Incomplete fusion for ^{16}O+^{165}Ho system

Saikat Bhattacharjee[1,3],* A. Mukherjee[1,3], Ashish Gupta[1,3], Rajkumar Santra[1,3],† D. Chattopadhyay[1],† N. Deshmukh[1],‡ S. K. Pandit[2], K. Ramachandran[2], Sangeeta Dhuri[2,3], Shilpi Gupta[2,3], V.V. Parkar[2,3], K. Mahata[2,3], A.Shrivastava[2,3], Rebecca Pachuau[4],§ and S.Rathi[5]
[1]*Saha Institute of Nuclear Physics, Bidhan Nagar, Kolkata - 700064, India*
[2]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, India*
[3]*Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, India*
[4]*Tata Institute of Fundamental Research, Mumbai - 400005, India and*
[5]*Vivekanand Education Society's College of Arts, Science & Commerce, Mumbai - 400071, India*

Introduction

Incomplete fusion (ICF) process for several nucleus-nucleus collisions has been extensively studied in the past decades [1]. Generally, at the near barrier region, complete fusion (CF) becomes the only contributor to the total fusion (TF) cross-section. However; at higher energies, the ICF process becomes an important contributor to the total fusion cross-section.To study the contribution of ICF at above barrier energies for ^{16}O+^{165}Ho system in a range ≈ 4-7 MeV/ nucleon, Kumar *et al.* [2] has measured the experimental cross-section of different evaporation residues occurring from the reaction of ^{16}O+^{165}Ho. This work suggests that the energy onset of ICF occurs at an energy between Coulomb barrier (V_b) and 1.14V_b, which corresponds to relative velocity v_{rel}/c= 0.036. To study the energy onset of ICF, the measurement was performed from V_b and upwards in small energy steps.

Experimental Details

The experiment was performed at the 14UD BARC-TIFR Pelletron-LINAC facility, Mumbai. Self-supporting, rolled, natural foils of ^{165}Ho, with thickness ∼ 1.02-1.9 mg/cm^2 were irradiated by beams of ^{16}O, in the energy range E$_{lab}$=79-85 MeV. Each target foil of ^{165}Ho was followed by an Al catcher foil, sufficiently thick to stop the heavy evaporation residues (ERs) produced in the reaction. As all the ERs were β-active and yielded delayed γ-rays, the activation technique was employed to determine the fusion cross sections for the system. After each irradiation, the target-catcher foil assembly was removed from the chamber and placed in front of an efficiency calibrated HPGe detector, which detected the delayed γ-rays emitted by the ERs.

TABLE I: Spectroscopic properties of the evaporation residues, resulting via ICF process that have been used to calculate the ICF cross-sections for the ^{16}O+^{165}Ho system.

Residue	$T_{1/2}$(hrs)	E_γ(keV)	I^γ(%)
^{176}Ta	8.09	1159.2	24.6
^{175}Ta	10.5	349.0	11.4
^{173}Ta	3.56	172.2	17.5
^{166}Tm	7.7	1273.54	15.0

The residues arising from fusion reaction were identified from the characteristic γ-rays emitted by the daughter nuclei and following the half lives of the residues. The Faraday Cup installed behind the target- catcher foil assembly measured and recorded the beam current which is essential for calculation of fusion cross-section and to observe the stability of

*Electronic address: saikat.bhattacharjee@saha.ac.in
†Present adddress: Tata Institute of Fundamental Research, Mumbai - 400005, India
‡Present address: School of Sciences, Auro University, Surat, Gujarat - 394510, India
§Present address: Department of Physics, Banaras Hindu University, Varanasi 221005, India.

