Systematic study of effect of target and projectile structures on fusion barrier distributions

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Introduction

The heavy ion fusion process near the barrier is strongly influenced not only by Coulomb repulsion and the collision dynamics, but also by the structure of the interacting nuclei[1]. The latter manifests itself by the enhancement of cross section near and below the Coulomb barrier. The observed enhancement in fusion cross section for many systems at energies near and below the Coulomb barrier than that expected from single barrier penetration model calculation, has been interpreted in terms of coupling of target and/or projectile degrees of freedom, such as static deformation, inelastic excitation and nucleon transfer to the relative motion. The coupling gives rise to a distribution of fusion barriers and passage over the lower barriers is responsible for the fusion enhancement at the lower energies. Though it is now well recognised that the coupling of projectile and/or target structure gives rise to a distribution of fusion barrier but the question of identifying the dominating channel which acts as the main doorway to the fusion and the relative importance of various channel couplings, still an open question. In order to determine the relative importance of target and/or projectile structure on fusion barrier distributions, we have carried out measurement on fusion barrier distribution in ^{4}He + ^{232}Th reaction and systematic analysis for reactions involving ^{4}He,^{12}C,^{16}O and ^{19}F projectiles on ^{232}Th target.

Experimental Details

The experiment was performed with ^{4}He beam from the 14 UD BARC-TIFR Pelletron accelerator facilities, Mumbai, India. A self-supporting ^{232}Th target of 2.0 mg/cm^2 thickness was bombarded with the alpha beam in the energy range E_{lab}= 16.0-30.0 MeV in steps of 1.0 MeV. A ΔE (50 μm)-E (150 μm) silicon surface barrier detector telescope was mounted at an angle of 160° to the beam direction to detect the outgoing particles. Another silicon surface barrier detector at an angle of 20° with respect to the beam direction was used to measure Rutherford scattering events for normalization. The scattered α particles were identified from the ΔE vs. E correlation plot. In the analysis quasi elastic scattering was defined as the sum of elastic plus target inelastic events. The ratio of quasi elastic cross section to the Rutherford were obtained by dividing the corresponding number of counts in the ΔE-E spectrum by the number of elastic events in the monitor. The ratios were normalized to unity at the energies well below the coulomb barrier. The quasi-elastic excitation function at the angle of 160° shown in Fig.1, were used to determine the fusion barrier distribution D_{qel}(E) using a point difference formula with a step of 2 MeV in laboratory frame. In order to compare the shape of D_{qel}(E, 160°) with that of D_{qel}(E, 180°), the energy scale of the former was reduced by the centrifugal energy E_{cent}.

Results and Discussion

The results on fusion barrier distributions for ^{4}He + ^{232}Th system along with ^{12}C, ^{16}O, ^{19}F + ^{232}Th systems obtained from [2] are shown in Fig.2. The fusion barrier distribution width increases with the projectile and target charge product Z_tZ_p and additional strucutures are seen in the barrier distribution for heavier projectiles. The Coupled channel (CC) calculations for fusion excitation function was performed using the program CCDEF[3]. The experimental fusion barrier distributions for ^{4}He + ^{232}Th, ^{12}C + ^{232}Th and ^{16}O + ^{232}Th systems are explained

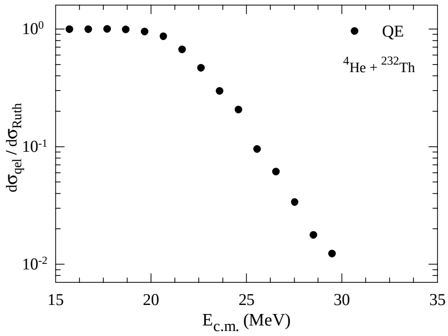

FIG. 1: Quasi-elastic scattering excitation function for ^{4}He + ^{232}Th.

by considering coupling of static target deformation with β_2=0.26 and 3^- inelastic state at 0.774 MeV with β_3=0.17 in CCDEF calculation, and no β_4 deformation is required for explaining the data. For ^{4}He + ^{232}Th the shape of the barrier is quite similar to that of the uncoupled barrier because of very small $Z_t Z_p$, due to which the coupling strength is low. It is observed that as the projectile charge increases the coupling strength increases and structures in the barrier distribution are seen due to target channel couplings. Whereas for ^{19}F + ^{232}Th along with the target channel couplings the following inelastic states of projectile at 0.197,1.346,1.544 and 2.780 MeV with β_2=0.55, β_3=0.33, β_2=0.58 and β_4=0.22 were required to couple in CCDEF calculation to fit the experimental data as shown in Fig. 2. For ^{4}He+ ^{232}Th system, only the target structure effect is observed in the fusion barrier distribution as ^{4}He nucleus being highly stable having first excited state at around 20 MeV, whereas for ^{19}F+ ^{232}Th reaction both target and projectile structure effects are observed because of presence of low lying excited states in case of ^{19}F nuclei.

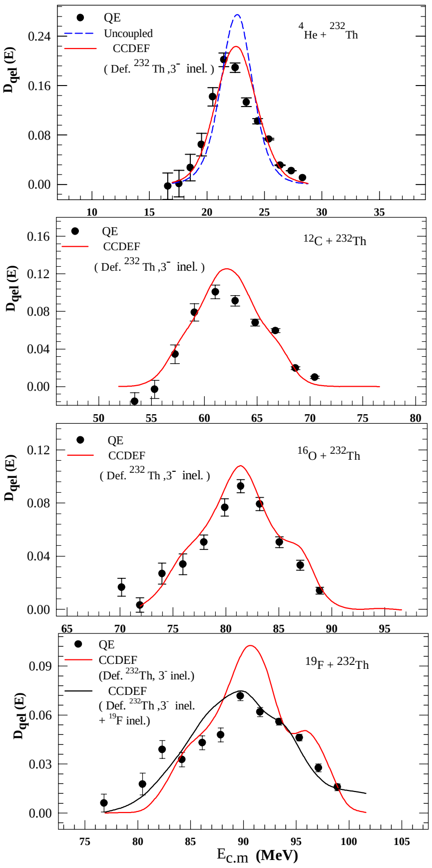

FIG. 2: Fusion barrier distribution for ^{4}He + ^{232}Th, ^{12}C + ^{232}Th, ^{16}O + ^{232}Th and ^{19}F + ^{232}Th. The continuous lines are the predictions of CCDEF calculations.

Summary and Conclusions

In the present work we have carried out fusion barrier distribution measurement for ^{4}He + ^{232}Th reaction. A systematic analysis has been carried out for ^{4}He + ^{232}Th, ^{12}C + ^{232}Th, ^{16}O + ^{232}Th and ^{19}F + ^{232}Th to find out the relative importance of different target and projectile couplings in explaining the measured barrier distributions. It is observed that the coupling strength increases with the product of the projectile and target charge, and the resulting additional structure which could be explained by coupled channel calculations.

References

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