R-matrix analysis for the $^{2}H(\alpha,\gamma)^{6}Li$ reaction cross sections

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Introduction

The ratio of the abundance of ^{6}Li to ^{7}Li is $\sim$ 5x10^{-2}, which is about three orders of magnitude larger than the theoretical estimate ($\sim$ 10^{-5}) based on big bang nucleosynthesis (BBN) theory. Predictions for the production of ^{6}Li during BBN require precise measurement of ^{2}H(α,γ)^{6}Li reaction rate. In the range of BBN energies, 50 $\leq$ E$_{c.m.}$ $\leq$ 400 KeV, the direct measurement is very difficult owing to small cross-sections. D. Chattopadhyay *et al.* has used an indirect method named Coulomb dissociation to measure the radiative capture cross sections for ^{2}H(α,γ)^{6}Li reaction and extract the astrophysical S-factor [1]. The measured S-factor provides a smaller value of astrophysical S-factor at Zero energy S(0)=2.0 $\pm$ 0.2 x 10^{-4} eV-barn, consistent with the theoretical predictions in contrast to the existing data by Keiner *et al.*[2] where S-factor remains constant in the astrophysically relevant energies.

The aim of the present work is to perform the R-matrix analysis to see the consistency between the capture cross sections and S-factors obtained from the above measurements as well as available literature data [3–5], and understand the contributions from different multipolar transitions. The parameters obtained from the analysis can be used to extrapolate the values of S-factor at lower energies of interest.

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1. R-matrix Analysis

The multilevel, multichannel R-matrix code AZURE2 [6] has been used for the *R*-matrix analysis of the derived capture cross sections for $\alpha+d \rightarrow {}^{6}\mathrm{Li} + \gamma$ reaction. The cross section data of the above measurement covers the energy range of E$_{cm}$ =75 keV to 425 keV, where there is no resonance of αd cluster in ^{6}Li. So, the major contribution to the capture cross section comes from the nonresonant capture of deuteron by α particle leading to the ground state of ^{6}Li. However, in addition to the direct capture process, the tails of the low lying broad resonances in ^{6}Li near the αd breakup threshold can also have some contribution in this energy region. Hence, the capture process is modeled including both nonresonant and resonant contributions.

TABLE I: *R*-matrix parameters for the resonant states and high energy background pole

Level	J^{π}	E_x (MeV)	Γ_{α} (keV)	Γ_{γ} (eV)
2	3^+	2.186	24	0.526
3	2^+	4.310	1300	4.02
4	2^+	5.366	541	5.13
5	1^+	5.650	1500	1.34×10^{-4}
6	1^-	15.00	5000	967.16

For the resonant contributions, four low lying resonances have been included in the analysis (as listed in Table I), are primarily of $E2$ nature. The resonance state at E$_{x}$=3.563 MeV with J$^{\pi}$=0^{+} and isospin T=1 has been excluded from the analysis because of its very small parity-violating α-decay width [7]. In

R-matrix analysis, the non-resonant or direct capture cross section is calculated with the contributions from *internal* and *external* radial region separated by *channel radius a*. High energy *background pole* is considered to treat the internal contribution while the external contribution, which has a given energy dependence, is determined from the spectroscopic quantity known as *asymptotic normalization coefficient* of the final bound state [8]. In the present case, the direct capture process around the Gammow region is assumed to be predominantly of $E1$ type. To ensure the $E1$ nature, only one background pole has been introduced with $J^{\pi}=1^{-}$. The asymptotic normalization coefficient or ANC of ground state of ^{6}Li is taken as 2.30±0.12 fm$^{-1/2}$ from Ref. [9]. It may be noted that the contribution from $E1$ remains dominant around the Gammow peak energies and upto 400 keV, however, these results differ from the Effective Field Theory calculation [10] where $E1$ contribution is found to be negligible.

As the present data does not have any resonance in the given energy range, in the analysis we have kept the energy locations and the α widths (Γ_{α}) fixed [7]. The radiation widths (Γ_{γ}) are left as free parameters during search. The location of high energy background pole is chosen to be 15.0 MeV and the α width is fixed at Γ_{α}=5.0 MeV, a value close to the Wigner limit. The γ-width of the 1^{-} background pole is varied as a free parameter.

The radius of entrance channel is fixed at 4.0 fm, a value greater than $1.25\times(A_d^{1/3}+A_{\alpha}^{1/3})$. The fitted parameters are tabulated in Table I. The results of R-matrix calculations reasonably reproduce the experimental data on both σ_{cap} and S-factor as shown in Fig 1.

In summary, we have performed the R-matrix analysis and found that the experimental data on capture cross sections and S-factor for ^{2}H(α,γ)^{6}Li reaction are consistent. The $E1$ contribution was found to be dominant at E<400 keV whereas $E2$ contribution dominates above 400 keV. Using the R-matrix results at relevant energies one can calculate the reaction rate corresponding to individual multipoles and hence the abundance of ^{6}Li.

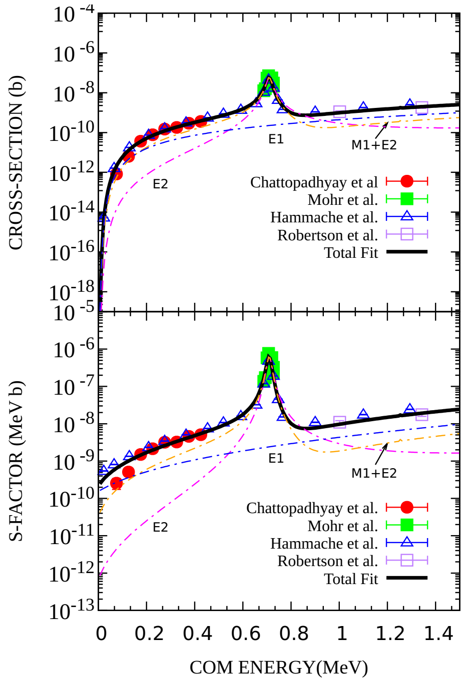

FIG. 1: Experimental data for capture cross section (upper panel) and astrophysical S-factor (lower panel) compared with the R-matrix calculations. Lines represent predicted contributions from different multipolar transitions.

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