Mass resolved angular distribution of fission products in $^{28}Si+^{232}Th$

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Introduction

Fission fragment angular distribution is a sensitive probe to investigate the contribution from non-compound nucleus fission. Mass resolved angular distribution of fission products offers a possibility to distinguish the non-compound nucleus (NCN) fission process, namely, pre-equilibrium fission [1] and quasi-fission [2]. Both NCN-processes lead to an anomalous fission fragment angular distribution. The two processes differ in the fact that in the case of pre-equilibrium fission, the fissioning system reaches inside the unconditional saddle point, whereas, in the case of quasi-fission, fissioning system escapes into the exit channel without being captured inside the unconditional saddle point. In earlier studies of mass resolved angular distribution in $^{16}O+^{232}Th$ [3] and $^{20}Ne+^{232}Th$ [4] reactions, angular anisotropy was observed to increase with decreasing asymmetry of mass division. This could be explained after including the contribution from pre-equilibrium fission [4,5]. The contribution from pre-equilibrium increases with deceasing mass asymmetry due to a decrease in the fission time scale arising from the change in potential energy in the vicinity of the saddle point. These observations suggest that the fission system reaches inside the saddle point at above barrier energies in these reaction systems. It is important to extend these studies to heavier projectiles to investigate which of the two NCN fission processes is dominant. In the case of heavier projectiles the composite system may not reach inside the unconditional saddle point if the beam energy is not sufficiently above the entrance channel Coulomb barrier.

In the present work mass resolved angular distribution has been measured in 28Si+232Th reaction at E_{lab}=166 MeV (E_{cm}/V_b=1.08) to investigate the contribution from NCN-fission process.

Experimental details

Experiments were carried out at BARC-TIFR Pelletron–LINAC facility, Mumbai. Self supporting target of ^{232}Th of thickness 1.5 mg/cm^2 was irradiated with ^{28}Si beam at beam energy of 170 MeV. The target was mounted at 45° with respect to the beam so the average energy at the centre of the target was 166 MeV. Irradiation was carried out for about 58 hrs. The recoiling fission products emitted in the forward hemisphere were collected in aluminum foil of thickness 6.75 mg/cm^2 mounted on the inner wall of a cylindrical chamber of length 130 mm and

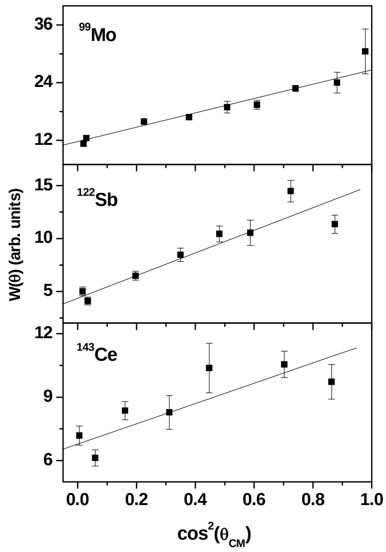

Fig. 1. Plot of W(θ_{cm}) vs. $\cos^2(\theta_{cm})$ for a few fission products. The solid lines are the linear fit to the experimental data

diameter 146 mm. The foil covered a lab angular range of 90° to 2.2° and an azimuthal angular range of 0°-180°. After the irradiation the catcher foils were cut into 10 strips of thickness around 20 mm and each strip corresponding to different θ_{lab} were assayed for the activity of the fission products using a HPGe detector coupled to a PC- based multichannel analyser. Gamma-spectra were analyzed using the spectrum analysis software PHAST to obtain the peak areas under the characteristic gamma-ray energy peaks of the fission products.

Results and discussion

From the gamma-ray peak areas, lab angular distributions for different fission products were obtained. These were transformed into centre of mass (CM) frame of reference using the standard kinematic equations assuming full momentum transfer. A plot of fission product angular distribution ($W(\theta_{cm})$ vs. $\cos^2(\theta_{cm})$) for some of the fission products corresponding to different mass asymmetry values is shown in Fig.1. The CM angular distributions were fitted using the equation:

$$\boldsymbol{W}(\boldsymbol{\theta_{CM}}) = \boldsymbol{a} + \boldsymbol{b}\cos^2(\boldsymbol{\theta_{CM}}) \qquad (1)$$

with ‘a’ and ‘b’ as variable parameter. It should be mentioned here fitting was also carried out to the plots of ‘$W(\theta_{cm})$ vs. θ_{cm}’. The results of the fitting were close to the values obtained using equation (1), however, the fitting errors were much larger in the latter case. Therefore, linear fitting (shown as solid lines in Fig. 1) was selected for the determination of angular anisotropies. From the linear fits, angular anisotropies were obtained as

$$\frac{\boldsymbol{W}(0)}{\boldsymbol{W}(90)} = 1 + \frac{\boldsymbol{b}}{\boldsymbol{a}} \qquad (2)$$

The anisotropy values for these fission products is given in Table I. Uncertainties quoted on the anisotropy values are due to fitting errors. It can be seen from the table that the angular anisotropy decreases with increasing mass asymmetry. Angular anisotropy values of other fission products were also consistent with this trend. This observation is similar to that in earlier studies on mass resolved angular distribution in $^{16}O+^{232}Th$ [3] and $^{20}Ne+^{232}Th$ [4] reactions which suggests pre-equilibrium fission to be the dominant NCN-fission process. However, increase in the anisotropy values in the symmetric region is larger compared to that observed in earlier studies [3,4]. This may be due to the larger contribution from pre-equilibrium fission owning to the smaller fission barrier and larger average angular momentum of the fissioning nucleus in the present study. This also results in the larger average angular anisotropy (given in the table I) compared to that observed in earlier studies at similar beam energies. While calculating the average anisotropy, anisotropy values of different fission products were weighted for their mass yields.

Table 1: Angular anisotropies of fission products with different mass asymmetry values.

Fission product	$\left.\frac{W(0)}{W(90)}\right\|_{expt}$	$\left\langle\frac{W(0)}{W(90)}\right\rangle$
^{99}Mo	2.13 ± 0.20	2.31
^{122}Sb	3.45 ± 0.33	
^{143}Ce	1.71 ± 0.28	

Results and discussion

In study of mass resolved angular distribution in $^{28}Si+^{232}Th$ reaction, angular anisotropy was observed to decreasing with increasing asymmetry of mass division. This observation is consistent with that in earlier studies at above barrier energies, indicating pre-equilibrium fission to be the dominant NCN-fission process.

References

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