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Study of the effects of orientation and deformation of Sn on fusion cross sections using proximity potentials

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Abstract :

Background: The deformed targets and its orientation with collision axis of the projectile and the target in the nuclear fusion reaction influence the fusion cross-section.

Statistical Analysis: The effects of static quadrupole and hexadecapole deformation of target are studied using various proximity potentials in the literature. Accordingly, the height and the position of the Coulomb interaction barrier for 18O+118Sn (deformed target) system is studied in this paper.

Findings: The nucleus-nucleus potential was found to depend strongly on the deformation parameters as well as the orientation of the deformed target. The fusion cross section of the mentioned system was found out by applying parameters of the various proximity potential on the Wong's formula. Also the result of a multi dimensional barrier penetration model (BPM) was assessed using CCFULL code. The fusion cross sections of approx 00, Prox 00DP, pro 77, Prox 88, modProx 88, Prox 10 over estimates the results obtained using BPM and the rest of the potentials under-estimates the result obtained using BPM technique.

Keywords: fusion cross-section, effects of deformation, effects of orientation, proximity potentials.

1. Introduction

Fusion-fission reactions study around the Coulomb barrier energies is one of the intense topic of research recently[1]. As such reactions are dramatically influenced by the internal structure and entrance channel parameters such as mass asymmetry and deformation of the interacting nuclei which are significantly governed to affect the probability of a compound nucleus (CN) system. The effect of entrance channel mass asymmetry has been studied by several authors and different mechanisms of entrance dynamics for different systems[2,3] are proposed. It is seen that the subbarrier fusion of spherical as well as deformed nuclei in the ground state is strongly enhanced by deformation of the nucleus[4,5]. The effect of deformation of one or both of the interacting nuclei in a reaction is found to be severe on the fusion cross-section at near barrier energies.

2. Literature Review

In the literature, the role of hexadecapole deformation (β_4) and quadrupole deformation (β_2) effects in sub-barrier fusion reactions for the various systems was surveyed. Using nucleus-nucleus interaction potentials, the fusion-fission dynamics was analyzed. In recent papers[6, 7] the authors have used various proximity potentials to predict the fusion barrier height and its position for a large number of reactions. They conclude that for asymmetric colliding nuclei, the potentials could reproduce the experimental data, on average, within 10% [8] and for symmetric colliding nuclei within 8% [7]. All the interacting nuclei considered here are spherical in nature. But the deformation as well as the orientation of the deformed nuclei is found to affect the fusion barriers as well[9].

3. Proposed Work

This paper attempts to study the effect of few of the proximity potentials on the fusion cross section. The fusion cross-sections induced by spherical nucleus (^{18}O) are investigated on a slight deformed nucleus ^{118}Sn within the theoretical approach which helps to quantify the role of static deformed potentials at sub-barrier energies. The fusion barriers are reproduced using different parameterizations for the nucleus-nucleus interaction potential. The interaction barrier heights and fusion barrier radii for the reaction ^{18}O + ^{118}Sn are determined using twelve different versions of nuclear potentials. The quadrupole and hexadecapole deformation parameters for the target used in our calculation are ^{118}Sn (β_2 = 0.003, β_4 = -0.008) [10]. The deformation of the target is found to affect the fusion barriers, and consequently, the fusion cross-sections. Besides the barrier parameters, namely, Coulomb barrier potential, V_B, barrier radius, R_B and the curvature of the barrier, $\hbar\omega$ are dependent on orientation (θ), that is, the angle made by the symmetric axis of a deformed nucleus with the collision axis, due to which, it is important to calculate the fusion cross-section by an orientation dependent potential. As such, the total interaction potentials are investigated and the fusion cross-section is calculated from the Wong's model[11] using parabolic approximation.

