Deciphering reaction mechanisms in ^{7}Li fusion with Zn

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Introduction

The weakly bound structure of projectiles (like ^{6,7}Li) renders a way to access various facets of mechanisms involved in heavy-ion reactions [1]. Reaction data in the heavy mass region is available in the literature, depicting a competing incomplete fusion (ICF) mechanism in addition to complete fusion (CF) in the low energy domain owing to the low breakup threshold (S_α=2.47 MeV for ^{7}Li). The ICF process results in the loss of incident flux due to breakup, leading to the CF suppression relative to the 1D-barrier penetration model at the above barrier energies [1]. For a better understanding, reaction mechanism dependencies on several entrance channel parameters like bombarding energy, α-separation energy, deformation parameter, mass asymmetry, Coulomb's factor ($Z_P Z_T$), etc. have also been put forth. Though, several enigmatic findings exist in the literature reflecting an inadequate understanding of reaction dynamics. Thus, to address the ambiguities prevalent in the light-medium mass region and to understand the entrance channel dependencies, we have studied ^{7}Li reaction on Zn.

Experiment

The experiment was executed at the 14UD BARC-TIFR Pelletron facility, Mumbai, India. $^{7}Li^{+3}$ beam in 2.8–6.1 MeV/A energy range impinged upon target foil stacks accommodating properly rolled 2.8 mg/cm^2 thick natural Zn foils backed with Al recoil catchers of 1.8 mg/cm^2 thickness. Al foils suffice the purpose of residue trapper and energy degrader. Post irradiation, γ-spectroscopy was employed to measure the activity induced in the target matrix, and populated residues were identified from their characteristic γ-rays and decay curves. Background subtracted photo-peak area was utilized to estimate the production cross sections of residues adopting the activation formula with all the sources of uncertainties considered.

Results and discussion

Analysis of γ-spectra assured the production of 14 residues namely, ^{72,71,70,69}As, ^{69,67}Ge, ^{68,67,66,65}Ga, ^{71m,69m,65}Zn, and ^{61}Cu populated via xn, pxn, αxn, αpxn and $2\alpha xn$ channels, respectively, in the reaction. To comprehend the mechanisms involved in reaction, the measured excitation functions (EF) of residues have been analyzed in comparison with theoretical predictions from PACE4 statistical model code. Monte-Carlo simulation based PACE4 code features the Hauser-Feshbach formalism to predict residual cross sections in the framework of complete fusion (CF) dynamics through equilibration of a compound nucleus (CN). The code adopts the Gilbert-Cameron formalism for level density (LD) with LD parameter a=A/K, where A is the mass number of CN and K is the free parameter. Since the target is natural, theoretical estimations have also been obtained by assuming the weighted contribution from each abundant isotope. For the present analysis, we realized K=8 as the optimum LD parameter as it grossly reproduces the xn-channel cross sections, shown in fig. 1(a), hinting the dominance of CF in xn-channel. A significant enhancement in the subsequent channel cross sections has been observed relative to optimal reference LD, implying the engrossment of the ICF mechanism in addition to the CF process in the population of residues, as PACE4 predicts only the CF cross sections. Fig. 1(b)

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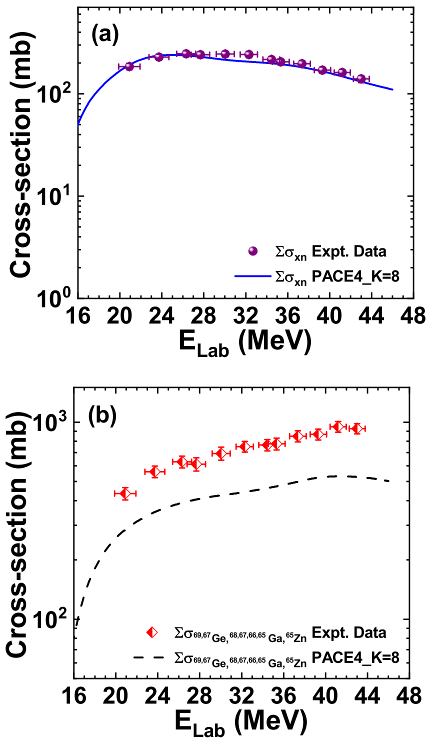

FIG. 1: (a) Comparison of the sum of measured residual cross sections from xn-channels with PACE4 (K=8) predictions. (b) Significant enhancement depicted by the sum of measured residual cross sections from p and α-emitting channels relative to theoretically predicted sum of residual cross sections for the same channels.

outlines a comparison of the sum of residual cross sections from p and α-emitting channels, depicting an enhancement relative to optimal theoretical predictions. The probable reason for the enhancement observed in p and α-emitting channels can be accredited to the role of the ICF process due to direct breakup (α+t) and/or transfer-induced breakup [2, 3] of ^{7}Li projectile in the field of the target nucleus. In the course to decipher an interplay of CF-ICF mechanisms, the strength of the ICF process in the reaction has been deduced by employing the data reduction method [3]. The ICF cross sections $\sigma_{\mathrm{ICF}} = \sigma_{\mathrm{TF}} - \sigma_{\mathrm{CF}}$ have been deduced, where σ_{CF} is the sum of PACE4 predicted cross sections and σ_{TF} is the sum of measured cross sections from the enhancement depicting channels as shown in fig. 1(b). The ICF strength fraction for the reaction comes out to be ≈2.5–4.1% per channel having a rising trend with incident energy within the studied energy range as exhibited by ICF cross sections. It should be pointed out that ICF is fed by several contributory reactions on account of the use of the natural target, augmenting the production of ^{69,67}Ge, ^{68,67,66,65}Ga, ^{65}Zn residues. The role of input angular momentum suggests the fusion of ℓ-boundaries as the range of critical angular momentum (ℓ_{crit}≈18–25$\hbar$ for ^{7}Li+^{64}Zn system) computed employing the Wilczyński's formalism [4] is found to be higher than the maximum angular momentum (ℓ_{max}) for reaction. Thus, the contribution from significant ℓ-bins below ℓ_{crit} to the population of ICF channels has been observed in addition to the ICF occurrence for partial waves above ℓ_{crit}.

Conclusion

Evaporation residue measurement has been performed for ^{7}Li+Zn system within the 21–43 MeV energy range. The EF analysis revealed the dominance of CF in xn-channels and an interplay of CF-ICF mechanisms in p and α-emitting channels owing to the direct and/or transfer-induced breakup of weakly bound ^{7}Li projectile. The ICF strength fraction has been estimated ≈2.5–4.1% per channel in the studied energy range.

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References

[1] L. F. Canto *et. al.*, Phys. Rep. **596**, 1 (2015)

[2] A. Shrivastava *et. al.*, Phys. Lett. B **718**, 931 (2013).

[3] D. Kumar *et. al.*, Phys. Rev. C **96**, 014617 (2017).

[4] J. Wilczyński *et. al.*, Nucl. Phys. A **216**, 386 (1973), Nucl. Phys. A **373**, 109 (1982).