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Colloquia: COMEX7

Study of Gamow-Teller giant resonance in ^{11}Li drip-line nucleus

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Summary. — Gamow-Teller (GT) transitions in an exotic neutron-rich nucleus ^{11}Li have been measured via the ^{11}Li$(p,n)^{11}$Be reaction at 182 MeV/u in inverse kinematics at RI Beam Factory (RIBF) of RIKEN Nishina Center. The neutron detector array PANDORA and the SAMURAI spectrometer were used to detect recoil neutrons and decay products produced in the (p,n) reaction, respectively. Preliminary results of kinematic correlation of recoil neutrons, corresponding to GT transitions, are presented for several decay channels of ^{11}Be reaction product. Fourteen decay channels with light-particle emission from ^{11}Be excited states, including seven new channels, are identified, in addition to the non-particle-emission channel from ^{11}Be ground or low-lying states.

1. – Introduction

The Gamow-Teller transition is the spin-isospin response associated with dynamical properties of nuclei based only on the spin and isospin degrees of freedom. It exhibits a strong collective state called GT giant resonance at a high excitation energy ~ 10 MeV, which provides constraints on the residual interactions driving the dynamics [1]. Experimentally, the GT giant resonance was investigated only in stable isotopes, which limited the isospin asymmetry factor $(N-Z)/A$ below 0.21 (^{208}Pb) [1, 2]. Recently, a new experimental method was developed to measure GT giant resonances with RI beams at intermediate energies [3, 4], which led to the observation of the GT giant resonance in the doubly magic neutron-rich unstable nucleus ^{132}Sn ($(N-Z)/A = 0.24$) [5].

With the aim to investigate a further highly isospin asymmetric region up to $(N-Z)/A$ =0.5, we started a program [6,7] at the RIKEN Radioactive Isotope Beam Factory (RIBF) to measure the spin-isospin responses of light nuclei along the neutron drip line. Recently, our first RIBF experiment (SAMURAI30) with 5 days of beam time at SAMURAI was performed to study the GT transitions including the GT resonances from the ^{11}Li and ^{14}Be drip line nuclei to the ^{11}Be and ^{14}B nuclei. Herein we present preliminary results of the ^{11}Li data.

Experimentally, we use the charge-exchange (CE) (p,n) reactions at intermediate beam energies (E/A >100 MeV) in inverse kinematics (*i.e.*, the beam particle is an RI of interest) in order to excite GT states up to high excitation energies, without Q-value limitation [8], as done in refs. [3-5]. A notable feature of this method is that it can use a thick liquid hydrogen target because recoil neutrons do not electromagnetically interact with the target material and can be detected outside the target without losing kinematic information of the (p,n) reaction such as the scattering angle and excitation energy. On the other hand, the recoil-neutron detection suffers from background due to neutrons scattering from walls and environmental γ rays. Therefore, the identification of the (p,n) reaction channel through the detection of decay products from the (p,n)-reaction product is required in order to improve the signal-to-noise ratio in the neutron detection. In our (p,n) experiments at RIBF, we use the PANDORA (Particle Analyzer Neutron Detector Of Real-time Acquisition) system [10-12] and the SAMURAI spectrometer [9] to detect recoil-neutrons and decay products emitted from (p,n) reaction residues, respec-

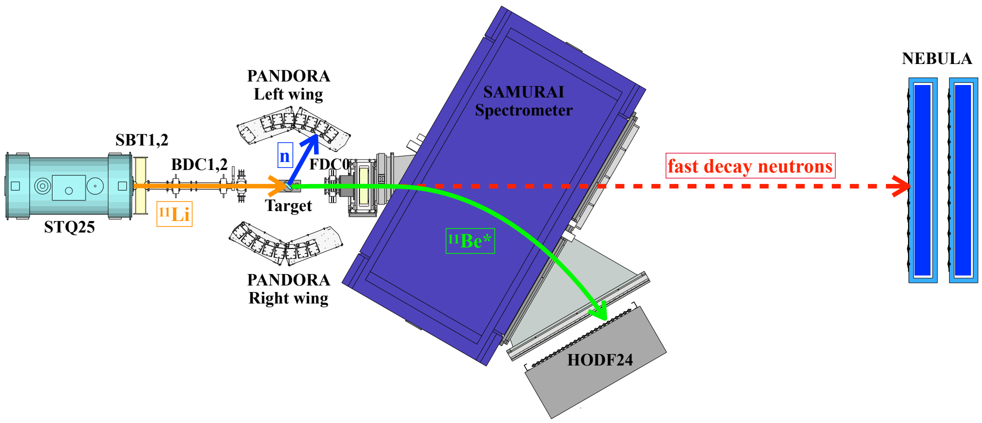

Fig. 1. – A schematic top view of the experimental setup around the SAMURAI spectrometer.

tively. In PANDORA, an additional parameter, the pulse-shape discrimination (PSD) can be used to eliminate γ-ray background events. The SAMURAI spectrometer has a large acceptance to cover decay particles with different rigidity and emission angles. As explained below, ^{11}Be final states emit a variety of decay particles consisting not only of Be isotopes, which are produced after neutron emission from ^{11}Be, but also of light nuclei such as d, t. Therefore, we emphasize that the use of the SAMURAI spectrometer was critically important to measure decay particles in the same setup.

