Experimental study of the stellar $^{12}C(\alpha,\gamma)^{16}O$ reaction

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The $^{12}C(\alpha,\gamma)^{16}O$ reaction plays an important role in stellar evolution at the helium-burning stage. Namely, it determines the mass fraction of ^{12}C and ^{16}O, and the iron-core mass before super-nova explosion [1, 2, 3]. Therefore, it is quite important to determine the cross section at the center-of-mass energy E_{cm} = 300 keV, which corresponds to the Gamow energy of the helium-burning region in stars. The $^{12}C(\alpha,\gamma)^{16}O$ cross section at around 300 keV, however, is difficult to determine with direct measurements, since it is expected to be as small as 10^{-17}b. Therefore, it is determined by extrapolating the cross section measured in the energy region above about 1 MeV with use of theoretical models. The estimated cross section, however, is still suffering from an ambiguity with a factor of about four [4], due to a large uncertainty in the existing experimental data. The uncertainty is mainly due to the extremely small cross section, the background due to the neutrons from the $^{13}C(\alpha,n)^{16}O$ reaction occurring in the carbon target, the change of the target thickness, and so on. Hence, we designed a new experiment in order to make a precise measurement of the cross section in the energy region below 1.75 MeV. In this experiment, we will use high-efficiency NaI(Tl) spectrometers with a large S/N value and an intense pulsed α beam. In order to test the performance of our experimental method, we measured the $^{12}C(\alpha,\gamma)^{16}O$ reaction at $E_{cm}\sim$ 1.6 MeV.

A schematic drawing of the experimental setup is shown in Fig. 1. A pulsed α beam (E_α = 2.275MeV) was provided by the 3.2MV Pelletron accelerator at Research Labolatory for Nuclear Reactors of Tokyo Institute of Technology. The time averaged beam intensity was about 5μA. The beam bursts were about 1.9 nsec wide (FWHM) and were separeted by 500nsec. This time resolution was sufficient to distinguish a true event from a background event due to neutrons. A target used in this experiment was a natural carbon (23.5mm in diameter, 1mm in thickness, and 99.999% pure). The capture γ-rays were detected with anti-Compton NaI(Tl) γ-ray spectrometers. Each spectrometer consisted of a 9 in ϕ $\times$ 8 in main NaI(Tl) detector, surrounded by a 13.5 in ϕ $\times$ 14.5 in NaI(Tl) annular detector for the Compton suppression and the veto against charged cosmic rays. And we surrounded the NaI(Tl) detectors with the sheildings of 5cm-thick lead for external

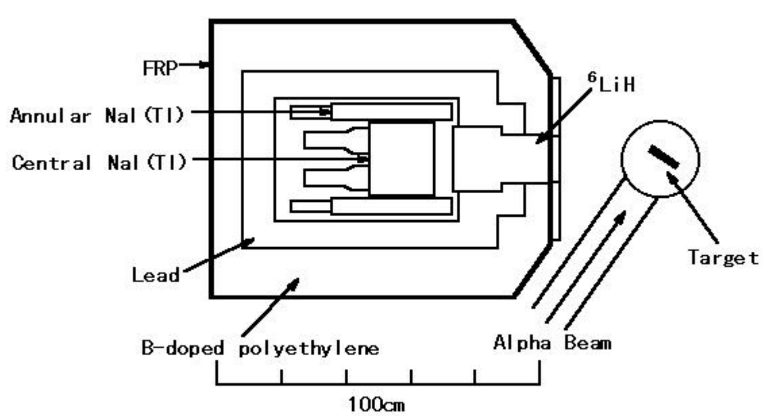

Fig. 1. Experimental setup. One of the two NaI(Tl) spectrometers is shown. They are placed at 125° with respect to the α beam direction.

