Exploring Quasi-fission Dynamics of ^{216}Th

A. Sultana[1,2,*], A. Sen[1,2], T.K. Ghosh[1,2], K. Atreya[1,2], S. Kundu[4], Pankaj Pant[1,2], K. Banerjee[1,2], K. Rani [1], S. Santra[2,3], A. Pal[2,3], A. Baishya[2,3], K. Mahata[2,3], P. C. Rout[2,3], S. Dhuri[2,3], T. Singh[2,3], M. Meher[2,3], and V. Kumar[2,3]
[1] *Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064, India*
[2] *Homi Bhabha National Institute, Anushakti Nagar, Mumbai 400094, India*
[3] *Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400085, India and*
[4] *UGC DAE CSR Kolkata, 700098, India*

Introduction

Understanding the reaction dynamics in synthesizing heavy (HE) and superheavy elements (SHE) is a key frontier in nuclear physics reserach. In heavy ion-induced fusion reactions, processes like fusion-fission, quasi-fission (QF), and transfer-induced fission occur near the Coulomb barrier, influencing the SHE formation [1]. The QF process, in which the composite system re-separates before acquiring a compact compound nucleus, is a major hurdle to the formation of heavy and super-heavy evaporation residues (ER). Numerous entrance channel parameters, especially charge product of nuclei (Z_pZ_t), mass asymmetry (α), nuclear deformation (β), isospin, shell effects, and collision energy, have profound effects on the dynamics of the QF process. A variety of experiments are currently underway worldwide to deepen our understanding of QF and FF dynamics.

Despite this, there remains a scarcity of robust theoretical models that can reliably quantify the extent of QF in nuclear reactions. To ensure their accuracy, any newly developed models must be rigorously validated against experimental data. Recent developments in theory, using the di-nuclear system (DNS) model and advanced statistical models [2], have predicted a significant increase in QF with increasing excitation energy in fusion reactions of ^{16}O and ^{19}F on pre-actinides targets ^{181}Ta and ^{184}W. Respectively our measurements on mass distribution for these two reactions were found to be contrary to the claims of the presence of QF predicted by the model [3]. The same theoretical model predicts QF in reaction ^{35}Cl+^{181}Ta. In a recent experiment we explored the presence of QF in the ^{35}Cl induced reaction to test the validity of the model. Presence of QF in a reaction can be observed from the fission fragment (FF) mass-angle correlations, or the broadening of FF mass distributions.

Experimental details

The experiment was conducted at the BARC-TIFR Pelletron Linac facility using pulsed ^{35}Cl beams, with energies near the Coulomb barrier [E_{cm}/V_B between 0.95 and 1.05]. A ^{35}Cl beam was bombarded on a ^{181}Ta target (270 μg/cm^2) to populate the ^{216}Th nucleus. Two position-sensitive multiwire proportional counters (12.5 cm × 7.5 cm) were placed at 35.6 cm and 35.1 cm from the target to detect fission fragments [4]. The detectors, mounted at 45° and 90° with respect to the beam axis, recorded the time of flight relative to the beam pulsing system. The detectors were operated at 2.7 Torr pressure of isobutane gas. The fragment masses were calculated from the time-of-flight difference method.

Results and discussions

At energies above and below the Coulomb barrier, the mass distributions of the fission fragments and the mass angle correlations were determined in the experiment. A representative Mass Angle Distribution (MAD) plot for the reaction at E_{cm} = 149.6 MeV (E_{cm}/V_B= 1.04) is shown in Fig.1. The

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[*] Electronic address: `ajmira.sultana1@gmail.com`

mass-angle correlation is related to the fission timescale, with stronger correlations in MAD indicating faster QF events, while weaker correlations suggest slower QF processes [5]. A clear and strong mass-angle correlation can be observed in the figure, suggesting the presence of fast QF in this reaction.

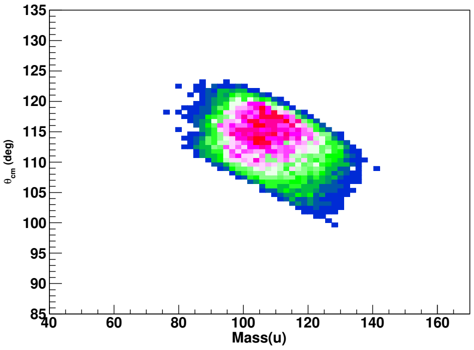

FIG. 1: The fission fragment mass-angle correlation of ^{216}Th at 62.4 MeV excitation energy.

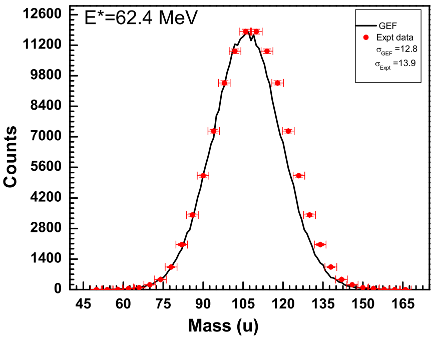

FIG. 2: The fission fragment mass distribution of ^{216}Th at 62.4 MeV excitation energy.

Fig.2 depicts the measured fission fragment mass distribution at an excitation energy of 62.4 MeV (E_{cm}/V_B= 1.04). The excitation energy is high enough that shell effects have minimal influence at this level, therefore wider mass distribution could indicate the presence of QF contribution. To understand the data, FF mass distributions are calculated using the semi-empirical model code GEF [6] for compound nuclear fission processes. It can be observed that the measured distributions are wider than the GEF calculations (as shown black solid line in Fig. 2). The experimentally determined width of the mass distribution is 13.9 u, while the semi-empirical GEF calcutaion predicts a width of 12.8 u. This wider mass distribution observed in the experiment provides additional evidence in favor of QF.

Both the wider mass distributions and mass-angle correlation indicate the presence of QF in this reaction. This is consistent with the theoretical predication of DNS model by Nasirov [2]. It may also be mentioned here that Laveen et al [7] measured the evaporation residue (ER) cross section for the ^{35}Cl+^{181}Ta reaction at similar excitation energies indicating the presence of QF.

Conclusion

Our measurement of fission fragment mass distribution in reaction ^{35}Cl+^{181}Ta indicates the presence of QF, the finding is consistent with the DNS model. We are at the interesting juncture to note that while the model could not explain the data for the light ion induced (e.g; ^{16}O and ^{19}F) reactions, however predictions with heavy ion induced reactions (e.g; ^{35}Cl) are consistent with experimental data.

References

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