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Indirect study of the $^{16}O+^{16}O$ fusion reaction toward stellar energies by the Trojan Horse Method

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Abstract

The ^{16}O+^{16}O fusion reaction is important in terms of the explosive oxygen burning process during late evolution stage of massive stars as well as understanding of the mechanism of low-energy heavy-ion fusion reactions. We aim to determine the excitation function for the most major exit channels, α+^{28}Si and p+^{31}P, toward stellar energies indirectly by the Trojan Horse Method via the $^{16}\mathrm{O}(^{20}\mathrm{Ne},\alpha^{28}\mathrm{Si})\alpha$ and $^{16}\mathrm{O}(^{20}\mathrm{Ne},p^{31}\mathrm{P})\alpha$ three-body reactions. We report preliminary results involving reaction identification, and determination of the momentum distribution of α-^{16}O intercluster motion in the projectile ^{20}Ne nucleus.

The ^{16}O+^{16}O fusion reaction is important in terms of the explosive oxygen burning process during late evolution stage of massive stars as well as understanding of the mechanism of heavy-ion fusion reactions at low energies. The astrophysical S-factor of such a heavy-ion fusion strongly depends on energy at corresponding stellar temperatures far below the Coulomb barrier. There are large discrepancies among different experiments [1–4], and among theoretical predictions [5,6], and is a lack of data below $E_{\mathrm{cm}} = 7$ MeV. We aim to determined the excitation function of the most major products, α+^{28}Si and p+^{31}P, of the ^{16}O+^{16}O reaction at stellar energies by the Trojan Horse Method (THM) [7].

We have performed THM measurements via the $^{16}\mathrm{O}(^{20}\mathrm{Ne},\alpha^{28}\mathrm{Si})\alpha$ and $^{16}\mathrm{O}(^{20}\mathrm{Ne},p^{31}\mathrm{P})\alpha$ three-body reactions at $E_{^{20}\mathrm{Ne}} = 45$ MeV at the Heavy Ion Laboratory, Warsaw, Poland, covering center-of-mass energy ranges of 8–15 MeV. In these three-body reactions, the α particles in the exit channels may act as the "spectator" through the quasi-free mechanism, where the momentum transfer of α decaying from the possible α cluster state in the projectile ^{20}Ne is sufficiently small. The momentum of the spectator is defined by masses and momenta of α and ^{20}Ne; $\boldsymbol{p}_s \equiv \boldsymbol{p}_\alpha - m_\alpha/m_{^{20}\mathrm{Ne}} \times \boldsymbol{p}_{^{20}\mathrm{Ne}}$. To guarantee quasi-free mechanism, the two-cluster α-^{16}O system in the nucleus ^{20}Ne should preferably be in s state, so that the momentum distribution of the spectator α is single-peaked at $p_s = 0$. Here we report preliminary p_s distribution investigated for the first time, which is crucial to determine the two-body reaction cross section by THM.

The experimental setup is illustrated in Fig. 1.

The $^{20}\mathrm{Ne}^{3+}$ beam was provided at 45 MeV from the $K = 160$ cyclotron with a typical intensity around 20 enA on target, and the production run was performed for about 180 hours in total. For the beam collimator, a ϕ6-, a ϕ3- and a ϕ2-mm hole are laid straight on the beam axis within a distance of 380 mm from the upstream, respectively. We used WO_3 evaporated onto Au backing as solid oxygen target with a typical thickness of 116 mg/cm^2 for

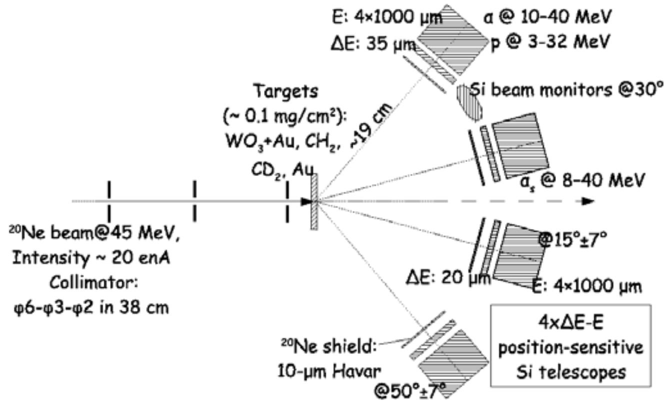

Figure 1: Schematic view of the experimental setup.

