ANC of 6.92 MeV (2^+) and 7.12 MeV (1^-)states from sub-Coulomb ^{12}C(^{6}Li,d) data

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Introduction

The determination of the astrophysical S-factor of the ^{12}C(α,γ) reaction at 300 keV requires a R-matrix extrapolation. This is because a direct measurement of this reaction at 300 keV is almost impossible due to the very small cross-section. The R-matrix extrapolation requires as input the asymptotic normalization constant (ANC) of mainly two ^{16}O states states viz. 6.92 MeV and 7.12 MeV on which the fit is most sensitive. The ANC of these two states have been determined from indirect measurements, mainly from ^{12}C(^{6}Li,d) and ^{12}C(^{7}Li,t) alpha transfer reactions. Most of these measurements [1,2] are done at above barrier energies as cross-sections are larger. However, the reactions at above barrier energies are not ensured to be peripheral in nature and so model dependence is expected in the extracted ANC values.

The transfer reactions if carried out at sub-coulomb energies are peripheral and the extracted ANC can be considered more reliable. There are however, very few measurements at sub-Coulomb energies due to the difficulties in low energy measurements. C. Brune et al [3] has measured both ^{12}C(^{6}Li,d) and ^{12}C(^{7}Li,t) reactions at incident energies of 2.7 to 7.0 MeV with the Coulomb barrier at around 5.2 to 5.3 MeV for the two systems. However, the measurements of Brune et al involve only excitation functions. The angular distributions give a more general nature of the reaction and an extraction of the ANC from angular distribution measurements are expected to give more reliable values. Very recently Avila et al [4] has measured the angular distributions for the inverse reaction ^{6}Li(^{12}C,d) at 5 and 9 MeV incident energies. The measurements are however restricted to only backward angles.

In this work, we determine the ANC of the 6.92 MeV and 7.12 MeV states of ^{16}O using the ^{12}C(^{6}Li,d) data of Heikkinen et al [5] measured at 4.5 to 5.0 MeV incident energies. The data spans over a larger angular span in comparison to Avila though the former data do not cover the very backward angles as in the Avila data. As the Heikkinen data has never been analyzed to extract the ANC we report the results of our analysis of the data.

The ANC method

Indirect method uses transfer reactions to determine the ANC of the bound states of the nuclei of interest. For example, for the ^{12}C(α,γ) reaction, the ^{12}C(^{6}Li,d) or the ^{12}C(^{7}Li,t) reaction can be used to determine the ANC of 16O bound states. The cross-section of the capture reaction depends upon the ANC of the bound state wave-function. To determine the ANC, transfer angular distributions are measured and compared with a direct reaction model for transfer reaction: such as the DWBA theory.

The ratio of the experimental to the theoretical cross-section is the experimental spectroscopic factor i.e

$$S_\alpha = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{expt}}{\left(\frac{d\sigma}{d\Omega}\right)_{DWBA}}$$

S_α is also defined as the normalization constant of the many body wavefunction (ψ) when expressed in terms of the single particle wavefunction (ϕ) of the state i.e

$$\psi = \sqrt{S_\alpha}\,\phi$$

The single particle wavefunction is obtained by a solution of the Schrodinger equation using a real $\alpha + {}^{12}C$ binding potential. The asymptotic radial behavior of all bound state wavefunctions can be considered similar to that generated by an infinite range Coulomb potential for bound states, known as the Whittaker function (W). The many body wavefunction can therefore be expressed as

$$\psi_{r\to\infty} = CW$$

and for the single particle wavefunction

$$\phi_{r\to\infty} = bW$$

b is the single particle version of the many body ANC, *C*. Combining the last three equations, we obtain

$$C = \sqrt{S_{\alpha}}\,b$$

In a sub-Coulomb reaction, S_α becomes inversely proportional to b^2 and *C* becomes model independent.

Results and discussions

Fig 1 and 2 shows the analysis of the ^{12}C(^{6}Li,d) angular distribution data of Heikkinen et al at 4.5 MeV. The black lines are the DWBA calculations with entrance channel optical potential due to Vineyard et al [6]. The blue line is corresponding calculation normalized to the data, The black dashed lines are the DWBA calculations with the entrance channel optical potential of Poling et al [7]. The corresponding calculation normalized to the data is shown by red lines. The calculations disagree largely at backward angles where there is no data. In fig. 2 calculations in terms of Vineyard potential is only shown. However the calculations reproduce the data in a wide angular range satisfactorily. The α+^{12}C binding potential radius and diffusivity parameters, that determine the ANC are adjusted to fit the experimental angular distributions. The ANC obtained in this work and that obtained in the other two sub-Coulomb extractions are shown in Table 1.

The mismatch of the ANC values in the present and previous values for the 7.12 MeV state needs to be investigated.

Table 1: Extracted value of ANC (C^2)

E^* (MeV)	C^2 (fm^{-1})		
	This work	Brune	Avila
6.92	1.81×10^{10}	1.29×10^{10}	1.48×10^{10}
7.12	76.8×10^{28}	4.33×10^{28}	4.39×10^{28}

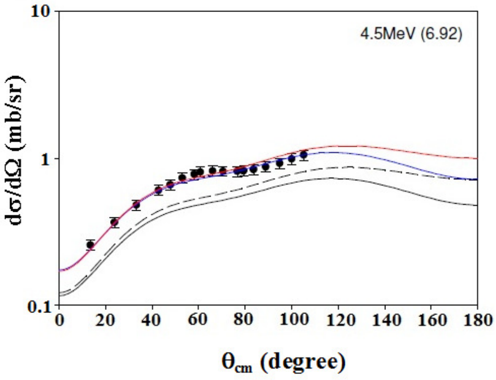

Fig.1 Comparison of ^{12}C(^{6}Li,d) data for 6.92 MeV state with DWBA calculations (details in text)

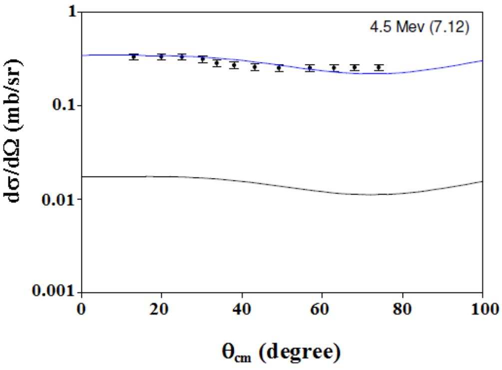

Fig. 2 Same as in Fig.1 except for 7.12 MeV state

A possible reason may be a normalization problem in the data. Fresh transfer and elastic scattering measurements over a large angular range are therefore required.

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