R-matrix analysis and the astrophysical S-factor calculation for E2 capture data of ^{12}C(α,γ) reaction at 300 keV

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Introduction

The ^{12}C(α,γ) reaction is a important reaction in nuclear astrophysics [1,2,3]. At the end of the He burning phase the rate of the $3\alpha \rightarrow$ ^{12}C and ^{12}C(α,γ)^{16}O reactions determine the ^{12}C/^{16}O abundance ratio but the contribution of the ^{16}O(α,γ)^{20}Ne reaction is very less due to very small cross-section. The rate of the triple-α reaction is well determined but large uncertainty is present in case of ^{12}C(α,γ)^{16}O reactions. The cross-section of the ^{12}C(α,γ) reaction at 300 keV is very low ($\sim 10^{-17}$ b), so it is difficult or allmost impossible to measure this cross-section at 300 keV in our laboratory system. For which we need a R-matrix extrapolation to calculate low energy cross-section where measurements are not possible. As such extrapolation is done from measured data at higher energy that requires as input, the alpha spectroscopic proerties of the nucleus of interest. The alpha spectroscopic properties can be determined from transfer reactions. In this case, these are the alpha partial widths of the unbound and Asymptotic Normalization constant (ANC) of the bound states of ^{16}O. The ANC's are of first interest as the ^{12}C(α,γ) capture reaction primarly proceeds through two sub-threshold states viz. 6.92 and 7.12 of ^{16}O. we have done a study of alpha transfer reaction ^{12}C(^{20}Ne,^{16}O)^{16}O at 150 MeV incident energy and extracted ANC value of 6.92 MeV state of ^{16}O. In this work, we have done a R-matrix analysis for E2 capture data of ^{12}C(α,γ) reaction to calculate the astrophysical S-factor at 300 keV using ANC value of 6.92 MeV of ^{16}O which is determined through the ^{12}C(^{20}Ne,^{16}O)^{16}O reaction at 150 MeV incident energy.

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R-matrix analysis and Astrophysical S-factor Calculation

The R-matrix theory is a theoretical framework to calculate compound nuclear cross-sections in presence of resonances. In this R-matrix theory we can write,

$$R = \gamma^2/(E_r - E) \tag{1}$$

where γ^2 is the reduced width of the states of compound nucleus and E_r is the resonance energy. The reduced width for bound states are related to the normalization constant of the bound state wavefunction with respect to the Whittaker function at large radial seperation. The reduced width is related with the ANC through the relation

$$\gamma^2 = (h^2/8\pi^2\mu R)W^2C^2 \tag{2}$$

Where W is the Whittaker function at large radial seperation and C^2 is the ANC of the bound state wavefunction.

Figure 1. shows the S_{E2} curve with the ^{12}C(α,γ) E2 capture data [4] have been described by a four level R-matrix fit (6.92 MeV sub-threshold state, 9.85 MeV state, 11.52 MeV state and a higher background equivalent state) assuming a radius R_0= 6.5 fm for the inner space with the nuclear interaction using AZURE2 code [6] and also this fitting is carried out with all parameters are fixed but the parameters of background state are consider as a freely varying

parameters. The ANC value of the 6.92 MeV sub-threshold state of ^{16}O has fixed at the value 1.245*10^5 $fm^{-1/2}$ which is determined through the ^{12}C(^{20}Ne,^{16}O)^{16}O reaction at 150 MeV incident energy.

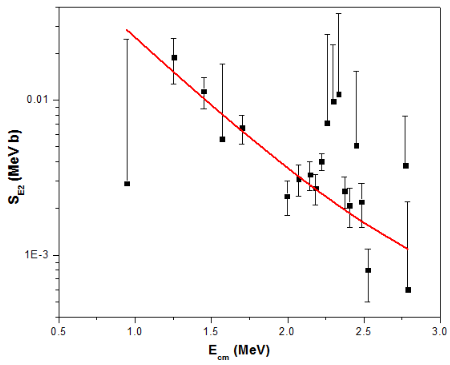

FIG. 1: Four level R-matrix fit (solid red line) of ^{12}C(α,γ) E2 capture data [4] (solid black square with error).

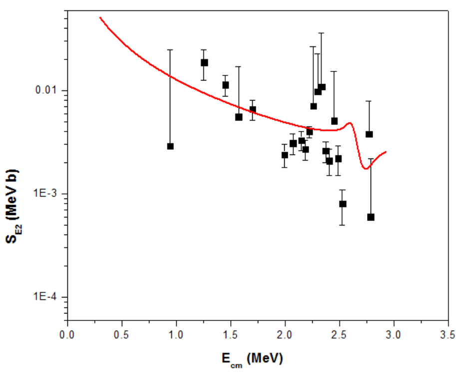

FIG. 2: Four level R-matrix fit (solid red line) of ^{12}C(α,γ) E2 capture data [4] (solid black square with error) which is extrapolated from 300 keV to 3.5 MeV.

Figure 2. shows the extrapolated S-factor curve into the range of burning temperature which is fitting with same parameters . In this fitting we extrapolate the astrophysical S-factor from 300 keV to 3.5 MeV. The extracted S_{E2} value from figure 2. at 300 keV is 51 $\pm$ 25 keV b.

Summary and Conclusions

R-matrix calculation of the E2 capture data of ^{12}C(α,γ) reaction has been done carefully. The fit was performed with fixed ANC values of 6.92 MeV of ^{16}O which is determined through the ^{12}C(^{20}Ne,^{16}O)^{16}O reaction at 150 MeV incident energy. All parameters of resonance states are fixed except the parameters of background state. The value of E2 S-factors at 300 keV has been extracted. More detailed calculations in order to improve the fit will be done in future.

References

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