Measurement of sub-barrier fusion cross sections for ^{19}F+^{181}Ta

Md. Moin Shaikh[1], S. Nath[1],* J. Gehlot[1], Tathagata Banerjee[1], Ish Mukul[2], R. Dubey[1], A. Shamlath[3], P. V. Laveen[3], M. Shareef[3], A. Jhingan[1], N. Madhavan[1], T. Rajbongshi[4], and P. Jisha[5]
[1] *Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi 110067, India*
[2] *Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot 76100, Israel*
[3] *Department of Physics, School of Mathematical and Physical Sciences, Central University of Kerala, Kasaragod 671314, India*
[4] *Department of Physics, Gauhati University, Guwahati 781014, India and*
[5] *Department of Physics, University of Calicut, Calicut 673635, India*

The fusion excitation functions at near barrier energies have been studied quite extensively in the last few decades to understand the effect of different intrinsic couplings on tunneling. It is well documented in the literature that coupling of different degrees of freedom to the entrance channel explains the larger fusion cross sections ($\sigma_{\rm fus}$) at sub-barrier energies compared to the predictions of one dimensional barrier penetration model (1DBPM). The coupling splits the single barrier into multiple barriers and transmission of flux through them leads to large enhancement of experimental $\sigma_{\rm fus}$. When the incident energy of the projectile decreases even further in the deep sub-barrier region, conflicting results have been observed. The measurements of symmetric systems [1–3], showed fusion hindrance with respect to the coupled-channels (CC) calculations at deep sub-barrier energies, with some exceptions [4, 5]. The observations for highly asymmetric systems are not very clear either, while ^{6,7}Li+^{198}Pt systems [6, 7] showed no sign of fusion hindrance, signature of fusion hindrance was observed for the system ^{16}O+^{208}Pb [8]. Hence, precision measurements of fusion excitation functions at deep sub barrier energies is of utmost importance.

Recoil separators have extensively been used to measure heavy ion-induced $\sigma_{\rm fus}$. However, unambiguous identification of the fusion product, *viz.* evaporation residue (ER), amongst overwhelmingly dominant background events becomes extremely challenging in the deep sub-barrier energies. We report here our measurement of $\sigma_{\rm fus}$ for the asymmetric system ^{19}F+^{181}Ta at sub-barrier energies, where no data existed previously.

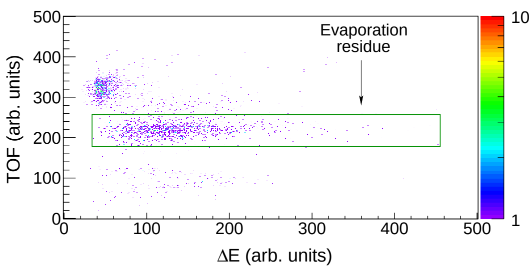

FIG. 1: Scatter plot between ΔE and TOF of the events recorded at the focal plane of HIRA at $E_{\rm lab}$ = 79.7 MeV.

The experiment was carried out at the 15UD Pelletron accelerator facility of IUAC, New Delhi. A pulsed ^{19}F beam, with pulse separation of 4 μs, was bombarded on a ^{181}Ta (170 μg/cm^2) target with a $^{\rm nat}$C (20 μg/cm^2) backing. ERs were separated from the background events using the recoil mass spectrometer, Heavy Ion Reaction Analyzer (HIRA). Two monitor detectors were placed at laboratory angle ($\theta_{\rm lab}$) 15.5° with respect to beam direction, in the horizontal plane, for absolute normalization of ER cross section ($\sigma_{\rm ER}$). ERs were recorded by a multi-wire propor-

*Electronic address: subir@iuac.res.in

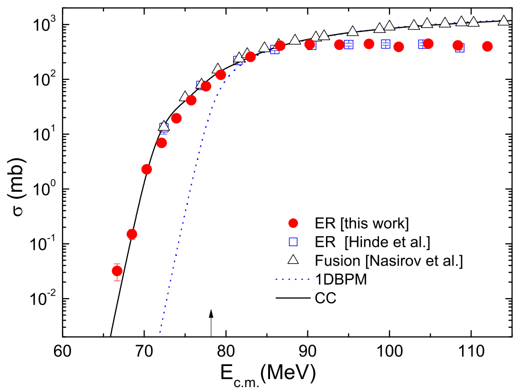

FIG. 2: The experimental fusion excitation functions for the system ^{19}F + ^{181}Ta along with the theoretical predictions.

tional counter (MWPC), having an active area of 15.0×5.0 cm^2, placed at the focal plane of HIRA. A very thin (0.5 μm) mylar foil was used as the entrance window of the MWPC to minimise loss of energy for the ERs. The HIRA was operated with 10 msr acceptance and at 0°. Time of flight (TOF) of the ERs were also recorded. Yields of ERs were extracted from the coincidence spectrum between energy loss ΔE (from the cathode of MWPC) and TOF. A representative spectrum at laboratory energy ($E_{\rm lab}$) 79.7 MeV is shown in Fig. 1.

