Investigation of reorientation effect in fusion barrier distribution in ^{24}Mg, ^{28,30}Si + ^{90}Zr reactions

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Introduction

Internal degrees of freedom of the fusing nuclei, such as vibrational, rotational, and neutron transfer play crucial role in the fusion dynamics. Coupling of these degrees of freedom with relative motion during fusion at energies around the barrier enhances the fusion cross section over one-dimensional barrier transmission predictions [1]. It has been proposed [2] that in case of static quadrupole deformation, the fusion cross section which is anticipated to be enhanced due to the above mentioned channel coupling would be suppressed owing to reorientation of the fusing partner in the mutual Coulomb field. The Fusion Barrier Distributions (FBDs) have been determined for numerous target-projectile combinations from quasi-elastic as well as fusion-excitation functions; however, only in few studies, the influence of "Coulomb Reorientation Effect (CRE)" has been witnessed [3].

The TDHF as well as CCFULL calculations presented in the Ref. [2] shows that Coulomb effect of heavy spherical target reorient the prolate deformed projectile towards the higher barrier. Above calculations emphasize that large deformation of the projectile along with large product of charges of projectile and target (Z_PZ_T) are the necessary conditions for the CRE to be visible. Ideally, reorientation of the projectile takes place owing to both Coulomb and nuclear fields. Therefore, the correct way to make the orientations of the projectile to be frozen in CCFULL calculations is to set the excitation energies of the rotational band to be zero. The calculations for ^{24}Mg+ ^{208}Pb presented in the Ref. [2] consider only Coulomb effect which shifts the FBD towards the higher barriers. It is very interesting to investigate the full reorientation effect. Recently, very precise FBD has been obtained for ^{24}Mg+ ^{90}Zr [4] as shown in the Fig. 1. These data show very minute effect of reorientation, shifting the FBD slightly towards the higher barrier. Such a small effect despite of large deformation of ^{24}Mg is attributed to the low Z_PZ_T (480) value.

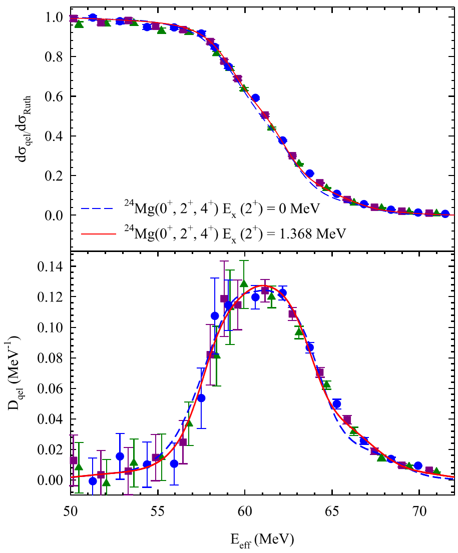

FIG. 1: Quasi-elastic excitation function (top panel) and derived barrier distribution (bottom panel) as also reported in Ref. [4]. Different lines represent the coupled channels calculations using the code CCFULL code.

Since the magnitude of the rotational band excitation energies is a crucial parameter as far as the reorientation effect is concerned, therefore, it would be interesting to investigate its influence on reorientation. With this motivation we have measured the FBDs ^{28,30}Si+ ^{90}Zr reactions from quasi-elastic scattering. The excitation energies of 2^+ state for ^{28,30}Si (1.779 and 2.23 MeV) are appreciably larger

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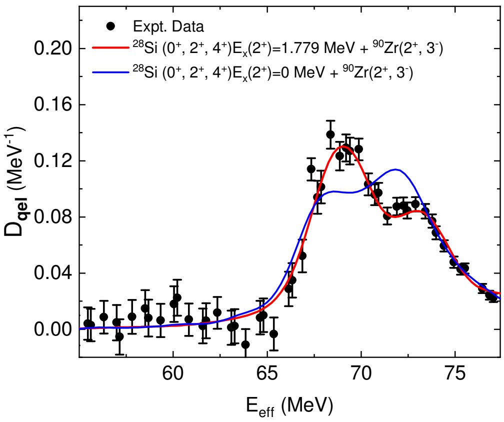

FIG. 2: Fusion barrier distribution in ^{28}Si+ ^{90}Zr reaction. Lines represent the coupled channels calculations with (reorientation effect) and without (no orientation effect) excitation energy of the rotational states of ^{28}Si.

