Role of neutron transfer in ^{28,30}Si+ ^{124}Sn fusion barrier distributions

L. S. Danu[1],[*] B. K. Nayak[1], D. C. Biswas[1], A. Saxena[1], E. T. Mirgule[1], R. K. Choudhury[1], and U. Garg[2]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400085, India and*
[2]*Physics Department, University of Notre Dame, Notre Dame, Indiana 46556, USA*

Introduction

The heavy-ion fusion dynamics at near- and sub-barrier energies in the presence of transfer channels having large positive Q-values is a topic of current interest. In a recent work [1], the enhancements of fusion cross sections at near and sub-barrier energies for the ^{124,132}Sn+^{40}Ca systems in comparison to ^{124,132}Sn+^{48}Ca systems have been observed, and are attributed to the presence of positive Q-value neutron transfer channels. Whereas no such enhancements have been observed for ^{124,132}Sn+^{58,64}Ni systems [2] in spite of the presence of positive Q-value transfer channels. There are other systems in the literature (see Ref [3–5]), which show large sub-barrier enhancements when there are positive Q-value neutron transfer channels. In all these cases, where the product of nuclear charges $Z_pZ_t \leq 1000$, the enhancements persists even after correcting for size effects. It will be of further interest to investigate the effect of positive Q-value transfer channels in the presence of projectile deformation, on sub-barrier fusion enhancements in heavy ion fusion reactions. With above motivation, in the present work, a comparative study of fusion barrier distributions for ^{28,30}Si+ ^{124}Sn systems have been carried out by quasi-elastic scattering measurements at backward angle.

Experimental Details

The experiment was carried out at 14UD BARC-TIFR Pelletron facility at Mumbai, using ^{28,30}Si beams on a self-supporting enriched ^{124}Sn target of thickness 210μg/cm^2. The measurements were carried out in steps of 1.0 MeV with ^{28}Si and 2.0 MeV with ^{30}Si in the energy range E$_{lab}$= 90-118 MeV. Two silicon surface barrier detectors at $\pm$ 20° were used to measure Rutherford scattering events for normalization. Two silicon surface barrier detector telescopes, $\triangle$E(15μm)-E(500μm) and $\triangle$E(25μm)-E(1.0 mm) were placed at angles of 160° and 140° with respect to the beam direction to detect the projectile-like fragments (PLF). The experimental barrier distributions D^{qel}(E) have been obtained from the quasielastic scattering data following procedure described in Ref [6].

[*]Electronic address: lsdanu@barc.gov.in

Data analysis and results

The experimental barrier distributions D^{qel}(E) for the ^{28,30}Si+^{124}Sn systems along with the CC calculations using CCFULL [7] are shown in Fig. 1. The deformation parameters and excitation energies included in the coupling scheme are listed in Table I. The D^{qel} for the ^{30}Si+^{124}Sn system is well reproduced by the CCFULL calculations after the inclusion of the inelastic couplings (the rotational states of ^{30}Si and 2$^+$, 3$^-$ vibrational states of ^{124}Sn) and the 2n transfer coupling. However, similar coupling scheme fails to reproduce D^{qel}(E) for the ^{28}Si + ^{124}Sn system. The calculation shows a more distinct peak like structure than the experimental one. An examination of the Q-values (listed in Table II) show that for ^{30}Si+^{124}Sn reaction only 2n transfer channel has positive Q-value, while the ^{28}Si + ^{124}Sn reaction has positive Q-values for 2n to 6n transfer channels.

TABLE I: Excitation energies E_{ex}, spin parities λ^π, and deformation parameters β_λ (from Ref [6, 8]).

Nucleus	Coupling	E_{ex}(MeV)	λ^π	β_λ
^{28}Si	rotational	1.72	2^+	β_2=-0.408
				β_4= 0.10
^{30}Si	rotational	2.23	2^+	β_2= 0.32
				β_4= 0.10
^{124}Sn	vibrational	1.132	2^+	β_{2^+}= 0.122
		2.614	3^-	β_{3^-}= 0.1532

TABLE II: Q-values (MeV) for ground-state to ground-state neutron pickup transfer channels for the ^{28,30}Si + ^{124}Sn systems.

System	$+1n$	$+2n$	$+3n$	$+4n$	$+5n$	$+6n$
^{28}Si+^{124}Sn	-0.014	4.649	2.243	5.456	0.831	1.883
^{30}Si+^{124}Sn	-1.9	1.357	-2.972	-1.607	-8.241	-8.531

