Study of Gamow-Teller transitions from $^{132}$Sn via the $(p,n)$ reaction at 220 MeV/u in inverse kinematics

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Abstract. The charge-exchange $(p,n)$ reaction at 220 MeV has been measured to extract the strength distribution of Gamow-Teller transitions from the doubly magic unstable nucleus $^{132}$Sn. A recently developed experimental technique of measuring the $(p,n)$ reaction in inverse kinematics has been applied to the study of unstable nuclei in the mass region around $A\sim100$ for the first time. We have combined the low-energy neutron detector WINDS and the SAMURAI spectrometer at the RIKEN radioactive isotope beam factory (RIBF). The particle identification plot for the reaction residues obtained by the spectrometer provides the clear separation of the CE reaction channel from other background events, enabling us to identify kinematic curves corresponding to the $(p,n)$ reaction. Further analysis to reconstruct the excitation energy spectrum is ongoing.

1 Introduction

The Gamow-Teller (GT) transition is the simplest among the spin-isospin responses of nuclei, characterized by the spin and isospin changes by one unit in nuclear wave function and no change in the spatial part. For medium heavy stable nuclei with neutron excess, it is well known that a major part of the sum-rule strength is pushed up to highly excited states so called GT giant resonance (GTGR) [1]. Therefore, measuring the GT strength distribution over a wide excitation energy region including the GTGR is essential for revealing the natures of the nuclear collectivity and the underlying residual interactions in the spin-isospin channel (see, e.g., Refs. [2, 3]).

The transition strength, $B$(GT), is connected to the half-life of an allowed $\beta$-decay. However, the excitation energy region that the decay can access is limited by the $Q$-value window. Instead the charge-exchange (CE) reactions at intermediate energies have long provided a powerful tool to populate such highly excited states and extract the strength through a well established relation between the measured cross section at the limit of null momentum transfer and $B$(GT) [4].

Recently, there was the development of a novel technique of measuring the CE $(p,n)$ reaction on unstable nuclei provided as a radioactive isotope (RI) beam in inverse kinematics and the technique was first applied to the study of GT transitions from the unstable nucleus $^{56}$Ni [5, 6]. The technique is based on the missing mass spectroscopy for reconstructing the momentum and energy transfers in the $(p,n)$ reaction, i.e. the low energy recoil neutrons originating from the target are detected and their energies and...
the laboratory scattering angles are used for obtaining the excitation energy and the scattering angle of the reaction. Thus, the reconstruction of the kinetic information does not depend on the final state of the reaction residue, although the reaction residue is detected in order to help the unambiguous assignment of the reaction channel. Owing to the simplicity of the missing mass spectroscopy, the application of the technique can be straightforwardly extended to a wider region of unstable nuclei with any mass or to higher excitation energies. It is contrast to the invariant mass spectroscopy, where all the decaying particles from the reaction residue must be identified and momentum analyzed and, therefore, the reconstruction of the kinematic information is more complex.

At RI beam factory (RIBF) of RIKEN Nishina Center, we are rapidly expanding the region of the spin-isospin study to a wide region of unstable nuclei using intense RI beams. In the present contribution, we show the experiment where the technique was applied to the region around the mass A=100 for the first time. The experiment was performed in order to study Gamow-Teller transition on the double magic nucleus $^{132}$Sn in April 2014. The data analysis is ongoing and, herein, we show preliminary results indicating the identification of the CE reaction channel and the reconstruction of the kinetic information works well as planned.

2 Experiment and preliminary results

Figure 1 shows a schematic view of the experimental setup around the target. A secondary beam of $^{132}$Sn at 220 MeV/nucleon was produced through abrasion-fission reaction with a 345 MeV/nucleon primary beam of $^{238}$U and transported to a 11 mm thick liquid hydrogen target [7, 8]. The particle identification (PID) for the beam was performed on an event-by-event basis by measuring the energy loss ($\Delta E$) in the ionization chamber at the F7 focal plane, the magnetic rigidity ($B_p$) and the time of flight (TOF) of the beam particles in the BigRIPS spectrometer [9]. The resulting cocktail beam had a total intensity of $1.4 \times 10^4$ pps, containing $^{132}$Sn with a purity of 45%. For tagging the CE reaction channels, the heavy residue separation for reaction residues produced from $^{132}$Sn beam particles. The Z resolution is $\sigma_Z=0.22$ corresponding to $4.5\sigma$ separation for $Z=50$ and 51. The $A/Q$ resolution is $\sigma_{A/Q}=0.14\%$ which corresponds to $5.4\sigma$ separation. The PID plot provides clear separation of the events due to the CE reaction channel from background events. Furthermore, owing to the large momentum ac-
ceptance (50%) of SAMURAI spectrometer, all the reaction residues associated with the CE reaction channel can be identified in the same setting.