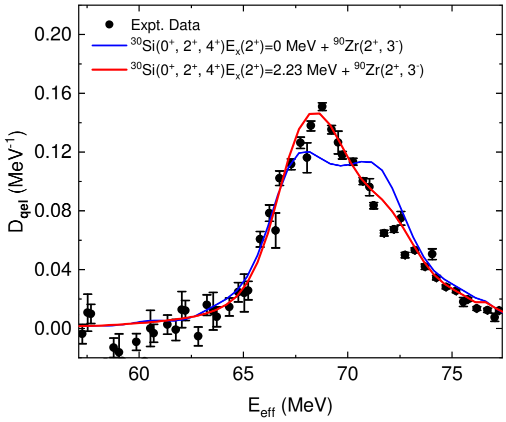

FIG. 3: Fusion barrier distribution in ^{28}Si+ ^{90}Zr reaction. Lines represent the coupled channels calculations with (reorientation effect) and without (no orientation effect) excitation energy of the rotational states of ^{28}Si.

than the ^{24}Mg (1.368 MeV).

Experimental Details

Quasi-elastic measurements were carried out using ^{28}Si and ^{30}Si beams from BARC-TIFR 14 MV Pelletron accelerator facility. Highly enriched (>95%) ^{90}Zr (150 μg/cm^2) was used as the target. Beam energies were used in the range of 70 to 102 MeV in steps of 2-MeV. Quasi-elastic events were extracted using four very thin ($\leq$ 25 μm) silicon surface barrier (SSB) detectors placed at backward angles with respect to the beam direction. Two SSB detectors placed at $\pm 20^\circ$ were used to measure Rutherford scattering events for the normalization purpose. Differential cross section for quasi-elastic events normalized with Rutherford scattering cross section were obtained as a function of centrifugal corrected center-of-mass energy for each telescope, $E_{\rm eff} = 2E_{\rm c.m.}/(1 + \text{cosec}(\theta_{\rm c.m.}/2))$. FBDs were determined from quasi-elastic excitation function using the relation:

$$D_{qel}(E_{\rm eff}) = -\frac{d}{dE_{\rm eff}}\left[\frac{d\sigma_{\rm qel}(E_{\rm eff})}{d\sigma_{\rm R}(E_{\rm eff})}\right], \qquad (1)$$

Results and Discussion

The FBDs for ^{28}Si and ^{30}Si projectiles are shown in the Figs. 2 and 3, respectively. Coupled channel (CC) calculations for QES excitation function were performed using the CCFULL code [5]. Rotational couplings of the projectiles and the vibrational couplings of the ^{90}Zr (2^+ and 3^-) are required to reproduce the experimental FBDs. The first three states (0^+, 2^+, 4^+) of the rotational band were included in the CC calculations. The values of β_2 (quadruple deformation) and β_4 (Hexadecapole deformation) are required respectively to be -0.33 and +0.1 (for ^{28}Si) and +0.33 and -0.1 (for ^{30}Si) to reproduce the experimental data. The sign of β_2 for ^{28}Si and ^{30}Si being respectively negative and positive is consistent with the fact that former is oblate and latter is the prolate in their respective ground states. Further CC calculations were carried out by setting the excitation energies of the rotational states to be zero thereby making the orientations of the projectiles to be frozen. In contrast to the nearby projectile, ^{24}Mg, the effect of reorientation for both Si-projectiles is quite significant for the same target, ^{90}Zr. The primary reason of this huge difference in behavior of Si-isotopes and ^{24}Mg should be the difference in their rotational band excitation energies. The energy of the 2^+ for ^{24}Mg, ^{28}Si, and ^{30}Si is respectively, 1.37, 1.73 and 2.23 MeV respectively.

In conclusion, for the similar $Z_P Z_T$ and similar deformation of the projectile, the reorientation effect in the field of spherical target is more prominent when rotational band excitation energies of the projectile are large.

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