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

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Theoretically, four low-lying ^{10}N levels are expected as broad and overlapping resonances[1,2]. 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_y) 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_y 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 ($(CH_2)_n$) 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 at 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 $(CH_2)_n$ degrader, because the multiple scattering effect, which is serious at d/R ∼0.8, can be highly reduced with a low-Z material.

The central thickness of the $(CH_2)_n$ 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 $(CH_2)_n$ 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 2.4×10^4 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.

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References

1) S. Aoyama, K. Kato, K. Ikeda, Phys. Lett. B **414**, 13 (1997).
2) E. Caurier et al., Phys. Rev. C **66**, 024314 (2002).
3) T. Teranishi, S. Sakaguchi, T. Uesaka et al., AIP Conf. Proc. **1525**, 552 (2013).
4) K.P. Artemov et al., Sov. J. Nucl. Phys. **52**, 408 (1990).
5) T. Kubo et al., Nucl. Instr. Meth. B **70**, 309 (1992).
6) O. B. Tarasov, D. Bazin, Nucl. Instr. Meth. B **266**, 4657 (2008).
7) J.F. Ziegler, M.D. Ziegler, J.P. Biersak, Nucl. Instr. Meth. B **268**, 1818 (2010).