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Barrier distribution from ^{28}Si+^{154}Sm quasielastic scattering: Coupling effects in the fusion process

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Abstract

Barrier distribution for the ^{28}Si+^{154}Sm system has been extracted from large angle quasielastic scattering measurement to investigate the role of various channel couplings on fusion dynamics. The coupled channel calculations, including the collective excitation of the target and projectile, are observed to reproduce the experimental BD rather well. It seems that the role of neutron transfer, relative to collective excitation, is in fact weak in the ^{28}Si+^{154}Sm system even though it has positive Q-value for neutron transfer channels.

1 Introduction

Interplay between nuclear structure and reaction dynamics is well established while explaining the enhancement of sub-barrier fusion cross sections, compared to one-dimensional barrier predictions. However, the role of neutron transfer in fusion dynamics is not fully understood. Recently, using diffusion model, Sargsyan *et al.* [1] reported for positive Q-value neutron transfer channels, fusion enhancement is significant only if the transfer leads to increase in the deformation of the colliding nuclei. In their study, for ^{28}Si + ^{154}Sm system, no fusion enhancement has been observed due to transfer coupling as the deformation of both projectile and target decreases after neutron transfer. On the contrary, reduced fusion cross section calculations by Shorto *et al.* [2] showed a significant effect of neutron transfer on fusion enhancement for the ^{28}Si + ^{154}Sm system. Such a contradictory result can limit the validity of the conclusion by Sargsyan *et al.* [1].

Moreover, both the above mentioned theoretical models have investigated the neutron transfer effect on fusion process through fusion excitation function. However, the barrier distribution (BD) provides deeper understanding about the intrinsic degrees of freedom involved in the fusion than the fusion excitation function alone. From the existing experimental fusion excitation function [3], we have extracted the BD and studied the coupling effect using `CCFULL` program [4], incorporating $\sim 10\%$ error in the data. But the uncertainty in the data forbids us from resolving the influence of various coupling channels on fusion enhancement as reported earlier [5].

In the present article, we have reported a precise measurement of quasielastic (QE) excitation function for the ^{28}Si+^{154}Sm system at large backward angles. From the measured data, BD has been extracted and coupled channel calculations have been performed to probe the effects of coupling on fusion dynamics through BD.

2 Experimental details

The experiment has been performed in the General Purpose Scattering Chamber (GPSC) facility at IUAC, New Delhi using ^{28}Si beam, from 15UD Pelletron, on ^{154}Sm target (typical thickness $\approx$ 180 $\mu g/cm^2$). Beam energy has been varied in steps of 2 MeV ranging from 90.0 MeV (25% below barrier) to 135.0 MeV (11% above barrier). The particle identification has been obtained using hybrid telescope detectors with gas ionization chamber as dE detector and PIPS detector as E detector. Four telescope detectors, two of them in plane and other two out of plane, each at an angle of 170° have been arranged in a symmetrical cone geometry to minimize the uncertainty due to beam misalignment and also to attain good statistics in small time. To check the consistency of the BD obtained from measured QE scattering events, one more telescope has been placed at an angle of 140°. Two 300 μm thick silicon detectors have been placed at $\pm 10°$ with respect to the beam direction for beam monitoring and normalization purpose.

3 Data analysis and results

The counts of elastic, inelastic and transfer events, from particle identification spectra, have been considered for the QE events as per definition. After centrifugal correction, the obtained QE cross sections, $\sigma_{qe}(\mathrm{E}, \theta)$, normalized to rutherford cross section, *i.e.*, $d\sigma_{qe}/d\sigma_R(E)$ for θ_{lab}=170° and 140°, have been shown in *fig. 1(left)*. The statistical error is found to be less than 1% at lower energies and around 2% at higher energies. The BD, $D_{qe}(E)$, as shown in *fig. 1(right)*, has been extracted from QE excitation function using the method given in *ref*. [6]. Similarity in BD structure from QE measurements at two different angles give a check on the consistency of the extracted experimental BD, as shown in *fig. 1(right)*.

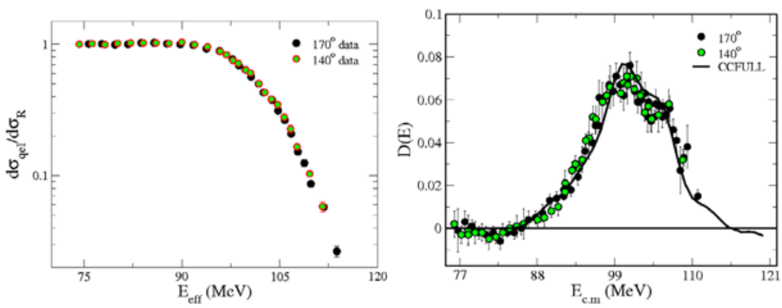

Figure 1: Left: Quasielastic excitation function obtained from two large backward scattering angles, *i.e.*, θ_{lab} = 170° and 140° for the system ^{28}Si+^{154}Sm. Right: Experimental barrier distribution (dots) for the ^{28}Si+^{154}Sm system with solid line representing the best fitted result of coupled channel calculation.

To quantitatively understand the experimental BD, quantum coupled channel (QCC) calculations have been performed using `CCFULL` code [4]. This program provides fusion excitation function from which BD has been extracted using the method mentioned in *ref*. [7]. The Woods-Saxon type interaction potential has been used with the parameters as given in *ref*. [5]. The various coupling parameters have also been taken from *ref*. [5]. At first, the rotational excitation of permanently deformed target, ^{154}Sm, has been considered in the calculation as reported for the ^{16}O+^{154}Sm system in the *ref*. [8]. It has been observed that only rotational coupling of ^{154}Sm is not able to reproduce the BD structure for the ^{28}Si+^{154}Sm system. Moreover, the BD for the ^{28}Si+^{154}Sm system seems to be wider as compared to the ^{16}O+^{154}Sm system. As coupling strength is proportional to the product of charges of the interacting nuclei. So, higher charge of projectile ^{28}Si, causing an increase in the coupling strength, may be attributed to the broader width for the ^{28}Si+^{154}Sm system. Furthermore, the vibrational excitation of projectile ^{28}Si has been considered in the coupled channel calculations in addition to rotational excitation of the target. The best fit to experimentally observed BD has been obtained with coupling involving three rotational states of target along with its octupole vibration and double phonons quadrupole vibrational excitation of projectile, as shown in *fig. 1* (*right*) with solid line. As the inelastic collective excitation alone could explain the experimentally observed BD, hence the CCFULL calculations do not reveal any significant influence of neutron transfer coupling on fusion enhancement.

4 Summary and conclusion

For ^{28}Si+^{154}Sm system, the projectile excitation, in addition to excitation of permanently deformed target, play a significant role in the fusion process. Furthermore, the coupled channel calculations predict that the inelastic excitation of target and projectile alone is sufficient to explain the experimental BD. In other words, it reveals weak influence of positive Q-value neutron transfer channel on fusion enhancement for the ^{28}Si+^{154}Sm system. Hence, our results show that increase in deformation parameter, as suggested by Sargsyan *et al.* [1], is a sufficient condition for fusion enhancement due to the presence of positive Q-value neutron transfer channels.

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