γ-ray from the (n,γ) and (n,n'γ) reaction, and 10cm-thick B-doped polyethylene for neutrons from the ^{13}C(α,n)^{16}O reaction. At the entrance of the detector, ^{6}LiH was used in order to absorb the neutrons without reducing the γ-rays from the ^{12}C(α,γ)^{16}O reaction.

Taking account of the α beam bombarding energy (E_α = 2.275MeV), the energy loss in the target, and Q-value of ^{12}C(α,γ)^{16}O reaction (7.162MeV), the average γ-ray energy of the true event is about 8.7 MeV. Fig. 2 shows the time spectrum of the γ-ray in the energy region of above 8.0 MeV. In Fig. 2 the small peak at about 280ns is due to the (α,γ) or (n,γ) reaction events at the carbon target position, and a broad peak at about 320ns is due to the γ-rays caused by thermal neutrons entering into the NaI(Tl) detector. The plateau region (below 240ns) is due to time-independent backgroud caused by thermal neutrons and cosmic rays. Therefore, a net γ-ray spectrum can be obtained by substracting the time-independent background (below 240ns region) from the foreground (around 280ns region). The result is shown in Fig. 3. There is a peak at around 8.7 MeV, which is considered to be due to the γ-ray from the ^{12}C(α,γ)^{16}O reaction. And additional peaks (E_γ = 8.0 MeV, 8.4 MeV and 10.1 MeV) were observed. These peaks are due to the (n,γ) reactions near the carbon target position. The response functions of the NaI(Tl) detector for above γ-rays are obtained with a Monte Carlo calculation. In Fig. 3, the result of the fitting with the response functions is shown.

From the result of this experiment, it is proved that our new experiment has enough sensitivity to measure the cross section in the energy region down to $E_{cm}\sim$ 1.2 MeV. In the future experiments, we will use an enriched ^{12}C target to reduce the yield of neutrons from the ^{13}C(α,n)^{16}O reaction. Since the amount of ^{13}C nuclei will be reduced by a factor of 20, the background caused by the ^{13}C(α,n)^{16}O reaction is expected to become negligible for the measurement of the ^{12}C(α,γ)^{16}O cross section in the energy region down to $E_{cm}\sim$ 1.2 MeV.

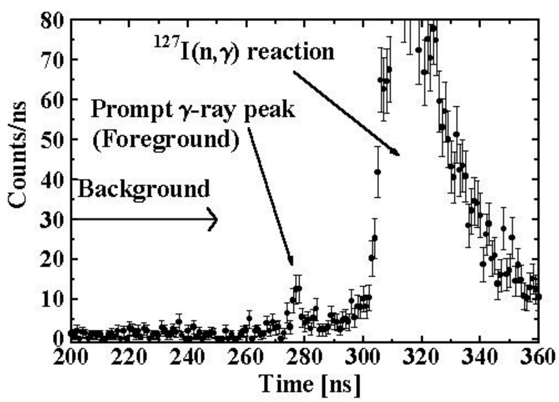

Fig. 2. The time spectrum for the events with $E_\gamma \geq$ 8.0 MeV events.

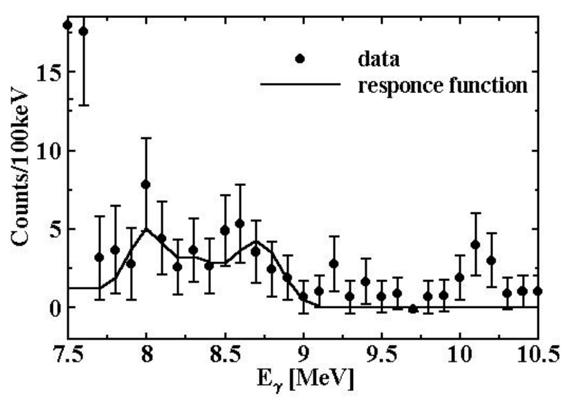

Fig. 3. Pulse height spectrum of the γ-ray. Time-independent background was subtracted.

References

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