Study of reactions populating unbound states for ^{7}Li+^{89}Y system around the Coulomb barrier

S. K. Pandit[1,2],* A. Shrivastava[1,2], K. Mahata[1,2], N. Keeley[3], V. V. Parkar[1,2], P. C. Rout[1], K. Ramachandran[1], I. Martel[4], C. S. Palshetkar[1], A. Kumar[1], P. Patale[1], A. Chatterjee[1], and S. Kailas[1]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, India*
[2]*Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094, India*
[3]*National Centre for Nuclear Research, ul. Andrzeja Sołtana 7, 05-400 Otwock, Poland and*
[4]*Departamento de Física Aplicada, Universidad de Huelva, E-21071 Huelva, Spain*

In the recent years, role of low breakup threshold on the reaction dynamics involving weakly bound nuclei has been the subject of current interest [1–3]. The present work is aimed to study the processes of direct breakup and nucleon transfer followed by breakup in detail for a weakly bound projectile ^{7}Li. A comprehensive data set comprising of elastic scattering, inclusive-α, 1n-stripping and 1p-pickup followed by breakup along with the direct breakup of the projectile have been obtained. Coupled channel calculations are performed to interpret the measured data.

The experiment was carried out at Pelletron-Linac facility, Mumbai, using ^{7}Li beam of energies 23, 28 and 30 MeV. Self-supporting ^{89}Y foil of thickness $\sim$2.0 mg/cm^2 was used as target. Two segmented large area Si-telescopes of active area 5 x 5 cm^2 (thicknesses ΔE $\sim$50 μm, E $\sim$1500 μm) and five telescopes consisting of Si-surface barrier detectors (thicknesses ΔE $\sim$ 20-50 μm, E $\sim$ 450-1000 μm) were used for coincidence measurement of the outgoing fragments. Two Si-surface barrier detectors (thicknesses 300 μm) kept at $\pm$20^{o} were used to monitor Rutherford scattering. The data were collected in an event by event mode, with the trigger generated from the E detectors. Multiplicity threshold was kept at one to measure elastic scattering and at two for the measurement of breakup fragments in coincidence.

The strips were calibrated using the known alpha energies from ^{7}Li+^{12}C reaction at 24 MeV. Particles were identified using energy loss information from ΔE and E. The observed α+t, α+d, and α+α coincident events were identified to be arising from direct breakup of ^{7}Li, 1n-stripping (^{6}Li) and 1p-pickup (^{8}Be) followed by breakup reaction channels, respectively. The fragments' identity (A), energy and relative angle were used to calculate their relative energy. The excitation energy of the ejectile prior to breakup were obtained by adding the breakup threshold to the measured relative energy. The coincidence efficiency of the detector for the detection of both the fragments depends on the velocity of the ejectile prior to breakup and the relative velocity of the fragments. Monte Carlo simulation technique was used to estimate the efficiency.

The measured angular distribution of elastic scattering is shown in Fig.1 (a). The errors on the data points are due to statistics. The $E_{\rm rel}$ spectra for α+α, α+d and α+t exhibit peaks at 92 keV, 710 keV and 2.16 MeV corresponding to the breakup of ^{8}Be (g.s.), ^{6}Li (2.18 MeV, 3^{+}_{1}) and ^{7}Li (4.63 MeV, $7/2^{-}$), respectively. The angular distribution for breakup of ^{7}Li from $7/2^{-}$ resonance state is shown in Fig. 1 (b). The integrated cross-sections were obtained assuming a Gaussian shape for the angular distribution. The measured total cross-section for breakup of ^{7}Li from $7/2^{-}$ (4.63 MeV) resonance state is 3.0$\pm$0.4 mb, which is found to be five times more than the prompt breakup (E_{rel} up to 1.7 MeV) cross-section (0.6$\pm$0.1 mb). The measured inclusive-α angular distribution is presented in Fig.1 (c). The total inclusive-α cross

