/3 of the corresponding $B(E2)$ of ^{6}Li$(3^+ \to 1^+)$, $10.9 \pm 0.9\ e^2$fm^4. Here we define the size factor:

$$S = \sqrt{\frac{9}{7}\frac{B(E2;\ ^{7}_{\Lambda}\mathrm{Li}(5/2^+ \to 1/2^+))}{B(E2;\ ^{6}\mathrm{Li}(3^+ \to 1^+))}}\,. \qquad (1)$$

It should be unity if the ^{6}Li core in $^{7}_{\Lambda}$Li is the same as the free ^{6}Li, but smaller than unity if the ^{6}Li core is contracted by the Λ-particle. In a di-cluster model ($\alpha + d$ for ^{6}Li), $S = R(^{7}_{\Lambda}\mathrm{Li})/R(^{6}\mathrm{Li})$ holds for the intercluster distance R. We can also write $S = \sqrt{\beta\langle r^2\rangle(^{7}_{\Lambda}\mathrm{Li})}/\sqrt{\beta\langle r^2\rangle(^{6}\mathrm{Li})}$ for the deformation parameter β and the mean square radius $\langle r^2\rangle$. The observed value is $S = 0.81 \pm 0.04$, which indicates a significant shrinkage of the ^{6}Li core in $^{7}_{\Lambda}$Li. Such shrinking effect was predicted by Motoba, Bandō, and Ikeda in 1983 [7] based on cluster model calculations as a general property of light hypernuclei; intercluster distances of α-d, α-t, and α-α for $^{7}_{\Lambda}$Li, $^{8}_{\Lambda}$Li, and $^{9}_{\Lambda}$Be, respectively, were found to be contracted by about 20% in their calculations. When a Λ, which is free from Pauli blocking, is added to a loosely bound light nucleus, it can occupy the 1s orbit and attracts surrounding nucleons, which results in a shrinkage of the system. Our result is the first evidence for this effect. Recently, Hiyama *et al.* made an $\alpha(^{5}_{\Lambda}\mathrm{He})$-$p$-$n$ cluster-model calculation and showed that the distance between the α cluster and the center of p and n is contracted while the distance between p and n is unchanged [8]. Their calculated size factor agreed well with our experimental value. Our measured $B(E2)$ corresponds to a shrinkage of the distance between α and the p-n center by 19 ± 4% in this model.

2.3 $^{9}_{\Lambda}$Be and its B(E2)

In the second experiment with Hyperball, a γ spectrum of $^{9}_{\Lambda}$Be was taken at Brookhaven National Laboratory (BNL E930) using the (K^-, π^-) reaction. We observed two $E2(\frac{5}{2}^+ \to \frac{1}{2}^+$ and $\frac{3}{2}^+ \to \frac{1}{2}^+)$ transitions at 3.05 MeV with an energy difference of only 31 keV [9]. The purpose of this experiment is to derive the strength of the spin-orbit force of a Λ in a nucleus. We confirmed a very small but finite size of the spin-orbit force from the small energy spacing between the $\frac{5}{2}^+$ and $\frac{3}{2}^+$ states.

These transitions are essentially the same as the $E2(2^+ \to 0^+)$ transition of ^{8}Be, of which $B(E2)$ cannot be measured because both of the ^{8}Be states are unbound. Since the peak structure has a partly broadened shape, $B(E2)$ was able to be derived [9] with DSAM in the same way as $^7_\Lambda$Li. The obtained value, $B(E2) = 5.7^{+2.1}_{-2.0}\ e^2\mathrm{fm}^4$, suggests a large shrinkage as theoretically expected [7]. It also gives valuable information on the size of ^{8}Be as well.

3 Future plans for impurity nuclear physics

The program of hypernuclear γ spectroscopy with Hyperball is presently in progress at BNL (E930). We measure level structures of $^{16}_\Lambda$O, $^{12}_\Lambda$C, $^7_\Lambda$Li etc. to obtain information on all the spin-dependent ΛN interactions including the tensor force and the nucleon-spin-dependent spin-orbit force. After E930, we will further study γ spectroscopy for various hypernuclei. In the following I will discuss several possible interesting phenomena related to impurity nuclear physics which we will investigate in the future.

