Mass resolved angular distribution of fission products in $^{16}O+^{238}U$ reaction at sub-barrier energy

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Introduction

Fission fragment angular distribution is a sensitive probe to investigate the contribution from non-compound nucleus (NCN) fission in heavy ion collisions. At beam energies not too high compared to the entrance channel Coulomb barrier, NCN fission can be divided into pre-equilibrium fission [1] and quasi-fission [2]. Both pre-equilibrium and quasi-fission lead to an increase in angular anisotropy due to the incomplete equilibration of *K*-degree of freedom, *K* being the projection of angular momentum on nuclear symmetry axis. The difference between the two processes lies in the fact that, in pre-equilibrium fission, the fissioning system reaches inside the unconditional saddle point. Whereas, in quasi-fission, the fissioning system escapes into the exit channel without being captured inside the saddle point leading to a suppression in formation of evaporation residues compared to the prediction of statistical theory. The process of NCN-fission and suppression in evaporation residue formation is not well understood in the light heavy ion induced fission of actinides. Based on the measurement of fission fragment angular distribution, Hinde *et al.* [3] reported presence of quasi-fission in $^{16}O+^{238}U$ reaction at sub-barrier energies. Based on the mass distribution measurement, Banerjee *et al.* [4] also reported contribution from quasi-fission in above system. However, Nishio *et al.* [5] did not observe any suppression in the evaporation residue cross section in this reaction. In these studies it was suggested that the anomalous angular distribution may be due to the contribution from pre-equilibrium fission. In our recent study, it was shown that the mass resolved angular distribution of fission products can be used to identify the presence of pre-equilibrium fission [6]. In the case of pre-equilibrium fission, angular anisotropy increases with decreasing asymmetry of mass division. Whereas, in the case of quasi-fission such a variation would be absent as fissioning system is not being captured inside the saddle point.

In order to investigate this aspect, mass resolved angular distribution has been measured in $^{16}O+^{238}U$ reaction at sub-barrier energy.

Experimental details

Experiments were carried out at BARC-TIFR Pelletron-LINAC accelerator facility, Mumbai. Self-supporting target of ^{nat}U (Thickness 3.0 mg/cm^2) was mounted at the entry of a cylindrical chamber having diameter 55.4 mm, and length 90.0 mm. Aluminum foils of thickness 6.75 mg/cm^2 (covering θ_{lab} from 90 to nearly 0 degree) were mounted at the inner wall of the chamber to collect the fission products recoiling out of the target. The target was irradiated with 87 MeV ^{16}O beam ($\langle E_{lab}\rangle$=85.3 MeV, E_{cm}/V_b=0.95) for about ~36 hrs. After irradiation, foils were cut into six stripes corresponding to different angles and were assayed for the gamma-ray activity of the fission products.

Results and discussions

From the gamma-ray activity of the fission products in different stripes, laboratory angular distributions of fission products were obtained, which were transformed into centre of mass (CM) frame of reference assuming full momentum transfer and using standard kinematic equations. The CM angular distributions were plotted as a function of $\cos^2\theta$ and were subjected to linear fit using equation $W(\theta)=a+b\cos^2\theta$. Fig. 1 shows the plot of '$W(\theta)$ vs $\cos^2\theta$' for some of the fission products. Solid

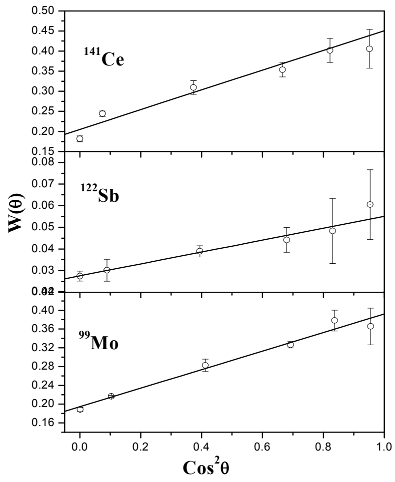

Fig. 1 Plot W(θ) versus $\cos^2\theta$ for ^{99}Mo. ^{122}Sb and ^{141}Ce.

lines are linear fit to the data. From the linear fit, angular anisotropy (W(0)/W(90)) was obtained as 1+b/a. A plot of angular anisotropy as a function of fission product mass is shown in Fig. 2. It can be seen from the figure that there is no systematic variation in the angular anisotropy with fission product mass. This observation is different from that observed in earlier studies in ^{16}O+^{232}Th [7] and ^{20}Ne+^{232}Th [6], in which angular anisotropy was observed to increase with decreasing asymmetry of mass division. Vorkapic and Ivanisevic [8] attributed the observed trend in ^{16}O+^{232}Th reaction to the decreasing time scale of the fission process with decreasing mass asymmetry and, thus, increasing contribution from pre-equilibrium fission. The mass asymmetry dependence of angular anisotropy in ^{20}Ne+^{232}Th reaction could also be explained on the similar ground [6]. In both these studies, the beam energy was above the entrance channel Coulomb barrier. However, as seen from Fig. 2, no such trend has been observed in the present study at sub-barrier energy. The mass independence of angular anisotropy suggests contribution from quasi-fission, in which fissioning system does not reach inside the saddle point. The average anisotropy is 2.09±0.19 which is close to the value observed by Hinde *et al.* [4] at similar beam energy. This value is higher than the expected value based on the statistical saddle point model indicating the contribution from NCN-fission, which appears to be dominated by quasi-fission. A correction for the contribution

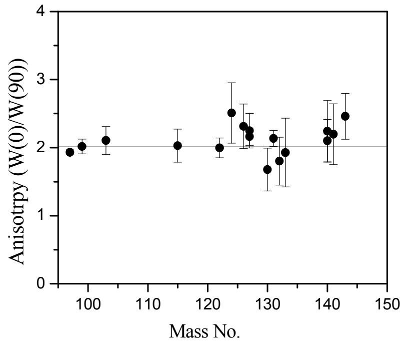

Fig. 2 Plot of angular anisotropy as a function of mass number.

from transfer induced fission (TF) would be necessary to confirm this observation. However, based on the mass distribution studies, it was observed that the contribution from TF is <30% and, therefore, TF is not likely to be the reason for washing out of the trend observed at above barrier energies.

Conclusions

Measurement of mass resolved angular distribution in ^{16}O+^{238}U reaction shows that the angular anisotropy is independent of mass asymmetry. This observation suggests that the fissioning system is not reaching inside the unconditional saddle point, indicating quasi-fission to be the dominant NCN fission process at sub-barrier energy rather than pre-equilibrium fission in the present reaction.

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References

[1] V. S. Ramamurthy and S. S. Kapoor, Phys. Rev. Lett. **54**, 178 (1985).
[2] W. J. Swiatecki, Phys. Scr. **24**, 113 (1981).
[3] D. J. Hinde *et al.*, Phys. Rev. Lett. **74**, 1295 (1995).
[4] K. Banerjee *et al.*, Phys. Rev. C**83**, 024605 (2011).
[5] K. Nishio *et al.*, Phys. Rev. Lett. **93**, 162701 (2004).
[6] R. Tripathi *et al.*, Phys. Rev. C **88**, 024603 (2013).
[7] Bency John *et al.*, Phys. Rev. C **51**, 165 (1995).
[8] D. Vorkapic and B. Ivanisevic, Phys. Rev. C **55**, 1997 (1997).