Determination of ANC for ^{13}C(p,γ)^{14}N$_{g.s.}$ capture from ^{13}C(^{3}He,d)^{14}N$_{g.s.}$ transfer reaction

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Introduction

The one nucleon radiative capture process at stellar energies proceeds through the tail of the nuclear overlap function of the bound state wavefunctions of the initial and final nuclei. The amplitude of the tail of the overlap function is determined by the factor, known as the asymptotic normalization coefficient (ANC). The same nuclear overlap function also occur in the one particle transfer matrix element determining the transfer reaction cross section. Thus the astrophysical S-factor for peripheral radiative capture reaction can be determined from the estimantion of the corresponding ANC-s from the peripheral nucleon transfer reaction [1].

We present here a systematic analyses of one proton transfer reaction ^{13}C(^{3}He,d)^{14}N at three different bombarding energies to extract the ANC value of the radiative capture reaction ^{13}C(p,γ) to the ground state of ^{14}N. The capture reaction ^{13}C(p,γ)^{14}N is astrophysically important on two counts. Firstly, it occurs in the CNO cycle before the the capture reaction ^{14}N(p,γ)^{15}O which is the slowest reaction controlling the rate of energy generation in the cycle [2]. Secondly, in the AGB stars, the capture reaction competes with ^{13}C(α,n)^{16}O, the seed reaction of neutrons for the s-process [3].

Earlier effort in this direction through the measurement of ^{13}C(^{3}He,d)^{14}N raection at 26.3 MeV and ^{13}C(^{14}N,^{13}C)^{14}N reaction at 162 MeV yielded a value of 18.2 fm$-$1 for the transfer to the ground state of ^{14}N [4]. This ANC value was subsequently used in a R-matrix analysis of the ^{13}C(p,γ)^{14}N radiative capture reaction data resulting into a total S-factor value of 7.6 ± 1.1 keV.b and a S(0) = 5.16 ± 0.72 keV.b for ground state capture. These values corroborate with the measured total and ground state capture S-factor values [5] with in the errorbars. A recent compilation on radiative capture of nucleons at astrophysical energies [6] presented a value of 9.30 fm^{-1} for the corresponding ANC obtained from the reanalysis of the same capture data within the framework of potential model. The difference in the ANC values extracted is quite significant. Interestingly, a recent precise measurement of ^{13}C(p,γ) capture reaction reported a value of S(0) = 3.94 keV.b for the transition to the ground state of ^{14}N [7].

Analysis

The existing data of ^{13}C(^{3}He,d)^{14}N ground state transfer measured at incident energies 22.3, 26.3 and 32.6 MeV [8] have been reanalyzed in the DWBA approach using the code FRESCO (Version FRES 2.4) [9**?**]. The transfer cross section can be parametrized in terms of the product of $(C^{He}_{dp})^2(C^{N}_{Cp})^2$ and the reduced DWBA cross section defined as $R^{DWBA} = \sigma^{DWBA}/(b^2_{proj}b^2_{res})$ where C-s are the corresponding ANC-s while b-s are asymptotic normalization constants for single particle bound state wavefunctions. For peripheral transfer reaction, the reduced cross section R is practically independent of the single particle ANC-s. This makes the extraction of the ANC-s independent of the choice of the single particle bound state potential parameters. In the analysis we have used for $^{3}He \rightarrow d + p$ a well known ANC value of 3.90±0.06 fm^{-1}. In the entrance and exit channels we have used the ^{3}He- and d- global optical potentials

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from Ref. [10, 11]. The R and a for bound state potentials have been kept fixed while the strength is varied to obtain the binding energy. The DWBA calculation have been performed in the *post* form with full remnant term of the potential. In general the proton transfer to ^{14}N$_{g.s.}$ can occur through the population of $p_{1/2}$ and $p_{3/2}$ orbitals. Thus we obtained the C^2 value which is the sum of both the contributions.

To maitain the peripherality condition, we have estimated the ANC values by fitting the angular distributions upto an angle that corresponds to a separation larger than the nuclear radius of 4.35 fm. This has been ensured by considering the classical relation $R\ l_{tr}/q_{tr} > 4.35 fm$. Thus to obtain the ANC for $^{14}N \rightarrow ^{13}C + p$ angular distribution upto 13.7^o have been considered for 22.3 MeV, upto 13.5^o for 26.3 MeV and upto 11.8^o for 32.6 MeV.

Results and Conclusion

The fits to the angular distribution data for ^{13}C(^{3}He,d)^{14}N$_{g.s.}$ at three different incident energies are shown in Fig. 1. Reasonably good fits are obtained for all the three energies with deviations occurring at higher angles for 26.3 and 32.6 MeV. However, the ANC-s are estimated from the fit to the data points within the first maximum of the angular distribution. The C^2 value for $^{14}N \rightarrow ^{13}C + p$ determined form the fit to the 22.3 MeV data is 17.84 fm^{-1}. This value corresponds to the value of 18.2 fm^{-1} of Ref.[12]. The analysis suggests that the ANC-s extracted from one proton transfer reaction data is still higher comapred to the value estimated from the capture measurement. To address the problem, more precise measurement at still lower incident energy is necessary.

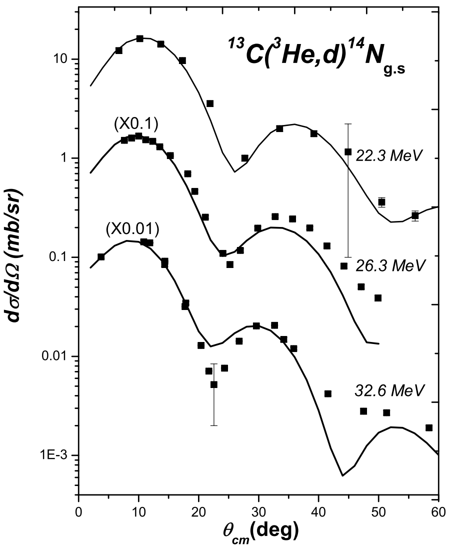

FIG. 1: DWBA calculations (solid line) showing the fits the one proton transfer reaction ^{13}C(^{3}He,d)^{14}N$_{g.s.}$. The data have been taken from EXFOR database [8].

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