Various versions of proximity potentials used here are based on the proximity force theorem. The nuclear part of the interaction potential is considered to be the product of a factor depending on the mean curvature of the interaction surface and a universal function (depending on the separation distance), which does not depend on the masses of colliding nuclei. In this paper, the 12 different versions of the nuclear proximity potentials used are Bass77, Bass80, Prox 77, Prox 88, modProx 88, Prox 00, Prox 00DP, Prox 10, CW 76, BW 91, AW 95 and Ngo 80. The detailed studies and formalism of all these potentials are presented in Ref. [8]. Using these potentials, the nuclear part of the interaction potential is calculated. Assuming that the size of the projectile is much smaller than the radius of the target, r_c, the Coulomb potential $V_c(r)$ can be approximated as

$$V_c = \frac{Z_P Z_T e^2}{2r_c}\left(3 - \frac{r^2}{r_c^2}\right) \quad \text{if } r \le r_c.$$

$$V_c = \frac{Z_P Z_T e^2}{r} \quad \text{if } r > r_c.$$

where Z_P, Z_T are the atomic numbers of the projectile and target respectively. The total interaction potential is then written as the sum of the long range Coulomb repulsive force, short range nuclear attractive force and the centrifugal term. Here the centrifugal term is taken to be zero as the angular momentum operator on which the centrifugal term is dependent is taken as zero.

The fusion barrier heights and positions for the different potentials mentioned above are found out by differentiating the above potentials with respect to inter-nuclear distance and equating it to zero; and from there the value of potential (fusion barrier heights) at the barrier radius or positions (the point where the highest peak in the plot of potential versus inter-nuclear distance occurs) is determined.

As the deformation and orientation of the interacting nuclei affect the fusion barrier, a correction for the Coulomb barrier given by Takigawa et al.[12] is applied for the deformed target.

The fusion cross sections are then calculated by the multi – dimensional barrier penetration model (BPM) under the parabolic approximation given in Ref. [9,11] by using the CCFULL[13] code. The results are then compared with each other.

4. Results and Discussions

To begin with, the nuclear part of the total interaction potential was calculated using the above mentioned 12 potentials on ^{18}O + ^{118}Sn. As the target considered here is assumed to be slightly deformed, the corrected Coulomb as well as nuclear part of the total potential, which depends upon the target orientation, is found for different orientations of 0^{o}, 45^{o} and 90^{o} as shown in figure 1.

Once the nuclear parameterizations are carried out with the help of the above plots, the parameters are used in Wong's formula, assuming a parabolic approximation, to calculate the fusion cross sections for the present

