On the Estimation of ^{6}Li(n,γ) Cross Sections

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Introduction

Neutron induced reactions on Li isotopes are having a renewed interest due to their involvement in nuclear astrophysics and Gen.IV nuclear reactors. In nuclear astrophysics, the abundances of ^{6}Li and ^{7}Li are highly influenced by the ^{6}Li(n,γ) reaction rates. In order to avoid the wrong estimations and biasing in the SBBN network calculations, the cross section for this channel has to be accurately measured.

The ^{6}Li(n,γ) reaction remains not well explored due to its small cross sections. Due to the higher Q-value for neutron capture, breakup levels populate more than the single particle levels. This suppresses the radiative neutron capture process in ^{6}Li. However, the direct reaction component involving the single particle levels contributes significantly to the radiative neutron capture through Direct Capture (DC) mechanism. There is only a single measurement on energy dependent cross section of ^{6}Li(n,γ) existing in the literature, by Ohsaki et al., for the neutron energy range of 20 to 80 keV. Due to the limitations with the ^{6}L target and lower cross sections, the direct measurement of ^{6}Li(n,γ) is potentially challenging[1].

Materials and Methods

Neutron capture in ^{6}Li populates initial capture state with an excitation energy of 7.25 MeV + E$_n(\frac{A}{A+1})$. This energy is well above the ^{7}Li $\rightarrow \alpha + t$ breakup threshold of 2.47 MeV. However, the transition from J_i to the $\alpha + t$ breakup continuum levels will not contribute to the radiative capture process. The population of breakup states results to the continuum breakup of ^{7}Li. Hence, the $3/2^{-}$ and $1/2^{-}$ states corresponding to ground and 477 keV are the only J_f states involving the radiative capture. The reformulation of direct capture formulation assumes that the $3/2^{-}$ and $1/2^{-}$ states are also a part of the single particle continuum states. However, for these states, the level density term generates the definite shape of the resonance[2].

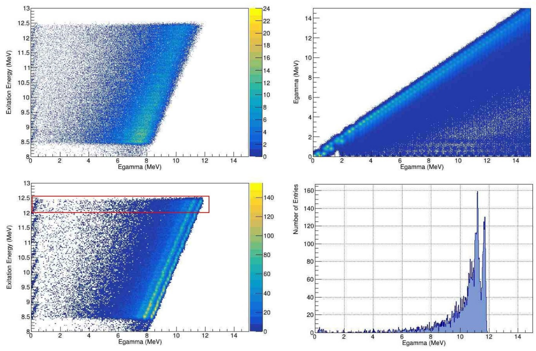

Figure 1: γ *Energy - Excitation energy matrix, Response matrix of LaBr$_3$ Unfolded matrix and projection*

The experiment is performed using 16 MeV proton beam from BARC-TIFR Pelletron facility, Mumbai, India. A ^{nat}Li target of 1.4 mg/cm^2 was used for the experiment. Two silicon detector telescopes having 25μm and 1500μm ΔE-E pairs, were mounted at $+55^\circ$ -55° at a distance of 7.5cm from the target to record the inelastically scattered protons. A $3'$ diameter and $7'$ length $LaBr_3$ scintillator, coupled to a fast photomultiplier tube, was placed at 90°, at the bottom side of the target. This was used for measuring the γ spectra. The distance between the target and $LaBr_3$ detector was 12 cm.

The inelastically scattered protons were identified from the E-ΔE correlation plot by proper gating. The γ events in the $LaBr_3$ scintillator, with the elastically scattered protons are identified. The events were converted to the excitation energy of ^{7}Li from the energy of elastically scattered protons, using two body kinematics. A correlation matrix between γ energy (E_γ) and excitation energy of ^{7}Li (E_x) was constructed. This matrix was unfolded to original γ matrix using response matrix for the current $LaBr_3$ detector. The unfolding procedure was done using in-house developed machine learning assisted unfolding algorithm by preserving the excitation energy information of the events. The measured E_γ - E_x matrix, simulated detector response matrix, unfolded E_γ - E_x matrix and the projected gamma spectrum is illustrated in figure 1.

Theoretical calculations are performed to reproduce the direct capture cross sections. A coupled channel method has been adopted for the calculation. n+^{6}Li is taken as the entrance channel mass partition and ^{7}Li+γ partition in the exit channel. The n+^{6}Li potentials by Chiba et al. was used for the calculations. The calculations were performed using coupled channel code. Theoretical spectroscopic factor for ^{6}Li+n from the shell model calculations by Cohen and Kurath have been used for the resonant states. An optimized average spectroscopic factor of 0.75 was used for α+t. The calculation has been limited to E_1 and M_1 mode of γ transitions and higher multipolarities have been neglected. Along with the calculations, statistical Direct Capture calculations were performed using Talys-1.95 nuclear reaction code. This is to account for the compound nuclear, pre-equilibrium and the continuum component of the direct capture mechanism. The Microscopic level densities (temperature dependent HFB, Gogny force) from Hilaire's combinatorial tables were used for the calculations of compound nuclear contribution as well as the continuum component of direct capture.

Results and Discussion

The FRESCO calculated discrete component of the Direct Capture is illustrated as the black solid line in Fig. 4. The calculations reproduce the experimental cross sections within the error bars, for the spectroscopic factors by Kohan and Kurath. This indicates that the major contribution of the ^{6}Li(n,γ) is from the discrete component of the direct neutron capture. Further, there exists a strong coupling of $5/2^-$, $7/2^-$ and $3/2^-$ levels, which lies above the neutron separation threshold of ^{7}Li, on $J_i \rightarrow 3/2^-$ and $J_i \rightarrow 1/2^-$ transitions. These resonant states are overlapping with the α+t breakup continuum and indicates a larger energy width. This coupling effect is emerged as the low energy tail along with γ colonies, corresponding to $J_i \rightarrow 3/2^-$ and $J_i \rightarrow 1/2^-$ transitions, in the experimental γ spectrum. Talys-1.95 calculated continuum component of Direct Capture, Houser-Feshback + Pre-equilibrium components are much lesser compared to the discrete component of the direct capture. Talys calculated discrete component of Direct Capture in ^{6}Li(n,γ) is also well in agreement with the experimental cross sections and FRESCO calculations. The inhibition of the compound nuclear component in ^{6}Li(n,γ) reaction is due to the lesser number of levels available in the ^{7}Li compound nucleus. Further the strong coupling of $\alpha + t$ breakup is also reducing the capture cross section significantly.

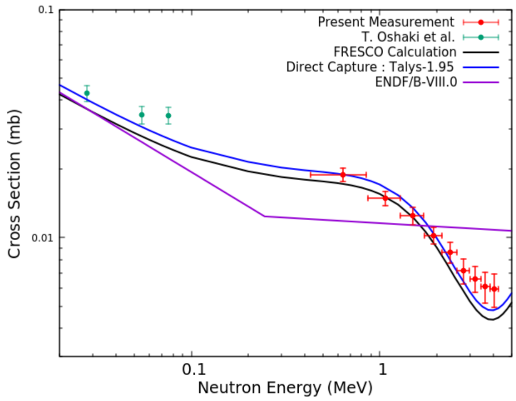

Figure 2: *The measured cross sections, compared with Fresco and Talys calculations, and ENDF/B-VIII.0 evaluations*

References

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