*Electronic address: sanat@barc.gov.in

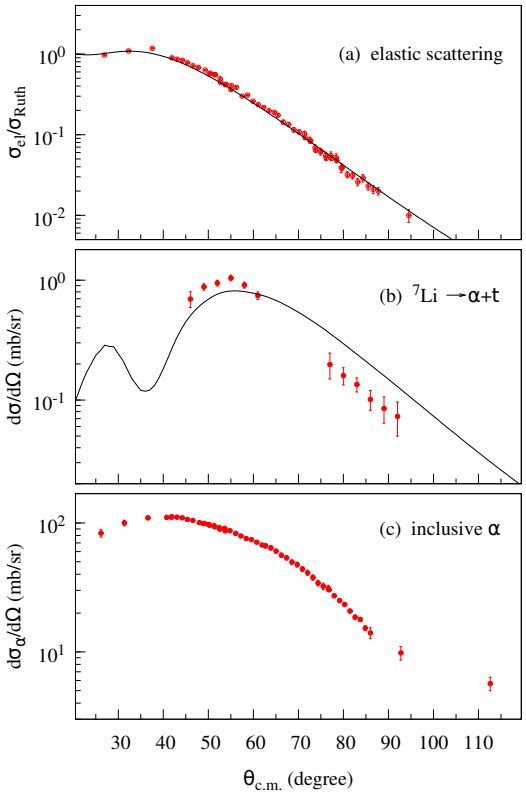

FIG. 1: Measured angular distribution of (a) elastic scattering, (b) direct breakup of ^{7}Li from $7/2^-$ resonance state and (c) inclusive-α, at E_{beam} = 28 MeV. Solid curves in (a) and (b) are corresponding to CDCC calculations.

section is 400±50 mb. The total ^{7}Li→α+t cross section (3.6 mb) accounts for ∼ 0.9 % of the inclusive-α yield at E_{beam}= 28 MeV. Total cross sections for 1n-stripping populating the ^{6}Li(3^+) resonance and 1p-pickup populating ^{8}Be(g.s.) are found to be 10.3±1.8 mb and 1.3±0.3 mb, respectively. Therefore, the cross sections of 1n-stripping account for ∼ 2.5 % and 1p-pickup only ∼ 0.65 % (where each ^{8}Be contributes two α-particles to the total yield) of the inclusive-α yields.

Continuum discretized coupled channels (CDCC) calculations have been carried out, using the code FRESCO, to understand the measured data. Watanabe-type folding potentials were used as target-projectile interaction potentials. The α+^{89}Y and t+^{89}Y optical potentials were taken from the global parameterizations of Refs. [4] and [5], respectively. The real and imaginary depths of these potentials were renormalized to fit the elastic scattering data. Calculated elastic scattering angular distributions at E_{beam} = 28 MeV are shown in Fig. 1 (a). The $\alpha + t$ continuum model space in momentum was limited to $0 \leq k \leq 0.8$ fm^{-1} with $\Delta k = 0.1$ fm^{-1}. The relative angular momenta (L) of $\alpha + t$ system 0−4 and couplings up to multipolarity $\lambda = 4$ were considered in the calculations. In addition to ground state $3/2^-$, the $1/2^-$ (E^* = 0.478 MeV) inelastic state and $7/2^-$ (E^* = 4.63 MeV) resonance state were also included in the calculations. The calculated angular distribution for breakup of ^{7}Li from $7/2^-$ resonance state is shown in Fig. 1 (b). The estimated α-evaporation cross-sections using the statistical model code PACE [6] is found to be contributing ∼ 15 % to the inclusive-α.

In summary, measured elastic scattering, inclusive-α, 1n-stripping and 1p-pickup followed by breakup along with the direct breakup of projectile for ^{7}Li+^{89}Y system at E_{beam} = 28 MeV are presented. Coupled channel calculations were carried out to understand the measured data. The present study shows that the total α-productions from direct breakup, 1n-stripping and 1p-pickup followed by breakup, and evaporated-α account for ∼ 20 % of the measured inclusive-α yields. This study supports our earlier observation, the main α-production mechanism must be due to other processes, presumably t-stripping/capture [2].

We thank Pelletron-Linac accelerator staff, Mumbai for providing steady and uninterrupted beam.

References

[1] L. F. Canto *et al.*, Phys. Rep. 596, 1 (2015).
[2] S. K. Pandit *et al.*, Phys. Rev. C 93, 061602(R) (2016).
[3] A. Shrivastava *et al.*, Phys. Lett. B **633**, 463. (2006).
[4] V. Avrigeanu *et al.*, Phys. Rev. C **49**, 2136 (1994).
[5] F. D. Becchetti, Jr. and G. W. Greenlees, Polarization Phenomena in Nuclear Reactions (University of Wisconsin Press, Madison, 1971).
[6] A. Gavron, Phys. Rev. C 21, 230 (1980).