I. 6. Proton Particle States in $^{69,71}$Ga Studied through (d, n) Reactions on $^{68,70}$Zn

Hosaka M., Miyamoto S., Inomata T*., Zhong G., Ishii K., and Orihara H.

Cyclotron and Radioisotope Center, Tohoku University
Department of Physics, Tohoku University*

The (d, n) reaction at sufficiently high incident energy may provide a powerful spectroscopic tool for probing single particle properties of nuclei since theoretical treatment for this reaction is more straightforward than other proton transfer reaction 1).

Several interesting problems are associated with the structure of A ~ 70 nuclei. An example is evidence of a shape transition around N = 40. Moreover, electron capture rates in these fp shell nuclei, most of which are so far parametrized based on shell model, play an important role in stellar collapse leading to the formation of a super nova 2-3). Such problems further include the topics in particle physics; double b-decay in A = 76 nuclei and p-p solar neutrino observation by $^{71}$Ga (GALEX at the Gran Dasso). Thus, test for such shell-model calculation by proper probe is essential. Single-particle properties studied by (d, n) reaction, for example, may provide a good place for a crucial test for model calculations.

The single particle properties of states in $^{69,71}$Ga have been examined through the (d, n) reaction 4) at E_d = 10 MeV, and by ($^3$He, d) reactions 5) at E$_{3He}$ = 15, 17 MeV. The previous (d, n) and ($^3$He, d) works may suffer from the ambiguities for the choice of optical-model parameters for complex particles, and from contribution of the compound nucleus formation process, since their deuteron energies are rather low.

In this report we present proton strength distributions obtained by sufficiently high energy (d, n) reactions. Observed cross sections have been interpreted successfully by adiabatic deuteron breakup approximation (ADBA) 6) where s-wave deuteron breakup-effects are taken into accounts.

The experiments were performed using a 25-MeV deuteron beam from the AVF cyclotron at Cyclotron and Radioisotope Center (CYRIC), Tohoku University. Neutron energies were measured by the time of flight technique. Twelve neutron detectors containing totally 23 litter of liquid-scintillator NE213 were set at a flight path of 44 m from the target, where the effective neutron detection solid angle was 0.23 msr. Angular
distributions of neutrons were measured using a beam swinger system. Detector efficiency for the most energetic neutrons was 3 %, which was determined by the \(^{7}\)Li(p, n)\(^{7}\)Be reaction through activation analysis. Details of the CYRIC TOF facility have been described elsewhere. Metallic foils of zinc enriched to 99 % in \(^{68}\)Zn and 98% in \(^{70}\)Zn with their thicknesses of 4.83 and 4.04 mg/cm\(^2\), respectively, were used as targets. Overall energy resolution was 200 keV (FWHM) for the most energetic neutrons leading to the low lying states in the residual nuclei. Gamma-ray events have been rejected by pulse-shape-discrimination technique. Errors in the absolute magnitudes of cross section are estimated to be less than 12 %, the dominant part of which is due to the uncertainty of the detector efficiency.

Measured angular distributions of emitted neutrons are shown in Figs. 1 and 2 along with theoretical predictions. The zero-range distorted-wave Born-approximation (DWBA) calculation for angular distributions has been accomplished with the code DWUCK\(^{4}\). Adiabatic deuteron potentials were derived from the sets of nucleon parameters at \(E_p = E_n = 1/2\ E_\alpha\); those for protons have been given by Becchetti and Greenlees \(^{10}\), while those for neutrons by Carlson et al \(^{11}\). Experimental spectroscopic factors \((S)\) is extracted from the following equation:

\[
\frac{d\sigma}{d\Omega}_{\text{exp}} = 1.55 \frac{(2J_f + 1)}{(2J_i + 1)} \frac{C^2 S}{(2j + 1)} \frac{d\sigma}{d\Omega}_{\text{DWUCK}} \left(\frac{mb}{sr}\right),
\]

where \(J_i\) and \(J_f\) are spins of initial and final states, respectively, and \(j\) is the spin of a transferred particle. \(C\) is the Clebsh-Gordan coefficient for isospin coupling. The values of \(C^2\) are 2/3 and 1/3 for the \(T = T_0 - 1/2\) and \(T_0 + 1/2\) states, \(T_0\) being the target isospin, respectively.