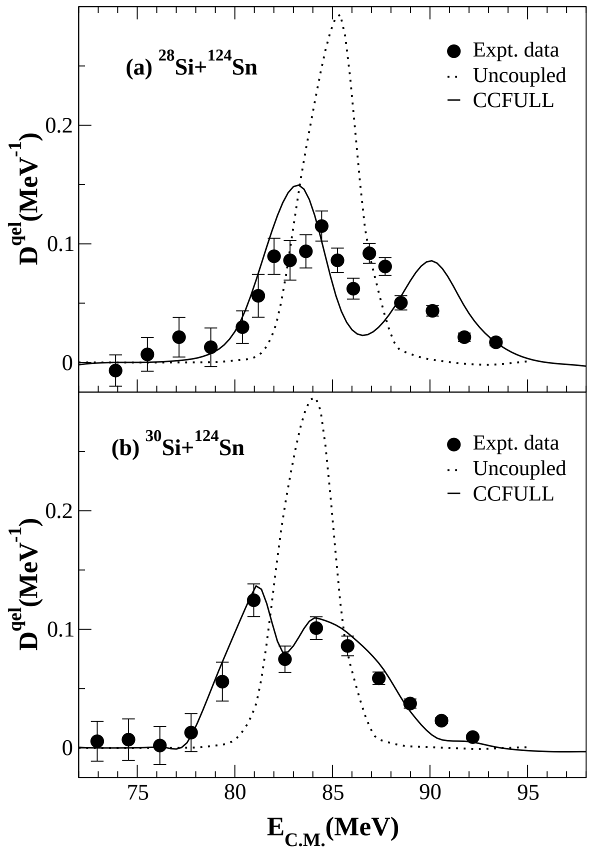

FIG. 1: D^{qel}(E) for the ^{28,30}Si+^{124}Sn systems alongwith the predictions of CCFULL calculations.

As only one 'neutron transfer channel' coupling option is available the CCFULL code, the Zagrebaev model [5] has been used to investigate the effect of neutron transfer in the ^{28}Si + ^{124}Sn reaction. According to Zagrebaev [5], neutron transfer can be incorporated in the CC calculations with the following penetration probability:

$$T(E,l) = \int f(B)\frac{1}{N_{tr}}\sum_{k}\int_{-E}^{Q_0(k)} \alpha_k(E,l,Q) \times P_{HW}(B;E+Q,l)dQdB, \quad (1)$$

where $f(B)$ is the normalised barrier distribution, $Q_0(k)$ is the Q-value for the ground-state to ground-state transfer of the kth neutron, P_{HW} is usual Hill-Wheeler formula of the quantum penetration probability, $\alpha_k(E,l,Q)$ is the probability for the transfer of k neutrons at the center-of-mass energy E and relative angular momentum l in the entrance channel to the final state with $Q \leq Q_0(k)$, and N_{tr} is the normalization constant for the transfer probability.

The CC calculations employing Zagrebaev approach, were performed using the **code** available in the Nuclear Reaction Video (NRV) webpage [9]. The prediction of NRV calculation are shown in Fig. 2 for two different β_4 values for ^{28}Si. The calculations using β_4=0.25 (default value in the code from Moller *et.al* [10]), predicts a much flatter barrier distribution than the experimental one. A good agreement between the D^{qel} and the calculation is obtained with the value β_4=0.1 taken from the Ref [6, 8]. The NRV calculations with $\beta_4 = 0.25$ and 0.1 (shown in Fig. 2), also clearly demonstrate the sensitivity of the barrier distribution on the deformation parameter β_4. This result is particularly important as it demonstrate the possibility of determining β_4 value of nuclei from barrier distribution measurements.

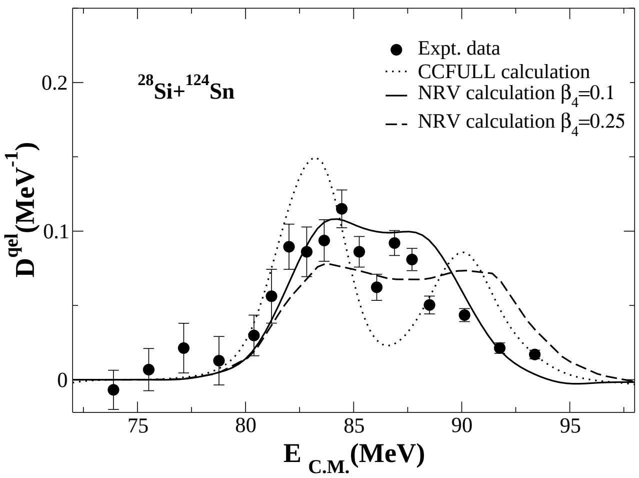

FIG. 2: D^{qel}(E) for the ^{28}Si+^{124}Sn reaction alongwith the predictions of NRV and CCFULL calculations.

References

[1] J. J. Kolata *et al.*, Phys. Rev. C **85**, (2012) 054603.

[2] Z. Kohley *et al.*, Phys. Rev. Lett. **107**, (2011) 202701.

[3] P. H. Stelson *et al.*, Phys. Rev. C **41**, (1990) 1584.

[4] A. M. Stefanini *et al.*, Phys. Rev. C **76**, (2007) 014610.

[5] V. I. Zagrebaev, Phys. Rev. C **67(R)**, (2003) 061601.

[6] B. K. Nayak *et al.*, Phys. Rev. C **75**, (2007) 054615.

[7] K. Hagino *et al.*, Comput. Phys. Commun. **123**, (1999) 143.

[8] S. Sinha *et al.*, Phys. Rev. C **64**, (2001) 024607.

[9] http://nrv.jinr.ru/nrv/

[10] P. Mollller *et al.*, Atomic Data and Nucl. Data Tables **59**, (1995) 185.