Probing reaction mechanisms in ^{12}C fusion with ^{181}Ta

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Introduction

Heavy-ion induced reactions involve the interaction of a large number of nucleons, which leads to several new nuclear reaction processes. Depending on the incident energy and various entrance channel parameters, complete fusion (CF), incomplete fusion (ICF), equilibrium (EQ) and pre-equilibrium (PEQ) emissions, and nucleon transfer processes are commonly expected [1, 2]. ICF has been observed in weakly bound and cluster structured projectiles below 10 MeV/nucleon energy. According to literature, PEQ emissions also start competing with compound nuclear processes at relatively higher energies [3, 4]. Hence, information about the emission of the light particles before or after the composite system's thermodynamic equilibration can be understood by comparing the measured excitation function with theoretical model estimations.

Interaction of heavy projectiles with heavy mass ($A > 120$) targets results in the formation of a massive excited compound nucleus (CN), which predominately de-excites through two modes, namely, evaporation of particles and fission followed by γ–ray emission. Fission fragment mass distribution (FFMD) is a useful observable as it provides insight into the dispersion parameters such as most probable mass and width parameter [5]. Studies for understanding fusion-fission (FF) dynamics in the preactinide region are of great interest nowadays due to limited experimental data, unlike the actinide region.

In this report, we have made an effort to explore the nuclear reaction processes involved in the fusion of ^{12}C + ^{181}Ta system.

Experiment

The experiment was performed at the 14UD BARC-TIFR Pelletron Accelerator facility, Mumbai, India. ^{12}C-ion beam having energy within 52 – 73 MeV in the laboratory frame of reference was bombarded on tantalum (^{181}Ta) targets, where each Ta target foil was backed with Al foil for energy degradation and catching the evaporation residues (ERs) in the forward beam direction. For estimating the energy degradation in each foil, SRIM code has been used. Pure (99.99%) natural Ta foils were prepared by the rolling method, having a thickness within 1.4 – 1.8 mg/cm^2. After the end of the bombardment, a precalibrated large volume high purity germanium detector coupled with a PC-based multi-channel analyzer and GENIE-2K software was used for γ–ray spectroscopic measurements. Based on characteristic γ–rays and decay profile, residues were identified, and the factors responsible for the uncertainty in the measurement of cross sections have been included.

Results and discussions

Excitation function for ^{190}Au, produced through ^{181}Ta(^{12}C, $3n$) reaction is represented in Fig. 1. PACE4 and EMPIRE3.2.2 nuclear reaction model codes have been adopted to estimate the cross section of ^{190}Au. Both the codes are based on the Hauser-Feshbach (HF) formalism for compound evaporation. However, the major difference is that EMPIRE considers all three major nuclear reactions during calculations, viz., direct, PEQ, and EQ, whereas PACE4 only considers EQ emissions. Level density parameter, $a = A/9$, has been used for PACE4 estimations, where A is the mass number of the CN. The Gilbert-Cameron level density model (GCM) has been used in EMPIRE calculation. Also, the exci-

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*Electronic address: moumita.maiti@ph.iitr.ac.in ton model with mean free path parameter 1.5 is used for the PEQ emission process.

It is evident from Fig. 1 that PACE4 is satisfying the measurements fairly well for the whole energy range except the lowest (52 MeV) and highest (72.7 MeV) energy points. In contrast, EMPIRE3.2.2 is overpredicting the data for energies >52 MeV. Therefore, the indistinguishability of PACE4 predictions with the measured data gives the idea about the absence of PEQ emission in the present study. Since PACE4 only considers EQ reaction formalism, which is based on the HF model, the formation of ^{190}Au can be regarded through a compound nuclear process.

The interacting partners in the present study are heavy, and several fission fragments within mass range $71 \leq A \leq 135$ have been identified along with ERs. Production of ^{71m}Zn, ^{74m}Br, ^{83}Br, ^{85m}Y, ^{86}Y, ^{93m}Mo, ^{104}Ag, ^{107}Rh, ^{122}Xe, ^{132}I, and ^{135}Ce fission fragments have been observed. Significantly large fission cross sections have been measured as compared to the theoretical estimations by PACE4 and EMPIRE, above the Coulomb barrier energies. Fig. 2 represents the FFMD at incident energy, $E_{lab} = 68.1 \pm 0.9$ MeV (excitation energy = 48.8 MeV). The Gaussian fitting ensures the broad and symmetric distribution, which signifies fission fragments' production through de-excitation of CN.

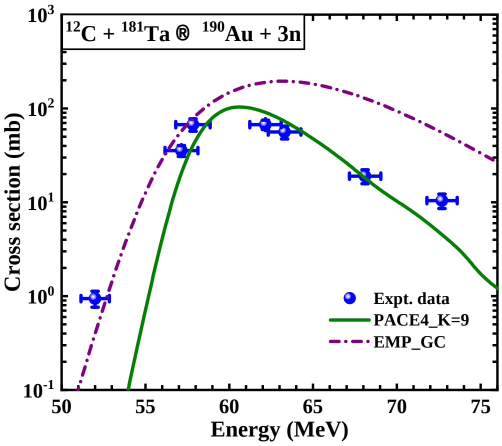

FIG. 1: Comparison of measured excitation function of ^{190}Au with theoretical predictions from PACE4 and EMPIRE3.2.2.

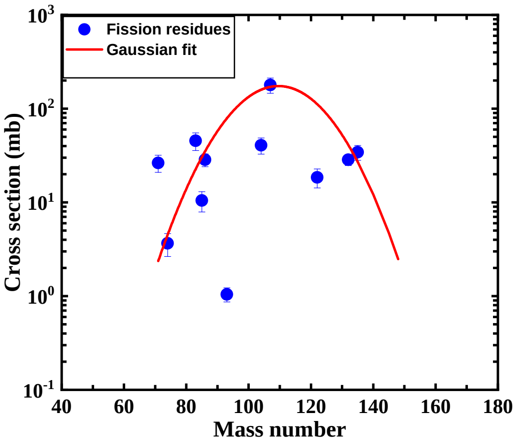

FIG. 2: FFMD at 68.1 MeV incident energy. Gaussian fit is represented by solid line.

Conclusion

Comparison of measured excitation function with the theoretical predictions for $3n$ channel residue, ^{190}Au, shows no sign of PEQ process in this energy range. Also, a total of 11 fission fragments have been identified at 68.1 MeV incident energy. It ensures the presence of the FF process.

Acknowledgments

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