Comparison of measured neutron angular distribution in ^{7}Li(p, n) reaction with the FRESCO calculation

A. S. Roy[1,2], K. Banerjee[2,3], R. Santra[2,3], P. Roy[2,3], S. K. Pandit[4], R. Shil[5], R. Datta[2,6], T. K. Rana[2,3], A. Sen[2,3], T. K. Ghosh[2,3], S. Kundu[2,3], G. Mukherjee[2,3], S. Mukhopadhyay[2,3], S. Manna[2], R. Pandey[2], D. Paul[2,3], K. Atreya[2,3], S. Basu[2,3], D. Pandit[2], D. Mondal[2], M. S. Mitra[1], M. S. Kulkarni[1,2], C. Bhattacharya[3,#]

[1]Health Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085
[2]HBNI, training School Complex, Anushaktinagar, Mumbai-400094
[3]Variable Energy Cyclotron centre, 1/AF Bidhan Nagar, Kolkata-700064, India
[4]Nuclear Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400085
[5]Siksha Bhavana, Visva-Bharati, Santiniketan-731235, India
[6]RP & AD, Bhabha Atomic Research Centre, Trombay, Mumbai-400085

^{7}Li(p, n) reaction is being used as a source of intense neutron beam for several studies nowadays. Lithium is considered as a favorable target over others because of metallic target, high neutron production cross section and monoenergetic neutrons emission [1]. At low proton bombarding energy, monoenergetic neutrons are generated, which are associated with ground and 1st excited states of ^{7}Be. Since ^{7}Be produced in this reaction is a weakly bound nucleus, it breaks into two fragments ^{4}He and ^{3}He when the excitation energy goes above its breakup threshold of 1.59 MeV. At this stage, the relative motion of internal cluster (α - ^{3}He) within ^{7}Be gives rise the quasi continuum levels in ^{7}Be. Coupling of these continuum levels of ^{7}Be with the exit neutron wave functions is the source of the continuous neutron energy distribution [2] when the incident proton energy is above the sum of the breakup threshold and Q – value of the reaction. In addition to the breakup through continuum states, neutrons from the breakup through resonance states ($7/2^-$, $5/2^-$) of ^{7}Be also start contributing at proton lab energies above 7.11 and 9.56 MeV respectively. In the neutron spectrum they appeared as peak like structures over the continuum distribution of neutrons.

Contribution of neutrons from g.s. ($3/2^-$) and 1st ($1/2^-$) excited states of ^{7}Be have been studied extensively [3, 4]. However neutron cross section data above the breakup threshold of ^{7}Be are sparse in literature [2]. In addition theoretical reproduction of the neutron angular distribution data is missing in the literature. In this paper FRESCO calculations are compared with the measured angular distribution.

The experiment was performed at K-130 Cyclotron, VECC using proton beams of energy 7 -14 MeV. Experimental setup and other details had been discussed in our previous paper [5]. Neutron energy spectra which was obtained by TOF technique was fitted with multiple Gaussian (for neutron peak) and exponential (For continuous breakup) function. The integral area under each Gaussians and the exponential parts were determined for all detector angles. These energy integrated cross section ($d\sigma/d\Omega$) were then plotted as a function of centre of mass angle $\theta_{C:M}$. The angular distributions of neutrons thus obtained for different exit channels are compared with the calculations done using Distorted Wave Born Approximation (DWBA) calculation performed with FRESCOX (ver. 7.1).

In (p, n) reaction the participating nuclei only exchange their charges whereas their masses remain nearly constant. The reaction may be assumed to propagate to the final products through different intermediate states. In our calculation we have chosen the following process as the main contributory mechanism for this reaction dynamics.

- Direct exchange of proton into neutron via pion exchange
- Two step transfer

i) Via d+^{6}Li intermediate state

^{7}Li(p, d)^{6}Li $\longrightarrow$ ^{6}Li(d,n)^{7}Be

ii) Via a ^{4}He + ^{4}He intermediate state

^{7}Li(p, ^{4}He)^{4}He $\longrightarrow$ ^{4}He(^{4}He, n)^{7}Be

Optical Model Potential (OMP) parameters are required for this two step transfer calculation. Main assumption is to take a mean field approach to estimate potential suitable for interaction between an incident particle and the target nucleus.