Unambiguous identification of ERs becomes increasingly challenging with decreasing $E_{\rm lab}$. A new method of identifying ERs amidst background events has recently been reported by Rajbongshi *et al.* [10]. Transmission efficiency of HIRA ($\epsilon_{\rm HIRA}$), crucially required for estimation of $\sigma_{\rm ER}$, was calculated using the semi-microscopic Monte Carlo code TERS [11].

Hinde *et al.* [12] had reported experimental ER and fission excitation functions for ^{19}F+^{181}Ta, measured at $E_{\rm lab}$ = 80–126 MeV. We extended the measurement upto $E_{\rm lab}$ = 74 MeV. This corresponds to nearly three orders of magnitude reduction in $\sigma_{\rm ER}$ compared to the cross sections reported earlier. It is evident from Ref. [12] that the fission cross section ($\sigma_{\rm fis}$) is insignificant compared to $\sigma_{\rm ER}$ at the range of $E_{\rm lab}$ (74–80 MeV) considered in the present work. Therefore, we considered $\sigma_{\rm ER}$ to be $\sigma_{\rm fus}$ in our work. On the other hand, at $E_{\rm lab}$ above the barrier, one has to consider that $\sigma_{\rm fus} = \sigma_{\rm ER} + \sigma_{\rm fis}$. Measured $\sigma_{\rm ER}$ along with $\sigma_{\rm fus}$, which was obtained from the work of Nasirov *et al.* [13] are shown in Fig. 2. We compared experimental $\sigma_{\rm fus}$ with the predictions of 1DBPM and CC calculation employing the code CCFULL [14]. Parameters of the Woods-Saxon potential, *i.e.* V_0, r_0 and a, were taken as 104.5 MeV, 1.12 fm and 0.70 fm, respectively.

Measured $\sigma_{\rm fus}$ appears to be well reproduced by conventional CC calculation in the range of $E_{\rm ab}$ considered in the present work. We intend to extend our measurement to deep sub-barrier energies in a future work to explore fusion hindrance, if any, which has especially been observed in symmetric reactions.

The authors thank the Pelletron staff of IUAC for providing beams of excellent quality throughout the experiment, Mr. Abhilash S. R. for assistance in fabricating the target and Mr. T. Varughese for support during the experiment.

References

[1] C. L. Jiang, *et al.*, Phys. Rev. Lett. **89**, 052701 (2002).
[2] C. L. Jiang, *et al.*, Phys. Rev. Lett. **93**, 012701 (2004).
[3] A. M. Stefanini, *et al.*, Phys. Rev. C **82**, 014614 (2010).
[4] A. M. Stefanini, *et al.*, Phys. Rev. C **92**, 064607 (2015).
[5] C. L. Jiang, *et al.*, Phys. Rev. C **82**, 041601(R) (2010).
[6] A. Shrivastava, *et al.*, Phys. Rev. Lett. **103**, 232702 (2009).
[7] A. Shrivastava, *et al.*, Phys. Lett. B **755**, 3326 (2016).
[8] M. Dasgupta, *et al.*, Phys. Rev. Lett. **99**, 192701 (2007).
[9] A. K. Sinha *et al.*, Nucl. Instrum. Meth A **339**, 543 (1994).
[10] T. Rajbongshi *et al.*, Phys. Rev. C **93**, 054622 (2016).
[11] S. Nath, Comput. Phys. Commun. **180**, 2392 (2009).
[12] D. J. Hinde, *et al.*, Nucl. Phys A **385**, 109 (1982).
[13] A. K. Nasirov *et al.*, Phys. Lett. B **686**, 72 (2010).
[14] K. Hagino, N. Rowleyi and A. T. Kruppa, Comput. Phys. Commun. **123**, 143 (1999).