Probing of incomplete fusion by measurements of excitation functions in ^{14}N + ^{124}Sn system

Amritraj Mahato[1], D. Singh[1,*], Pankaj K. Giri[1], Sneha B. Linda[1], Harish Kumar[2], Suhail A. Tali[2], Siddharth Parashari[2], Asif Ali[2], Rakesh Dubey[3], M. Afzal Ansari[2], R. Kumar[3], S. Muralithar[3], and R. P. Singh[3]

[1]*Department of Physics, Central University of Jharkhand, Ranchi - 835205, INDIA*
[2]*Deptartment of Physics, Aligarh Muslim University, Aligarh- 202002, INDIA*
[3]*Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi - 110067, INDIA*
** email: dsinghcuj@gmail.com*

Introduction

The study of dynamics of heavy ion induced complete (CF) and incomplete fusion (ICF) reactions have been a subject of resurgent interest in the field of nuclear physics for past few decades. In case of complete fusion (CF) process, entire projectile fuses with the target and the highly excited compound system decays by evaporating low energy nucleons and α-particles at the equilibrium stage. Whereas in case of ICF reactions, only a part of the projectile fuses with the target nucleus, leading to transfer of a fraction of the incident momentum to the target nucleus, while the remainder behaves as a spectator and moves in the forward cone. The first evidence of ICF was observed by Britt and Quinton [1]. Major advances in the understanding of ICF dynamics took place after the charged particle-γ coincidence measurements by Inamura *et al.* [2] for ^{14}N + ^{159}Tb system at beam energy about ≈7 MeV/nucleon. Several theoretical models have been proposed to explain the ICF dynamics such as, Sum-rule model of Wilczynski *et al.*, Break up fusion model by Udagawa and Tamura, etc. However none of them could satisfactorily reproduce the experimental data at energies below 10 MeV/nucleon. This makes the study of ICF still an active area of investigation. Some recent studies show the dependence of ICF dynamics on various entrance channel parameters [3].

In the present work the excitation functions (EFs) of evaporation residues (ERs) populated via CF and/or ICF, in the ^{14}N + ^{124}Sn system have been measured in the projectile energy range ≈ 4-7 MeV/nucleon.

Experimental details

The experiment was performed using $^{14}N^{6+}$ beam delivered by 15 UD Pelletron accelerator at Inter University Accelerator Centre (IUAC), New Delhi. The isotopically enriched ^{124}Sn targets of thickness ≈ 0.1- 0.6 mg/cm^2 have been used. Recoil catcher activation technique has been employed for the present measurement of excitation functions. Aluminum catcher foils of thickness ≈ 1.0-1.5 mg/cm^2 have been placed after the targets to trap the recoiling particles. The thickness of targets and Al-backing foils has been measured by weighing method using microbalance as well as by the measurement of energy loss of 5.487 MeV α-particles emitted from standard ^{241}Am source. A stack consisting of six ^{124}Sn targets along with Al-backings was bombarded with energetic $^{14}N^{6+}$ beam of energy 85 MeV. The irradiation was carried out in General Purpose Scattering Chamber (GPSC) facility at IUAC, New Delhi, which has an In-Vacuum transfer facility to minimise the time lapse between the stop of irradiation and start of counting. Keeping in view the half-lives of interest, the stack was irradiated by ^{14}N beam for ≈7 hours. The beam current was about 2-4 pnA as monitored using a Faraday cup installed behind the stack. The respective energies of ^{14}N ion beam at each target were calculated using SRIM-2013. The activities produced in these foils were recorded at different time intervals using a pre-calibrated High Purity Germanium Detector (HPGe) detector of 100cm^3 active volume. The software CANDLE has been used for recording the data and during analysis process. The energy and efficiency calibration of HPGe detector was done using ^{152}Eu γ-ray source of known strength. The identification of ERs produced has been done by the identification of their characteristic γ-ray in the recorded spectrum and also by their decay curve analysis, following their half-lives. The production cross-section (σ) for different ERs has been measured using the standard formalism given in [4].