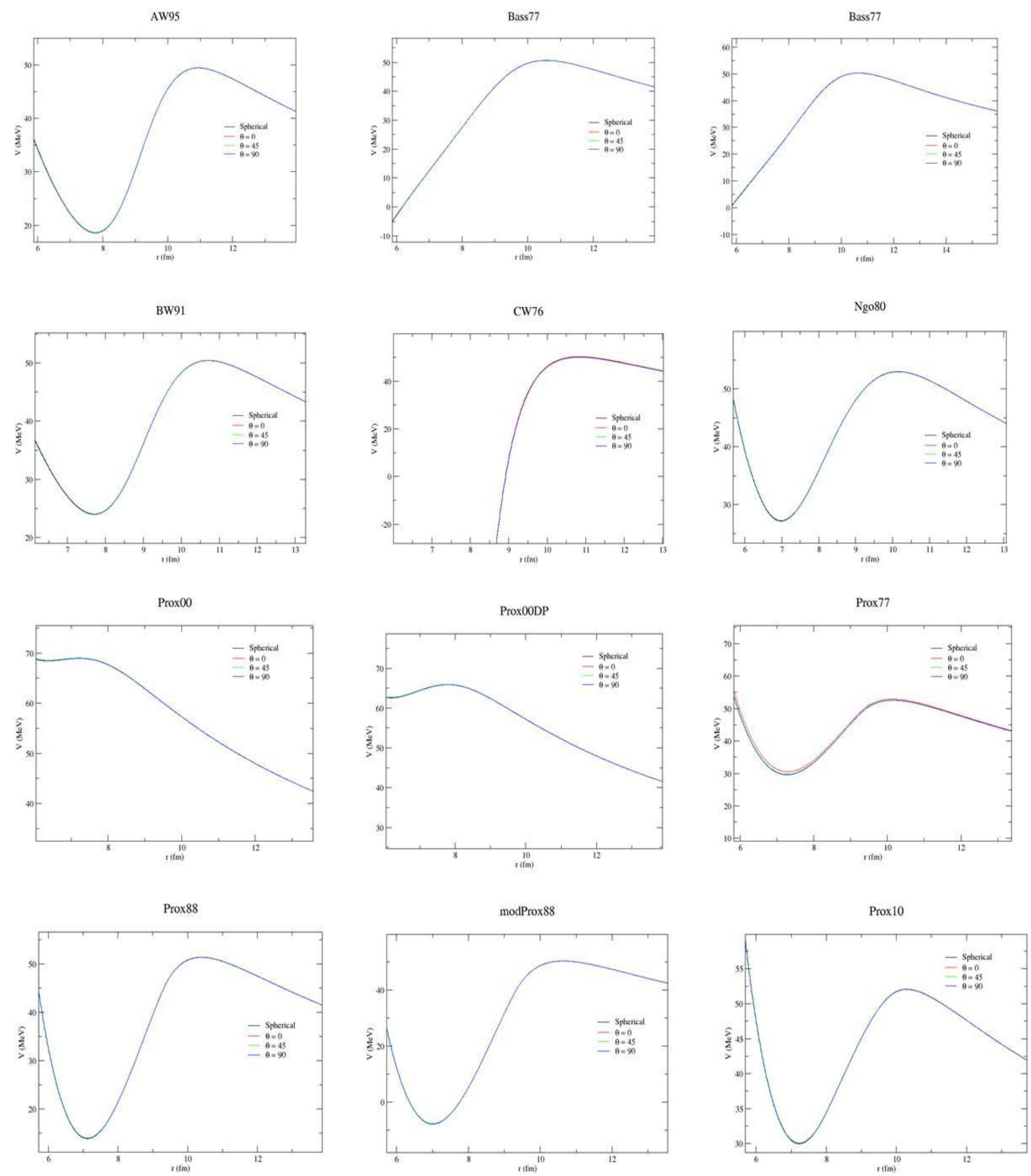

Figure 1: The total potential V (MeV) as a function of inter-nuclear distance r (fm) at different orientations for the reaction $^{18}O + ^{116}Sn$.

systems which are plotted in figure 2. The fusion cross sections are also calculated using multi-dimensional model (BPM) with the help of CCFULL code.

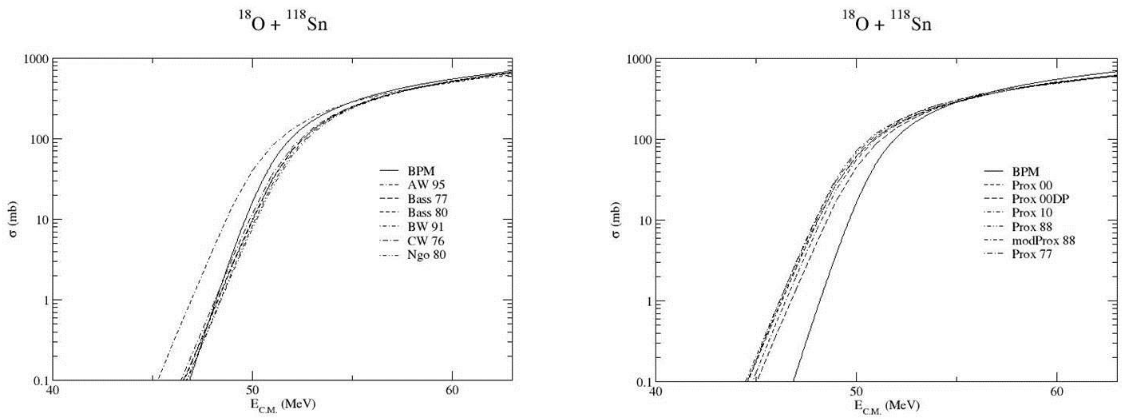

Figure 2: The fusion cross sections σ (mb) as a function of centre of mass energy $E_{C.M.}$ (MeV).

5. Conclusions

From the above work it was found that Prox 00, Prox 00DP, Prox 88, Prox 77, Prox 10, modProx 88 overestimates the fusion cross section due to that of BPM and the remaining potentials under-estimates that. It is to be seen what the experimental results reveal which is yet to be done indeed in future.

6. References

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