Excitation functions of residues in ^{13}C+^{169}Tm interaction at $E_{Lab} \approx$ 4-7 MeV/A

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Introduction

The understanding of light heavy-ion (HI) induced reactions has been a topic of great interest in recent years [1]. At energies around the Coulomb barrier, the most dominant reaction process is the fusion of the entire projectile with the target nucleus leading to the formation of the compound nucleus (CN)[2, 3]. Nevertheless, incomplete fusion (IF) has been found as a competing fusion-like process at energies just above the Coulomb barrier [4]. In the IF process, incident HI is assumed to break into fragments (predominantly into α-clusters), one of the fragments may fuse with the target nucleus and the remenant moves almost with the same velocity as that of the incident projectile in the forward direction. The presence of IF at slightly above barrier energies ($E_{Lab} \geq V_b$) and its influence on complete fusion (CF) at relatively higher energies gained resurgent interest in the recent years [1, 4]. Few important issues related to IF reaction dynamics which need further investigation are the dependence of IF on (i) projectile energy, (ii) entrance channel mass asymmetry, (iii) input angular momenta (ℓ-values), (iv) deformation of the interacting partners, etc. Several models [4] have been reported in literature to explain the mechanism of IF processes, but none of these models are found to explain IF contributions at the projectile energies of interest. In order to get detailed information regarding the IF reaction dynamics and in view of the availability of limited data covering only a few projectile-target combinations at E_{Lab}/A $\approx$ 4-8 MeV, we have undertaken a program of precise measurement and analysis of (i) excitation functions (EFs) to determine the IF strength function, (ii) recoil range distributions (RRDs) as a proof of fusion incompleteness, and (iii) spin distributions (SDs) as a sensitive tool to probe IF dynamics. In the present work, an attempt has been made to deduce the IF stength function from the analysis of EFs and the influence of IF on CF in ^{13}C+^{169}Tm reactions in the energy range $\approx$ 50-86 MeV, using offline γ-ray spectrometry, has been studied. The present results are compared with existing ^{12}C+^{169}Tm data [5], to study the entrance channel effect.

Experimental details

The experiments have been performed using $^{13}C^{6+}$ ion beam on ^{169}Tm target at the Inter University Accelerator Centre (IUAC), New Delhi, India using 15 UD Pelletron Accelerator facility. The targets of ^{169}Tm ($\approx$ 99.9%) of thickness $\approx$ 1.45 - 3.0 mg/cm^2 and Al-catchers ($\approx$ 1.5-2.5 mg/cm^2) were prepared by rolling method. Targets followed by Al-catcher foils have been irradiated in the General Purpose Scattering Chamber having an in-vacuum transfer facility. Several stacks of target-catcher assembly have been irradiated to cover a wide energy range $\approx$ 50-86 MeV. Keeping in mind the half-lives of interest, samples were irradiated for $\approx$ 8-10 hrs with beam current of $\approx$ 5 pnA. The activities induced in

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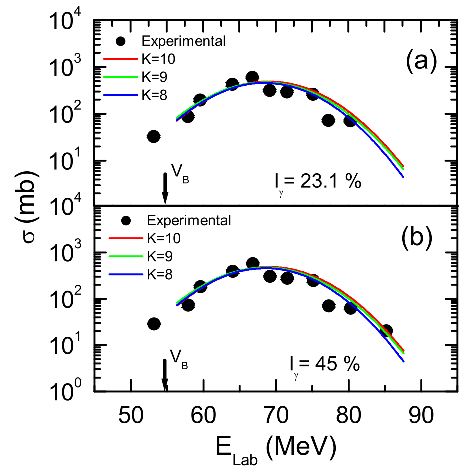

FIG. 1: EFs for reaction ^{169}Tm(^{13}C,4n)^{178}Re deduced from E_γ (a) 106.06 keV and (b) 237.19 keV

the samples were recorded by counting each target alongwith the catcher foil kept behind using a pre-calibrated HPGe γ-ray spectrometer of 100 c.c. active volume coupled to a CAMAC based CANDLE software. The intensities of the characteristic γ-rays have been used to determine the cross-sections for the residues populated via CF and/or IF processes.

Results and Discussion

In order to examine the influence of IF on CF, the EFs for several reactions viz., ^{169}Tm(^{13}C,4n)^{178}Re, ^{169}Tm(^{13}C,5n)^{177}Re, ^{169}Tm(^{13}C,6n)^{176}Re, ^{169}Tm(^{13}C,p4n)^{177}W, ^{169}Tm(^{13}C,p5n)^{176}W, ^{169}Tm(^{13}C,p6n)^{175}W, ^{169}Tm(^{13}C,α)^{178}Ta, ^{169}Tm(^{13}C,α2n)^{176}Ta, ^{169}Tm(^{13}C,α3n)^{175}Ta, ^{169}Tm(^{13}C,α4n)^{174}Ta and ^{169}Tm(^{13}C,3pn)^{177}Hf have been measured. Experimentally measured cross-sections have been compared with those calculated using statistical model code PACE4 (based on Hauser-Feshbach theory) [6]. The code PACE4 is based on CN deexcitation by Monte Carlo procedure. In this code, the level density parameter a(=A/K), is one of the important parameters, where A is the mass number of the nucleus and K is a free parameter. The value of the K may be varied to match the experimental data. In the present work we tested the experimental data using different values of level density parameters from A/8 to A/10 MeV^{-1}. Furthermore, it may be pointed out that the PACE4 calculations do not take IF into account. As a representative case, the experimentally measured and theoretically calculated EFs and the effect of the variation of above parameter 'K' for the reaction ^{169}Tm(^{13}C,4n)^{178}Re identified by two different intense (I_γ) characteristic γ-lines are shown in Fig.1(a) and (b) respectively. As can be seen from this figure the EF for 4n channel is in good agreement with the predictions of code PACE4, which indicates the production of this channel via CF process only. Similar observations have been obtained for other *xn* and *pxn* channels, indicating their population via CF process only. Further, in order to look into the production mechanism of α-emitting channels, the experimentally measured EFs have been compared with the PACE4 calculations. The measured EFs for α-emitting channels are found to be significant enhanced over the calculated values. This enhancement may be attributed as the contribution of IF. For a better understanding of IF process, the strength function of incomplete fusion has also been deduced and found to be energy dependent. An attempt has also been made to understand the CF suppression at above barrier energies. Further details regarding the effect of projectile structure and α-Q-value on the IF strength function will be presented.

References

[1] A. Diaz-Torres et al., J. Phys. G: Nucl. Part. Phys. **37**, 075109 (2010)

[2] F. Schussler et al., Nucl. Phys. A **584**, 704 (1995)

[3] E. Gadioli et al., Nucl. Phys. A **641**, 271 (1998)

[4] Abhishek Yadav et al., Phys. Rev. C **85**, 034614 (2012) and ibid. **85**, 064617 (2012)

[5] P. P. Singh et al., Phys. Rev. C **80**, 064603 (2009).

[6] A. Gavron, Phys. Rev. C **21**, 230 (1980)