R-matrix analysis of the $^{12}C(\alpha,\gamma)$ reaction with inputs from $^{12}C(^{7}Li,t)^{16}O^{*}$ transfer reaction

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Introduction

The $^{12}C(\alpha,\gamma)$ reaction at 300 keV determines the ratio of ^{16}O to ^{12}C abundance at the end of helium burning in stars [1]. The direct measurement of the cross-section of this reaction is almost impossible with the presently available techniques. Extrapolation of the cross-section or the astriophysical S-factor from higher energy data is presently adopted. There are several direct measurements of the $^{12}C(\alpha,\gamma)$ reaction but the lowest energy upto which measurement has been done is only upto 1 MeV [2].

R-matrix extrapolation of the E2 and E1 capture data is complicated by the lack of knowledge of the cluster structure of the 6.92 MeV (2^+) and 7.12 MeV (1^-) states of ^{16}O. In this paper we report a study of the E2 capture data that is analysed with the ANC of the 6.92 MeV state determined from $^{12}C(^{7}Li,t)$ alpha transfer measurements.

Alpha transfer measurements have been traditionally used to determine the ANC of subthreshold states that influence capture reaction cross-sections. The $^{12}C(^{6}Li,d)$ and $^{12}C(^{7}Li,t)$ reactions have been widely used for the determination of ANC of ^{16}O states that enter into the R-matrix analysis of the $^{12}C(\alpha,\gamma)$ reaction. The angular distributions for these reactions have been measured by a number of workers at above barrier energies [3,4,5] and only one measurement of total cross-section has been performed at sub-Coulomb energies [6]. The ANCs are determined by a comparison of the measured cross-sections with respect to a Distorted-Wave-Born Approximation (DWBA) analysis. This implicitly assumes a direct alpha transfer process in the reaction. As $^{6,7}Li$ are loosely bound interms of an alpha cluster structure it is likely that the projectile breaks up before the transfer occurs. Recently, this aspect of the $^{12}C(^{6}Li,d)$ and $^{12}C(^{7}Li,t)$ reactions were studied in the framework of the Continuum Discretized Coupled Reaction Channel (CDCC-CRC) theory. The results are found to be much improved and are the ANC derived in this way differs from those derived from DWBA analysis. In report we present a R-matrix analysis of the low energy E2 $^{12}C(\alpha,\gamma)$ data using the ANC derived from $^{12}C(^{7}Li,t)$ angular distribution measurements at 20 MeV.

R-matrix theory & analysis

The R-matrix theory is a suitable theoretical framework to calculate compound nuclear cross-sections in presence of resonances.

The entire configuration space is divided into two regions. The region inside a certain radius has the nuclear and Coulomb interaction and outside the radius is only Coulomb interaction. The matching of the logarithmic derivative of the inside and outside wavefunction at this radius determines the amplitudes and the cross-section. In the framework of the R-matrix theory the logarithmic derivative of the inside wavefunction is described in terms of two parameters viz. the reduced width (γ^2) and the resonance energy (E_r).

$$R = \frac{\gamma^2}{E_r - E}$$

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 separation. This asymptotic normalization constant (ANC) determines the cross-section at zero relative energy as low energy reactions interact with the peripheral part of the bound state wavefunction only. The reduced width is related with the ANC through the relation

$$\gamma^2 = \frac{\hbar^2}{2\mu R} W^2 C^2$$

The 4 level R-matrix fit in the framework of the code AZURE [7] of the E2 $^{12}C(\alpha,\gamma)$ capture data of Ouellete et al [8] is shown in figure1. The 2^+ levels that are included in the fit are the 6.92 MeV, 9.58 MeV, 11.52 MeV. A background level at 20 MeV is also included to take into account the non resonant contribution. In figure 1, the fit is carried out with the reduced width and ANC as freely varying parameters. The gamma width are adopted from the literature. The low energy behaviour of the calculated S-factor is determined by the ANC of the 6.92 MeV subthreshold state and is fitted value comes to 1013905.159187 $fm^{-1/2}$

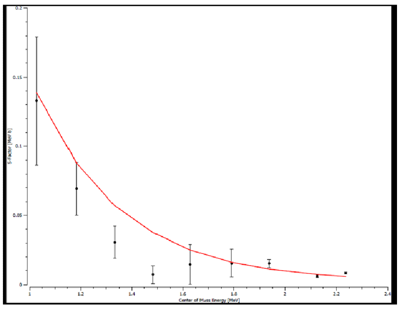

Fig. 1 R-matrix (AZURE) fit of E2 $^{12}C(\alpha,\gamma)$ data of Ref [8]. The level parameters allowed to vary freely.

In figure 2 we show the R-matrix fit of the E2 S-factor again involving the 4 2^+ levels but with the ANC of the 6.92 MeV state fixed at the value (196000.000000 $fm^{-1/2}$) from the 12C(7Li,t) alpha transfer measurements performed at 20 MeV.

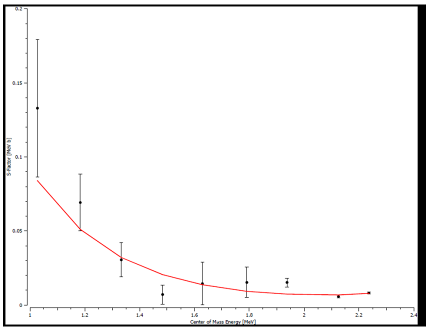

Fig. 2 R-matrix (AZURE) fit of E2 $^{12}C(\alpha,\gamma)$ data of Ref [8]. The ANC are obtained from $^{12}C(^7Li,t)$ measurement and CDCC-CRC analysis.

Summary & Conclusions

R-matrix analysis of the E2 capture data of $^{12}C(\alpha,\gamma)$ reaction was carried out. The fit was performed with both the ANC of 6.92 MeV state left freely varying and that determined from alpha transfer measurements. The ANC derived from our measurent involves the breakup transfer process. Analysis with ANC s determined from other measurements and including other E2 $^{12}C(\alpha,\gamma)$ data in the fit will enable a better understanding of the $^{12}C(\alpha,\gamma)$ reaction.

References

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