Into the fission valleys of heavy elements (HE) and super heavy elements (SHE)

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An overview of the physics that we are pursuing at Variable Energy Cyclotron Centre (VECC), Kolkata, India in the context of recent development of nuclear fission studies will be presented. We performed several experiments in Indian accelerator facilities (Mumbai, New Delhi pelletron and Kolkata Cyclotron) to understand shell effects in pre-actinides and actinides nuclei. We have studied the quasi-fission process for serval heavy elements (HE) and Super Heavy Elements (SHE). While studies on HE are carried out in Indian facilities using the MWPC developed at VECC, SHEs are studied using CORSET detectors in collaboration with JINR, Dubna. I will present how we used fission fragment mass and total kinetic energy distributions as probes to explore shell effects and quasi-fission that are important for the formation of (super) heavy elements.

Synthesis of heavy elements (HE) and super heavy elements (SHE) is achieved in the laboratory by fusing two heavy nuclei. The fusing projectile and target nuclei are required to have enough kinetic energy to fuse to form compound nucleus (CN). However, the evolution of the fusion path is actually governed by complicated multi-dimensional potential energy surface (PES), which depends critically upon the entrance channel parameters e.g; mass asymmetry, beam energy, deformation etc. The fusing nuclei may reach a fusion meadow in the potential energy landscape, equilibrate to form CN; it may then cool down through particle evaporation to form evaporation residue, or it may undergo shape oscillations through unconditional saddle point to reach the fission valley. Alternatively, the fusing system may bypass the fusion meadow and directly reach the fission valley; this is known as quasi-fission.

The topography of the PES is far too complex to predict theoretically the path followed by the system in its evolution from the ground state to scission. This is because of possible microscopic effects such as shell effects that may affect the PES. So, it is important to use different experimental probes along with phenomenological explanation or microscopic calculation for exploring the various aspects of the formation mechanism of HE and SHEs. We are engaged in the study of the interplay of dynamics (fusion-fission vs quasi-fission) and microscopic effects (nuclear shell effects) in the fusion-fission process, using mainly fission fragment mass distribution as the probe [1-8].

The recent discovery [9] of asymmetric fission in the nucleus ^{180}Hg has initiated a flurry of interest. The general understanding of the role of nuclear shell effects in the fusion-fission dynamics is put into a question. A number of theoretical models have recently been developed that however claim to successfully explain the observed asymmetric fission of ^{180}Hg and predict the shape of mass distributions of other pre-actinide nuclei for which experimental data are rare. We have systematically investigated fission fragment mass-energy distributions of several pre-actinide and actinides nuclei.

For example [3], Fig 1 upper panel shows the half-mass distribution in the fission of ^{214}At produced in reaction ^{9}Be+^{205}Tl. The experimentally observed mass distribution is asymmetric at 31.1 MeV excitation energy. To explain the observed distribution, it is fitted with the red shaded Gaussian that accounts for the symmetric distribution (expected from the liquid drop model prediction), and the green shaded Gaussian can be described by a weaker shell effect (around A=138). Together they fit the experimental mass distribution as shown by the black line. In the lower pannel we show the histogram that represents the difference between the liquid drop (LD) Gaussian function and the experimental data. The red line in the right-hand *y* axis of the lower pannel, indicates the driving potential calculated using the two-center shell model [10]. Driving potential shows a minima around A=138.

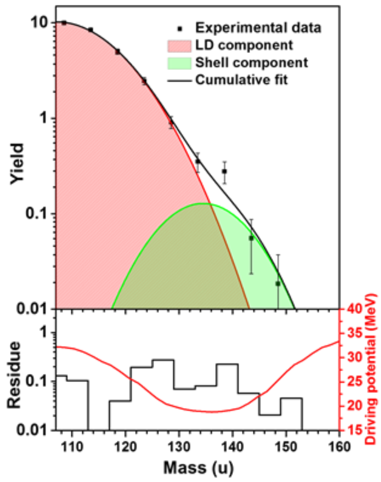

Fig. 1: Exploring fission dynamics of HE ^{214}At (see text for details).

The experimentally observed shape of the mass distribution in the fission of the pre-actinide nucleus ^{214}At is consistent with the predictions from a recently developed macroscopic-microscopic calculation [11] that emphasizes the role of the structure (shell effects) of the PES. At the same time, the observed asymmetry in the mass distributions could also be explained qualitatively in the framework of a two-center shell model (TCSM) that predicts a dip in the driving potential (as shown in the lower panel in Fig 1) considering shell effects of the nascent fragments. This clearly brings out the feature that, although the shell effects of the nascent fragments are not explicitly included in the dynamical calculations, they are implicitly incorporated in the PES calculation.

Our experiments, carried out at the Dubna cyclotron facility, to study of fusion-fission dynamics of the Flerovium (Z=114), as shown in Fig 2, allow us to have a more systematic understanding of the formation mechanism of the SHE. We investigate the decrease of fusion probability with entrance channel mass asymmetry and charge products in the ^{48}Ti, ^{52}Cr and ^{84,86}Kr induced reaction in comparison with that in the reactions with ^{48}Ca beam. Fusion probabilities are calculated from the measurements. The quantitative information of fusion probabilities helps to realistically estimate the required beam time for a new SHE synthesis experiment.

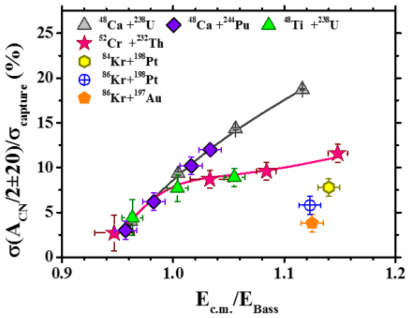

Fig. 2: Measured contributions of the symmetric fragments to the capture cross sections for different target projectile systems relevant to the synthesis of SHE.

A survey of the above activities, along with the new results from recent experiments, carried out at VECC, TIFR, IUAC, India and Dubna, Russia, will be presented in the symposium.

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