Heavy-ion double charge exchange reaction on $^{9}$Be

H. Matsubara$^{a}$, M. Takaki$^{a,b}$, T. Uesaka$^{a}$, S. Shimoura$^{b}$, N. Aoi$^{c}$, M. Dozono$^{a}$, T. Fujii$^{b}$, K. Hatanaka$^{c}$, T. Hashimoto$^{c}$, T. Kawabata$^{d}$, S. Kawase$^{b}$, K. Kisamori$^{a,b}$, Y. Kikuchi$^{b}$, Y. Kubota$^{b}$, C.S. Lee$^{a}$, H.C. Lee$^{b}$, Y. Maeda$^{e}$, S. Michimasa$^{b}$, K. Miki$^{a,c}$, H. Miya$^{b}$, S. Noji$^{b}$, S. Ota$^{b}$, S. Sakaguchi$^{f}$, Y. Sasaki$^{m}$, T. Suzuki$^{c}$, L.T. Tang$^{b}$, K. Takahisa$^{c}$, H. Tokieda$^{b}$, A. Tamii$^{c}$, K. Yako$^{b}$, Y. Yasuda$^{c}$, N. Yokota$^{d}$, R. Yokoyama$^{b}$, and J. Zenihiro$^{a}$

$^{a}$RIKEN (The Institute of Physical and Chemical Research)
$^{b}$Center for Nuclear Study, Graduate School of Science, University of Tokyo
$^{c}$Research Center for Nuclear Physics (RCNP), Osaka University
$^{d}$Department of Physics, Kyoto University
$^{e}$Department of Applied Physics, Kyusyu University
$^{f}$Department of Physics, Kyushu University

1. Introduction

The $^{9}$He nucleus has the largest $A/Z$ ratio of 4.5. Although it is unbound, the first excited state of $^{9}$He is reported to have a remarkably narrow width at a level of 100 keV [1]. Because the $^{10}$He ground state is also unbound, neutron pickup reactions, such as $(p, d)$ and $(d, t)$ reactions, cannot be applied to investigate the level structure of $^{9}$He. Thus, small number of works have been devoted to study the energy levels, widths and spin-parities in $^{9}$He. Most of their spin-parities and widths, however, are still uncertain or scarcely known, as summarized in Table 1.

We have developed a new powerful probe to study neutron rich nuclei, which is heavy-ion double charge exchange (HIDCX) ($^{18}$O, $^{18}$Ne) reaction by making use of the high resolution spectrometer Grand Raiden (GR) at the Research Center for Nuclear Physics (RCNP), Osaka University. This probe has noticeable advantages i.e. (a) unstable nucleus can be investigated even by using stable nuclei for a target and for a beam, (b) missing mass measurement enables us to observe an excitation energy spectrum both below and above the particle threshold, (c) out-going particles of $^{18}$Ne can be clearly identified through the spectrometer because the $^{9}$B nucleus is unbound and thus an $A/Q$ value for $^{18}$Ne is unique, and (d) the HIDCX transition rate between $^{18}$O$_{g.s.}$ and $^{18}$Ne$_{g.s.}$ is expected to be relatively large because of overlapping for their wavefunctions in $r$-space, which arises from the fact that they are in the supermultiplet members. It should be noted that the advantage (d) is essential for the HIDCX measurement since a double charge exchange transition is considered to be a two-step reaction and its rate is usually small. Therefore, the ($^{18}$O, $^{18}$Ne) reaction that has a large transition rate would provide us to investigate the unbound nucleus $^{9}$He from the stable nucleus $^{9}$Be.

2. Experimental setup

The experiment was performed at the WS course of the RCNP. A primary beam of $^{18}$O was accelerated up to 1432 MeV (79.6 MeV/nucleon), which is the maximum at the RCNP by the coupled cyclotrons. A typical beam intensity was 20 pnA. A beam energy spread was 1 MeV (FWHM) including an effect owing to detector system at the focal plane of the GR spectrometer. The $^{18}$O beam bombarded a self-supported foil target of $^{9}$Be with an areal density of 5.0(1) mg/cm$^2$, where the natural abundance in beryllium is 100%. The scattered particles were momentum-analyzed by the GR spectrometer. Then, they were detected by the focal plane detector system, which consists of two vertical drift chambers (VDC’s) and two plastic scintillation counters. Thicknesses of the two scintillators were 1 and 3 mm from the upstream. Coincident signals from the scintillation counters were used to trigger the data acquisition (DAQ) system. The detail of the experiment can be found in Ref. [2].

3. Result and discussion

The particle identification to select $^{18}$Ne was realized by using the information of Time-of-Flight between RF from the accelerator and the triggering signals and by making use of its unique $A/Q$ value. Detailed descriptions for the analysis may be found in Ref. [3]. An excitation energy spectrum of the $^{9}$Be($^{18}$O, $^{18}$Ne)$^{9}$He reaction at 0-0.6$^\circ$ is compared with that of $^{12}$Be($^{18}$O, $^{18}$Ne)$^{12}$Be reaction as shown in Fig. 1. Although the same beam, the same detector system, and the same analysis procedure were applied for both $^{9}$Be and $^{12}$C, only continuous increment caused by quasi free scattering are seen in the spectrum of $^{9}$He. There are no prominent signals. Figure 2 shows coupling-channel.

### Table 1. Energy levels and widths in $^{9}$He.

<table>
<thead>
<tr>
<th>$E_x$ (MeV)</th>
<th>$J^\pi$</th>
<th>$\Gamma$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1/2$^+$</td>
<td></td>
</tr>
<tr>
<td>1.10</td>
<td>1/2$^-$</td>
<td>0.1</td>
</tr>
<tr>
<td>2.26</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td></td>
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calculations by the code ECIS with assuming two-phonon states to reproduce the HIDCX transition. The microscopic form factors were obtained [4] by folding the projectile and the target transition densities with the USD and SFO effective interactions, respectively. The simplest transition path assumed for the calculation is double Gamow-Teller transitions from the $^9$Be($3/2^-$ g.s.) to the $^9$He($1/2^-$ g.s.) via the $^9$Li($3/2^-$ g.s.). The calculation indicates that the differential cross section is less than 1 nb/sr owing to a tiny B(GT) value from the $^9$Be($3/2^-$ g.s.) to the $^9$Li($3/2^-$ g.s.). Because 10 nb/sr was the lower detection limit in the previous experimental condition, the cross section to $^9$He was too small to be observed. Spatial deformation of $^9$Be [5] is supposed to cause small overlapping of wavefunction between $^9$Be and $^9$Li, resulting in small cross section to $^9$He.

As a next step for establishment of the HIDCX ($^{18}$O, $^{18}$Ne) reaction as a spectroscopic tool, we are planning to measure $^{13}$C($^{18}$O, $^{18}$Ne)$^{13}$Be reaction since the nucleus $^{13}$Be is unbound. The calculation predicts the differential cross section of 20-40 nb/sr at 0° for a transition to $^{13}$Be g.s.. Because the cross section predicted is one thirds of $^{12}$C($^{18}$O, $^{18}$Ne)$^{12}$Be g.s., the HIDCX ($^{18}$O, $^{18}$Ne) reaction on $^{13}$C would be the first successful application for spectroscopy of unbound nucleus.

References