Typical angular distributions for each transfer \(\ell\) value are illustrated in Fig. 2. In general, good agreements between the experiment and theory have been obtained for the angular distribution shape. Spectroscopic strengths \((2J_f + 1)C^2S\) obtained by the analyses with two types of calculation are compared in TABLE 1. In the \(^{68}\)Zn(d, n)\(^{69}\)Ga, the preliminary analysis suggests that 25 % of the \(2p_{3/2}\) hole-strength concentrate on the ground state, while 40 %, and 54 % of the \(2p_{1/2}\) and \(1f_{5/2}\) hole-strengths on the 0.319- and 0.574-MeV states, respectively. Meanwhile, \(2p_{3/2}\) and \(1f_{5/2}\) hole-strengths in the \(^{70}\)Zn(d, n)\(^{71}\)Ga reaction are split into two states in \(^{71}\)Ga. The \(2p_{1/2}\) and \(1f_{5/2}\) hole-strengths are, respectively, 39 % and 52 %, which are almost same in magnitudes with those in the \(^{68}\)Zn(d, n)\(^{69}\)Ga reaction. On the other hand, the \(2p_{3/2}\) hole-strength of 37 % for the \(^{70}\)Zn(d, n)\(^{71}\)Ga reaction is notably large.

In a summary, we have observed proton single-particle states in \(^{69}\)Ga and \(^{71}\)Ga by the (d, n) reaction with a sufficiently high deuteron beam. Adiabatic deuteron break up
approximation has been successfully applied to explain angular distributions of emitted neutrons, and to reduce hole-strength distribution for relevant orbital.

References

9) Kunz P. D. unpublished.

Table 1. Levels of $^{69}$Ga and $^{71}$Ga and spectroscopic factors from the (d, n) reactions on $^{68}$Zn and $^{70}$Zn.

<table>
<thead>
<tr>
<th>Jπ</th>
<th>$E_X$ (MeV)</th>
<th>$C^2S$</th>
<th>$C^2S(2j+1)$</th>
<th>$S$</th>
<th>$S(2j+1)$</th>
<th>$\Sigma$</th>
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<tr>
<td>$^{69}$Ga</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/2-</td>
<td>0.0</td>
<td>0.35</td>
<td>1.40</td>
<td>0.23</td>
<td>0.94</td>
<td></td>
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<tr>
<td>1/2-</td>
<td>0.319</td>
<td>0.60</td>
<td>1.20</td>
<td>0.40</td>
<td>0.80</td>
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<tr>
<td>5/2-</td>
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<td>0.80</td>
<td>4.80</td>
<td>0.54</td>
<td>3.21</td>
<td>4.95</td>
</tr>
<tr>
<td>$^{71}$Ga</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/2-</td>
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<td>0.42</td>
<td>1.68</td>
<td>0.28</td>
<td>1.12</td>
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<tr>
<td>1/2-</td>
<td>0.511</td>
<td>0.13</td>
<td>0.52</td>
<td>0.086</td>
<td>0.35</td>
<td></td>
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<tr>
<td>5/2-</td>
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<td>1.16</td>
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<tr>
<td></td>
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<td></td>
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<td>1.56</td>
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Fig. 1. Differential cross sections for neutrons from the $^{68}$Zn(d, n)$^{69}$Ga reaction leading to the low-lying states. Curves are microscopic ADBA calculations.
Fig. 2. Same with Fig. 1 but for the $^{70}$Zn(d, n)$^{71}$Ga reaction