Shell effects in fission fragment mass distributions

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According to Liquid Drop Model (LDM), nuclei with atomic number (Z) greater than 104 can't survive from fission as the LDM fission barrier vanishes. However super heavy elements (SHE) beyond Z=104 has been synthesized in the laboratory. The stability of these SHE originates from the shell effects in nuclei. While bulk properties of nuclei are well explained by LDM, the shell properties of nuclei can be incorporated by adding a shell-correction term to the LDM energy as prescribed by Strutinsky [1]. As a result, while liquid drop barrier height diminishes smoothly with increase in Z as the nuclear fissility increases, the shell correction terms which retains the fluctuations in the shell model energy alters the fission barrier and gives a large barrier to decay that can increase alpha or fission half-lives by several orders of magnitude. Asymmetry in fission fragment mass distribution in actinides is a direct consequence of shell effects.

It is generally believed that shell effects are washed out at higher excitation energies and angular momentum. For the production of SHE by heavy ion bombardment on actinides targets, the compound nuclei are always formed with an excitation energy exceeding few tens of MeV. So constraining the excitation energy at which shell effects washes out is important in the context of production of SHE. From the measurement of fission fragment mass distributions, we show direct evidence that nuclear shell effect washes out an excitation energy of around 40 MeV.

The experiment was performed with ^{4}He beam on a self supporting ^{232}Th target at the K-130 cyclotron at VECC, Kolkata to produce ^{236}U at wide excitation energy range (21-64 MeV). For detecting fission fragments, two large-area (20 cm × 6 cm) position-sensitive multi-wire proportional counters (MWPCs)[2] were placed at the folding angle, covering 67^0 and 83^0 respectively, on either side of the beam axis. For each fission event, the time difference of the fast anode pulses of the detectors with respect to the pulsed beam, the X and Y positions and the energy loss of fission fragments were measured. The detectors were operated at a pressure of about 3.0 torr of isobutane gas. The polar angle of emitted fission fragments could be determined with accuracy better than 0.2^0 while the accuracy in azimuthal angle was about 0.8^0. Beam flux monitoring as well as normalization was performed using a faraday cup and the elastic events collected by a silicon surface barrier detector. The event collection was triggered by the detection of a fission fragment in any of the MWPC detectors along with the beam pulse of the Cyclotron. The masses of the fission fragments were determined event by event from precise measurements of flight paths and flight time differences of the complimentary fission fragments.

From the measured mass distributions, it is found that the shape of the mass distributions changes gradually from symmetric to asymmetric as excitation energy is lowered. Typical mass distributions at three representative energies are shown in Fig 1. At the lower excitation energies (Fig.1a),the mass distributions could be fitted by three Gaussians, one with peak position at the symmetric mass ($A \sim$

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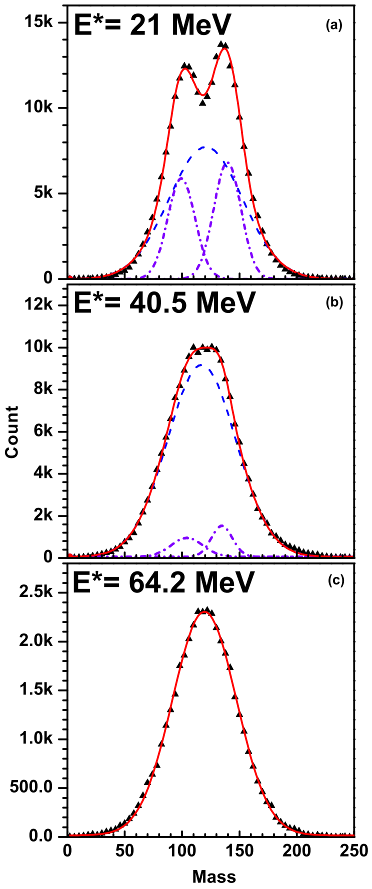

FIG. 1: Mass distribution of ^{236}U at different representative excitation energies

118) and the other two at around $A \sim 132$ and $A \sim 100$. In this fitting, the widths of the distributions were varied but the intensities of the two asymmetric distributions (peaking at $A \sim 100$ and $A \sim 132$) were constrained to be equal to obtain a best fit (lowest χ^2) to the experimental mass distribution. The dot-dashed(violet) line represents the fitting for the asymmetric components and the dashed(blue) line for the symmetric component. The solid(red) line is the overall fitting of the measured mass distribution. It is interesting to note that the mass distributions with E*> 40 MeV (Fig.1c) are best fitted with a single Gaussian, peaking around the symmetric mass division.

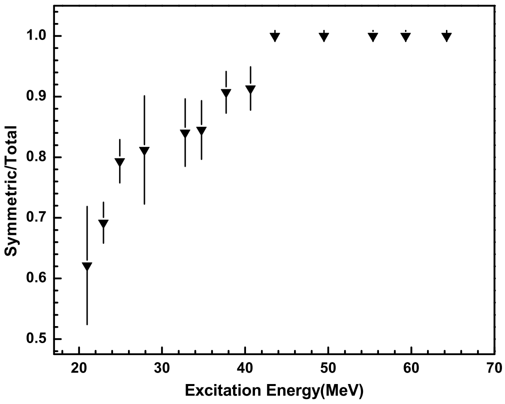

FIG. 2: Area of the symmetric mode with the total area of the distribution

The deviation of the mass distributions from symmetric mode can be characterized by the ratio of the area of the symmetric to the total area of the fitted distributions. This is plotted as a function excitation energy as shown in Fig2. It is evident that the probability of fission from the symmetric mode increases with excitation energy. The asymmetry in mass distribution observed in our experiment, arising at lower excitation energies is due to the manifestation of shell effects and the gradual suppression of the asymmetric mode with increasing excitation energy is a direct evidence of washing out of shell effects. The change over occurs at excitation energy ~40 MeV.

In conclusion, we show direct evidence that nuclear shell effect is washed out at an excitation energy ~40 MeV.

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References

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