Simultaneous R-matrix analysis of $^{13}C(\alpha, n)$ and $^{13}C(\alpha, \alpha)$ reactions at astrophysical energies

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Introduction

The reaction $^{13}C(\alpha, n)^{16}O$ occurs primarily in low mass Asymptotic Giant Branch (AGB) stars in Helum burning stage at temperatures less than 10^8K. It produces neutrons for the *s*-process nucleosynthesis of heavy elements in the subsequent evolution of the stars. The Gamow window or the effective astrophysical energy for the reaction at temperatures around 0.9 x 10^8 K is $\sim$ 140-230 keV. It is important, therefore, to know the rate of the reaction with minimum uncertainty in the Gamow window at relevant temperatures to correctly model the AGB stars.

Direct measurement exists down to centre of mass energies above $\sim$ 279 keV. Hence, to obtain the reaction rates in the Gamow window at required temperatures for *s*-process in AGB stars, extrapolation of excitation function of cross section or astrophysical S-factor to lower energies is necessary.

The extrapolation of σ(E) or S(E) to lower energies has a strong influence from a $1/2^+$ sub-threshold resonance state in ^{17}O at -3.0 keV with the $^{13}C+\alpha$ threshold at 6.359 MeV. The presence of the sub-threshold state significantly enhances the formation cross section of ^{17}O through the $^{13}C + \alpha$ channel at low energies, especially below 100 keV centre of mass energies. Alpha spectroscopic factor or Asymptotic Normalization Constant (α-ANC) for this state is the most important parameter that determines the $^{13}C(\alpha, n)^{16}O$ reaction rate at Gamow energy window relevant to AGB stars. Two recent measurements of the α-ANC for the $1/2^+$ sub-threshold state in ^{17}O at 6.356 MeV, using the Trojan Horse method and sub-Coulomb -transfer reaction, reported the Coulomb modified squared ANC value for the state as $7.7 \pm 0.3(stat) fm^{-1}$ [1] and $3.6 \pm 0.7 fm^{-1}$ [2], respectively. We will present a phenomenological R-matrix model fit to the existing $^{13}C(\alpha, n)^{16}O$ and $^{13}C(\alpha, \alpha)^{13}C$ data to fix the parameters of the model and subsequently extrapolate to the relevant astrophysical energies to obtain the $^{13}C(\alpha, n)^{16}O$ cross section. Eventually, the effect of ANC value of the -3 keV sub-α-threshold state on extrapolation and astrophysical reaction rate will be investigated.

Model

The phenomenological R-matrix model calculation has been performed with multi-channel, multi-level code AZURE2[3]. In the simultaneous analysis, we fitted the $^{13}C(\alpha, n)^{16}O$ reaction data from Harissopulos, *et al.* [5], Heil, *et al.* [6] and Drotleff, *et al.* [7]. The elastic scattering data for fitting were taken from Heil, *et al.* [6] and Mynbayev, *et al.* [8].

Calculation and Results

The R-matrix calculation has been performed with channel radii values of 5.2 fm for $^{13}C + \alpha$ channel and 4.7 fm for $^{16}O + n$ channel. In Fig.1, the solid line represents the model calculation with the Coulomb modified squared α-ANC = 3.6 fm^{-1} [2] and with neutron partial width, $\Gamma_n = 124 \pm 12$ keV [4]. Corresponding fits to the elastic scattering data of Mynbayev, *et al.* [8] at 0^o and Heil, *et al.* [6] at 74^o are shown in Fig. 2 and Fig. 3, respectively.

The analysis yielded a reaction rate of 3.75 x 10^{-14} cm^3/mole/s at T $\sim$ 0.1 x 10^9 K. The value is within the error bar of the rate

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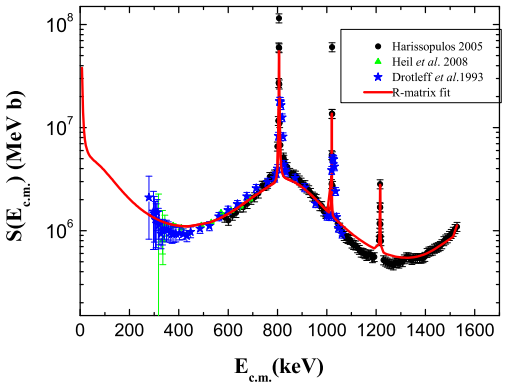

FIG. 1: R-matrix fit to the S(E) data [5, 6] for the reaction $^{13}C(\alpha,n)^{16}O$ using AZURE2 (solid line)

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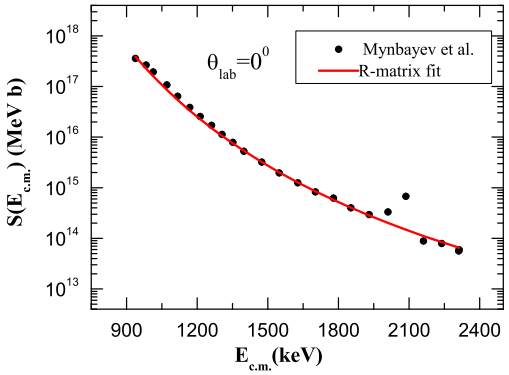

FIG. 2: R-matrix fit to the Elastic scattering data at 0^o from Ref. [8].

of 4.6±1.0 x 10^{-14} cm^3/mole/s reported by Heil, *et al.* [6] but much less than the tabulated value of 7.24 $^{+1.25}_{-4.98}$ x 10^{-14} cm^3/mole/s in NACRE I [9]. Further analysis including the available $^{16}O+n$ elastic scattering data to constrain energy locations of the neutron resonances below the 6.356 MeV α-thresholdis in progress. The uncertainty in the reaction rate due to the variation in the available α-ANC values of the 6.356 MeV sub-α-threshold state and the discrepancy in the value of Γ_n of state

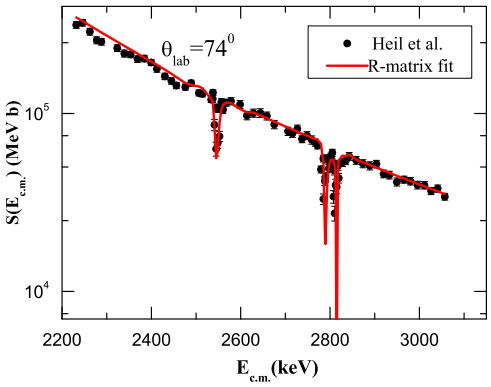

FIG. 3: R-matrix fit to the Elastic scattering data at 74^o from [6].

will be presented.

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