I. 2. Measurement of Decay $\alpha$ Particles from the 15.1 MeV $0^+$ State in $^{16}$O via the $^{12}$C($^{16}$O,$^{16}$O*[\(\alpha + X\)])$^{12}$C Reaction

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The excited state of 15.1 MeV $0^+$ in $^{16}$O is considered to be the 4-$\alpha$ condensed state\(^1\). The concept of the $\alpha$ condensed state was proposed by Tohsaki et al\(^2\). They explained the 7.65 MeV, $0_2^+$ state of $^{12}$C as the 3-$\alpha$ condensed state in which all constituent $\alpha$ clusters condensed into the lowest S-orbit, and loosely bound. As for the 4-$\alpha$ condensed state, it is not established. In this study, we measured decay $\alpha$ particles from the 15.1 MeV $0^+$ state in $^{16}$O via the $^{12}$C($^{16}$O,$^{16}$O*[\(\alpha + X\)])$^{12}$C reaction in order to investigate the 4-$\alpha$ condensed state. Since the wave function of 4-$\alpha$ condensed state has a large overlap amplitude of the $\alpha + ^{12}$C(0$^+_1$) channel, the branching ratio of this decay channel is considered to be large in comparison with the cascade statistical model.

The experiment was performed at the CYRIC 41 course beam line by using the large scattering chamber. The 160 MeV $^{16}$O$^{5+}$ beam accelerated in the K=110 MeV AVF cyclotron was transported into the large scattering chamber in the experimental room TR-4 and bombarded the self-supporting carbon target. The experimental setup was almost same as the test experiment reported previously\(^3\) and details were reported in Ref.\(^4\). Here, we present the brief outline of the experiment and procedures specified to this experiment. The beam current was typically 10 pnA. The target was the natural carbon foil of the 51.5 $\mu$g/cm$^2$ thick and rotated by 45° against the beam axis in order to keep the energy loss of the recoil carbon below 400 keV. The recoil $^{12}$C was catch in SSDs placed at 61° (SSD0), 48.5° (SSD1). SSD2 placed at 73.5° was used for the beam position monitor. The kinetic energy of recoil $^{12}$C from elastic scattering of $^{16}$O+$^{12}$C changes drastically when the recoil angle changes. If the beam position shifts by 1 mm, the recoil energy changes about 600 keV. In this experiment, we used the position sensitive detector (PSD) of the 50 mm×50 mm size and 994 $\mu$m thick, which is a double sided silicon strip type and has 16 strips in...
each side, for the detector of decay particles. We measured decay particles in three angles of the PSD, 9°, 17.5°, 26° to cover decay-α particles from the $^{16}\text{O}^{-}\rightarrow^{12}\text{C}(\text{g.s.})$ channel. We installed two BGO detectors in order to estimate the contribution of the $^{12}\text{C}(^{16}\text{O},^{16}\text{O}^*_{(\alpha+X)})^{12}\text{C}(2^+)$ reaction. However, it was so small that it was neglected in this analysis. The detectors setup in the large scattering chamber is shown in Fig. 1.

The particle identifications for both SSD and PSD were done by the TOF method. The $^{12}\text{C}(^{16}\text{O},^{16}\text{O}^*)$ reaction was reconstructed by kinematical condition of the angle and kinetic energy of the recoil $^{12}\text{C}$. The missing mass energy of the reaction was calculated as follows,

\[ M_x = M(^{16}\text{O}) + E_x(^{16}\text{O}) - E_{\text{c.m.}}(\alpha) - E_{\text{c.m.}}(^{12}\text{C}) \]

where $M(^{16}\text{O})$ is the mass of the $^{16}\text{O}$ nucleus, $E_x(^{16}\text{O})$ is the excitation energy of $^{16}\text{O}^*$, which was fixed at 15.1 MeV. The energy of the decay particle in the center of mass system, $E_{\text{c.m.}}(\alpha$ or $^{12}\text{C}$), which was not detected in the PSD, was calculated kinematically by using that of the detected particle. Obtained missing mass spectra were shown in Fig. 2. The peak around $M_x = 0$ MeV was corresponding to the $\alpha^{+}^{12}\text{C}(\text{g.s.})$ channel, on the other hand, that around $M_x = 4.5$ MeV was corresponding to the $\alpha^{+}^{12}\text{C}(2^+)$ channel. The branching ratio was obtained by multiplying this spectrum by the detection efficiency of the PSD. The detection efficiencies were estimated by a simple simulation program. The branching ratio between the $\alpha^{+}^{12}\text{C}(\text{g.s.})$ and the $\alpha^{+}^{12}\text{C}(2^+)$ channels was obtained to be about 7:3 from the missing mass spectrum of the decay $^{12}\text{C}$ at 9° of the PSD by assuming that all decay $^{12}\text{C}$ came from the 15.1 MeV 0+ state in $^{16}\text{O}$. It was consistent with the predicted number of Ref. 1). However, that obtained from decay $\alpha$ was inconsistent with the result of the decay $^{12}\text{C}$ due to the complicated loci of the decay $\alpha$. Figure 3 shows the 2-dimensional histograms on $\theta_{\text{decay}}$ vs $E_{\text{decay}}$. $\theta_{\text{decay}}$ is the angle between the scattered $^{16}\text{O}^*$ and the decay particle. $E_{\text{decay}}$ means the kinetic energy of the decay particle. Upper figures (a), (b) of Fig. 3 show experimental results. Lower figures (c), (d) show results of the simple simulation. As shown in figures (b) and (d), loci below 5° were complicated. To understand these loci, more precise analysis is needed.

References


Figure 1. Detectors set-up in the large scattering chamber.

Figure 2. Missing mass spectra obtained from decay-particles. (a): Missing mass spectrum obtained from decay-α measured in the PSD at 26°. (b): That obtained from decay-α measured at 17°. (c): That obtained from decay-12C measured at 9°.

Figure 3. The 2-dimensional histograms on $\theta_{\text{decay}}$ vs $E_{\text{decay}}$. (a) and (b) are experimental results obtained from the decay $^{12}$C (a) and the decay $\alpha$ (b). (c) and (b) are results of the simple simulation program for the decay $^{12}$C (c) and decay $\alpha$ (d). In the simulation, the branching ratio of each decay channel was assumed to be same.