3.1 $^7_\Lambda$He —drastic change of valence neutrons

When a Λ is added to the ^{6}He ground state, the skin-like valence-neutron wave functions are expected to shrink, because the Λ in the $1s$ orbit makes the nuclear potential much deeper. In addition, the unbound $^6\mathrm{He}(2^+)$ state becomes bound by a Λ, and the $E2$ transitions $(\frac{5}{2}^+, \frac{3}{2}^+ \to \frac{1}{2}^+)$ can be observed [10]. The $B(E2)$'s of these $^7_\Lambda$He transitions are calculated to be only 1/10 of the corresponding $B(E2)$ of the $^6\mathrm{He}(2^+ \to 0^+)$ transition, reflecting the drastic change of the valence neutron wave functions [11]. Experimental determination of the level energies and the $B(E2)$ will provide valuable information on the structure of ^{6}He and the effect of a Λ on the valence neutrons in it.

In order to populate the excited states of $^7_\Lambda$He, we need to use the (K^-, π^0) reaction on ^{7}Li target employing a π^0 spectrometer. In the present case, these $E2$ transitions are competing against the weak decay of Λ. If we assume the weak decay rate of these states to be $(200\ \mathrm{ps})^{-1}$, then the lifetimes of these states are 140 ps and 170 ps, and the branching ratios for the $E2$ γ transitions are 42% and 17%. We will directly measure the lifetimes of these excited states with charged particles (π^- or proton) from the weak decay. Combined with the branching ratios of these $E2$ transitions, the $B(E2)$'s can be derived.

3.2 $^{20}_\Lambda$Ne —clustering and shrinkage

The shrinking effect by a Λ is a sensitive probe to see the clustering feature of each nuclear state. For example, $^{20}_\Lambda$Ne is an interesting hypernuclei in which we expect a different degree of shrinkage dependent on the clustering feature of the ^{19}Ne states. A cluster model calculation predicted a negative-parity ground state in this sd-shell hypernucleus.

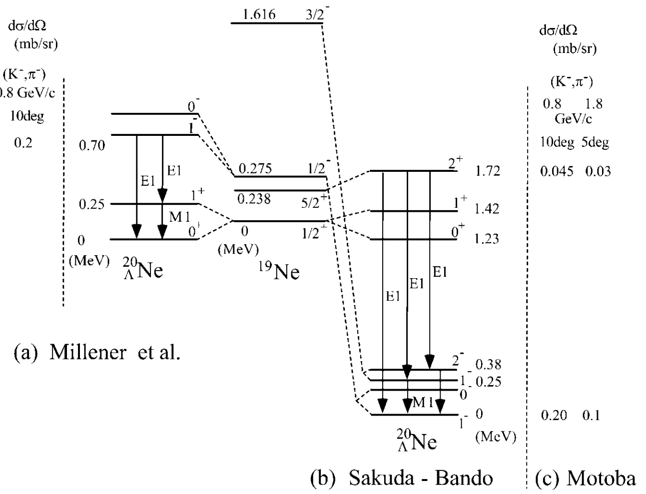

Fig. 5. Level scheme and transitions of $^{20}_\Lambda$Ne. The expected level scheme and the cross-section are calculated by Millener *et al.* with the shell model (a) [12] and with the cluster model by Sakuda and Bandō (b) [13]. (c) shows estimated cross-sections by Motoba [14] using $^{18}_\Lambda$O cross-sections calculated by Yamada *et al.* [15]

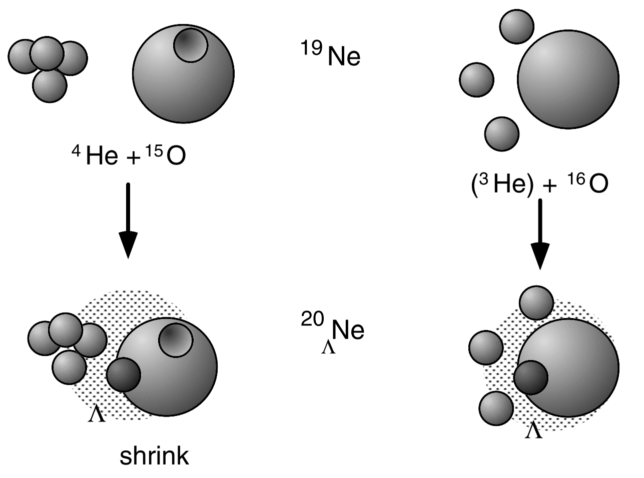

Fig. 6. Cluster-model prediction of the shrinking effect of $^{20}_\Lambda$Ne. When a Λ is added, the negative-parity states having the α-^{15}O cluster structure shrink more than the positive-parity states having a compact (shell-like) structure.

