I. 7. Search for the Bandhead of the Hoyle State + α Cluster Structure in ^{16}Ovia the ^{12}C(^{16}O,^{16}O*[α+X])^{12}C Reaction

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The α-particle condensate has gained much attention in light nuclei. The concept of the α-particle condensate was proposed by Tohsaki et al[1]. The 7.65 MeV 0_2^+ state of ^{12}C has been considered to be a candidate for the 3α particle condensate in which all constituent α clusters enter into the lowest S-orbit, and loosely bound. The 7.65 MeV 0_2^+ state of ^{12}C is called Hoyle state which plays an important role of the nucleosynthesis heavier than ^{12}C. However, the 4α particle condensate state in ^{16}O has been not established, yet. According to the α condensate model, the 15.1 MeV 0^+ state is considered to be a candidate of the 4α particle condensate[2]. In the previous experiment, we have measured decay α particles from the 15.1 MeV 0^+ state in ^{16}O via the ^{12}C(^{16}O,^{16}O*[α + X])^{12}C reaction in order to investigate the 4α-particles condensate in the ^{16}O nucleus[3]. Since the wave function of the 4α-particles condensate state in ^{16}O has a large amplitude of the ^{12}C(0_2^+)+α channel, the decay width of the 15.1 MeV 0^+ state to the ^{12}C(0_2^+) + α channel was considered to be large compared to other channels. However, although the decay α particles to the ground state (g.s.) and the first 2+ state of 12C from the 15.1 MeV 0+ state were observed, decay α particles to the 12C(02+) + αchannel were not detected. Due to the Coulomb barrier, the decay to the 12C(02+)+α channel is considered to be suppressed.

Recently, the 15.1 MeV 0+ state is considered to have a character of the superfluidity from the viewpoint of a rotational band with a 12C(02+) + α cluster structure[4]. They claimed the moment of inertia for the 15.1 MeV 0+ state is drastically reduced due to the superfluidity in the 4α condensate state. In addition to the superfluidity of the ^{12}C(0_2^+) + α cluster structure, they also claimed there was a band head 0^+ state at around 16.6 MeV.

However, no 0^+ state have been reported in experimental studies so far. In the experiment of inelastic α scattering at E_α = 386 MeV in RCNP, Osaka University, we obtained the preliminary result for the existence of the 0^+ state at around 16.6 MeV with a width of about 1 MeV. In this study, we measured decay α particles from the around 16.6 MeV region in ^{16}O via the $^{12}C(^{16}O,^{16}O^*[\alpha+X])^{12}C$ reaction in order to search for the band head 0^+ state with a $^{12}C(0_2^+)$ + α cluster structure.

The experiment was performed at the CYRIC 41 course beam line by using a 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 to the self-supporting carbon target. The experimental setup was same as the previous experiment[5)]. The beam current was typically 10 p nA. The target was the natural carbon foil of the 50.0 μg/cm^2 thick and rotated by 45° against the beam axis in order to keep the enegy loss of the recoil carbon below 400 keV. The recoil ^{12}C was caught in the silicon detectors at 61° (SSD0) and 48.5° (SSD1). For monitoring the beam position, the energy of the recoil ^{12}C from elastic scattering of ^{16}O + ^{12}C was measuring at 73.5° during the experiment. If the beam position shifted by 1 mm, the energy of the recoil ^{12}C changed about 600 keV. For a detector of decay α particles, we used the position sensitive detector (PSD) of the 50 mm×50 mm size and 994 μm thick, which is a double-sided silicon strip type and has 16 strips in each side. We measured decay particles in three angles of the PSD at 9°, 17.5°, and 26° to cover decay-α particles from the $^{16}O^* \rightarrow \alpha$ + ^{12}C(g.s.) channel. We also installed two BGO detectors in order to estimate the contribution of the $^{12}C(^{16}O,^{16}O^*[\alpha + X])^{12}C(2^+)$ reaction. However, it was so small that it was neglected in this analysis.

