# Role of continuum in reaction dynamics involving weakly bound nuclei

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Exploring the properties of weakly-bound stable/unstable nuclei is a topic of current interest [1, 2] and also focus of the next generation of high-intensity isotope-separator on-line (ISOL) radioactive ion beam facilities. Presence of loosely bound cluster structure and exotic shapes are the distinct features seen in these nuclei with respect to the tightly-bound nuclei. Due to the low breakup threshold, population of the continuum is probable and consequently a large coupling effect is expected in the reactions involving the weakly bound nuclei at energies around the Coulomb barrier. Continuum states can be populated by direct inelastic excitation of the projectile (breakup) or nucleon transfer, leaving the ejectile in an unbound state (transfer-breakup) [1–4]. Another dominant reaction mode is transfer/capture of one of the cluster-fragment from bound/unbound state of the projectile to the target nuclei. Capture of a cluster-fragment from unbound states of the projectile can be looked upon as a two-step process, breakup followed by fusion (breakup-fusion) or incomplete fusion (ICF). This process is indistinguishable from the direct stripping of the cluster-fragment. However, it has been shown that breakup-fusion reaction is dominant over the one step stripping reaction. The admixture of these two reaction processes is generally referred to as fragment-capture [4].

In case of reaction involving weakly bound nuclei with $\alpha+x$ cluster structure, e.g. $^{6,8}$He, $^{6,7}$Li, and $^{7,9}$Be, $\alpha$-particle production is found to be large compared to that of the complementary fragment. Investigation of the mechanisms responsible for the large $\alpha$-particle production cross sections is also a topic of current interest. Contributions to the alpha yield arising from different reaction mechanisms, such as breakup, transfer-breakup, cluster transfer, transfer followed by evaporation, incomplete fusion, compound nuclear evaporation, etc are entangled and it is not trivial to separate them from inclusive measurements. Experimentally it is challenging to disentangle these reaction processes, and exclusive measurements are essential.

In the present thesis, extensive study of reactions populating the continuum, viz, breakup, transfer-breakup and fragment-capture, have been carried out for weakly bound projectile $^7$Li on targets around $Z$=40 $N$=50. To study the breakup and transfer-breakup reaction mechanisms, breakup fragments in coincidence have been measured for $^7$Li+$^{93}$Nb, $^{89}$Y systems at near Coulomb barrier energies. The measurement of energy-angle co-relation of the breakup fragments were carried out using two segmented Si-detector telescopes having large solid angle coverage and high granularity [5].

The fragment-capture reaction mechanism has been studied by measuring $\gamma$-rays, emitted from the composite systems in coincidence with the non captured fragment for $^7$Li+$^{93}$Nb system at near Coulomb barrier energies [7]. Indian National Gamma Array (INGA) was used to measure the prompt $\gamma$-rays [6]. Three Si surface barrier telescopes were kept inside the scattering chamber at 35°, 45° and 70° for the detection of charged particles around the grazing angle. The off-beam $\gamma$-ray activity were measured using an efficiency calibrated high-purity germanium (HPGe) detector setup with low background [7] .

Various breakup processes, breakup of $^7$Li ($^7$Li$^* \rightarrow \alpha + t$) together with 1$p$-pickup fol-

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lowed by breakup ($^8$Be $\rightarrow$ $\alpha + \alpha$) and 1$n$-stripping followed by breakup ($^6$Li $\rightarrow \alpha + d$) were disentangled by using the 3-body kinematics method. The conversion of the energy and scattering angle from the laboratory frame to the c.m. frame of the target-projectile in event-by-event mode automatically takes care of the Jacobian of the transformation. The breakup events from direct and resonance states were identified by extracting the relative energies. A simulation code on 3-body kinematics has been developed using the Monte Carlo technique to interpret the observables of different breakup processes and to estimate the efficiency for coincident detection of the breakup fragments. The energy spectra of each outgoing fragments were reproduced by simulation. The absolute cross-sections of all the above mentioned breakup processes have been extracted. Angular distributions for elastic scattering, neutron and proton transfer to bound states of $^6$Li and $^6$He, respectively, have also been measured. The cross sections for $\alpha+\alpha$ events from one proton pickup have been found to be smaller than those for $\alpha+d$ events from one neutron stripping and $\alpha + t$ events from direct breakup of $^7$Li. Coupled channels Born approximation (CCBA) and continuum discretized coupled channels (CDCC) calculations were performed to explain the large number of observables. The mechanism direct transfer to unbound states of the ejectile, is responsible for the $\alpha + \alpha$ and $\alpha + d$ production.

The different fragment-capture reaction mechanisms were identified by measuring prompt $\gamma$-rays arising from the residue in coincidence with the outgoing particles. The absolute cross-sections of residues arising from capture of various fragments and complete fusion reaction have been extracted from the measurements of the characteristic $\gamma$-ray transitions employing in-beam and off-beam methods.

The measured $t$-capture cross-sections are found to be more than $\alpha$-capture cross-sections at all the energies. The present study shows that the $t$-capture mechanism is the dominant reaction channel for the production of $\alpha$-particle and account for 62-73% of the measured $\alpha$-inclusive cross-sections. The 2$n$ stripping ($^5$Li$^* \rightarrow \alpha + p$) cross-sections along with 1$p$ pickup ($^8$Be$^* \rightarrow \alpha+\alpha$), inelastic excitation ($^7$Li$^* \rightarrow \alpha + t$) and 1$n$ stripping ($^6$Li$^* \rightarrow \alpha + d$) explains $\sim$15% of the inclusive-$\alpha$ cross-sections. The statistical model calculations were performed to estimate the compound nuclear contribution in the cross-sections of residues populated in $t$-capture and $\alpha$-capture reactions. The predicted compound nuclear contribution of $\alpha$-evaporation from the statistical model calculations account for 10-20% of the $\alpha$-inclusive cross-sections. The combination of $\alpha$-production due to, (a) $t$-capture, (b) evaporation from compound nucleus, and (c) breakup and nucleon transfer followed by breakup, explain almost all the measured $\alpha$-inclusive cross-sections for $^7$Li + $^{93}$Nb system at the measured energy range [7]. A systematic behavior of the $t$-capture and inclusive-$\alpha$ cross-sections for reactions involving $^7$Li over a wide mass range has also been carried out. The present measurements along with the systematic study for different systems suggest that the main source of the $\alpha$-production mechanism is $t$-capture. A complete data set together with the theoretical analysis has been reported in this thesis.

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