Fission of the heaviest element of periodic table

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Introduction

One of the frontier research area of modern science is the quest for extending the periodic table. Elements above Z=104 are known as super heavy elements (SHE). While the last SHE, Og (Z=118) was identified more than a decade ago, experiments to discover the elements Z=119, 120 are being carried out all over the world. Og was discovered in the reaction ^{48}Ca + Cf target, which is the heaviest target which can fabricated for prolonged experiments. One of the methods which might lead to the discovery of the newer elements is by employing projectiles heavier than Ca, like Ti, Cr, etc, along with actinide target. However, the phenomena of quasi fission which is detrimental to the production of the super heavy elements increases with the increase in the charge product ($Z_P Z_T$) of the reaction.[1] It has been observed that the probability of formation of compound nucleus decreases drastically when projectiles heavier than Ca are used in the reaction.[2] The complex phenomena of quasi fission is influenced by a number of factors like the deformation of the target and projectile nuclei, the difference in the isospin of target and projectile nucleus, etc. Thus, understanding the dynamics of the quasi fission process is important in order to choose the optimum target projectile combination for the discovery of the SHE.

One of the candidate projectiles heavier than Ca is ^{56}Fe. The synthesis experiments, carried out at mass separator facilities coupled with the accelerator facilities at laboratories around the world are months long experiments as the ER cross section for such reactions are in orders of pico barns. However, the fission cross section for SHE is quite high. Thus, by studying the fission fragment characteristics of such reactions, a lot of information can be obtained. The information such attained can thus be employed for selection of the optimum target projectile combination for the synthesis experiments. One such combination reaction for the synthesis of the Og (Z=118) composite is ^{56}Fe on ^{238}U. Examining the characteristics of the fission fragments would throw light into the dynamics of the reaction. The experiment was designed to observe the fission fragment mass in coincidence with the total kinetic energy of the fragments, thus allowing the separation from fragments arising from fusion fission to those arising from quasi fission.

Experimental details

The experiment was carried out at the U400 cyclotron facility at the Flerov Laboratory of Nuclear Reactions (FLNR), Joint Institute of Nuclear Reactions (JINR), Dubna, Russia. ^{56}Fe beams of energy 310 MeV was bombarded on a thin target of ^{238}U of thickness around 100 μgm/cm^2. The fission fragments were detected using the CORSET setup [4], which consists of a pair of MCP based start and position sensitive MCP based stop detectors. The position sensitive stop detectors were of dimensions 9 cm X 7 cm. The start detectors were placed at 4.4 cm from the target and the stop detectors were placed at 24.4 cm from the target, thus the flight path of 20 cm. The detectors were placed symmetrically at an angle of 58° from the beam axis corresponding to the folding angle corresponding to Viola's systematics [5]. The analysis procedure outlined the [4] was used for analysis of the data.

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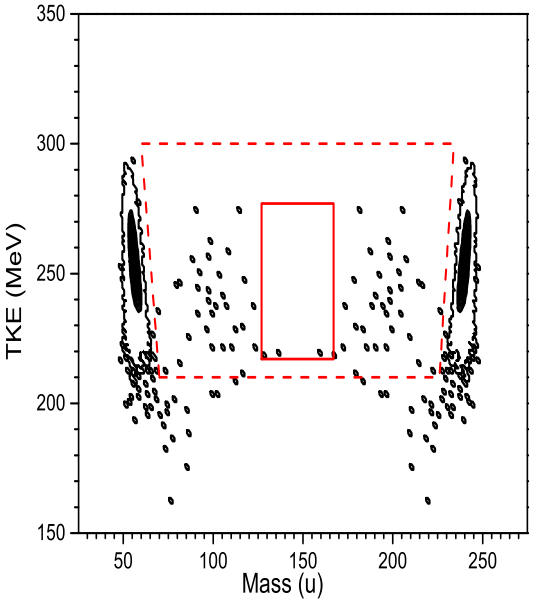

FIG. 1: The mass-total kinetic energy(TKE) distribution from the reaction ^{56}Fe + ^{238}U at E$_{lab}$= 310 MeV. The rectangular gate with the solid lines corresponds to A$_{CN}$/2 ± 20u corresponding to the symmetric fragments and the gate with the dashed lines corresponds to quasi fission like events.

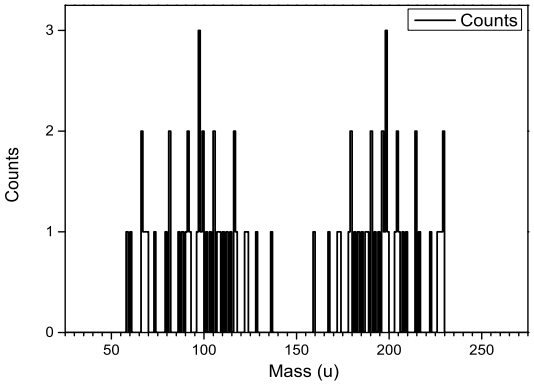

FIG. 2: Mass distribution of events in the quasi fission gate (dashed lines) in fig 1.

Result

The mass-total kinetic energy (MTKE) plot has been shown in fig 1. The MTKE distribution has been analysed with two different gates. A gate corresponding to the symmetric fragments A$_{CN}$/2 ± 20u, where A$_{CN}$ is the mass number of the compound nucleus, if formed in the reaction, is shown in the fig 1 by solid lines. To analyse all the other fission like events, a second gate corresponding to all fragments which may have originated from asymmetric quasi fission is shown by dashed lines in fig 1. The dashed gate has been drawn in order to separate the quasi fission events from the deep inelastic events, with the logic that events arising from DIC are mostly projectile like and target like, while quasi fission being more equilibrated compared to the DIC events split more symmetrically compared to DIC. Detailed discussion for the choice of the gate can be found in [3]. Significantly less number of events in the region A$_{CN}$/2 ± 20u, implies that quasi fission completely dominates the reaction studied here. The selected events found in the larger mass gate is shown in fig 2. It is worth noting that the mass distribution of the heavier fragment is centred around 200-210 u, near the ^{208}Pb shell closure. An analysis of the TKE of such fragments show that they mostly originated from quasi fission as they deviate from the TKE as predicted by Viola's systematics [5] corresponding to fusion fission events.

Discussion

The reaction ^{56}Fe + ^{238}U studied here implies that quasi fission starts completely dominating as the projectile is changed from the ^{48}Ca to ^{56}Fe . It has been observed that the reaction products are originated in mostly asymmetric quasi fission with almost no symmetric fragments present. An influence of the ^{208}Pb shell closure on the quasi fission phenomena has also been indicated in this study.

References

[1] M.G. Itkis,*et. al.*, Nucl. Phys. A **787**, 150 (2007).
[2] K.V. Novikov,*et.al.*, Phys. Rev. C. **102**, 044605 (2020).
[3] A. Sen,*et.al.*, Phys. Rev. C. **105**, 014627 (2022) references therin.
[4] E.M. Kozulin,*et. al.*, Instrum. Exp. Tech. **51**, 44 (2008).
[5] V.E. Viola,*et. al.*, Phys. Rev. C **31**, 1550 (1985).