Figure 1(a) shows the kinematic calculation of the recoil 12C energy and angle for the excitation energy of ^{16}O at Ex = 16.5 MeV, which is shown by a bold solid line. The red-hatched region shows the acceptance of SSD0. The crossed area between the kinematic calculation of the recoil ^{12}C and the acceptance of SSD0 corresponds to the SSD0 energy from 8.3 to 9.3 MeV, as shown in Fig. 1(b). Since the width of the 0^+ state obtained in the RCNP experiment is about 1 MeV, cross section of this excitation energy decreases gradually toward the high excitation energy. Figure 2 shows the missing mass spectrum of the reaction obtained by gating this energy region. The missing mass was calculated from the recoil ^{12}C and one of decay particles by assuming the $^{16}O^* \rightarrow ^{12}C+\alpha$ decay. The decays of the ^{12}C(g.s.)+α and $^{12}C(2^+)+\alpha$ channels are clearly seen in Fig. 2.

The count ratio between the ground state and the first 2^+ state is about 4:3. In order to estimate the branching ratio between these two channels, we carried out the Monte-Carlo simulation and compared with the count ratio obtained in this experiment. The estimated branching ratio is about 1:1. The ratio of the $^{12}C(2^+) + \alpha$ channel is larger than the previous reported 15.1 MeV 0^+ state in ^{16}O[2). The decay to the $^{12}C(0_2^+) + \alpha$ channel could not be separated from other decay channels and background. Further investigations are needed.

References

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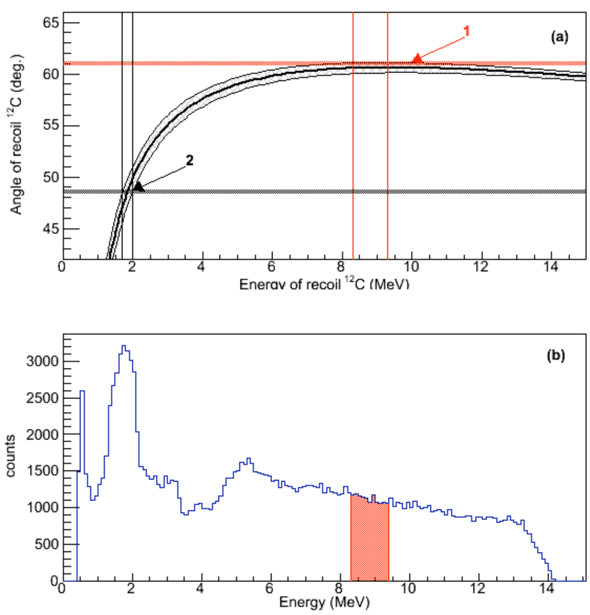

Figure 1. (a) The kinematic calculation of the recoil 12C energy and angle. (b) The energy spectrum obtained in the SSD0 detector. The red-hatched region corresponds to the excitation energy of about 16.5 MeV in ^{16}O.

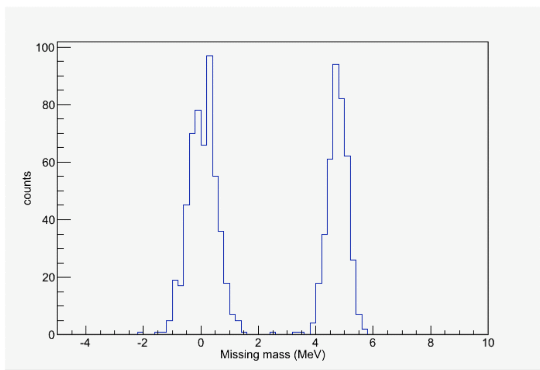

Figure 2. The missing mass spectrum obtained from decay ^{12}C particles. The peak around 0 MeV corresponds to the $^{12}C(g.s.) + \alpha$ decay channel. That around 4.4 MeV corresponds to the $^{12}C(2^+) + \alpha$ decay channel. The branching ratio between $^{12}C(g.s.) + \alpha$ and $^{12}C(2^+) + \alpha$ channel was estimated to be about 1:1.