Astrophysical Factor for the Neutron Generator ^{13}C(α,n)^{16}O Reaction in the AGB Stars

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About half of all elements heavier than Iron are produced in Stellar environment through the s process. Reaction $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ is considered to be the main source of neutrons for the s processes at low temperatures in low mass stars at the asymptotic giant branch [1]. Accurate knowledge of the $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ reaction rates at relevant temperatures $(0.8-1.0)\times 10^{8}$ K would eliminate an essential uncertainty regarding the overall neutron balance and will allow for better tests of modern Stellar models with respect to $^{13}\mathrm{C}$ production in AGB stars (see [2] and references therein). The rate of the $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ reaction at temperatures $\sim 10^{8}$ K is uncertain by $\sim 500\%$ [3] due to prohibitively small reaction cross section at energies below 300 keV. Directly measured $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ cross section is only available at energies above 279 keV (see [3] and references therein). Below this energy the astrophysical S factor is dominated by the contribution from the $1/2^{+}$ sub-threshold resonance in $^{17}\mathrm{O}$ at 6.356 MeV excitation energy, which is just 3 keV below α threshold. It was assumed in recent NACRE compilation [3] that this resonance has a well developed α cluster structure. This assumption leads to a strong enhancement of the cross section at low energies [3]. Recently an attempt has been made by Kubono et al. [4] to determine the contribution of the subthreshold 6.356 MeV in $^{17}\mathrm{O}$ to the astrophysical factor for $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ at low energies by measuring the α-particle spectroscopic factor of this state. However, analysis of the data brings large uncertainty to the extracted spectroscopic factor [4,5]. It is the main goal of this work to resolve this controversy and to develop a technique which allows determining the contribution of sub-threshold resonances to the $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ reaction cross sections using a model-independent approach. Until now the ANC method has been applied to determine the astrophysical factors for radiative capture processes [6]. Here we present the first case of application of the ANC method to determine the astrophysical factor for the $^{13}\mathrm{C}(\alpha,\mathrm{n})^{16}\mathrm{O}$ reaction at astrophysically relevant energies by measuring the ANC for the virtual synthesis $\alpha + {}^{13}\mathrm{C} \to {}^{17}\mathrm{O}(6.356\ \mathrm{MeV},1/2^{+})$ using the sub-Coulomb α-transfer reaction $^{13}\mathrm{C}({}^{6}\mathrm{Li},\mathrm{d})^{17}\mathrm{O}(6.356\ \mathrm{MeV},1/2^{+})$. The ANC of the 6.356 MeV state in $^{17}\mathrm{O}$ was measured in the α-transfer reaction $^{13}\mathrm{C}({}^{6}\mathrm{Li},\mathrm{d})^{17}\mathrm{O}$ performed at two sub-Coulomb energies 8.0 and 8.5 MeV of $^{13}\mathrm{C}$ at Florida State University Tandem-LINAC facility. Choice of inverse kinematics, $^{13}\mathrm{C}$ beam and $^{6}\mathrm{Li}$ target, allowed to make measurements at very low energies in c.m. system and to avoid background associated with admixture of $^{12}\mathrm{C}$ isotope in $^{13}\mathrm{C}$. Normalizing the DWBA cross section of the peripheral reaction to the experimental one and knowing the ANC for $\alpha + d \to {}^{6}Li$ we can determine the ANC for $\alpha + {}^{13}\mathrm{C} \to {}^{17}\mathrm{O}(6.356\ \mathrm{MeV},1/2^{+})$. The extracted ANC, unlike the spectroscopic factor, does not depend on the number of the nodes of the α-particle bound state wave function and geometrical parameters of the Woods-Saxon potential. The total uncertainty in determination of the square of the ANC is determined by 7% statistical uncertainty, 7% systematic uncertainty, and 20% of the uncertainty due to the ambiguity of the optical potential parameters. Using the determined ANC we calculated the astrophysical factor $S(0) = [2.5 \pm 0.2(\mathrm{stat}) \pm 0.2(\mathrm{syst}) \pm 0.5(\mathrm{theor})] \times 10^6$ MeVb. The calculated astrophysical factor is dominated by the contribution of the subthreshold state $^{17}\mathrm{O}(6.356\ \mathrm{MeV}, 1/2^+)$. Besides we took into account the contribution of the low energy tail of the higher lying resonances and the background. This value is ten times smaller than adopted in NACRE compilation [3] and a factor of 5 higher than in [4].

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