In this work, the experimental setup and a preliminary result of the SAMURAI30 experiment are presented in sects. **2** and **3**, followed by the summary in sect. **4**.

2. – Experiment

The experiment was performed at the RIBF of RIKEN. A secondary cocktail beam of unstable nuclei, ^{11}Li and ^{14}Be, was produced via the fragmentation reaction of a 230-MeV/u ^{18}O primary beam on a 14-mm-thick ^{9}Be target with the BigRIPS separator [13]. The beam consisted of ^{11}Li at the average energy of 182 MeV/u with intensity of 2.5×10^5 particle/s and ^{14}Be at 198 MeV/u with intensity of 1×10^5 particle/s with purity of 48% and 19%, respectively. The triton contamination was below 30%.

Figure **2** shows a schematic view of the experimental setup around the SAMURAI spectrometer. The secondary beam was transported onto a 10-mm-thick, 60-mm diameter liquid hydrogen (LH) target (rotated by 45°) at the secondary target position of SAMURAI.

Recoil neutrons produced via the (p, n) reaction in the secondary target were detected by using the neutron detector setup which were placed so as to surround the LH target. The neutron detector setup consisted of 27 PANDORA plastic scintillators and 13 additional scintillator bars of WINDS [14]. Each PANDORA bar consists of an EJ-276 (former EJ-299-33M and EJ-299-34) plastic scintillator bar [15], which are sensitive to the differences between neutrons and gamma rays [16], and are coupled to a multiplier tube (PMTs) [17] at each end. PANDORA has a neutron-gamma discrimination capability comparable to the systems with similar type plastics in the literature [18-20]. Kinematic energies of neutrons were obtained by employing the so-called neutron time-of-flight (TOF) method. The distance between the LH target and PANDORA or WINDS (*i.e.*, the neutron flight path length) was around 125 cm. The origin for the TOF was deduced from the beam-timing information measured by using the beam-line scintillators SBT1 and SBT2. The left and right wings of the neutron detector setup covered the laboratory recoil angular region of 47°–113° and 62°–134°, respectively, with 3.25° steps, with respect to the beam line. From the position of each neutron detector, the emission angles of recoil neutrons were deduced. The threshold for the light output in the scintillators was set to be 50 keV_{ee}, corresponding to 200 keV proton energy. All bars had duplicated readout; CAEN V1730 modules were used for charge and PSD information while an analog circuit was used for timing and triggering. The properties of PANDORA and details of the digital readout were reported previously [10, 11].

The reaction residues entered into the SAMURAI spectrometer. The magnetic field of the spectrometer was set to 2.75 T. At the exit, a wall (HODF24 detector) of 24 plastic scintillator bars with dimensions of $1200^W \times 100^H \times 10^D$ mm^3 was installed, to measure the trajectories, energy loss, and TOF (from SBTs) of the reaction residues. The decay particles including d, t, α, ^{6}He, $^{7-9}$Li, and $^{9-11}$Be isotopes were detected with HODF24. Protons were outside of the SAMURAI acceptance and stopped in the inner wall of the SAMURAI magnet gap. NEBULA was used to detect the fast decay neutrons of the reaction products (decays by $1n$ and $2n$ emissions). In the analysis presented herein, the information of the neutron detection at NEBULA is not used. An example of particle identification plots obtained with HODF24 is presented in ref. [12].

3. – Analysis and preliminary results

From the emission angles and kinematic energies of recoil neutrons, the scattering angles in the center-of-mass system (θ_{CM}) and the excitation energies (E_x) of the ^{11}Li$(p,n)^{11}$Be reaction are calculated on the basis of event by event. The PSD method is applied to eliminate γ-ray background events [12]. As mentioned in the introduction, it is required to further improve the signal-to-noise ratio by selecting events associated only with the CE (p,n) reaction. For this purpose, we select events where all the decay charged particles except protons (*e.g.*, d and ^{9}Li in the case of the d+^{9}Li channel) identified in coincidence.

The selected (p,n)-reaction events are grouped into different channels depending on the combination of particles detected with the spectrometer. Figure **3** shows fifteen channels identified in this work. Fourteen channels represented with dotted arrows correspond to light-particle emission decays from excited ^{11}Be states. The other is non-particle-emission channel where ground or low-lying excited states of ^{11}Be were populated by the (p,n) reaction and ^{11}Be particles were detected with the spectrometer. The channels colored with red are newly identified in this work, while the others are reported by β-decay studies in ref. [21] and references therein.

