Direct measurement of the $^4\text{He} (^{12}\text{C}, ^{16}\text{O}) \gamma$ reaction cross section near stellar energies

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The $^{12}\text{C} + ^4\text{He} \rightarrow ^{16}\text{O} + \gamma$ reaction is one of the key reactions in stellar He-burning, but its total cross section at stellar energy ($E_{cm} = 0.3$ MeV) has not been measured yet, in spite of many experiments made in the world for about a half century. At Kyushu University Tandem accelerator Laboratory (KUTL), we have been making direct measurement of the $^4\text{He} (^{12}\text{C}, ^{16}\text{O}) \gamma$ total cross section below $E_{cm} = 2.4$ MeV for about 20 years. We have measured the total cross section at $E_{cm} = 2.4$, 1.5 and 1.2 MeV. Now we are preparing to measure the cross section at 1.0 MeV. The direct measurement was made from $E_{cm} = 5$ MeV down to 1.9 MeV at Ruhr University, Bochum. We use a pulsed $^{12}\text{C}$ beam and a windowless $^4\text{He}$ target, and detect all the $^{16}\text{O}$ recoils in a charge state. A usually continuum $^{12}\text{C}$ beam from our tandem accelerator is pulsed by a pre-buncher, a main buncher, and a beam chopper. Our tandem accelerator was designed to be used at the acceleration voltage of 6-10 MV. For the $^4\text{He} (^{12}\text{C}, ^{16}\text{O}) \gamma$ experiment we need to use it at 1.3-1.8 MV where beam transmission is very low, then we have invented an acceleration-deceleration method for the tandem accelerator. We have developed a blow-in windowless He target based on an original idea. To separate $^{16}\text{O}$ recoils from the $^{12}\text{C}$ beam, we developed a recoil-mass separator. To reject $^{12}\text{C}$ backgrounds, we developed a long-time chopper, and an ionization chamber. Now, we are preparing to measure time-of-flight of $^{16}\text{O}$ recoils and $^{12}\text{C}$ backgrounds. Many original instruments and the experimental results will be presented. Finally we discuss what are necessary for future direct measurement of the $^4\text{He} (^{12}\text{C}, ^{16}\text{O}) \gamma$ total cross section below 1.0 MeV, down to 0.7 MeV. A dynamitron accelerator and hard-working researchers may be inevitable.

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