*Electronic address: *a.singharoy@vecc.gov.in*
Retired

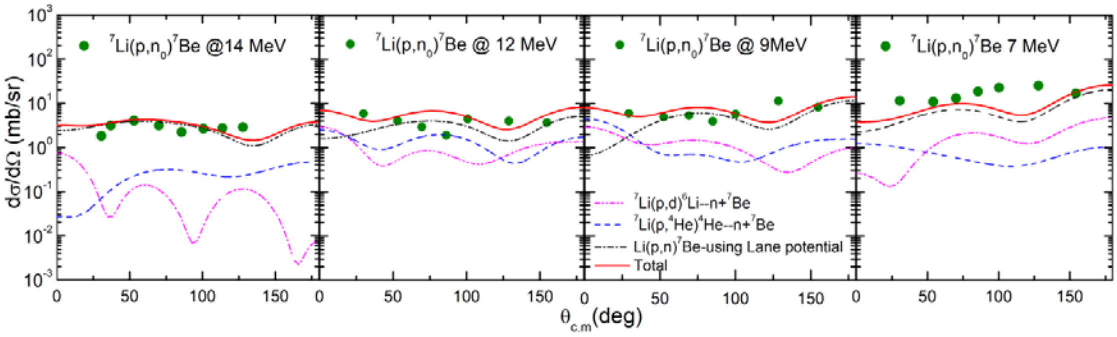

Figure 1: Measured angular distribution of neutrons associated with g.s of ^{7}Be along with FRESCO calculation.

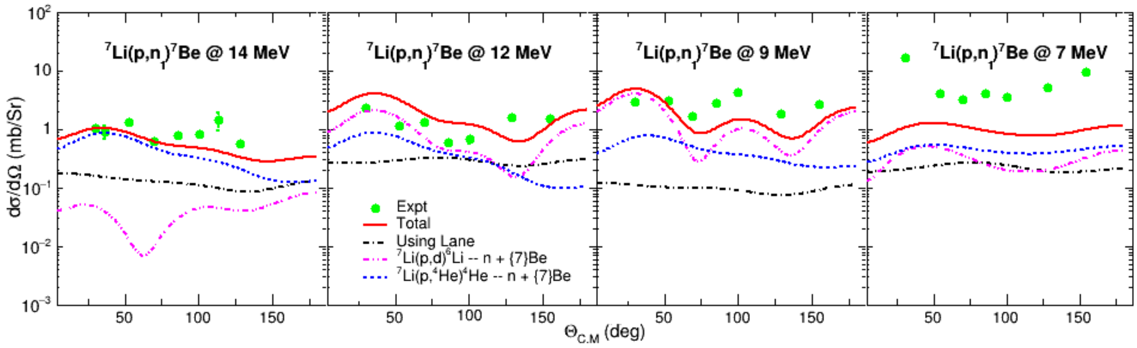

Figure 2: Measured angular distribution of neutrons associated with 1st excited state of ^{7}Be along with FRESCO calculation.

In the two step transfer calculation, the global sets of OMPs were used for p + ^{7}Li, n + ^{7}Be, d + ^{6}Li channel estimated from Ref.[6]. For charge exchange calculation, Lane potential was used. The results of present DWBA calculation along with angular distribution data are shown in Fig. 1 and Fig. 2 for ground and 1st excited states, respectively. Dashed lines in the figures represent theoretical calculations for individual contributions of different process involved in the reaction mechanism and solid line is incoherent sum of all individual contribution.

Most of the calculated distributions reproduce the measured angular distribution data for 7 to 14 MeV range without any scaling although the shape of the calculated distributions slightly varies from the measured data. For 7 MeV, calculations deviates from the experimental data both for g.s. and 1st exited states. This deviation is more for 1st excited states than the g.s. of ^{7}Be. Looking into figures, it is quite evident that at 7 MeV the calculated distribution is found to be lower than the measured data. Whereas, for higher energies up to 14 MeV, the calculations closely predict the measured data. At 7 MeV, mismatches between the two angular distributions may be due to the presence of resonances at this energy. Figure also indicate that the g.s. angular distribution is closely reproduced by the direct exchange of proton into a neutron where the two step transfer contribution is order of magnitude less than the direct exchange process. For 1st excited states all the three different processes taken in our calculations seems to be important.

References:

[1] I. S. Anderson et al., Phys. Rep., 654 (2016)

[2] C. V. Midhun et. al., Phys. Rev. C 104, 054606 (2021).

[3] M. W. McNaughton, et. al., Nucl. Instr. Meth.,130,555 (1975).

[4] C. H. Poppe., et al., Phys. Rev. C,14, 438 (1976).

[5] A. S. Roy, et al., Proc. of DAE Symp. on Nucl. Phys. 66, 627 (2022).

[6] A. J. Koning and J. P. Delaroche, Nuclear Physics A 713 (2003) 231–310