Does vibrational excitation influence surface diffuseness? study through quasi-elastic scattering

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Introduction

We discuss the influence of channel coupling on the surface diffuseness parameter of an inter-nuclear potential (Woods-Saxon form) for heavy-ion reactions. To this end, we analyze the experimental quasi-elastic cross sections for the ^{12}C + ^{105,106}Pd and ^{13}C + ^{105,106}Pd systems, for which the data have been available in Ref. [1]. While Ref. [1] focused on extracting the barrier distributions, our aim in this paper is to extract the surface diffuseness parameter using the deep-subbarrier data. The chosen target nuclei, ^{105,106}Pd, exhibit low-energy vibrational excitations ($E^* \approx 0.5$ MeV for the first excited state in ^{104,106}Pd). The projectile, ^{13}C, along with the chosen target, is an ideal candidate to study the effect of transfer coupling due to the existence of weakly bound valence nucleon. Moreover, since the ^{12}C + ^{105,106}Pd systems have a negative Q-value for the neutron pick-up reactions (see Table I), a comparison with the ^{13}C + ^{105,106}Pd systems will elucidate the influence of transfer coupling on the surface diffuseness parameter.

Theoretical Calculations

To perform a systematic study, the single-channel and coupled-channel calculations have been performed using a scattering version of the `CCFULL` program [2]. For the coupled-channels calculations, we have included the double quadrupole phonon excitations in the target nuclei in the harmonic oscillator limit, in order to understand the influence of vibrational coupling on the surface diffuseness parameter. The deformation parameter and the excitation energy for ^{106}Pd are given by β=0.229 and E^*=0.512 MeV, respectively [1]. For the ^{105}Pd nucleus, we have taken the average in the adjacent nuclei, that is, ^{104}Pd and ^{106}Pd, which leads to β=0.219 and E^*=0.534 MeV. The nuclear potential used in the calculations has a real and an imaginary components, both of which are assumed to have a Woods-Saxon form. The imaginary part simulates a compound nucleus formation. We have chosen the strength to be large enough so that the flux does not reflect inside the barrier once the barrier is overcome. In the calculations, an imaginary potential with the depth parameter of 30 MeV, the radius parameter of 1.0 fm, and the diffuseness parameter of 0.4 fm have been used. For the real part of the nuclear potential, the potential depth V_0 is fixed to be 185 MeV. The value of radius parameter r_0 is then adjusted for a particular value of the diffuseness parameter such that the Coulomb barrier height V_B for each system becomes the same as that for the Bass potential [3]. This is possible because the effect of variation in V_0 and r_0 on the Coulomb barrier height compensates with each other in the surface region.

Results and Discussion

FIG. 1 shows the comparison of coupled-channel calculations obtained with several values of the surface diffuseness parameter, a_0, for the ^{12}C + ^{105}Pd system. Best fitted value of a_0 has been obtained after χ^2 fitting. Similar calculations have been performed for ^{12}C + ^{106}Pd and ^{13}C + ^{105,106}Pd systems (not shown here). Results obtained are summarized in Table I. It is apparent from the table that the diffuseness parameter decreases in the coupled-channels calculations as compared to the single-channel calculations with inert target nuclei, showing the significant influence of

TABLE I: Diffuseness parameter (a_0), for the systems studied in the present work, from single channel (sc) and coupled channel (cc) calculations. Q-values for neutron transfer channels are also tabulated. Here negative and positive sign corresponds to pick-up and stripping reaction, respectively.

System	a_0 *from sc*	a_0 *from cc*	Q *value* $(-1n)$	$(-2n)$	$(+1n)$	$(+2n)$
^{12}C + ^{105}Pd	0.80±0.04	0.69±0.04	−9.161	−15.744	−2.148	−3.953
^{12}C + ^{106}Pd	0.94±0.07	0.78±0.05	−12.185	−16.082	−4.615	−3.532
^{13}C + ^{105}Pd	0.64±0.05	0.60±0.05	+4.615	−7.571	+1.082	−7.681
^{13}C + ^{106}Pd	0.76±0.04	0.68±0.03	+1.59	−7.908	−1.385	−7.261

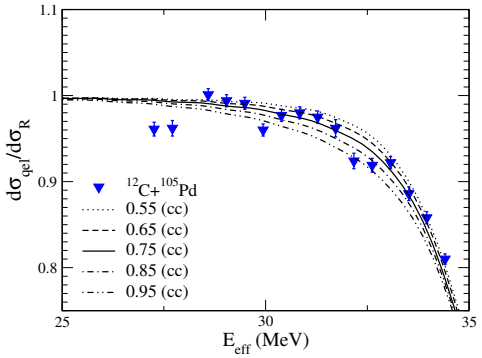

FIG. 1: Comparisons of the coupled-channel calculations for the quasi-elastic excitation function obtained with several values of the surface diffuseness parameter, a_0, in the nuclear potential for the ^{12}C + ^{105}Pd system.

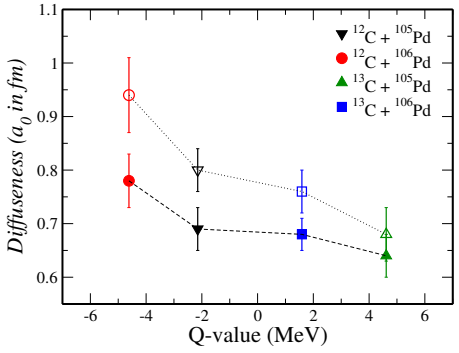

FIG. 2: (Color online) The extracted surface diffuseness parameter for the ^{12,13}C+^{105,106}Pd systems as a function of the Q-value for the neutron transfer channels. The open and filled symbols represent the results of the single-channel and the coupled-channel calculations, respectively. The lines are to guide the eye.

vibrational coupling on a_0. In order to investigate the role of transfer couplings, we have plotted in FIG. 2 the optimum value of surface diffuseness parameter as a function of the Q-value for neutron transfer. Since the two-neutron (2n) transfer is a second step process, the most important transfer channel is a one-neutron (1n) transfer. Hence, we have plotted the surface diffuseness as a function of the Q-value for the 1n transfer channels. It can be observed from the figure that, as a general trend, the surface diffuseness decreases as the transfer Q-value increases. This might indicates that the difference in the surface diffuseness parameter between the ^{12}C projectile and the ^{13}C projectile could be attributed to the influence of neutron transfer coupling.

Conclusions

While earlier studies have reported a negligible influence of vibrational excitation on the surface diffuseness parameter for spherical systems [4], we find a significant effect for the C+Pd systems. Our systematic study also reveals influence of transfer couplings on the surface diffuseness parameter.

References

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