Figure 5 shows expected relevant low-lying levels and transitions of $^{20}_\Lambda$Ne. The left part of fig. 5 is expected from a naive picture, where energies of (0^+, 1^+) and 1^- states are taken from a shell model calculation [12]. The right part shows a result of the cluster model calculation by Sakuda and Bandō [13]. Here the negative-parity states

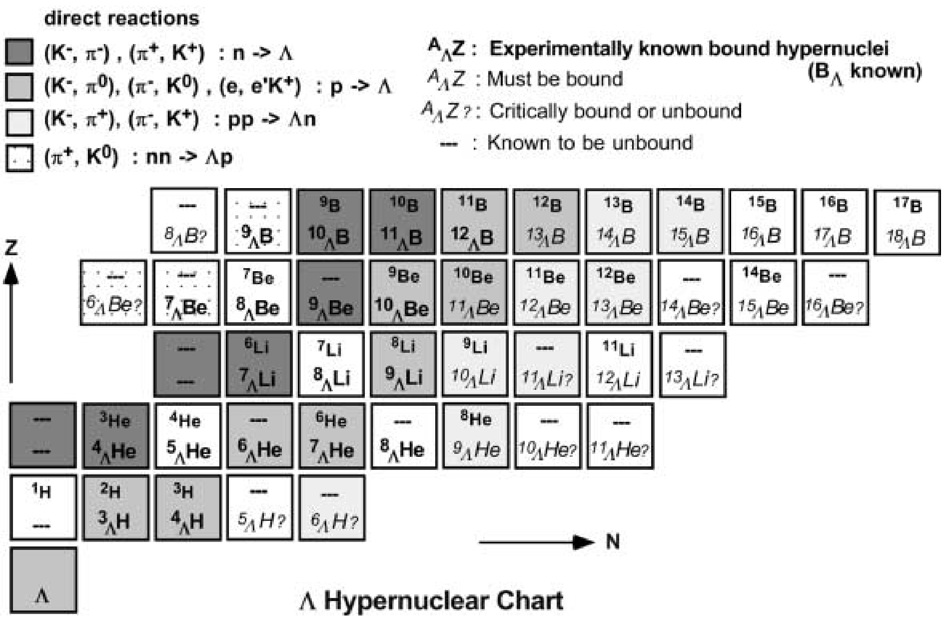

Fig. 7. Hypernuclear chart. Hypernuclei are shown together with each core nucleus (normal nucleus without Λ).

of which the structure is ${}^{16}_{\Lambda}$O(p-hole state) + ^{4}He, have much lower energies than the 0^+ and 1^+ doublet of the ^{16}O + ${}^{4}_{\Lambda}$He structure. It is because the negative-parity states in ^{19}Ne, having a well-clusterized ^{15}O(p-hole state of ^{16}O) + ^{4}He structure, shrink when a Λ is added, while the positive-parity states, having ^{16}O + ^{3}He structure, are not well-clusterized but rather spherical and thus the shrinkage by a Λ is expected to be smaller, as illustrated in fig. 6.

As shown in fig. 5, the expected pattern of γ transitions in each case is different from the other. In the latter case, the γ transitions stem mainly from the population of the 2^+ state which has a sizable cross-section in the (K^-, π^-) reaction. As shown in fig. 5, the cross-section of ${}^{20}_{\Lambda}$Ne was assumed to be the same as that of ${}^{18}_{\Lambda}$O, which was calculated for the 0.8 GeV/c (K^-, π^-) reaction by Yamada *et al.*[15]. By observing all the transitions shown in fig. 5 we can reconstruct the level scheme.

3.3 Effects of Λ on neutron-rich nuclei

Let us consider the case that a Λ is added to bound or unbound nuclei near the neutron or proton drip lines. It is expected that a Λ makes unbound nuclear states bound and γ spectroscopy becomes available to investigate their structures, as already discussed for ${}^{7}_{\Lambda}$He. It is interesting to ask how the halo or skin structures of those nuclei are modified by the addition of a Λ.

