Experimental study on inflation of the 2_2^+ state in ^{12}C

Y. Fujikawa, T. Furuno, T. Goto, K. Inaba, Y. Kanada-En'yo, T. Kawabata, K. Mizutani, S. Okamoto, Y. Sakaguti, Y. Takahashi, T. Takeda, C. Takimoto, M. Tsumura, I. Sakata[1], M. Ito[2] and M. Nakao[2]
Dept. of Phys., Kyoto University, Kitashirakawa-Oiwake, Sakyo, Kyoto 606-8502, Japan
[1]*Dept. of Phys., University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[2]*Dept. of Pure and Applied Physics, Kansai University, 3-3-35 Yamate-cho, Suita-shi, Osaka 564-8680, Japan*

The 0_2^+ state in ^{12}C, which is called the Hoyle state, is known to have spatially well-developed 3α cluster structure. It is considered that the radius of the Hoyle state is 2–3 times larger than that of the ground state, and thus, the Hoyle state is much more dilute than usual states. This is different from the well-known fact that the nuclear density is saturated and independent of the kind of nuclei. Therefore, we should experimentaly determine the radius of the Hoyle state.

However, it is not easy to measure radii of excited states. Although it is naively expected that the nuclear radius reflects on the diffraction pattern of the angular distribution of the scattering cross section, the diffraction pattern in inelastic scattering is related to the density distributions of not only the excited state but also the ground state. The relationship between the angular distribution of the cross section and the radius of the excited state is not trivial.

Recently, M. Ito proposed to measure the inelastic scattering for the 2_2^+ state in ^{12}C instead of the Hoyle state [1]. M. Ito pointed out that the angular distribution of the cross section for the $\Delta L = 0$ transition is not sensitive to the radius of the excited state but that for the $\Delta L = 2$ transition has a certain sensitivity. The 2_2^+ state is the rotational excited state of the Hoyle state and is considered to have the large radius like the Hoyle state. The 3α resonating-group method (RGM) calculation [2] suggests that the radii of the 2_2^+ state and the Hoyle state are 4.0 fm and 3.5 fm, respectively, while that of the ground state is as small as 2.4 fm.

The experiment was carried out at the W course in Research Center for Nuclear Physics (RCNP), Osaka University. A proton beam at 53.3 MeV bombarded the ^{12}C target with a thickness of 2.8 mg/cm^2, and the scattered protons were analyzed by the Raiden spectrometer [3]. We measured the differential cross sections of the elastic proton scattering and inelastic proton scattering exciting the 2_1^+, 0_2^+, and 3_1^- states in ^{12}C.

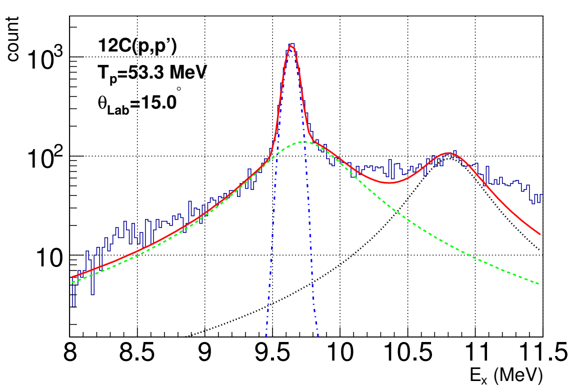

Figure 1: Excitation-energy spectrum of ^{12}C(p,p') at $\theta_{\rm Lab} = 15.0°$. The dashed, dotted, and dash-dotted lines show the fitting result for the sum of the 2_2^+ and 0_3^+ states, the 1_1^- state, and the 3_1^- state, respectively, while the solid line is the sum of these four states.

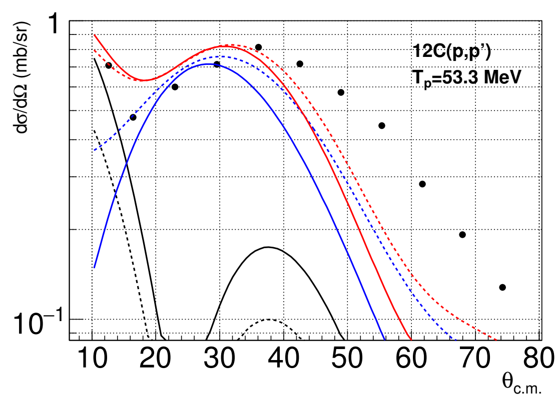

Figure 2: Sum of the measured cross section of the 2_2^+ and 0_3^+ states compared with the theoretical calculation (see text).

These 0_3^+ and 2_2^+ states around $E_x = 10$ MeV in ^{12}C are broad states, and thus they overlap each other in the excitation-energy spectrum as shown in Fig. 1. Therefore, it is difficult to separately determine the respective differential cross sections. We fit the excitation-energy spectra in E_x=9.17–10.14 MeV assuming the narrow peak due to the 3_1^- state and the broad bumps due to the 2_2^+ and 0_3^+ states. The dashed, dotted, and dash-dotted lines in Fig. 1 show the fitting result for the sum of the 2_2^+ and 0_3^+ states, the 1_1^- state, and the 3_1^- state, respectively, while the solid line is the sum of these four states. The measured cross sections for the sum of the 2_2^+ and 0_3^+ states were compared with the theoretical calculation in Fig. 2. The transition densities for the 2_2^+ and 0_3^+ states used in the calculation were taken from the 3α RGM calculation [2]. The black and blue solid lines show the calculated cross sections of the 2_2^+ and 0_3^+ states, while the red solid line is the sum of the

2_2^+ and 0_3^+ states. The calculated cross sections of the 2_2^+ and 0_3^+ states were normalized to fit the experimental data. As shown in Fig. 2, the theoretical calculation does not reproduce the experiment at the backward angles. We also performed another calculation assuming that the radius of the 2^+ state is small (2.54 fm) as shown by the dashed lines in Fig. 2. The angular distribution for the smaller radius shifts to the forward angles opposite to the experiment, but the calculation does not still reproduce the experiment.

In the previous measurement of the ^{12}C(α, α') reaction, the theoretical calculation using the 3α RGM wave function reasonably explained the experiment [4]. The reason of this discrepancy between the (p, p') and (α, α') reactions are still unknown. Further investigation of this discrepancy is strongly desired.

The authors are grateful to RCNP for deep understanding about the importance of the undergraduate education with the hands-on training at the large accelerator facility. The present work was performed as a graduation research by the undergraduate senior students at Kyoto University (KADAIKENKYU P4). All processes of the research project were performed by the undergraduate students under the supervision of the faculties.

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