Barrier distributions derived from fusion cross-section for $^{28}Si+^{142}Ce$

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Introduction

For heavy-ion fusion reactions, the cross sections at energies near and below the coulomb barrier are strongly influenced by coupling of the relative motion of the colliding nuclei to nuclear intrinsic motions. Such couplings can be described in terms of changes in the potential barrier between interacting bodies, leading sometimes to its splitting into several components around the one-dimensional barrier giving rise to a distribution of barriers. This type of distribution can be most easily visualized for reactions involving a deformed nucleus [1]. In this case, the potential depends on the orientation of the deformed nucleus. The concept of barrier distribution can be extended also to systems with a non-deformed target [2], where the coupling between the relative motion and vibrational excitations in the colliding nuclei and/or transfer processes gives rise to the distribution. The fusion cross section is then given by an average over the contributions from each fusion barrier with appropriate weight factors. Thus, the shape of the barrier distribution can be directly linked to the coupling of channels that are important in governing the fusion around the barrier. In other words, the barrier distributions may be used as a powerful tool to get information related to the structure of the interacting nuclei.

In this work, the coupled-channel analysis have been performed for the system ^{28}Si+^{142}Ce, taking into account the different coupling effects. N. Rowley et al. [3] has explained that the representation of the barrier distribution could be obtained by taking the second derivative of the product $E_{c.m}\sigma_{c.m}$, w.r.t. $E_{c.m}$. Here, the experimental barrier distribution has been obtained from the experimental fusion cross-section reported in ref. [4].

Calculations details

The coupled-channel calculations have been performed using the CCFULL code, to get the theoretical fusion cross sections. It uses the ingoing-wave boundary condition inside the coulomb barrier to account for fusion, along with the isocentrifugal approximation, which works well for heavy ions. The details of this code are given in ref. [5]. The nuclear potential is given by V_0, R_0 and A_0; where V_0 is the depth parameter of the Woods-Saxon potential, R_0 is the radius parameter, and A_0 is the surface diffuseness parameter. These parameters are obtained by fitting the excitation function above the barrier because this high energy part is insensitive to the coupling effects. From the experimental and calculated fusion cross sections with finite energy intervals, the second derivative of Eσ can be obtained using a point difference formula. For data with equal energy steps, i.e. ΔE = (E_2-E_1) = (E_3-E_2), the expression at energy (E_1 + $2E_2$ + E_3)/4, is given by

$$\frac{d^2(E\sigma)}{dE^2} = \frac{(E\sigma)_3 - 2(E\sigma)_2 + (E\sigma)_1}{\Delta E^2} \quad (1)$$

where (Eσ)$_i$ are evaluated at energies E_i. The statistical error δ_c associated with the second derivative at energy E is approximately given by

$$\delta_c \simeq \left(\frac{E}{\Delta E^2}\right)[(\delta\sigma)_1^2 + 4(\delta\sigma)_2^2 + (\delta\sigma)_3^2]^{\frac{1}{2}} \quad (2)$$

where the $(\delta\sigma)_i$ are the absolute cross section uncertainties.

Results and discussion

In the present work, the target is ^{142}Ce which has spherical ground state shape. The

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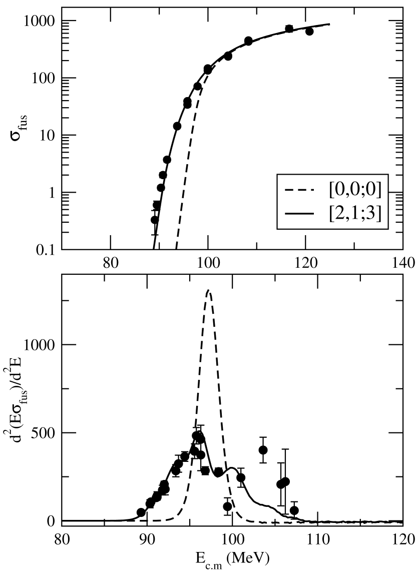

FIG. 1: Excitation function (upper) and barrier distributions (lower) for ^{28}Si+^{142}Ce. Dots are the experimental data and lines are theoretical calculations. The notation $[n_{2^+}, n_{3^-}; n_{2^+}]$ gives the number of phonons included in the calculation.

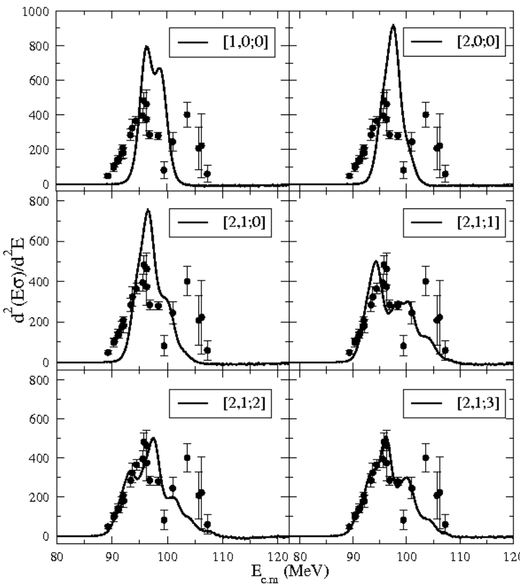

FIG. 2: Experimental (dots) and theoretical (lines) barrier distributions for ^{28}Si+^{142}Ce, with coupling given in the box.

low-energy level schemes of ^{142}Ce are characterized by strong vibrational quadrupole (2^+) and octupole (3^-) excitations that can be included in the coupled channel calculations. The experimental fusion cross-section is shown as dots in upper panel of Fig. 1, the corresponding error bars are smaller than the size of the dot so not visible. The theoretical fusion cross-sections obtained from CCFULL are shown by different lines. The lower panel shows the barrier distributions obtained from the corresponding fusion cross-sections. The dashed line is the single channel calculation i.e. without any coupling, which is not able to reproduce the experimental data. So, the coupled channel calculations have been performed involving the different vibrational states of ^{142}Ce and ^{28}Si as shown in Fig. 2. It is observed that the coupling involving double phonons excitation of 2^+ and single phonon excitation of 3^- state of ^{142}Ce along with the three phonons excitation of 2^+ state of ^{28}Si is able to reproduce the experimental fusion cross-section as well as barrier distribution. The fit is quite good at low energies but in the high energy side, there is small deviation from the experimental distribution. Also the uncertainties in the distribution are very large in this region. It is also observed from the distribution that the average fusion barrier for the system is slightly shifted towards the lower energy side as compared to the single barrier.

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