Fusion and quasifission dynamics in heavy nuclei

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Though the last stable element in the periodic table was added nearly a century ago, the synthesis and study of new heavy elements and their isotopes continues to be a hot topic in nuclear physics. Significant progress has been achieved so far, with superheavy elements (SHEs) up to Z=118 [1] having been created in the laboratories. The existence of an island of stability for such massive nuclei is believed to be due to the strong stabilising effects of proton and neutron shell closures. Though different methods have been proposed for the synthesis of SHEs, heavy ion fusion is the only established route that could achieve this goal succesfully for the Z > 100, till date.

The mechanism of fusion in very heavy systems is significantly different from that of the lighter systems. For heavy reactions, the system after capture often udergoes fission from a more elongated shape instead of reaching the compact compound nucleus (CN) shape. Such a split before achieving the compact CN shape reduces the fusion probability significantly. This competing nonequilibrium process is called quasifission [2, 3] and is partly responsible for the very low production cross sections of the SHEs. The probability of quasifission and the characteristics of its products strongly depend on the diffusive motion of the system after capture, over the multi-dimensional potential energy surface. Even though the surest indication of fusion is the evaporation residue (ER) produced, it is not practical to measure these low yield fusion products, particularly for heavy systems, to make a systematic study to optimise the best reaction for SHE synthesis.

In order to understand quasifission and fusion-fission processes, a series of fission measurements have been performed at the Australian National University, populating very heavy composite systems. The binary fragments from the reactions were detected using the CUBE fission spectrometer [4]. Being a fully dynamical process, a key quantity characterising the quasifission is its timescale - which is the sticking time between the capture and the breakup. The measurements of the full range of mass-splits between the projectile and target over a wide range of scattering angle using the CUBE detectors allow us to generate the mass angle distribution (MAD) of the fragments, which provides the most direct information on quasifission timescales.

The MADs and mass ratio distributions for the ^{34}S+^{232}Th forming the ^{266}Sg system at different beam energies are shown in Fig. 1, for example. The change of mass evolution with beam energy is clearly visible in the MADs, indicating the influence of deformation alignment of the deformed target nuclei. An interesting observation in heavy systems such as ^{34}S+^{232}Th [5], ^{30}Si+^{232}Th[6], ^{28}Si+^{238}U [6], ^{40}Ca+^{238}U [7] is the effect of shell closure in the Pb region in determining the quasifission outcomes. The mass-asymmetric component (predominantly originating from the tip collisions with the deformed target) peaks between 200 and 208 amu, indicating the role of shell closure due to Pb. The experimental observations

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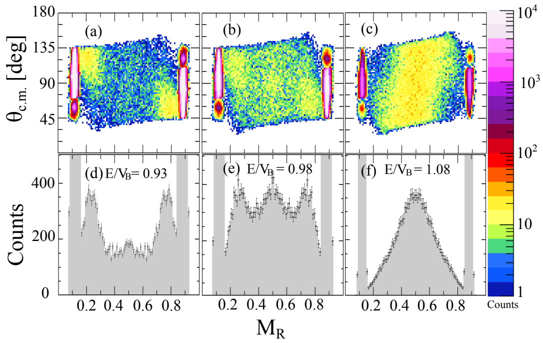

FIG. 1: Panels (a-c): MAD for the $^{34}S+^{232}Th$ reaction forming ^{266}Sg at different beam energies. Panels (d-f): The mass ratio distributions of the fragments.

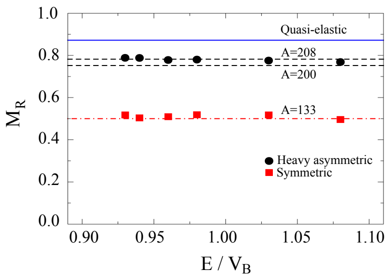

FIG. 2: Average mass ratio of the heavy asymmetric fragments and the symmetric fragments as a function of E/V_B. The mass-asymmetric components are scattered between A=200 and 208.

are observed to be consistent with TDHF calculations [7]. The component originating from the equatorial collisions are peaked around mass-symmetry. The average mass ratio of the fragments from the $^{34}S+^{232}Th$ reaction as a function of E/V_B is shown in Fig. 2.

The angular distribution of the fragments from the MAD provides crucial information about the sticking time distribution. This sticking time information can be combined with the measured mass ratio distributions to obtain information about the mass evolution with time. Relying on these concepts, the MADs were simulated for different reactions using a phenomenological model [5, 8] assuming classical trajectories for the incoming and outgoing nuclei. For very heavy systems such as the $^{34}S+^{232}Th$ three different hypotheses were tested yielding the same MAD and similar average sticking times. While the quasifission events originating from tip collisions show an average sticking time of 7×10^{-21}s for the $^{34}S+^{232}Th$ reaction, a longer sticking time of 11×10^{-21}s is required for the relatively lighter reactions such as $^{40}Ca+^{192}Os$.

Recent experimental results and theoretical findings will be presented in the conference.

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