Figure **3** shows a two-dimensional plot of θ_{CM} and E_x values reconstructed for recoil neutrons associated with several decay channels. In each figure, a clear kinematic correlation between the measured kinematic energy and the laboratory scattering angle can be seen. The forward scattering peak (2°-7° in the center-of-mass system) suggests GT transitions are dominant. It is also very interesting to see that these kinematic loci all have strong intensities around 19 MeV. This means that GT giant resonance lies at the same location irrespective of the difference of the decay channel. We note that the preliminary results still have to be corrected for the acceptance of the SAMURAI spectrometer, which is ongoing.

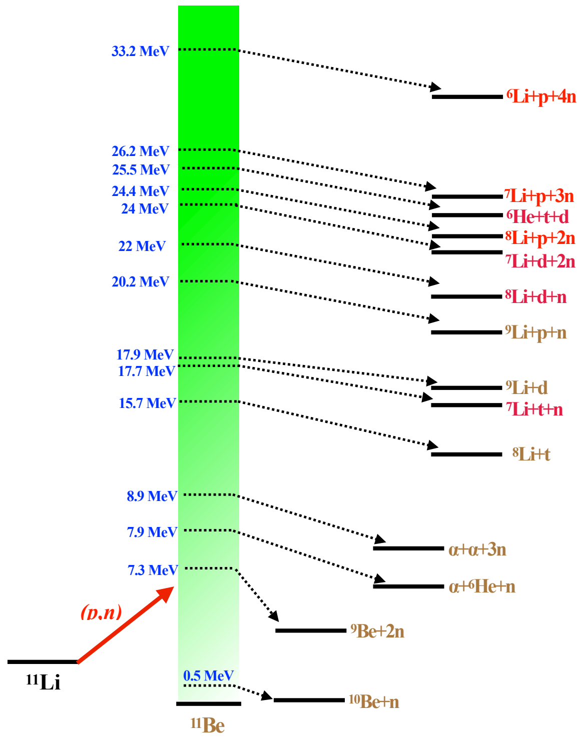

Fig. 2. – A summary of decay channels of ^{11}Be final states produced from the ^{11}Li(p,n) reaction, identified by using the SAMURAI spectrometer.

4. – Summary

The ^{11}Li$(p,n)^{11}$Be reaction at the average beam energy of 182 MeV/u were measured to study the GT transitions in ^{11}Li with the PANDORA recoil-neutron detector array and with the SAMURAI spectrometer. Fourteen channels corresponding to light-particle emission decays from ^{11}Be excited states, including seven new channels, were successfully identified, thanks to the wide acceptance of the SAMURAI spectrometer, in addition to the non-particle-emission channel from the ground state or low-lying excites of ^{11}Be. Clear kinematic correlation has been observed in each channel. Further analysis is ongoing to reconstruct the excitation energy spectra of GT transition strengths in ^{11}Li, taking into account the acceptance of the SAMURAI spectrometer.

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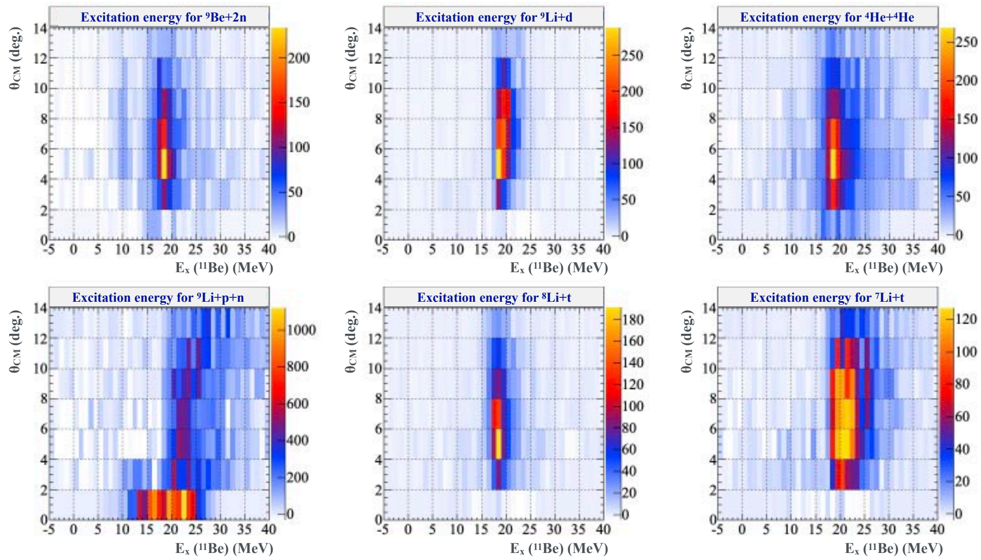

Fig. 3. – Kinematic correlation between $\theta_{\rm CM}$ and E_x for the ^{11}Li$(p,n)^{11}$Be reaction at 182 MeV/u, where ^{11}Be final states decay to ^{9}Be+$2n$, ^{9}Li+d, ^{4}He+^{4}He, ^{9}Be+$p+n$, ^{8}Li+t, and ^{7}Li+t. See the text for details.

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