Mean-field calculations by Tretyakova and Lanskoy [16] showed that weakly bound neutrons in neutron-rich nuclei are affected by a Λ in the $1s$ orbit through shrinkage of the core nucleus. Such effects are shown to be sensitive to the ΛN and NN forces used in the calculation. For example, the energy level of the ground $\frac{1}{2}^+$ state of ^{11}Be ($S_n = 0.505$ MeV) corresponding to a $2s_{1/2}$ valence neutron is rather insensitive to ΛN and NN forces, while the excited $\frac{1}{2}^-$ state of ^{11}Be ($S_n = 0.180$ MeV) corresponding to a $1p_{1/2}$ valence neutron is sensitively affected by them; it is deeply bound when the ΛN interaction is strongly attractive, while it is less bound or unbound for weaker ΛN interactions. This effect is more enhanced when the NN forces giving a larger compressibility is adopted. It is because a smaller size of the ^{10}Be+Λ core gives the $1p_{1/2}$ orbit less attraction, and the larger spin-orbit potential due to a larger derivative of the nuclear density gives more repulsion to the $1p_{1/2}$ orbit. Since binding energies of these states are less than 1 MeV, γ spectroscopy is necessary to reveal such effects in neutron-rich hypernuclei.

3.4 Production of neutron-rich hypernuclei

Figure 7 shows the "hypernuclear chart" shown together with corresponding normal nuclei without a Λ. In thick letters shown are bound hypernuclei observed so far. In italic letters shown are hypernuclei not observed yet. Here, hypernuclei which are critically bound or unbound are indicated with "?", while hypernuclei which must be bound are shown without "?". Since a Λ-particle makes the nuclear system more stable, the region of the bound nuclei is extended when a Λ is added. It is interesting to investigate how far the drip lines are shifted outwards.

Experimentally, however, the production and the identification of neutron-rich hypernuclei are difficult. In the one-step direct reactions such as (K^-, π^-), (K^-, π^0), (π^+, K^+), (π^-, K^0), and $(e, e'K^+)$, only a limited region in the hypernuclear chart can be accessed, as shown in fig. 7. On the other hand, the (K^-, π^+) and (π^-, K^+) reactions can populate neutron-rich hypernuclei such as

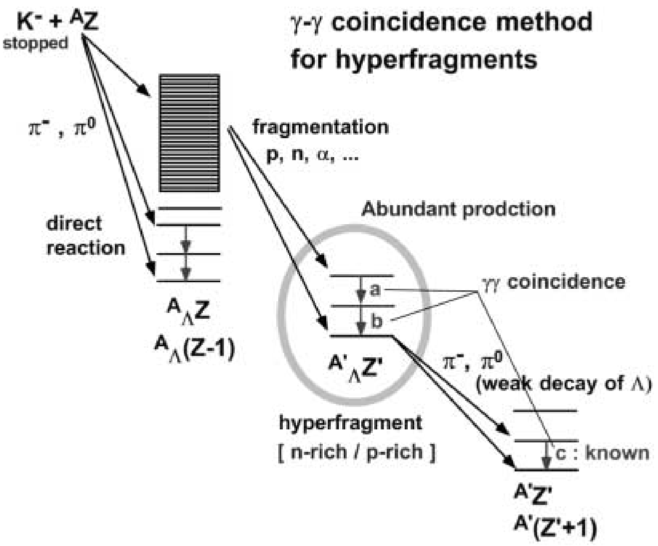

Fig. 8. γ-γ coincidence method for hyperfragments produced from stopped K^- absorption.

${}^{9}_{\Lambda}$He, ${}^{11}_{\Lambda}$Li, ${}^{12}_{\Lambda}$Be, ${}^{16}_{\Lambda}$C, etc. They are two-step direct reactions though pion charge exchange ($K^-p \to \Lambda\pi^0$, $\pi^0 p \to \pi^+ n$, etc.) or Λ-Σ coupling ($K^-p \to \Sigma^-\pi^+$, $\Sigma^- p \to \Lambda n$, etc.), and the production rates in the (stopped K^-,π^+) reaction are expected to be of the order of 10^{-5} per stopped K^- for ${}^{12}_{\Lambda}$Be [17], which is not too far from the present limit of the experimental sensitivity [18]. A measurement of their γ-rays in coincidence may be possible in the future when a much higher-intensity K^- beam is available.