Results and discussion

The EFs of nine evaporation residues populated through xn (x= 5, 6, 7), pxn (x= 6), αxn (x= 0, 2, 4, 5) and αpxn (x= 2) channels, which may be formed via CF and/or ICF in the ^{14}N + ^{124}Sn system, have been measured. As a representative case, the measured EFs for the residues populated via xn, pxn and αxn (x= 2) channels are shown in Fig.1.

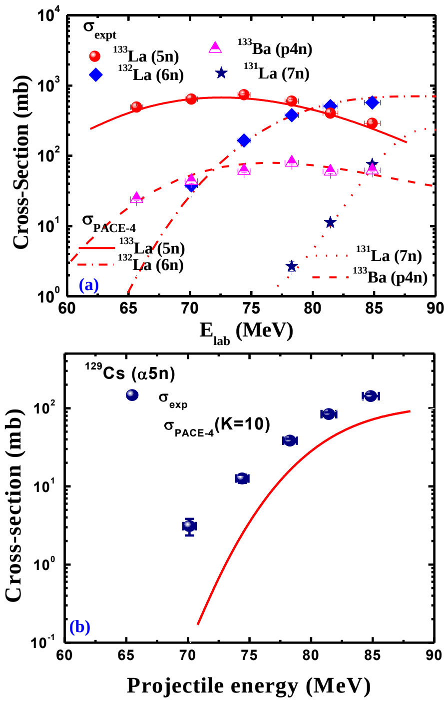

Fig. 1 The experimentally measured EFs along with PACE-4 calculations for (a) xn (x=5, 6, 7) and p4n-channels and (b) α5n channel.

The measured EFs have been compared with the theoretical predictions calculated using code PACE-4 [5], which is based on CN-model. In these calculations, the level density parameter a= A/K (K= 10) has been taken. As can be seen from Fig.1 (a), the xn and pxn channels are populated only by CF process and are satisfactorily reproduced by PACE-4 predictions. While in case of α-emitting channels, the measured EFs are found to be enhanced over the theoretical predictions, as shown in Fig.1 (b).

The ICF fraction F_{ICF}, which is a measure of the relative contribution of ICF process over the CF process, has also been deduced and compared with other systems available in literature. It has been found that the ICF fraction increases with entrance channel mass asymmetry $(A_T-A_P)/(A_T+A_P)$, but independently for different projectiles at same relative velocity $v^{relt} = \sqrt{2(E_{cm} - V_{CB})/\mu}$, as shown in Fig. 2.

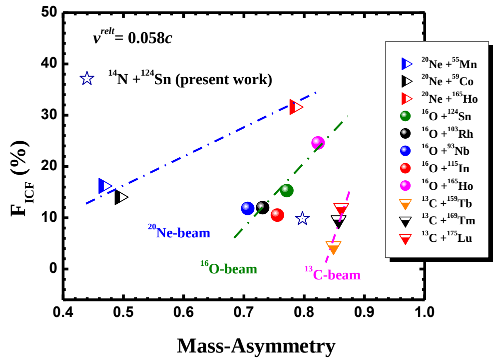

Fig. 2 The ICF fraction as a function of mass asymmetry for the present system along with others from literature.

Acknowledgements

Authors are thankful to the Head, DOP, CUJ, Ranchi and Director, IUAC, New Delhi for providing necessary facilities to carry out this work. D. S. thanks UGC, DST and A. M. thanks UGC for financial support.

References

[1] H. C. Britt and A. R. Quinton, Phys. Rev. **124,** 877 (1964)
[2] T. Inamura *et al.* Phys. Lett. B **68,** 51 (1977)
[3] D. Singh *et al.* Phys. Rev. C **97**, 064610 (2018)
[4] M. A. Ansari *et al.* Ann. Nucl. Energy **11**, 607 (1984).
[5] A. Gavron, Phys. Rev. C **21**, 230 (1980).