Asymptotic normalization coefficients from the $^{14}N(^{3}\text{He},d)^{15}O^*$ reaction and astrophysical factor for $^{14}N+p\rightarrow^{15}O^*+\gamma$


The $^{14}N(p,\gamma)^{15}O$ reaction is one of the most important reactions in the CNO cycle. As the slowest reaction in the cycle, it defines the rate of energy production and, hence, the lifetime of stars that are governed by hydrogen burning via CNO processing. There are controversial reports in the literature about S-factor for the $^{14}N+p\rightarrow^{15}O+\gamma$ capture at stellar energies (see [1] and the references therein). The latest measurements of the capture cross section at energies $E > 0.187$ MeV showed that at low energies the capture is dominated by a combination of direct and resonant capture and interference from the tails of the subthreshold and first resonances [1]. Taking into account that the absolute normalization for the direct capture $S$ factor to the subthreshold state can be determined by its asymptotic normalization coefficient (ANC), we measured this ANC and, simultaneously, the ANCs for the ground and five other excited states in $^{15}O$ to determine more accurately the $S$ factors for transitions to the subthreshold and other states. In order to determine the ANCs for $^{14}N+p\rightarrow^{15}O$, the $^{14}N(^{3}\text{He},d)^{15}O$ proton transfer reaction has been measured at an incident energy of 26.3 MeV. Angular distributions for proton transfer to the ground and five excited states were obtained. ANCs were then extracted from comparison with both DWBA and CCBA calculations. Our measured ANCs are in a very good agreement with those reported in [2]. Using the measured ANCs, we fit the astrophysical $S$ factors for transitions to the ground and excited states and the total $S$ factor using the $R$-matrix method. In our analysis, we accurately account for interference effects by splitting the resonance amplitudes into the internal and channel terms. We find that for captures to all the states except for the ground state, the $S(0)$ factors are almost entirely determined by the corresponding ANCs. Here we report the final results of our analysis. The astrophysical factor for the capture to the ground state, $1/2^-$, 0.00 MeV, is $S(0) = 0.15 \pm 0.07$ keVb, which is significantly lower than the value $S(0) = 1.55 \pm 0.34$ keVb found in [1]. The calculated $S(0)$ astrophysical factor for the capture to the third excited state, $3/2^-$, 6.18 MeV, is $S(0) = 0.13 \pm 0.02$ keVb. The capture to the fourth excited state, $3/2^-$, 6.79 MeV, dominates all others and the calculated astrophysical factor is $S(0) = 1.4 \pm 0.20$ keVb. According to [1] the captures to other states contribute about 3% to the total $S(0)$ factor and have been neglected here. The total calculated astrophysical factor at zero energy is $S(0) = 1.70 \pm 0.22$ keVb. Correspondingly our calculated production rate of $^{15}O$ is significantly lower than was previously calculated [1].

References