Anomalous fragment angular distributions in the fission of composite systems formed in ^{28,30}Si+ ^{180}Hf Reactions

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Introduction

Fragment angular distribution provides valuable information about the mechanism of heavy ion fusion-fission. Transition state models [1] are extensively used to explain the experimental angular distribution in fusion-fission. However, it is observed that the onset of non-equilibrium processes such as quasi-fission, pre-equilibrium fission and fast fission leads to anomalous angular distributions and anisotropies. These processes show strong entrance channel dependences. Here, we report the angular distribution studies for the ^{28,30}Si+^{180}Hf systems populating the compound nuclei ^{208,210}Rn.

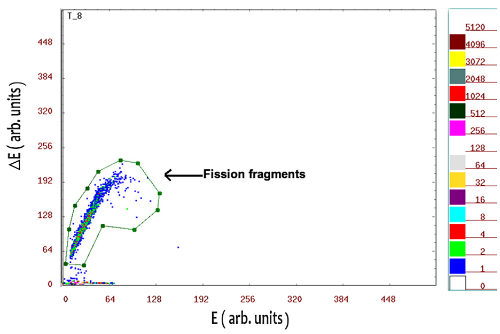

FIG. 1: Scatter plot of energy (E) versus energy loss (ΔE) of reaction products for the system ^{28}Si + ^{180}Hf at 184 MeV beam energy with the hybrid telescope detector kept at 80^o lab angle.

Experiment and data analysis

Measurements were performed at the Inter University Accelerator Centre (IUAC), New Delhi, using the scattering chamber facility of National Array of Neutron Detectors. ^{28,30}Si beams were accelerated using the Pelletron accelerator and super conducting linear accelerator facilities, before bombarding with the isotopically enriched ^{180}Hf targets. Measurements were performed in the beam energy range of 136 - 204 MeV. The binary fragments produced in the reactions were detected using 16 hybrid telescope detectors [3]. A scatter plot of ΔE vs E for a telescope mounted at 80^o w.r.t the beam direction, for the ^{28}Si+^{180}Hf at 184 MeV beam energy is shown in FIG. 1. The fission fragments are well separated from other possible events reaching the detector. Two Passivated Implanted Planar Silicon (PIPS) detectors were mounted at $\pm$13^o with respect to the beam to monitor the beam.

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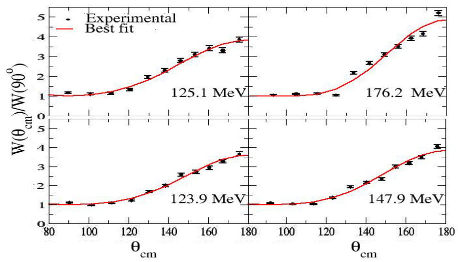

FIG. 2: Measured fission fragment angular distributions for the two reactions ^{28}Si+ ^{180}Hf (top panels a and b) and ^{30}Si+^{180}Hf (bottom panels c and d) at different beam energies. Solid red curve is a fit to the experimental distribution.

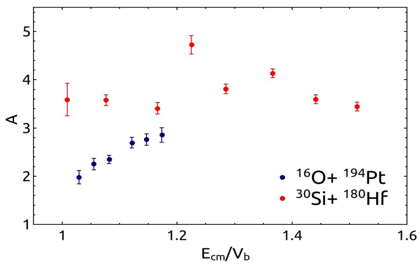

FIG. 3: Anisotropies for the ^{16}O + ^{194}Pt and ^{30}Si+^{180}Hf reactions populating the CN ^{210}Rn as a function of E_{cm}/V_b.

Fission fragment angular distribution $W(\theta_{cm})$ is obtained [1] from the fission yields registered in the fission detectors. The Rutherford events registered in the monitor detectors were used for the cross section normalisation. The angular distribution is fitted using a Legendre polynomial for obtaining the angular anisotropy values. Typical angular distributions are shown in FIG. 2 for the two reactions, along with the fitted distributions. Total fission cross section is obtained by integrating the differential cross sections.

The experimental angular anisotropy for the ^{30}Si+^{180}Hf reaction is compared with that of ^{16}O+^{194}Pt reaction in FIG. 3. Though both reactions populate the same CN ^{210}Rn, the anisotropy values are significantly larger for the ^{30}Si+^{180}Hf reaction at similar energies. It was reported [4] that the ^{16}O+^{194}Pt reaction proceeds via true CN formation. Hence,

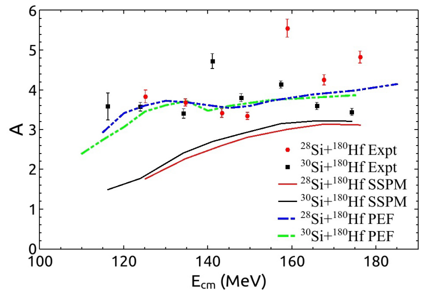

FIG. 4: Comparison of calculated and experimental anisotropies for the reactions ^{28,30}Si+ ^{180}Hf.

the larger A observed in the ^{30}Si+^{180}Hf reaction could be an indication of non-equilibrium events in this reaction.

Experimental anisotropies of two reactions are compared with the SSPM results (solid lines) in FIG.4. SSPM calculations [1] fail to reproduce the anistropies at all energies for both reactions. Further, the pre-equilibrium fission (PEF) probability ($P_{PEF}(l) = e^{-0.5B_f(l)/T}$) is significantly higher for these reactions at measured energies. Results of PEF calculations [5] are also shown in FIG. 4 (dashed lines). It may be noted that PEF calculations reasonably reproduce the experimental anisotropies for both reactions.

Conclusion

Fission fragment angular anisotropies are observed to be inconsistent with SSPM calculations for ^{28,30}Si+^{180}Hf reactions in the measured excitation energy range. PEF calculations reasonably reproduce the results in the entire range of energy, for both systems.

References

[1] R. Vandenbosch, J.R. Huizenga, Nuclear Fission, Academic Press, New York, (1973).
[2] A. J. Sierk, Phys. Rev. C, 33(6), (1986)
[3] A Jhingan *et al.*, Proceedings of the DAE Symp. on Nucl. Phys. 59, (2014)
[4] E.Prasad *et al.*, Nucl. Phys. A 882, (2012).
[5] R. G. Thomas et al., Phys. Rev. C, 65,(2002)