Another possible method to produce neutron-rich hypernuclei is to use a hyperfragment production from stopped K^- absorption. It is known since the '60s that stopped K^- absorption on light target nuclei gives rise to an abundant production of various light hyperfragments. It is how the already observed hypernuclei in fig. 7 were produced. It is expected that K^- absorption, releasing about a 30 MeV energy, leads to formation of hyperon compound nuclei, which is followed by fragmentation or evaporation to form a hyperfragment [19]. The production rate of each hypernuclear species was calculated with the Antisymmetrized Molecular Dynamics (AMD) [20], which well reproduced the observed production rates of a ${}^{4}_{\Lambda}$H fragment from stopped K^- on light targets [21]. According to this calculation, production rates of ${}^{8}_{\Lambda}$He and ${}^{11}_{\Lambda}$Be from ^{12}C target are estimated to be relatively large, 2×10^{-4} and 5×10^{-4} per stopped K^-, respectively. They correspond to event rates of about 10^2 per hour including single γ-ray detection efficiency in the present K^- beam intensity. How to identify hyperfragment species and to enhance signal-to-background ratio is a problem.

Previously, detection of monoenergetic π^- from hypernuclear weak decay (${}^{A}_{\Lambda}Z \to^{A} [Z+1] + \pi^-$) was used to identify hyperfragment species, but the huge background from a free Λ-decay as well as a limited π^- momentum resolution deteriorates the sensitivity of the identification. Here we propose to measure γ-rays from excited states of the daughter nucleus after the hypernuclear weak decay (${}^{A}_{\Lambda}Z \to^{A} [Z+1]^* + \pi^-$ or ${}^{A}Z^* + \pi^0$) to identify the parent hypernucleus as illustrated in fig. 8. Such γ transitions from daughter nuclei were already observed in our ${}^{7}_{\Lambda}$Li spectrum; the ^{7}Be(430 keV) and ^{7}Li(478 keV) γ-rays were observed in the ${}^{7}_{\Lambda}$Li bound region spectrum (see fig. 2).

The γ-γ coincidence method as shown in fig. 8 will enable us to identify unknown hypernuclear γ transitions and to drastically enhance the signal-to-background ratio due to the excellent energy resolution of Ge-detectors. For this purpose, however, we require a Ge-detector system having a much larger efficiency than the present Hyperball. A realistic evaluation of the feasibility of this type of experiments is in progress [22].

3.5 Experiments at 50 GeV PS

Hypernuclear γ spectroscopy is one of the most important subjects at the 50 GeV high-intensity proton synchrotron (50 GeV PS) which is under construction as a joint project between KEK and JAERI (Japan Atomic Energy Research Institute). Planned experimental programs in hypernuclear physics are summarized in ref. [23].

The K^- beam with 10–100 times higher intensity than the present BNL AGS allows us to perform various experiments including neutron-rich (and proton-rich) hypernuclei. The direct (K^-,π^+) reaction as well as the hyperfragment production can be used to study neutron-rich hypernuclei. Possible effects of a Λ on collective motions in heavier hypernuclei will also be able to be investigated. It would be particularly interesting to see a possible larger shrinking effect induced by two Λ's in $1s$ orbit in double Λ hypernuclei. Together with a study of the baryon-baryon interactions of strangeness -2 systems, it will provide a clue to approach hyperonic nuclear matter which is expected to be stable in the center of a neutron star.

4 Summary

We constructed Hyperball, a Ge-detector array for hypernuclear research, and started γ spectroscopy experiments. In the first experiment at KEK, we observed four γ transitions in ${}^{7}_{\Lambda}$Li and established the level scheme. We measured the $B(E2)$ of ${}^{7}_{\Lambda}$Li and observed a significant shrinkage of the ^{6}Li core induced by a Λ-particle.

This result opened a new area of nuclear physics called "impurity nuclear physics". Nuclear properties can be drastically changed by introducing a Λ-particle, which can be investigated by high-resolution γ spectroscopy through detailed level scheme and transition probabilities. Interesting changes of nuclear structures are expected for various type of hypernuclei including neutron-rich hypernuclei, which will be investigated in the future. γ-γ coincidence for hyperfragments from stopped K^- absorption is a hopeful method to produce neutron-rich hypernuclei and study their structures. Such studies will be further extended in the 50 GeV PS.

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