First direct measurement of the $^{11}C(\alpha, p)^{14}N$ stellar reaction by an extended thick-target method†

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The $^{11}C(\alpha, p)^{14}N$ reaction is one of the important α-induced reactions competing with β-limited hydrogen-burning processes in high-temperature explosive stars.[1,2] We directly measured its reaction cross sections for the (α, p_0), (α, p_1) and (α, p_2) transitions to derive the total reaction rate at relevant stellar temperatures by an extended thick-target method featuring the time of flight of the recoil proton corresponding to each transition. This report is a condensed version of our article.[3]

The measurement was performed in inverse kinematics with ^{11}C beams at 10.12 MeV and 16.86 MeV produced at CRIB (Center for Nuclear Study Radioactive Ion Beam separator[8]). The experimental setup consisted of two beam-tracking monitors (PPAC: parallel-plate avalanche counter and MCP: microchannel plate detector), a ^4He gas target, and ΔE-E position-sensitive silicon detectors at three different angles. We carefully designed the target length (140 mm) and pressure (400 Torr). Such an extended gas target enables us to differentiate the transitions to the ground state and the excited states of ^{14}N in time of flight (TOF) between the first PPAC and the silicon telescopes. The observed TOF vs. recoil proton energy had several loci with a typical TOF difference of 5 ns so that the different excited-state transitions were identified and extracted. The present (α, p_1) and (α, p_2) cross sections are about one order of magnitude smaller than the (α, p_0) one, and those of the Hauser-Feshbach calculation[4] appear to be larger than the present experimental data.

Figure 1 shows the absolute $^{11}C(\alpha, p)^{14}N$ reaction rates of the present data and the currently available data[4–6] (upper) and their ratios to the CF88[5] data (lower). The hatched regions in the lower panel indicate the errors of the present rates. In the νp-process temperature range ($T_9 = 1.5$–3)[2], the present (α, p_0) reaction rate is enhanced from the CF88 rate by about 40% at most, mainly due to the resonances around 0.9 MeV and 1.35 MeV, which were not taken into account in the previous compilation works.[5,6] The contribution from the (α, p_1) and (α, p_2) reaction rate to the total reaction rate is about 20% of the (α, p_0) at most. The new total reaction rate lies between the previous (α, p_0) rate[5] and the total Hauser-Feshbach rate,[4] which supports the validity of relevant explosive hydrogen-burning process scenarios such as the νp-process that proceeds via the $^{11}C(\alpha, p)^{14}N$ reaction in addition to the triple-α process.

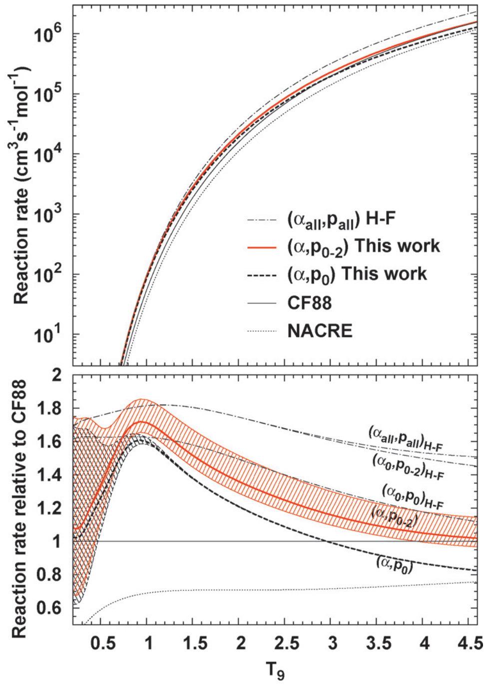

Fig. 1. Absolute $^{11}C(\alpha, p)^{14}N$ reaction rates of the present data and the currently available data[4–6] (upper) and their ratios to the CF88[5] data (lower). The uncertainties of the present (α, p_0) rate and total rate are drawn as hatches attached in the bottom panel.

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