Study of incomplete fusion sensitivity to projectile structure from forward recoil range distribution measurement

Harish Kumar[1*], Suhail A. Tali[1], M. Afzal Ansari[1**], D. Singh[2], Rahbar Ali[3], Siddharth Parashari[1], Asif Ali[1], Pankaj K. Giri[2], Sneha B. Linda[2], R. Kumar[5], R. P. Singh[5] and S. Muralithar[5]

[1]*Department of Physics, Aligarh Muslim University, Aligarh - 202 002, India*
[2]*Centre for Applied Physics, Central University of Jharkhand, Ranchi - 835 205, India*
[3]*Department of Physics, G. F. (P. G.) College, Shahjahanpur - 242 001, India*
[4]*Department of Physics, Jamal Mohammed College, Tiruchirappalli - 620 020, India*
[5]*Inter-University Accelerator Centre, New Delhi - 110 067, India*
*amu.harish@gmail.com
**drmafzalansari@yahoomail.com

Introduction

In recent years, continuous efforts have been put forth in the understanding of fusion like reactions, where the projectile break-up may takes place and one of the two fragments fuses with the target nucleus at low incident energies around 4-8 MeV/nucleon [1-3]. Such reactions are termed as incomplete fusion (ICF) or massive transfer reactions. Non availability of any theoretical model below 10 MeV/nucleon energies and nature of transferred mass makes the ICF study still a resurgent field of interest. The ICF behavior with various entrance channel parameters especially mass-asymmetry, projectile structure, projectile α-Q-value and Coulomb effect (Z_PZ_T) could also not be established explicitly. Existing studies based on excitation functions (EFs), forward recoil range distribution (FRRD) and spin distribution measurements show that ICF contributes significantly along with complete fusion (CF). The FRRDs measurement being a sensitive probe to differentiate the CF and ICF processes on the basis of recoil ranges gives the direct measure of full and/or partial linear momentum transferred (LMT) from the projectile to the target nucleus [2,3]. As in case of ICF, the partial amalgamation of projectile with target nucleus takes place, thereby the partial LMT leads the ICF products to be trapped at shorter depth in the stopping medium as that of CF products.

Recently, the projectile structure is also found to affect the ICF process by using α- and non-α-cluster structured projectiles which is explored in terms of projectile α-Q-value [3,4] and is still limited only for a very few systems. Keeping in view the recent aspects especially the projectile structure effect on ICF, the present work is carried out in the series of experiment by using α- and non-α-cluster structured projectiles. Presently, the FRRDs of evaporation residues (ERs) produced in $^{13}C + ^{175}Lu$ system have been measured at ≈ 88 MeV energy. In this work, an attempt has been made to have a better knowledge of projectile α-Q-value effect on ICF.

Experimental Procedure

The present experiment for the FRRDs measurement of ERs populated in $^{13}C + ^{175}Lu$ system was performed at IUAC Inter University Accelerator Centre (IUAC), New Delhi. The target of ^{175}Lu prepared by rolling technique was followed by a stream of thin Al-catcher foils of thickness lying between ≈ 24 - 45 μg/cm^2. The vacuum evaporation method was adopted for thin Al-catcher foils preparation, which served as the stopping medium. The Al-foils of proper thickness were chosen such that the recoiling residues produced via CF and/or ICF may get trapped completely at their respective catcher foil thicknesses. The irradiation of target-catcher assembly with ^{13}C ion-beam at energy ≈ 88 MeV was carried out in the General Purpose Scattering Chamber (GPSC) for about 16 hrs. The beam flux estimation was done from the total charge collected in the Faraday cup, placed behind the irradiated samples and a pre-calibrated 100cc HPGe detector coupled to a CAMAC based software FREEDOM was used for the recording of γ-ray activities build-up in each catcher foil.

