Estimation of electron screening potential for important astrophysical ^{6}Li(p,α)^{3}He reaction

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INTRODUCTION

Cosmological Li puzzle is a topic of great interest in modern Nuclear Astrophysics. For precise estimation of the abundance of ^{6}Li, accurate knowledge of the reaction cross-sections from all possible sources of production and destruction is essential. The major production and destruction sources of ^{6}Li in early universe are the reactions ^{4}He(d,γ)^{6}Li and ^{6}Li(p,α)^{3}He respectively. Electron screening plays an important role in determining the cross sections of both ^{4}He(d,γ)^{6}Li and ^{6}Li(p,α)^{3}He reactions. Electrons around the target nucleus effectively screen the coulomb potential at ultra low energies and thus reducing the height of the coulomb barrier. As a result the cross-section is enhanced by a factor $\exp(\frac{U_e \pi \eta}{E})$ and is given by [1]

$$\sigma(E) = \sigma_{bare}(E) exp(\frac{U_e \pi \eta}{E}) \qquad (1)$$

where, U_e is the electron screening potential $U_e(=\frac{Z_1 Z_2 e^2}{R_a})$ where, R_a is atomic radius.

In case of ^{6}Li(p,α)^{3}He reaction, the value of enhancement factor due to electron screening has a lot of ambiguities. Several attempts have been made to extract the electron screening potential for ^{6}Li(p,α)^{3}He system, but their values differ from each other as well as from the adiabatic limit [1]. In the present work, a fresh theoretical analysis has been attempted using the R-Matrix formalism using the Multichannel Multi-level code AZURE2 [2] to understand the electron screening potential for ^{6}Li(p,α)^{3}He. The newly measured experimental data of ^{209}Bi(^{6}Li,^{7}Li)reaction has been used to obtain the asymptotic normalization constant (ANC). This ANC is used as an input to the R-matrix analysis to explain the existing data for S-factor as a function of energy and obtain an estimate of the electron screening potential.

RESULTS AND DISCUSSIONS

A calculation using finite range distorted wave-born approximation(FRDWBA) has been performed to explain the differential cross-sections of ^{209}Bi(^{6}Li,^{7}Li)^{208}Bi reaction measured at 25 MeV using the 14-UD Pelletron-Linac facility in Mumbai.
In the FRDWBA model, the asymptotic normalization coefficient of ^{6}Li+n is extracted by comparing the experimental cross-section of the transfer reaction ^{6}Li+(n+^{208}Bi) $\rightarrow$ (^{6}Li+n)+^{208}Bi with the model predicted cross-section as shown in Fig. 1. For ^{209}Bi(^{6}Li,^{7}Li$_{g.s.}$)^{208}Bi, neutron can transfer to both 1p$_{3/2}$ and 1p$_{1/2}$ orbits of ^{7}Li with probabilities of ratio 1.5 [3]. The variation of the spectroscopic amplitudes "Cs" of these two overlaps with "b" (that depend on the shape of the Woods-Saxon potential) ,obtained from the fit to the measured transfer angular distribution, is shown in the inset of Fig. 1. The product of "Cs" and "b" (known as ANC) obtained for ^{6}Li+n is found to be independent on the shape of the potential.

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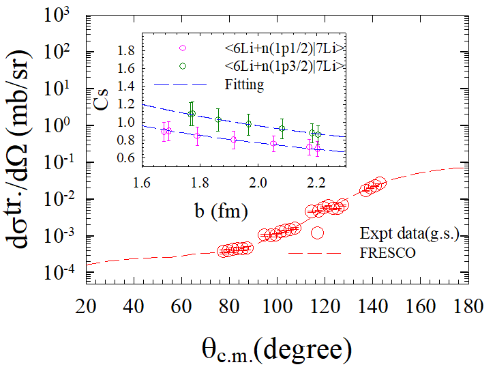

FIG. 1. Experimental cross-section of 1n pickup corresponding to g.s. of ^{7}Li. The inset shows the variation of "Cs" with "b" (Single particle ANC).

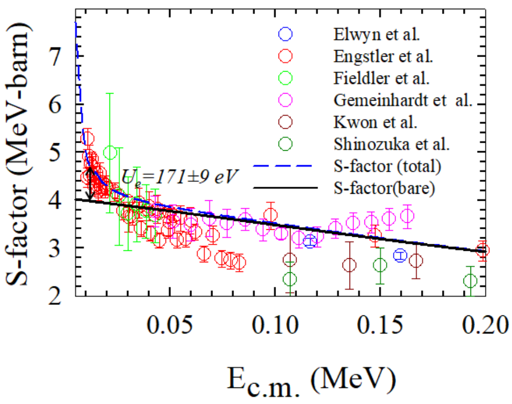

FIG. 2. Comparison of experimental S-factor with R-MATRIX calculation. Solid line represent the bare S-factor obtained from bare cross-section and dashed-line represent the total S-factor obtained from the bare+enhanced(due to electron screening) cross-section.

Since ^{7}Li is the mirror nucleus of ^{7}Be, the ANC of ^{6}Li+n is expected to be the same as the ANC of ^{6}Li+p [4]. The ANC thus extracted above has been used as an input for the R-Matrix calculation.

In the R-Matrix analysis both ^{6}Li(p,p)^{6}Li and ^{6}Li(p,α)^{3}He channels have been included to enhance the constraint on partial widths. The analysis includes g.s. and seven next higher lying excited states upto 11.01 MeV of compound ^{7}Be nuclei. Next, the high energy background poles for s and p-waves are introduced at 30.0 MeV, about 19 MeV above the highest excitation energy, to take care of the contribution of non-resonant processes of internal region. For the contribution of external region, the asymptotic normalization coefficients obtained from the transfer reaction ^{209}Bi(^{6}Li,^{7}Li)^{208}Bi are used. Electron screening potential is then extracted from the simultaneous fitting of the existing literature data for S-factor through entire region of energies and the value is found to be U_e = 171±9 eV, consistent with the adiabatic limit (175 eV). The results of the R-Matrix analysis is shown in Fig. 2.

CONCLUSIONS

In this work, we report an improved electron screening potential of ^{6}Li(p,α)^{3}He using the R-Matrix formalism and the existing experimental data for energy dependent S-factors. The extracted screening potential is found to be consistent with the value of the adiabatic estimate. The detailed study of R-Matrix analysis presented here provides a good foundation for the understanding of the electron screening potential and their effect on astrophysical S-factor.

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