Determination of astrophysical S-factor of ^{2}H(α,γ)^{6}Li from the Coulomb dissociation measurement

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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 using "baryon to photon ratio" as a parameter. Several studies have been made to resolve this discrepancy but it is far from being fully understood. Predictions for the production of ^{6}Li during BBN require precise measurement of ^{2}H(α,γ)^{6}Li reaction rate, the one of the key production mechanisms of ^{6}Li. In, BBN, this reaction occurs at energies in the range of $50 \leq E_{c.m.} \leq 400$ KeV. However, at these energies, the direct measurement is very difficult or even impossible owing to small cross-section because of Coulomb repulsion of the interacting particles. A straightforward solution to overcome this problem is offered by the indirect method of Coulomb dissociation[1].

Keiner *et al.*[2] have estimated the astrophysical S-factor of ^{2}H(α,γ)^{6}Li and found that S-factor remains constant in the astrophysically relevant energies in contrary to theoretical predictions. Later Hammache *et al.*[3] pointed out that the mixing of nuclear part with the Coulomb one is the main reason for the Constant S-factor in Ref. [2]. Hammache *et al.*[3] performed the Coulomb dissociation measurement of ^{6}Li using a higher energy (150 A MeV) ^{6}Li at GSI, but they were also not able to separate out the nuclear part from the Coulomb one experimentally. In order to obtain the correct value of astrophysical S-factor of ^{2}H(α,γ)^{6}Li reaction, the measurement of breakup cross section of ^{6}Li by ^{209}Bi target at a sub-Coulomb barrier energy has been performed. The results of the experiment are highlighted in this paper as follows.

Experimental details

Exclusive measurements have been carried out for ^{6}Li+^{209}Bi reaction at a beam energy E_{beam}= 25 MeV, using the 14-UD Pelletron-Linac facility in Mumbai. Five sets of strip telescopes were used to detect the breakup fragments in coincidence and placed side by side to cover a total angular range of about $\sim 93°$. Two Si-surface barrier detectors (of thicknesses $\sim 1000\mu$m) kept at $\pm$ 20° were used to monitor the incident flux by measuring the Rutherford scattering. In addition, there were five single telescopes of silicon surface barrier detectors placed on the scattering chamber to measure the elastic scattering angular distribution covering additional angular range.

Results and Discussions

Using the energies and laboratory detection positions of two breakup fragments of each coincident event, the values of 'θ,ϕ' of outgoing ^{6}Li (for $\alpha + d$ breakup), 'Q-Value' and α-d relative energy 'E_{rel}' were reconstructed and corresponding efficiency of the detector array has been obtained by a Monte-Carlo simulation. The efficiency corrected relative energy distribution 'E_{rel}' between two coin-

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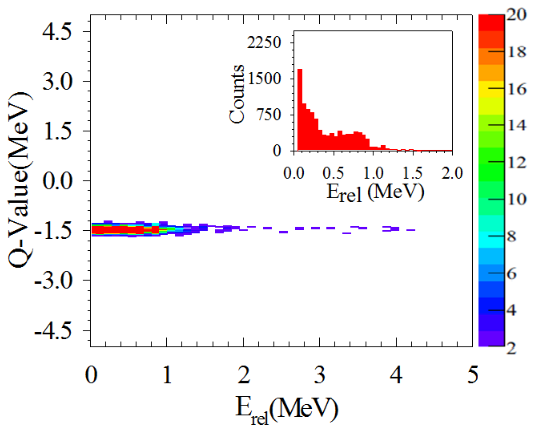

FIG. 1: Two-dimensional plot of ‘E_{rel} versus Q-value’ showing the distribution of events with projectile-like and target-like excitations. The inset shows the efficiency corrected relative energy distribution.

cidence breakup fragments thus obtained for $\alpha + d$ breakup have been shown in the inset of Fig. 1. From this distribution, it is observed that the breakup of ^{6}Li into $\alpha + d$ mainly proceeds via direct mode as no peaklike structure is observed near the 1st resonant excitation (0.71 MeV). Next, to find out the excitations of the residual target nuclei, the Q-value distributions were also obtained using the expression of Ref. [4]. Two-dimensional plots of ‘E_{rel} versus Q-value’ can reveal the excitations of both projectile-like and target-like nuclei as shown in Fig. 1. It is observed that the most of the events are centered around Q-values equal to $\sim$ -1.47 MeV, corresponding to the ground state of ^{209}Bi.

Finally, from the efficiency corrected relative energy distribution, the relative energy dependent cross-section was extracted. This cross-section is known as Coulomb dissociation cross-section from which the photo-disintegration cross-section can be calculated using the following relation:

$$\frac{d\sigma}{dE_\gamma} = \frac{1}{E_\gamma} n_{E\lambda} \sigma^{photo}_{E\lambda} \qquad (1)$$

where, $n_{E\lambda}$ is the virtual photon number.

The inverse reaction of photo-dissociation cross-section is the radiative capture reaction, from where the astrophysical S-factor of ^{2}H(α,γ)^{6}Li reaction is extracted as follows

$$S = \sigma^{cap} E_{rel} e^{(2\pi\eta)} \qquad (2)$$

and is shown in Fig. 2.

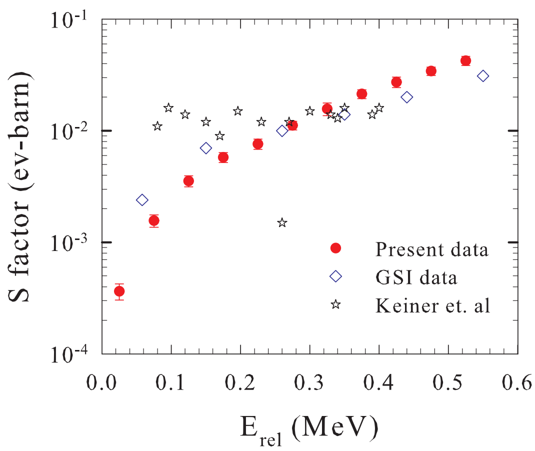

FIG. 2: Variation of astrophysical S-factor with relative energy.

In summary, we have extracted the astrophysical S-factor for ^{2}H(α,γ)^{6}Li reaction using Coulomb dissociation method. In comparison to the existing data, the present data is more consistent and gives a smaller value of astrophysical S-factor at Zero energy S(0)=2.0 $\pm$ 0.2 x 10^{-4} ev-barn. Using this result one can calculate the reaction rate and hence the abundance of ^{6}Li.

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