Results and Discussion

Presently, the FRRDs of several ERs produced in the interactions of ^{13}C with ^{175}Lu target have been measured at energy ≈ 88 MeV. The ERs are interpreted to be populated via CF and/or ICF process on comparing the measured mean recoil ranges of FRRDs with the theoretical ranges calculated using the code SRIM. As shown in Fig. 1(a), the FRRD pattern of residue ^{181}Re is resolved into two Gaussian peaks at cumulative depth ≈ 348 μg/cm^2 and ≈ 239 μg/cm^2, respectively. Both observed recoil ranges agree well with theoretical recoil ranges (≈ 327 μg/cm^2 for ^{13}C fusion and ≈ 229 μg/cm^2 for ^{9}Be fusion) calculated using the code SRIM. It may infer that the fusion of ^{9}Be with target (if ^{13}C is assumed to break-up into ^{9}Be + ^{4}He) also contributes significantly along with CF. The relative contribution is found to be ≈ 11% for the fusion of fragment ^{13}C and ≈ 89% due to fusion of ^{9}Be. Present observation exhibits the fact that the projectile may also break-up into its fragments in the vicinity of target nuclear field.

In order to have the better insight into the projectile structure effect on ICF, the ICF probability function (F_{ICF}) deduced from present FRRDs analysis of ^{13}C + ^{175}Lu system along with that obtained from the EFs analysis of ^{12,13}C + ^{175}Lu systems [4] has been plotted against the projectile α-Q-value at same relative velocity (v_{rel} = 0.074c) and shown in Fig. 1(b). This figure shows clearly that the ICF probability is higher for less negative α-Q-value projectile ^{12}C (≈ –7.16 MeV) than more negative α-Q-value projectile ^{13}C (≈ –10.64 MeV) with the same target ^{175}Lu. Conclusively, the projectile structure affects strongly the ICF process which is interpreted in terms of projectile α-Q-value more effectively. It is also quite clear from Fig. 1(b) that F_{ICF} obtained from present FRRDs analysis have nearby the same value as that obtained from EFs analysis of ^{13}C + ^{175}Lu system [4], indicating the self-consistency with EF findings.

The authors are thankful to the Director, IUAC, New Delhi for providing the necessary experimental facilities throughout the work. One of the authors HK also thanks to UGC-DAE-CSR-KC for awarding Fellowship under the Research Project: UGC-DAE-CSR-KC/CRS/13/NP01.

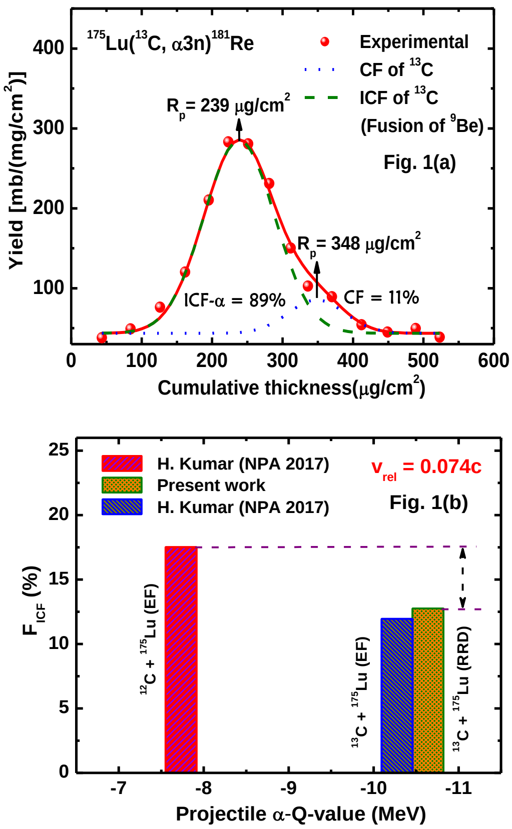

Fig.1: (a) Experimentally measured FRRD for residue ^{181}Re and **(b)** a comparison of deduced F_{ICF} (%) from the present FRRDs analysis along with that obtained from the EFs analysis [4] on the basis of projectile α-Q-value at same relative velocity (v_{rel} = 0.074c).

References

[1] B.S. Tomar *et al.*, Phys. Rev. C **49** (1994) 941.

[2] [4] D. Singh *et al.*, Phys. Rev. C **79** (2009) 054601.

[3] Abhishek Yadav *et al.*, Phys. Rev C **86** (2012) 014603; Phys. Rev. C **85** (2012) 064617.

[4] Harish Kumar *et al.*, Nucl. Phys. A **960** (2017) 53.