WO_3 and 193 mg/cm^2 for Au. Three silicon beam monitoring detectors were installed at 30°. For the reaction product measurement, four ΔE-E silicon telescopes were mounted symmetrically with respect to the beam axis at 15° and 50°. The thickness of each ΔE layer at 15° was 20 μm in order

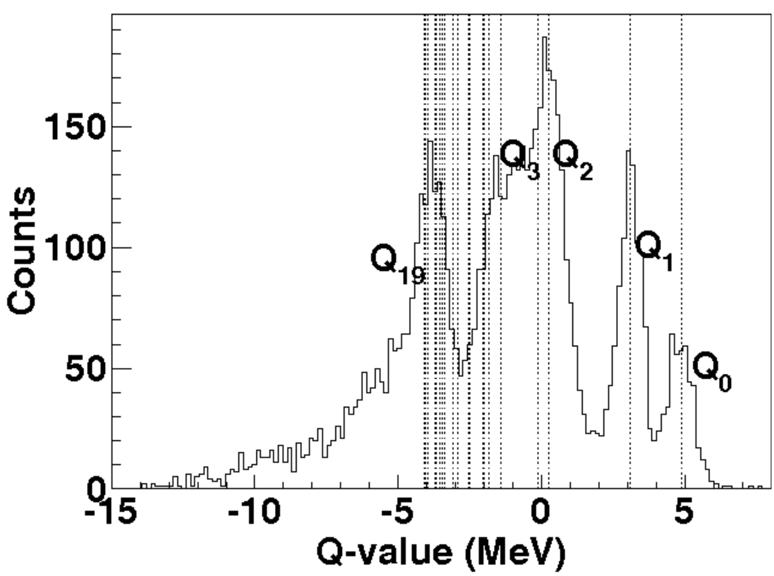

Figure 2: Q-value spectrum of the $^{16}O(^{20}Ne, \alpha^{28}Si)\alpha$ channel. The dotted lines corresponds to the excited states of ^{28}Si.

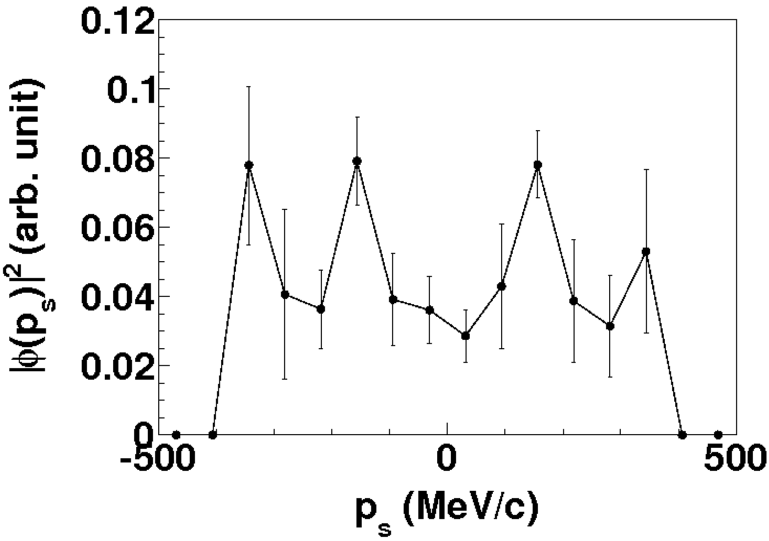

Figure 3: Preliminary momentum distribution of α in ^{20}Ne.

to measure low-energy spectator α, while that at 50° was 35 mm focusing on higher energy up to 40 MeV of α of the coincidence pair. Each E layer consisted of a stack of four 1-mm-thick silicon detectors for high-energy proton up to 32 MeV. The first E layer was position-sensitive by charge division, and the distances from the target were typically 190 mm. We put a 10-mm Havar foil right in front of each ΔE layer in order to prevent the detectors from plenty of beam scattering on W and Au in the target. During the production run with the WO_3 target, we mostly observed protons and α particles in the ΔE-E telescopes.

By selecting only α-particle data, we confirmed that the peaks found in the Q-value spectrum which is defined by $Q = E_{28\mathrm{Si}} - E_{20\mathrm{Ne}} + E_{\alpha 1} + E_{\alpha 2}$ correspond well to the excited energy of ^{28}Si nucleus as shown in Fig. 2, which evinces the $^{16}\mathrm{O}(^{20}\mathrm{Ne}, \alpha^{28}\mathrm{Si})\alpha$ reaction.

The preliminary momentum distribution is show in Fig. 3, assuming energy and angular distribution of the differential cross section of the two-body reaction $^{16}\mathrm{O}(^{16}\mathrm{O}, \alpha)^{4}\mathrm{He}$. The fact that the momentum distribution does not have the maximum value around $p_s = 0$ suggests that the three-body reactions $^{16}\mathrm{O}(^{20}\mathrm{Ne}, \alpha^{28}\mathrm{Si})\alpha$ and $^{16}\mathrm{O}(^{20}\mathrm{Ne}, p^{31}\mathrm{P})\alpha$ might not proceed through the 0^+ ground state of ^{20}Ne dominantly but the 2^+ first excited state. Further data analysis to determine the two-body cross section of interest is ongoing, also for the $^{16}\mathrm{O}(^{20}\mathrm{Ne}, p^{31}\mathrm{P})\alpha$ channel.

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