The target was surrounded by WINDS (Wide-angle Inverse-kinematics Neutron Detectors for SHARAQ) to detect recoil neutrons. WINDS consists of 61 plastic scintillators with dimensions of 600×100×30 mm$^3$. In this experiment 12 scintillators of the ELENS array [11] with dimensions of 1000×45×10 mm$^3$ were also installed. The left and right walls with respect to the beam line covered the angular region from 20 to 122 degrees with 5 degree steps. Top and bottom walls covered the angular region from 16 to 74 degrees with 3.5 degree steps. Each detector was placed such that the 30-mm wide (WINDS) or 10-mm wide (ELENS) plane faced the target and placed at a distance of 900 mm (1200 mm) from the target for the left and right (top and bottom) walls. Therefore, the ambiguity of flight-path-length (FPL) for the neutron ($\Delta$FPL/FPL) was ±5.6% (4.2%) for left and right (top and bottom) walls.

The scattering angle ($\theta_{\text{lab}}$) in the laboratory frame was mainly determined by the position of the scintillator bars. The angular resolution was estimated to be $\pm0.95$ degree ($\pm0.72$ degree) for left and right (top and bottom) walls. The neutron energy ($E_n$) was determined by measuring the neutron TOF, for which the time reference was taken from the plastic counters SBT1,2. The absolute TOF scale was obtained by measuring prompt $\gamma$-rays whose TOF can be reliably calculated from the light velocity and the flight path length. The resolution in neutron energy was estimated to be $\pm11\%$, mainly due to $\Delta$FPL/FPL. Figure 4 shows the kinematic correlations for the $^{132}$Sn$(p,n)$ reaction at 220 MeV/nucleon. WINDS covered the laboratory angles from 20 to 90 degrees and the neutron kinetic energies from 0.2 to 20 MeV as shown by the shaded area. The threshold for the light output in the scintillator was set to

![Figure 2](image-url)  
Figure 2. (Color online) Decay scheme of $^{132}\text{Sb}$ produced from the CE $(p,n)$ reaction on $^{132}\text{Sn}$. The heavy residues identified with SAMURAI, $^{130-132}\text{Sb}$, are enclosed with circles.
Figure 5. (Color online) Neutron spectra as a function of neutron energy ($E_n$) and scattering angle in laboratory frame ($\theta_{\text{lab}}$) for the $^{132}\text{Sn}$ beam component and for events associated with the heavy fragments in the spectrometer: (a) $^{132}\text{Sb}$, (b) $^{131}\text{Sb}$, (c) $^{130}\text{Sb}$.

3 Summary

The charge-exchange ($p,n$) reaction has been measured on doubly magic unstable nucleus $^{132}\text{Sn}$. We have combined the low-energy neutron detector WINDS with the SAMURAI spectrometer at RIKEN RIBF and applied the experimental technique of measuring the ($p,n$) reaction in inverse kinematics to unstable nuclei in the mass region around $A\sim 100$ for the first time. The atomic number $Z$ and mass-to-charge ratio $A/Q$ of the beam residues was determined with resolutions of $\sigma_{A/Q}=0.14\%$ and $\sigma_{Z}=0.22\%$, respectively. By using the PID information, the events due to the ($p,n$) reaction populating excited states in a wide energy region including the GTGR were identified and the kinematic curves were clearly identified. It implies that the ($p,n$) study has been successfully extended to unstable nuclei in the mass region around $A=100$, although the analysis of reconstructing the excitation energy spectra is ongoing.

Acknowledgements

We are grateful to the RIKEN RIBF accelerator crew for their efforts and support. This work was supported by a Grant-in-Aid for Scientific Research (No. 274740187) from the Japan Society for the Promotion of Science, US NSF [PHY-01102511], and the Hungarian OTKA Foundation, Grant No. K106035.

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