Coupled channel calculation of fusion cross section of ^{16}O + ^{144}Sm reaction using Proximity Potential

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Introduction

There are two main ingredients of sub-barrier fusion, the potential and the tunneling, which have broad implications. It is now well known that Coulomb interactions alone cannot define a fusion barrier. Nuclear interactions play an equally important role in deciding the outcome of a reaction [1]. The inter-nucleus potential is an important ingredient in the description of heavy ion collisions of all types at all energies and its systematic properties are a basic feature of nuclear systems. Various nuclear potential such as Woods-Saxon Potential, Proximity Potential, Double Folding Potential, etc. are available for this purpose. Among this, two important nuclear potentials are well known Woods-Saxon potential (WS) and Proximity potential. Woods-Saxon potential parameterized by Akyüz-Winther potential [2] is a function of the relative distance between two colliding nuclei, whereas Proximity potential of Blocki [3] is a function of separation between the surfaces of the approaching nuclei. It is commonly known that this potential can be written as a product of geometrical factor, which is proportional to the reduced radii of colliding nuclei, and a universal function. With this perhaps, the proximity potential, which makes use of the nuclear surface tension and surface diffuseness, offers a simple formula for the nucleus-nucleus interaction energy.

In order to study the role of proximity potential in the coupled-channel formalism, we have calculated fusion cross section (CS) and fusion barrier distribution (BD) for ^{16}O + ^{144}Sm using the code CCFULL. The aim of this study is to see whether this shallow potential approach works to explain the fusion data for spherical projectile – spherical target reaction ^{16}O + ^{144}Sm at near and above the barrier energies within the coupled channel formalism.

Calculational details

Standard coupled channel calculation code CCFULL [4] uses Woods-Saxon potential which is a deep attractive nuclear potential. In this code, the depth, range and the surface diffuseness parameters of the potential have been determined by fitting the experimental fusion cross section at high energies. Instead of such an approach, here we have modified this code using the Proximity potential of Blocki [3] as the nuclear potential which is given below,

$$V(r) = 4\pi\gamma b \frac{C_1 C_2}{C_1 + C_2} \phi\left(\frac{z}{b}\right)$$

where $\gamma = \gamma_0[1-(k_s\,(N-Z)^2)/A^2]$ is nuclear surface energy coefficient, b = width (diffuseness) of nuclear surface, C_i = Siissamann Central radii, ϕ = universal proximity potential, z = r - (C1+C2) is the distance between the nuclear surfaces of the projectile and target [3, 5]. The surface energy constant γ_0, the surface-asymmetry constant k_s and b of the potential have been determined by fitting the experimental fusion cross section at high energies.

In the present work, the effect of coupling of low lying vibrational states of target nucleus ^{144}Sm is investigated. In particular, the effect of couplings of low lying 3^- and 2^+ vibrational states are studied. We consider the projectile nucleus ^{16}O to be inert. The values of the parameters such as deformation parameter β_λ, and excitation energy E_λ are taken from the ref. [6] and are given in Table I. The experimental data for ^{16}O + ^{144}Sm are taken from the ref. [7].

Table-I: The deformation parameters, excitation energies, and the multipolarities of the states of different nuclei used in the CC calculations.

Nuclei	J^π	E_x (MeV)	β_λ
^{144}Sm	3^-	1.81	0.21
	2^+	1.66	0.11

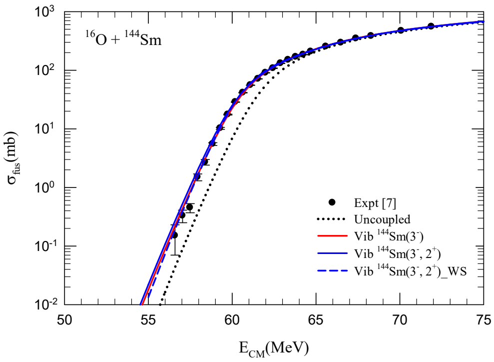

Fig. 1. Comparison of CCFULL calculations of Proximity potential with expt. data and Woods-Saxon form for the fusion cross section ^{16}O + ^{144}Sm system.

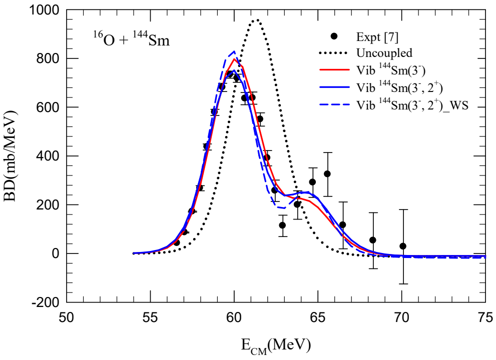

Fig. 2. Comparison of CCFULL calculations of Proximity potential with expt. data and Woods-Saxon form for the fusion barrier distribution ^{16}O + ^{144}Sm system.

The parameters of the Proximity form of the nuclear potential for ^{16}O + ^{144}Sm, γ_0 = 1.61MeV/fm^2, k_s = 2.3, b = 0.99 fm are chosen in such a way that the calculated cross section fit well with the experimental data at the highest energies. The fusion BD has been extracted with the usual three-point formula and an energy step of 2.0 MeV.

Results and Discussion

Fig. 1 and 2 show the calculated and the experimental fusion cross section and fusion BD for ^{16}O + ^{144}Sm system, respectively.

As seen in Fig. 1, the dotted line is the result when the projectile (^{16}O) and target (^{144}Sm) are assumed to be inert i.e. no excitation level, which gives a single peaked structure in BD which is shown in Fig. 2. Then we introduce the coupling of single vibrational state 3$^-$ of ^{144}Sm which is denoted by red solid line. This calculation fails to explain the structure of barrier distribution. Then we introduce the result of CC calculations taking into account the coupling to two single vibrational phonon states (2$^+$, 3$^-$) of ^{144}Sm. Here we have not included their mutual excitation. This calculation is denoted by blue solid line. This result matches well with the experimental data at higher energies as well as lower energies. With this coupling of 3$^-$ and 2$^+$ of ^{144}Sm, we get the best fit with the measured BD, as shown in Fig. 2, which is denoted by blue solid line.

Then we compare the calculations of fusion cross section and fusion BD of Proximity potential with that of the calculation with the Wood-Saxon potential which is denoted by blue dashed line. We can see in Fig. 2 that the BD of Proximity potential agrees with the experimental BD much better than those of Woods-Saxon potential.

Conclusion

The present coupled-channel calculations with proximity potential for the ^{16}O + ^{144}Sm reaction agree very well with the experimental fusion cross sections as well as the fusion barrier distributions. Our study indicates that the proximity potential, which is shallow potential as compared with the Woods-Saxon potential, is adequate in coupled-channel calculation for the analysis of the heavy-ion fusion reactions.

References

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