Kinematics of fission fragment folding angular distribution and its mechanism for $^{18}O+^{232}Th$ reaction at 110.9 MeV.

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Fission fragment folding angle measurement is often used to differentiate between the low momentum and full momentum transfer events leading to fission. This method is particularly useful when the fission followed by the transfer has to be differentiated from the complete fusion (CF) followed by the fission based on its characteristic momentum transfer. The amount of momentum transfer in the fusion reaction will dictate the folding angle of the complementary fission fragment. Any deviation in observed fission folding angle distribution from the desired folding angle will provide information about the incomplete fusion-fission process or fission induced after the transfer of few nucleon or cluster of nucleus. In all the cases projectile transfers few nucleons to the target and momentum transferred in such collision is different than the full momentum transfer, resulting different folding angle than the CF process.

Fig.1 shows the vector diagram of transfer fission events in a co-planner geometry. The fission fragment folding angle distribution is shown in Fig.2 for the ^{232}Th target with the ^{18}O beam at the beam energy of 110.9 MeV. Silicon ΔE-E telescope and MWPC were used for measuring the fission fragments in coincidence. Details of experimental setup is given in Ref. [1]. In the figure the counts are plotted with respect to the fission fragment folding angle θ_{FF}. Angle of the silicon surface barrier detector is specified in the figure at the top. The experimental folding angle distributions were fitted by Multi-Gaussian curve.

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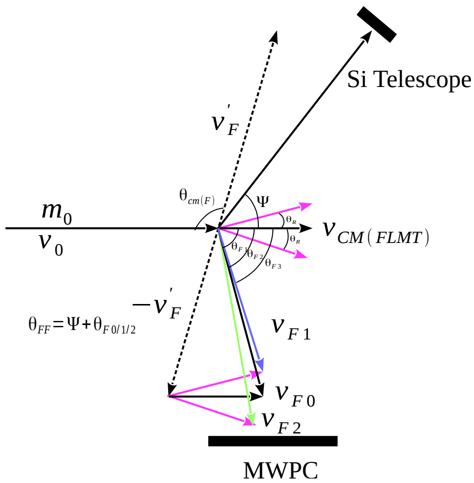

FIG. 1: Vector diagram for the mechanism of fission after few nucleon transfer.

Sum of all Gaussian components is plotted to the best fit for the experimental data with the help of plotting software Gnuplot. Parameters of Gaussian distribution functions are varied to get the best fit to the experimental data. The broader central peak shown in Fig2 is due to the Complete Fusion-Fission (CFF) and Full Linear Momentum Transfer (FLMT) events. The other two smaller peaks appearing along side of the CFF peak are due to the Transfer Fission (TF). Kinematics given below and detailed simulations has been discussed in P. Bhattacharya *et al* in Ref. [2]. Similar structure in the fission fragment folding angle distributions which we reported in this manuscript has been observed in $^{19}F+^{232}Th$ [2], $^{18}O + ^{208}Pb$ [3] and $^{28}Si+^{238}U$ [4][5] reactions for energies ranging from wide range of energies.

Fig.1 shows the vector diagram of transfer fission events in a co-planner geometry. Silicon

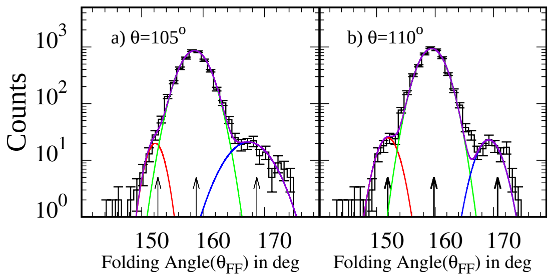

FIG. 2: Fission fragment folding angle distribution.

detector mounted in telescope is placed at an angle of Ψ. The large area MWPC is mounted at an angle $\theta_{F0/1/2}$ in folding angle configuration, where complimentary fission fragment is detected. Fission fragment folding angle θ_{FF} is given by,

$$\theta_{FF} = \Psi + \theta_{F2/0/1}$$

Where, $\theta_{F2/0/1}$ denotes three polar angles made by the fission fragment with respect to the beam axis for three recoils conditions. θ_{f0} is angle made by the fission fragment detected in the MWPC for the CFF or FLMT, where are $\theta_{F2/1}$ are the angle made by the fission fragment due to TF for the two recoil conditions, where θ_R is the angle of recoiling particles with respect to beam axis. Ejectile angle is calculated by knowing the grazing angle, then from two-body kinematics of assuming one neutron transfer. The recoil angle θ_R and momentum, energy and the recoil velocity of the fissioning nucleus can be easily calculated from two body kinematics. After the transfer of few nucleons or cluster of nuclei total kinetic energy released in fission from given mass and charge of the fissioning nucleus can be calculated assuming symmetric mass split using Viola systematics[6]. V'_F is velocity of fission fragment assuming symmetric mass split in the center of mass of the fissioning nucleus due to complete fusion fission events and $\theta_{cm}(F)$ is the angle of the fissioning nucleus in the center of mass system. $V_{CM}(FLMT)$ is the velocity of the center of mass assuming the full momentum transfer

$$V'_F \cos\theta_{cm(F)} = V_\Psi \cos\Psi - V_R \cos\theta_R$$

where V_R is the velocity of recoiling nucleus making an angle of θ_R due to the partial momentum transfer or fission taking place after the transfer of few nucleons or cluster of nucleus. Similarly *sin* component can be calculated.

Angle made by the complimentary fission fragment due to partial momentum transfer in fission after the transfer is given by,

$$\theta_{F1} = \tan^{-1} \frac{V_\Psi \sin\theta_\psi - 2V_R \sin\theta_R}{-V_\Psi \cos\theta_\psi + 2V_R \cos\theta_R}$$

Arrow indicated in fission fragment folding angle distribution indicates expected peak due to the complete fusion-fission events (CFF) or full linear momentum transfer(FLMT) events around 160^o and other two peaks are the expected fission fragment folding angles because of fission taking place to the incomplete momentum transfer events or fission after the transfer (TF). The two peaks observed due to TF.

In summary, we can separate different fission mechanism namely complete fusion-fission and transfer fission mechanism using large area detectors and simple kinematics in the fission fragment folding angle distribution. This technique can be used to study angular distributions of different fissioning systems at above barrier energies.

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