Barrier distribution measurement for ^{48}Ti+^{232}Th system using quasi-elastic scattering

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The super-heavy elements (SHEs) are synthesized in laboratories through nuclear (hot and cold) fusion reactions. Classically, for fusion to occur, the incident particle has to overcome the fusion barrier and to maximize the fusion probability, the bombarding energy need to be chosen accordingly. Moreover in heavier systems due to coupling to nuclear intrinsic degrees of freedom the fusion barrier splits into a distribution of barriers called fusion barrier distribution (BD). The average value from the distribution gives the most probable fusion barrier which may be different from classical fusion barrier depending upon the target projectile combination. Hence, the quantitative information of the fusion barrier plays a vital role in the synthesis of SHE.

For Pb-based cold fusion reactions, populating the SHEs, the fusion BDs have been systematically measured [1] and theoretically studied [2] in ^{48}Ti, ^{54}Cr, ^{56}Fe, ^{64}Ni, ^{70}Zn, ^{76}Ge and ^{86}Kr + ^{208}Pb reactions. Recently, the production of Z=120 element has been tried through ^{64}Ni + ^{238}U hot fusion reaction at GSI [3]. However, it was unsuccessful because of the very small production cross-sections. Since ^{238}U nucleus is prolately deformed, the most probable barrier may depend on its orientation. Hence it may significantly influence the probability of fusion which in turn may influence the production of SHEs. To study the effect of target orientation, we measured the BD in the ^{48}Ti+^{232}Th reaction forming SHE ^{280}Cn$_{112}$; where ^{232}Th has similar collective states as ^{238}U. To extract the BD, the technique of Quasi-elastic (QE) scattering at large backward angles is utilized.

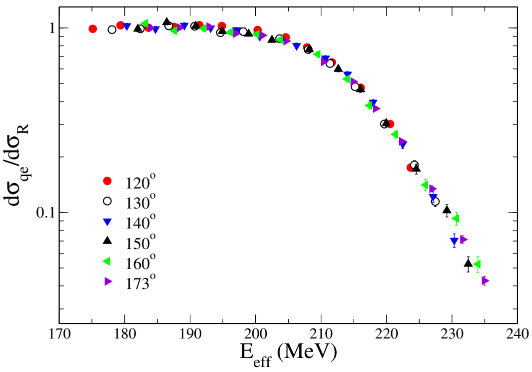

FIG. 1: Measured quasi-elastic (QE) excitation function at different angles.

The experiment was performed using the Pelletron + LINAC accelerator facility of the IUAC, New Delhi. To measure the QE events, the detectors were placed at angles from 160° to 120° with an angular pitch of 10° and at 173° w.r.t the beam direction. The experimental details are available in Ref. [4]. As each scattering angle corresponds to scattering at a certain angular momentum, hence the cross-section is scaled in energy by taking into account the centrifugal correction. Fig. 1 shows the excitation function obtained from data measured at θ_{lab}= 173^0 and 160^0 to 140^0, as a function of E_{eff}, where E_{eff}=$2E_{cm}/(1+\text{cosec}(\theta_{cm}/2))$ corrects

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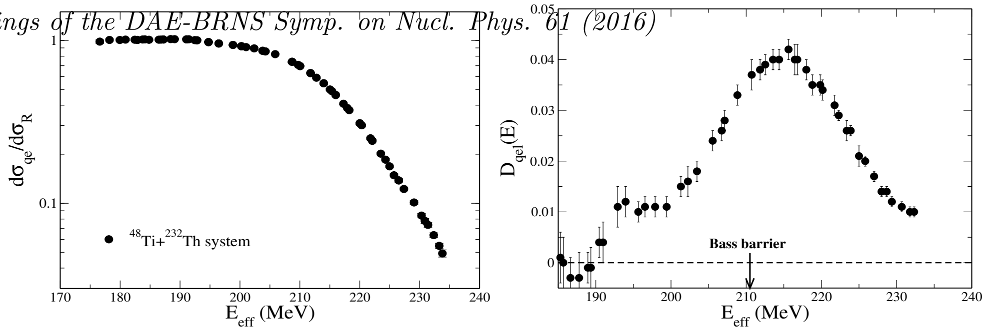

FIG. 2: Final experimental QE excitation function (left) after smoothing and the corresponding barrier distribution (right) for the ^{48}Ti+^{232}Th system.

for centrifugal effects. So combining the data from all detectors, the QE excitation function with energy step of less than 1 MeV is obtained. However, there is small scattering in the data from different detectors. It is removed by smoothing the data considering the average of the consecutive points. After smoothing, the final QE cross-section $\sigma_{QE}(E)$, relative to the Rutherford scattering cross-section $\sigma_R(E)$ as a function of center of mass energy E is shown in fig. (2). Using this excitation function, the BD is extracted by taking its first derivative, that is $-d(\sigma_{QE}(E)/\sigma_R(E))/dE$ (shown in fig. (2)).

From extracted experimental BD, it is observed that the average experimental barrier for ^{48}Ti+^{232}Th system forming the compound nucleus ^{280}Cn is lying on higher energy side of the Bass barrier. This observation is in contrast to that for the ^{70}Zn+^{208}Pb system [1] forming same compound nucleus where the average experimental barrier is reported as lying on lower energy side of the Bass barrier. Hence the intrinsic properties of target projectile combination seem to play a significant role in deciding the most probable experimental fusion barrier relative to the Bass barrier. The first major differences between the above mentioned two systems is deformation of the target nucleus and other is the positive Q-value neutron transfer channels. Hence the permanent deformation of target ^{232}Th (whereas ^{208}Pb is spherical) due to its re-orientation effect may lead to some increase in the barrier energy. Depending upon the density overlap of the interacting nuclei, in cold fusion the barrier position is proposed to be higher and barrier height is lower, however for hot fusion it is opposite [5], i.e., position is lower and height is higher w.r.t Coulomb barrier. Apart from this the BD for ^{48}Ti+^{232}Th system appears to be wider than that for ^{70}Zn+^{208}Pb system. However the width of BD depends upon the coupling strength and coupling strength is proportional to the $Z_tZ_p\beta$ where Z_t and Z_p are the charges of the target and projectile, respectively, and β is average deformation parameter for the system. Here the value of Z_tZ_p for ^{48}Ti+^{232}Th system (1980) is smaller as compared to that for ^{70}Zn+^{208}Pb system (2460). It seems that the deformation of ^{232}Th in ^{48}Ti+^{232}Th is responsible for its wider BD even though the Z_tZ_p is smaller compared to that for ^{70}Zn+^{208}Pb. Furthermore, the Q-value for 2n transfer channel for ^{48}Ti+^{232}Th system is large positive (+7.523) in comparison to that for ^{70}Zn+^{208}Pb system (+0.618). Hence it may be the other possible factor for the increased BD width.

However for the heavier systems such as ^{48}Ti+^{232}Th, there is chance of other events to get released along with the quasi-elastic like deep-inelastic collisions (DIC) or other non-compound processes. So one needs to separate the pure QE events to get the useful information. To ensure the contribution of DIC events, we need to calculate the DIC cross-section at the energies consider here which we are going to do in the future. For theoretical interpretation of observed BD, the coupled channel calculations are also under progress.

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