Fission fragment mass distribution of ^{225}Pa

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1.Introduction

Quasi fission and fusion fission are two competing phenomena affecting the formation probability of Super Heavy Elements (SHE). The dynamics of quasi-fission needs to be well understood for the synthesis of SHE. The factors that governs whether a fusing system will follow fusion-fission or quasi-fission pathway, are the entrance channel of the reaction; namely the entrance channel mass asymmetry α, defined as $(A_T-A_P)/(A_T+A_P)$ [A_P,A_T being the projectile and target mass, respectively], the charge product of the target and projectile combination Z_PZ_T (where Z_P,Z_T being projectile and target atomic number), shell structure of the colliding nuclei, and deformations /orientations of the target and projectile. These variables are often strongly correlated, thus making it difficult to disentangle the effect of a single variable.

Shape and variation of the width of the fission fragment mass distribution (FFMD) with excitation energies are good observables to decipher the presence or absence of quasi-fission (and fast fission).However, at lower excitation energies (< 40 MeV), the width of the mass distribution may be simultaneously affected by the orientation dependent quasi-fission and nuclear shell effects. Study of FFMD at higher excitation energies is thus suitable to isolate these two effects. At higher excitation energies (well above the Coulomb barrier), the role of target/projectile deformation/orientation on the fusion process is also minimal.

A recent theoretical calculation [1] performed in the framework of the di-nuclear system and advanced statistical models, predicted dramatic increase of quasi-fission with increase in excitation energies for fusion of ^{16}O,^{19}F induced reactions on pre-actinide targets having entrance channel parameters lower than the Businaro Gallone mass asymmetry (α_{BG}) values. Measurement [2] of FFMD for these systems, however, indicated the absence of quasi fission. It is to be mentioned that the measurement [2] was constrained to near barrier energies.

Here we report the FFMD of two new reactions, with ^{16}O and ^{20}Ne beams on pre-actinide targets, both having mass asymmetries lower than α_{BG}, up to the excitation energy as high as 110 MeV ($E_{c.m.}/V_{cb} \sim 1.75$) where $E_{c.m}$ is centre of mass energy and V_{cb} represents coulomb barrier. The reactions ^{20}Ne+^{205}Tl (Z_PZ_T = 810) and ^{16}O+^{209}Bi (664) also populated the same compound nucleus ^{225}Pa at similar excitation energies. The result of the experiment provides benchmark data to test the new fission dynamical models.

2. Experiment

The experiment was performed with ^{20}Ne and ^{16}O beams from the K-130 cyclotron at the Variable Energy Cyclotron Centre, Kolkata, India. Beams of ^{20}Ne and ^{16}O in the laboratory energy ranges of 145-180 MeV and 116-160 MeV were bombarded on ^{205}Tl (300 μg/cm^2) and ^{209}Bi targets (400 μg/cm^2). For the detection of fission fragments, two large-area (20 cm × 6 cm) position-sensitive multiwire proportional counters (MWPCs) [3] were placed at the calculated folding angle. The folding angles were selected on the basis of Viola's systematics [4] which corresponds to symmetric fission fragments. The detectors were operated at low pressure of 3 torr. The time of arrival of the fission fragments, the position of impact of the fission fragment and the energy loss of the fission fragment was recorded in a VME based data acquisition system using LAMPS.

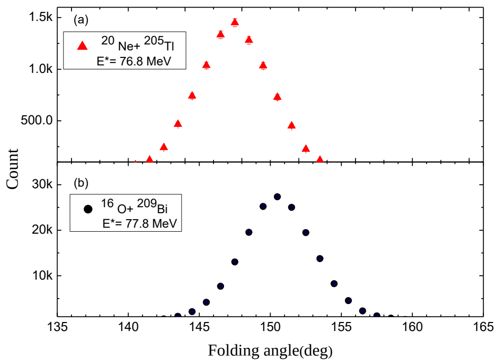

Fig.1: The representative folding angle distributions for (a) ^{20}Ne+^{205}Tl and (b) ^{16}O+^{209}Bi reactions at similar excitation energy.

3. Results and discussions

The representative folding angle distributions for the ^{20}Ne+^{205}Tl and ^{16}O+^{209}Bi reactions are shown in Fig.1. Both the systems showing single Gaussian folding angle distribution and peak position are consistent with the corresponding full momentum transfer events. The mass distributions have been obtained for both the systems by putting small gate in folding angle distribution to ensure full momentum transfer events. A representative mass distribution is shown in Fig.2, where the distributions are found to be symmetric in nature.

We compare the variance of the obtained mass distributions of fission fragments for different entrance channels. Figure 3 shows that the variance of the mass distribution increases with increase in excitation energies. However, no indication of sudden or stiff increase in the width of the mass distribution is observed, indicting absence of quasi fission for both the systems. The minor increase in the width of the mass distribution for the ^{20}Ne+^{205}Tl reaction compared to the ^{16}O+^{209}Bi at similar excitation energy can be explained by considering the higher angular momentum brought in by the heavier ^{20}Ne beam.

In conclusion, the measurement of fission fragment mass distributions for reaction ^{20}Ne+^{205}Tl and ^{16}O+^{209}Bi, populating the same compound nucleus, do not provide evidence of quasi-fission up to the excitation energy 110 MeV. The detailed experimental study along with the model calculation for the mass distribution will be presented in the symposium.

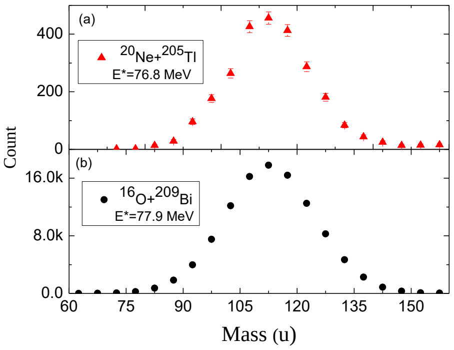

Fig.2: The representative mass distribution for (a) ^{20}Ne+^{205}Tl and (b)^{16}O+^{209}Bi at similar excitation energy.

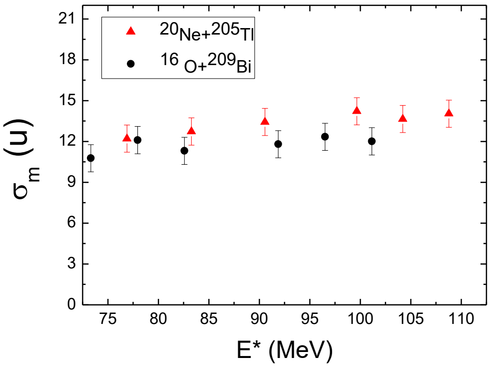

Fig.3: Variation in width of mass distribution as a function of excitation energy

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Reference

[1] A. K. Nasirov et al., Phys. Lett. B **686**, 72 (2010).
[2] A. Chaudhuri, Phys. Rev. C **94,** 024617 (2016).
[3] T. K. Ghosh et al., Nucl. Instrum. Methods Phys. Res. A **540**, 285 (2005).
[4] V. E. Viola, K. Kwiatkowski, and M. Walker, Phys. Rev. C **31**, 1550 (1985).