Coupled-channel calculation of fusion cross section of ^{16}O + ^{154}Sm reaction using modified Proximity Potential

Nisha Chauhan, S. S. Godre*
Department of Physics, Veer Narmad South Gujarat University, Surat – 395007, India
* *email: ssgodre@yahoo.com*

Introduction

In recent years, many theoretical and experimental efforts have made for understanding the Heavy-ion fusion reaction. This reaction is based on Quantum tunneling through the Coulomb barrier formed by the strong competition between the Coulomb repulsion force and the nuclear attractive force of the two colliding nuclei. 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 + ^{154}Sm using the code CCFULL [4]. We also investigated the role of modified Proximity potential in the coupled-channel formalism for spherical-spherical heavy-ion reaction ^{16}O + ^{144}Sm [5] using CCFULL code. The aim of this study is to see whether this shallow potential approach works to explain the fusion data for spherical projectile – deformed target reaction ^{16}O + ^{154}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,

$$V\left(r\right)=4\pi\gamma b\frac{C_1C_2}{C_1+C_2}\phi\left(\frac{z}{b}\right)$$

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 = Süssamann Central radii, ϕ = universal Proximity potential, $z = r - (C1+C2)$ is the distance between the nuclear surfaces of the projectile and target [3]. In the present study, 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 rotational states of target nucleus ^{154}Sm is investigated. In particular, the effect of couplings of low lying 2^+ to 6^+ rotational states are studied. We consider the projectile nucleus ^{16}O to be inert. The values of the parameters such as deformation parameter β_2 = 0.33, and excitation energy E_2 = 0.082MeV, are taken from the ref. [6]. The experimental data for ^{16}O + ^{154}Sm are taken from the ref. [7].

The parameters of the Proximity form of the nuclear potential for ^{16}O + ^{154}Sm, γ_0 = 1.99 MeV/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.

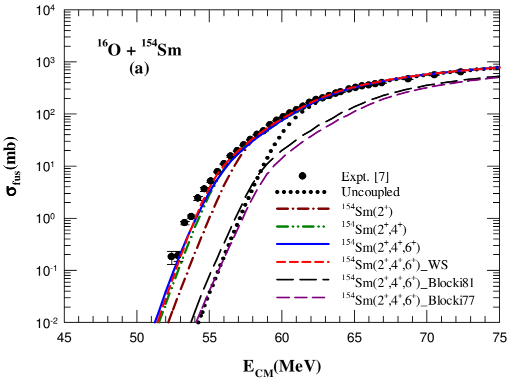

Fig. 1. Comparison of CCFULL calculations of Proximity potential with expt. data and Woods-Saxon form for the fusion cross section ^{16}O + ^{154}Sm system.

Results and Discussion

Fig. 1 and 2 show the calculated and the experimental fusion cross section and fusion BD for ^{16}O + ^{154}Sm system, respectively.

As seen in Fig. 1, the dotted line is the result when the projectile (^{16}O) and target (^{154}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 rotational state 2^+ of ^{154}Sm which is denoted by dashed-dotted line. This calculation fails to explain the structure of barrier distribution. Then the calculation with the inclusion of coupling to multi rotational excitation (2^+, 4^+ and 6^+) of ^{154}Sm is shown in fig. 1 as solid line, we get the best fit with the measured BD, as shown in fig. 2, which is denoted by solid line.

The present calculation of fusion cross section and fusion BD with the above couplings using the modified Proximity potential is compared with the corresponding calculations using Woods-Saxon potential, original Proximity potential (Blocki77 and Blocki81 [3]). It can be seen that fusion BD for calculations using modified Proximity potential agrees very well with the experimental BD as well as the calculation using Wood-Saxon potential which is denoted by red dashed line.

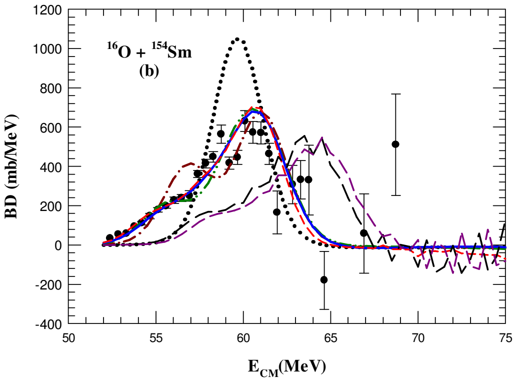

Fig. 2. Comparison of CCFULL calculations of Proximity potential with expt. data and Woods-Saxon form for the fusion barrier distribution ^{16}O + ^{154}Sm system.

Conclusion

The present coupled-channel calculations with modified Proximity potential for the ^{16}O + ^{154}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 and it seems to be indicate that Proximity potential is not a fixed parameter potential.

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