Production of low-energy 4.17 MeV/nucleon $^9$C beam with polyethylene degrader at RIPS


Theoretically, four low-lying $^{10}$N levels are expected as broad and overlapping resonances$^{1-3}$. The level structure of $^{10}$N is very important to understand resonances in $^{10}$Li because $^{10}$N and $^{10}$Li are the mirror nuclei expected to have a similar structure. The information of $^{10}$Li levels can be used to constrain the $^9$Li+n potential, which is required for constructing the three-body model of the borromean nucleus $^{11}$Li.

We proposed to measure the excitation function of the (differential) cross section and vector analyzing power ($A_v$) for the $^9$C+$p$ reaction to determine these broad resonances$^3$. The thick-target method in inverse kinematics$^4$ will be used for the measurement. In this method, the excitation functions for the cross section and $A_v$ will be scanned with a single beam energy utilizing the energy loss of the beam particle in the target. The range of center-of-mass energy is set to 1–5 MeV to cover the theoretically expected ground state of $^{10}$N and several excited states.

In September 2015, a test $^9$C+$p$ resonant scattering experiment was conducted at RIPS, where the production of a low-energy $^9$C beam was tested and the excitation function was measured with an unpolarized polyethylene $(\text{CH}_2)_n$ target. A $^9$C beam was produced using a 70-MeV/nucleon $^{12}$C primary beam with an intensity of 400 particle-nA and a 4-mm Be primary target at RIPS. The configuration of RIPS is described in Ref. [5]. A wedge-type degrader with $d/R = 0.8$, where $d$ is the central thickness of the degrader and $R$ is the range of $^9$C with a central momentum, was used at F1 to degrade the $^9$C beam energy. In order to realize a high transmission efficiency of $^9$C from F1 to F2, a conventional aluminum F1 degrader was replaced with a new $(\text{CH}_2)_n$ degrader, because the multiple scattering effect, which is serious at $d/R \sim 0.8$, can be highly reduced with a low-Z material.

The central thickness of the $(\text{CH}_2)_n$ degrader was set to 316 mg/cm$^2$ so that the energy loss of the $^9$C beam was equal to the energy loss in the standard Al degrader with 444 mg/cm$^2$ thickness. The wedge angle of the degrader was set to 5 mrad based on the LISE++ code$^6$ calculation. The intensity of the $^9$C beam was measured at F2 for the two cases using the standard Al degrader and the $(\text{CH}_2)_n$ degrader at F1. The latter was 1.8 times higher than the former, which shows improvement of transmission using the low-Z material for the F1 degrader.

The $^9$C beam energy was determined using the time-of-flight (ToF) measured between a 0.5-mm-thick plastic scintillator installed at F2 and one of two position-sensitive Parallel Plate Avalanche Counters (PPAC) at the F3 focal plane. The energy of the $^9$C beam was precisely controlled by a rotatable thin polyethylene degrader installed at the F2 focal plane. The correction for the energy loss in the PPACs was calculated based on the SRIM code$^7$. The beam energy determined in this analysis was 4.17 MeV/nucleon with an energy spread of $\sigma = 0.73$ MeV/nucleon.

The identification of the secondary beam particles was conducted based on the RF and ToF information. Thus the measured purity and intensity of the $^9$C beam were 15% and $2.4 \times 10^4$ pps at F3, respectively. These purity and intensity values are sufficiently high for the planned resonant scattering experiment.

In conclusion, a 4.17-MeV/nucleon $^9$C beam was successfully produced with a thick F1 degrader at RIPS. In the experiment, the transmission of the degraded beam was improved by suppressing multiple scattering effects in the thick F1 degrader using a low-Z material.

References