INFLUENCE OF POSITIVE Q-VALUE NEUTRON TRANSFER COUPLING ON FUSION ENHANCEMENT IN ^{28}Si+^{154}Sm REACTION* **

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Recently, the barrier distribution (BD) for the ^{28}Si+^{154}Sm system has been measured by our group using the quasi-elastic scattering technique. Here, we present the results of coupled-channel calculations performed to reproduce the measured BD. The inelastic excitation of target and projectile alone explains the experimentally observed BD very well, even though the system studied has large positive Q-value for neutron transfer channels. Hence, the results reveal no significant influence of positive Q-value neutron transfer channels on fusion enhancement for the ^{28}Si+^{154}Sm system.

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1. Introduction

The nuclear intrinsic degrees of freedom such as inelastic excitation, neutron transfer, static or dynamic deformation get coupled to the relative motion of the interacting nuclei and affect the fusion dynamics. Experimental signatures of these coupling have been observed in fusion cross-section measurements via fusion enhancement and structure in fusion barrier distribution (BD) [1]. Comparison of these experimental results with coupled-channel predictions has established the role of various couplings in the heavy-ion fusion mechanism [1]. However, even among these couplings, the role of neutron transfer is not yet well-understood.

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Recently, Sargsyan *et al.* [2] reported that for positive Q-value neutron transfer channels, fusion enhancement is significant only if the transfer leads to an increase in the deformation of the colliding nuclei. They have concluded that positive Q-value is necessary, and the increase in deformation of colliding nuclei is a sufficient condition for neutron transfer induced fusion enhancement. For the ^{28}Si + ^{154}Sm system, as deformation of both projectile and target decreases after neutron transfer, no fusion enhancement has been observed and it is in accord with the conclusion. On the contrary, reduced fusion cross-section calculations by Shorto *et al.* [3] showed a significant effect of neutron transfer on fusion enhancement for the ^{28}Si + ^{154}Sm system. Such contradictory results can limit the validity of the conclusion by Sargsyan *et al.* [2] in the deformed projectile–target combination. Besides this, the analyzed experimental data for the ^{28}Si + ^{154}Sm system in both the above-mentioned studies has been borrowed from Gil *et al.* [4] where no information about experimental errors has been provided. However, from similar experimental setups, an error estimation in fusion cross section of $\sim$ 10% has been reported. So, better precision data for the ^{28}Si + ^{154}Sm system is required to conclude whether neutron transfer has any influence on its fusion enhancement.

Moreover, these theoretical models have investigated the neutron transfer effect on fusion through fusion excitation function only. It is a well-established fact that BD provides deeper insight of the intrinsic degrees of freedom involved in the fusion than fusion excitation function alone [1]. Recently, the precise BD measurement for the ^{28}Si+^{154}Sm system has been performed by our group. The aim of this article is to investigate the role of neutron transfer coupling in fusion of the above-mentioned system through BD study. As an attempt, the coupled-channel calculations have been performed with various coupling schemes to reproduce the observed BD.

2. Results and discussion

The experimental details and the data analysis for the extraction of BD are available in Ref. [5]. To explain the measured BD, the coupled-channel calculations have been performed using a scattering version of the CCFULL program [6]. The real and imaginary components of nuclear potential are assumed to have a Woods–Saxon form. For the imaginary part, a depth parameter of 30 MeV, radius parameter of 1.0 fm, and surface diffuseness parameter of 0.3 fm are used. For the real part, $V_0 = 185$ MeV, $a = 0.65$ fm and $r_0 = 1.11$ fm are used, which yields an uncoupled barrier height of 102.23 MeV (close to the Bass value of 102.90 MeV). The inclusion of rotational excitation of ^{154}Sm considerably improves the fit but the calculations converge after inclusion of the 2^+, 4^+ and 6^+ states with results that still fall short of the experimental data. Thus, it reveals that coupling to excited states of the ^{28}Si projectile cannot be ignored. So the rotational and vibrational excitation of ^{28}Si has been further studied individually. The value of hexadecapole deformation parameter, $\beta_4 = 0.10$ for the ^{28}Si [7] is used in our initial calculations.