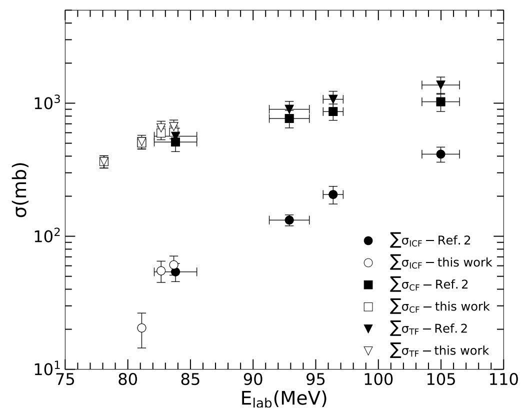

FIG. 1: Experimentally measured CF and TF cross-sections for $^{16}O+^{165}Ho$ system, measured by Kumar *et al.* [2] and in this work.

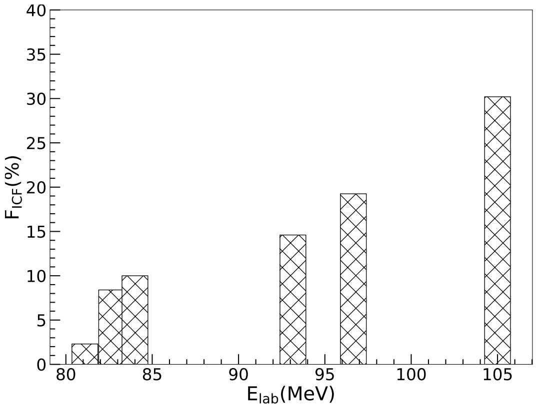

FIG. 2: Percentage ICF Fraction (F_{ICF}) for the $^{16}O+^{165}Ho$ system, at different lab energies.

the current during irradiation. For the system $^{16}O+^{165}Ho$, two different ICF processes are possible within the measured energy range. At first, the ^{16}O nucleus breaks into ^{12}C and α, and afterwards one of the fragments fuses with ^{165}Ho target. For $^{12}C+^{165}Ho$ reaction with α as a spectator, the ERs of Ta are obtained. For $\alpha+^{165}Ho$, the Tm ER was produced.

Analysis and Results

If N_γ represents the number of counts under a particular γ-ray peak, corresponding to a given ER in the spectrum, then from the principle of radioactive decay the corresponding ER cross-section (σ_{ER}) can be obtained from the following equation [3]:

$$\sigma_{ER} = \frac{N_\gamma \lambda e^{\lambda t_w}}{N_B N_T \epsilon_\gamma F_\gamma (1 - e^{-\lambda t_c})(1 - e^{-\lambda t_{irr}})} \tag{1}$$

where N_B is the number of incident nuclei, N_T is the number of target nuclei per unit area, λ is the decay constant of the ER, t_{irr} is the irradiation time, t_w is the time elapsed between the end of irradiation and the beginning of counting, t_c is the counting time, ϵ_γ is the efficiency of the detector for a given γ-ray energy, and F_γ is the absolute intensity of a γ-ray decay.

The CF cross-sections for $^{16}O+^{165}Ho$ has already been meaured at energies below and above V_b [4]. The ICF measurement, together with the previous CF work suggests that the energy onset of ICF occurs at a relative velocity $v_{rel}/c = 0.027$. This value of v_{rel}/c is close to the nearby strongly bound projectile system $^{20}Ne+^{165}Ho$ [5]; for which the estimated $v_{rel}/c = 0.025$, at the energy onset of ICF.

Acknowledgments

We sincerely thank the staff of BARC-TIFR Pelletron facility for an uninterrupted supply of beam. We would like to extend our gratitude towards Dr. Sanjoy Pal of TIFR, Mumbai; for helping with the digital data acquisition.

References

[1] V. Jha, V.V. Parkar, and S. Kailas, Phys. Rep. **845**, 1 (2020) and references therein.
[2] K. Kumar *et al.*, Phys. Rev. C, **87**, 044608 (2013).
[3] P.R.S. Gomes, and T.J.P. Penna, Nucl. Instrum. Meth- ods Phys. Res. A **280**, 395 (1989).
[4] Saikat Bhattacharjee et al., Proc. DAE Symp. Nucl. Phys **64**, 405 (2019).
[5] D. Singh *et al.*, Nucl. Phys. A **879**, 107 (2012).