Study of fission reactions involving weakly bound projectiles

A. Pal[1,2*]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, India and*
[2]*Homi Bhabha National Institute, Anushaktinagar, Mumbai - 400094, India*
(Dated: October 14, 2019)

Introduction

Reactions involving weakly bound projectiles like ^{6,7}Li and ^{9}Be are known to exhibit many interesting features such as fusion suppression at above barrier energies, absence of threshold anomaly in the real part of optical potential, large alpha particles production etc. There are also few anomalies in fission observables like enhancement of FF angular anisotropies compared to the SSPM calculations, enhancement of the width of the folding angle distributions at below barrier energies for inclusive fission as compared to complete fusion (CF)-fission and also enhancement of peak to valley ratio (P/V) for inclusive fission as compared to ones for CF-fission. In literature, it has been argued that breakup or transfer induced fission is supposed to play a role for the above anomalies. Hence the present thesis work focuses on the study of the effects of projectile breakup on fission by measuring the basic observables like fission fragments angular distributions (FFAD), fission fragments mass distribution (FFMD), fission fragments folding angle distributions (FFFAD) etc. in reactions involving weakly bound projectiles aiming to resolve some of the anomalies in fission observables. Therefore, few exclusive coincidence measurements between FF and projectile like fragments (PLF) have been carried out to identify the individual breakup/transfer induced channel and find out their effect on inclusive fission. It may be mentioned that neutron induced fission cross-sections can be determined utilizing those transfer/breakup induced fission channels as "surrogate reactions". The thesis work also contains developmental works of two MWPC detectors which is necessary tools for such kind of studies.

*Electronic address: asimpal@barc.gov.in

Results

Inclusive and exclusive FF angular distributions have been measured at three near barrier projectile energies for ^{6}Li+^{232}Th system. To investigate the reason behind the enhancement of measured anisotropies compared to SSPM predictions, angular anisotropy for breakup or transfer induced fission has been obtained exclusively in the rest frame of the recoiling nuclei. The angular anisotropy for the α,d and p-gated fission has been found to be equal or slightly more than the ones for inclusive fission. But, the estimated anisotropy of transfer/breakup-induced fission considering the PLF emission in all possible angles comes out to be less than or equal to the ones observed for the inclusive fission, which leads to the conclusion that the observed enhancement in the anisotropy for total fission compared to the SSPM predictions at near-barrier energies is not due to the contribution from breakup- or transfer-induced fissions[1].
Similarly, inclusive and exclusive FFFAD and FFMD are measured in ^{6,7}Li+^{238}U reactions. FFFAD for total fission in laboratory frame for both the reactions show shoulder structure near main peak. The present measurements confirm that the FFFADs in coincidence with different PLFs (mainly α) indeed peak at those angles where kink like structures in inclusive FFFAD were observed. Now, mass distributions for ICF fission have been exclusively measured for finding the reason behind the difference in P/V ratio between CF and inclusive fission. Interestingly, it has been observed that P:V ratios of FF mass distributions for all the transfer- or

ICF-fission channels are found to be higher than the ones for total fission for a particular beam energy, thereby causing the above difference. Here it may be emphasized that mass distributions of several nuclei, namely ^{243,244}Pu and ^{241}Np, which cannot be populated by stable target and projectile, have been obtained in this study. For all the fissioning nuclei (^{240,241}Np, ^{241,242,243,244}Pu), the theoretical calculations with modified shell correction parameter for symmetric fission, agree with the experimental data reasonably well. It implies that the value of the shell correction for symmetric fragments plays an important role in FF mass distribution [2]. In addition, the cross-sections for individual ICF or transfer induced fission channels in ^{6,7}Li+^{238}U reactions have been obtained by using (a) the coincidence efficiency between two MWPC detectors using a Monte Carlo simulation, (b) the geometrical efficiency of the MWPC detectors and (c) excitation energy dependent fission probabilities. As an application of breakup or transfer induced fission reaction, ^{235}U(^{6}Li,d) and ^{232}Th(^{6}Li,d) reactions have been studied as surrogate reactions to determine the cross sections for the ^{238}Pu(n,f) and ^{236}Np(n,f) reactions in the equivalent neutron energy range of 13.0-22.0 MeV and 9.9-22.0 MeV respectively [4].
Two Multi-Wire Proportional Counters (MWPC), being integrated parts for such kind of studies, having active area of 12.5cm x 7.5cm each, have been developed for measuring position and time-of-flight of the fission fragments [5].

Conclusions

The effect of projectile breakup or nucleon transfer on fission dynamics in reactions involving weakly bound projectiles and actinide targets are already known in the literature and some of these effects have been explained qualitatively. However, the present thesis work focusses on finding out the quantitative explanations of these effects by carrying out exclusive measurements of the transfer/breakup fission events. The results of these studies led to several interesting conclusions. we concluded that the enhancement in fission fragments angular anisotropy compared to statistical model prediction is not due to breakup or transfer effect. The enhancement in experimental anisotropy could be explained using ECD k-state model calculation. On the other hand, positive effect of breakup or transfer induced fission on inclusive FF mass and folding angle distributions have been concluded. Breakup or transfer induced fission is found to be responsible for increasing the peak to valley ratio of inclusive FF mass distributions at near barrier energies and also for enhancing the width of the folding angle distributions at below barrier energies. In addition, fission dynamics of few nuclei which can not be populated using stable target and projectile, have been studied in the present thesis works. Shell effect for symmetric fission channel have been found to play a crucial role in the fission dynamics. Further, incomplete fusion cross-sections have been determined from the present coincidence measurement which may be a powerful tool to measure ICF cross-sections and may be complementary to the widely used gamma counting technique. From one of the coincident measurements, fast neutron induced fission cross-sections useful for Generation IV reactor have been measured. The present thesis works also include development of two MWPC detectors, which are primary tools to measure fission fragments and investigate fission dynamics at energies around the Coulomb barrier

References

[1] A. Pal *et al.*, Phys. Rev. C **96**, 024603 (2017).
[2] A. Pal *et al.*, Phys. Rev. C **98**, 031601 (R) (2018).
[3] A. Pal *et al.*, Phys. Rev. C **99**, 024620 (2019).
[4] A. Pal *et al.*, Phys. Rev. C **91**, 054618 (2015).
[5] A. Pal *et al.*, Proceedings of DAE-BRNS Symp. on. Nucl. Phys. **62**, 1140 (2017).