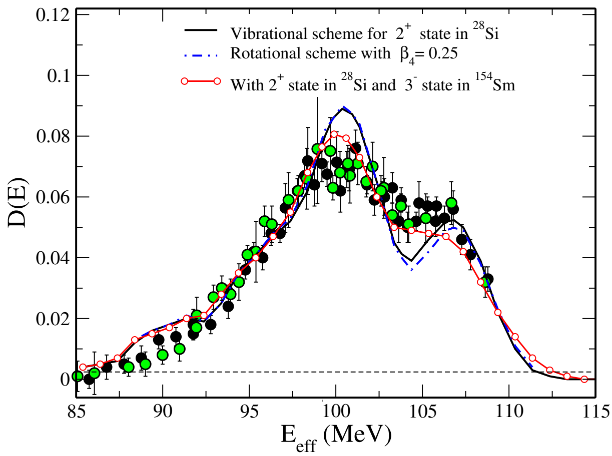

Fig. 1. Coupled-channels predictions compared with experimental QE barrier distributions for the ^{28}Si+^{154}Sm system. The plot shows results obtained with vibrational as well as rotational couplings for the first 2^+ state of ^{28}Si.

TABLE I

Change in deformation parameter (β_2) on the two-neutron transfer for reactions involving ^{28}Si projectile and different target nucleus along with its influence on fusion as observed in literature. For projectile ^{28}Si, β_2 value gets reduced from 0.4070 to 0.3150 (β_2 for ^{30}Si) on transfer of two-neutron ($2n$).

System	Q-value ($2n$ transfer)	β_2 target (before transfer)	β_2 target (after $2n$ transfer)	Enhancement due to transfer	Ref.
^{28}Si + ^{92}Zr	+3.250	0.1027	0.0894	Yes	[9]
^{28}Si + ^{94}Zr	+4.128	0.0900	0.1027	Yes	[10]
^{28}Si + ^{68}Zn	+1.832	0.2050	0.2180	Yes	[11]
^{28}Si + ^{94}Mo	+1.335	0.1509	0.1058	No	[12]
^{28}Si + ^{100}Mo	+4.865	0.2309	0.1683	Yes	[12]
^{28}Si + ^{115}In	+2.769	0.0739	0.1000	Yes	[13]
^{28}Si + ^{120}Sn	+3.494	0.1075	0.1105	Yes	[14]
^{28}Si + ^{124}Sn	+4.647	0.0953	0.1036	Yes	[7]
^{28}Si + ^{142}Ce	+6.486	0.1277	0.1015	Yes	[15]
^{28}Si + ^{154}Sm	+5.247	0.3410	0.3064	No	this work

In the literature, there is a range of positive values of β_4 parameter. The best theoretical value is probably that due to Möller and Nix [8], $\beta_4 = 0.25$. When the calculations are repeated using this value, the new rotational results barely differ from those for the vibrational calculation (as shown in Fig. 1) [5]. The only other significant collective state in this system is the 3^- octupole state of ^{154}Sm and its inclusion in the calculations does indeed smear the theoretical BD to give a final result in a good agreement with the data (Fig. 1). As the inelastic excitation alone could reproduce the experimentally observed BD for the ^{28}Si+^{154}Sm system, the CCFULL calculations reveal no significant influence of neutron transfer coupling on fusion mechanism. For comparison, we have listed in Table I the reactions involving ^{28}Si projectile and different target nucleus along with its influence on fusion as observed in literature. The β_2 of target, before and after two-neutron transfer, is also tabulated.

3. Summary

The coupled-channel calculations performed in this work show that the inelastic excitation of ^{28}Si and ^{154}Sm reproduce the experimental BD very well, without the need for any additional coupling such as neutron transfer. Thus, the results indirectly reveal no significant influence of neutron transfer coupling on fusion enhancement for ^{28}Si+^{154}Sm system, in accord with the Sargsyan *et al.* [2]. Even though the conclusion given by Sargsyan *et al.* [2] seems to be true for the present system, there are few systems studied in literature where fusion enhancement is observed even on decreased deformation parameter (Table I). So it has been realized that the role of neutron transfer in the heavier system is more complicated and need a better understanding.

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