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The ^{8}Li$(d, p)^{9}$Li reaction and astrophysical ^{8}B$(p, \gamma)^{9}$C reaction rate

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Abstract

Angular distribution of the ^{8}Li$(d, p)^{9}$Li$_{\text{g.s.}}$ reaction at $E_{\text{cm}} = 7.8$ MeV was measured in inverse kinematics. The square of asymptotic normalization coefficient (ANC) for the virtual decay $^{9}\text{Li} \to {}^{8}\text{Li} + n$ was derived to be $1.33 \pm 0.33\ \text{fm}^{-1}$ through distorted wave Born approximation (DWBA) analysis, for the first time. According to charge symmetry, (ANC)^2 for $^{9}\text{C} \to {}^{8}\text{B} + p$ was then extracted to be $1.14 \pm 0.29\ \text{fm}^{-1}$. We have deduced the astrophysical S-factors and reaction rates for direct capture in ^{8}B$(p, \gamma)^{9}$C at energies of astrophysical relevance using the ANC for $^{9}\text{C} \to {}^{8}\text{B} + p$ extracted from the mirror system.

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1. Introduction

Nucleosynthesis of light nuclei is impeded by the gap at mass number $A = 8$, where no stable nuclei exist. In some astrophysical environments, however, this gap

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can be bypassed via the reactions involving unstable nuclei ^{8}B and ^{8}Li, such as ^{8}B$(p,\gamma)^9$C, ^{8}Li$(\alpha,n)^{11}$B, ^{8}Li$(n,\gamma)^9$Li and ^{8}Li$(d,p)^9$Li, to synthesize $A > 8$ nuclides. The ^{7}Be$(p,\gamma)^8$B$(p,\gamma)^9$C$(\alpha,p)^{12}$N$(p,\gamma)^{13}$O reaction chain is considered as one of the possible alternative paths to the 3α process for transforming the nuclei in the pp chains to the CNO nuclei in the peculiar astrophysical sites where the densities ($\geqslant 2 \times 10^7$ g/cm^3) and temperatures ($T_9 \sim 0.1$–0.4) are so high that the proton- and α-capture reactions become faster than the competing β-decays [1]. The ^{8}B$(p,\gamma)^9$C reaction may play an important role in the evolution of massive stars with very low metallicities [1,2], and thus has increasingly attracted both theoretical and experimental studies [1,3–8]. There are several microscopic and systematic calculations, and their results are in large discrepancy [1,3,4]. As for the experiments, it is very difficult to directly measure this reaction at energies of astrophysical relevance because of very small cross section and low intensity of the available ^{8}B beam at present. Some indirect approaches have been applied to the study of this reaction [5–8]. Beaumel et al. [5] measured the ^{8}B$(d,n)^9$C angular distribution in inverse kinematics with a 14.4 A MeV ^{8}B beam, and then derived the ANC for the virtual decay $^9\text{C} \to {}^8\text{B} + p$ and the astrophysical $S_{18}(0)$ factor for the ^{8}B$(p,\gamma)^9$C reaction. Trache et al. [6] analyzed the cross section data for one-proton-removal reaction of ^{9}C on four different targets (C, Al, Sn and Pb) [9], and employed the Glauber model [10] to deduce the ANC and $S_{18}(0)$ factor. Recently, Motobayashi [7] extracted the S_{18} factors in energy range 0.2–0.6 MeV by Coulomb dissociation approach ($S_{18}(0)$ factor can be then obtained through an extrapolation by the slope of theoretical S-factor curve). Most recently, Enders et al. [8] studied the proton-removal from ^{9}C on a carbon target at $E = 78.3$ A MeV and derived the ANC and astrophysical $S_{18}(0)$ factor. The $S_{18}(0)$ obtained from Ref. [7] is significantly larger than other three ones.

The ^{8}Li$(d,p)^9$Li reaction not only leads to the production of ^{9}Be (via the ^{9}Li β-decay) which acts as a precursor to heavier nuclides, but also can serve as a surrogate reaction to extract the ^{8}B$(p,\gamma)^9$C and ^{8}Li$(n,\gamma)^9$Li reaction rates for the direct capture. To date, only a few experiments for the ^{8}Li$(d,p)^9$Li reaction have been carried out by using the secondary ^{8}Li beam. An earlier measurement, performed at $E_{\text{cm}} = 1.5$–2.8 MeV [11], presented an upper limit of the cross section, though no ^{9}Li event was detected. Very recently, the angular distributions for different states in ^{9}Li were measured at $E(^8\text{Li}) = 76$ MeV to obtain information on the spins, parities and single-neutron spectroscopic factors [12]. In the present work, we measured the ^{8}Li$(d,p)^9$Li$_{\text{g.s.}}$ angular distribution at $E(^8\text{Li}) = 39$ MeV through the coincidence detection of ^{9}Li and recoil proton, and derived the ANC for the virtual decay $^9\text{Li} \to {}^8\text{Li} + n$ based on DWBA analysis, and then deduced the ANC for $^9\text{C} \to {}^8\text{B} + p$ based on charge symmetry. We have also calculated the direct capture S-factors and reaction rates for ^{8}B$(p,\gamma)^9$C at astrophysically relevant energies. Most recently, a short paper concerning the ^{8}Li$(d,p)^9$Li$_{\text{g.s.}}$ angular distribution and indirect determination of the astrophysical ^{8}Li$(n,\gamma)^9$Li$_{\text{g.s.}}$ reaction rates has been published elsewhere [13].

2. Experimental procedure and results

The measurement of ^{8}Li$(d,p)^9$Li angular distribution was performed using the secondary beam facility GIRAFFE [14,15] built at the HI-13 tandem accelerator of China