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The effect of the nuclear state equation on the surface diffuseness parameter of the Woods–Saxon potential in the heavy ion fusion reactions

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Abstract

The interaction potential in the fusion reactions of ^{12}C, ^{16}O, ^{28}Si and ^{35}Cl on ^{92}Zr have been calculated using a nucleon–nucleon force of the type M3Y and an additional repulsive interaction which simulates the effects of the incompressibility of the nuclear matter. The free parameters of this repulsive force have been chosen in such a way that fully explains the properties of the nuclear matter in the region where the nuclear densities of the interacting nuclei completely overlap. The effect of this repulsive force on the diffuseness parameter of the Woods–Saxon potential has also been discussed. The results of our studies reveal that accounting for these corrections in the calculation of the total potential leads to an increased value of the diffuseness parameter of about 0.73 fm. Furthermore, accounting for the effects of the intrinsic properties of the interacting nuclei on the calculation of the fusion cross section, the values of the cross section have been calculated using the CCFULL code.

Keywords: Surface diffuseness; Heavy-ion potential; Incompressibility; Repulsive core

1. Introduction

The interaction potential consisting of an attractive nuclear force and a repulsive long-range Coulomb force plays a crucial role in the study of heavy ion interactions. Since the repulsive Coulomb force can be calculated with great accuracy the main remaining task is the calculation

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of the nuclear potential. The Woods–Saxon (WS) potential that is commonly used to describe such interactions is given by

$$V(r) = \frac{V_\circ}{1 + \exp[(r - r_\circ A_P^{1/3} - r_\circ A_T^{1/3})/a]} \tag{1}$$

where $V_\circ$, $r_\circ$ and a are the depth, radius, and diffuseness parameters, respectively. Here r is the distance between the center of mass of the projectile nucleus with the mass number A_P and that of the target nucleus with the mass number A_T. In coupled-channel formalism the nuclear potential used is usually of the form of the WS potential. Recent systematic studies of the heavy ion cross section data using this formalism reveal that in order to have an agreement between the theoretical and experimental cross section data a WS nuclear potential with a diffuseness parameter of 0.8 to 1.4 fm is needed [1–5], which is greater than the accepted value of 0.63 fm obtained from the scattering studies [6–8]. There have been different attempts in order to explain this discrepancy [9,10]. In some studies the Double Folding (DF) model [11] has been employed and the nuclear potential has been calculated using the sudden approximation where the reaction occurs in such a short time that the densities of the interacting nuclei do not have enough time to get deformed. When the densities of the two nuclei completely overlap, the density of the nuclear matter becomes twice the saturated density and this contradicts the incompressibility property of the nuclear matter. In order to remove this contradiction in the calculation of the nuclear interaction a repulsive additional force has been used in the NN interaction [12]. The main reason that does allow one to add an additional repulsive force to the NN interaction is the Pauli exclusion principle which does not permit the total density in the overlap region to exceed the saturated density. Recently it has been shown that this modification explains the steep-fall off effect in the interaction of the heavy ions [13–20]. As this repulsive term affects the internal and external parts of the nuclear potential in places where the fusion reaction is sensitive to them (see Fig. 1), we have been motivated to see to what extant this can affect the diffuseness parameter in the heavy ion interactions. To this end we have studied the fusion reactions of ^{12}C, ^{16}O, ^{28}Si and ^{35}Cl with ^{92}Zr. The reason for choosing these reactions is that they have been studied with coupled-channel formalism and it has been shown that [1] the experimental data of the fusion cross section can be fully explained using the WS potential but with a diffuseness parameter of about 0.8 fm.

In Section 2 we shall briefly discuss the simulation method that is employed to calculate the internuclear potential, and the repulsive core potential. In Section 3 we have discussed the effect of repulsive core potential on the calculation of the total potential. Section 4 is devoted to some concluding remarks.

2. Nuclear potential

In order to calculate the nuclear potential of the candidate reactions we have employed a simulation technique that we have used in our previous studies [21]. In this simulation technique we can use the densities of the neutrons and protons of the interacting nuclei in the calculation of the nuclear potential. This capability allows us to account for the effect of the surface nucleons in the calculation of the interaction potential [22]. In the special case where the nuclear matter density of the interacting nuclei is assumed to be proportional to their charge density (i.e. $\rho_A = \rho_Z A/Z$), and the spin and isospin dependent terms in the M3Y interaction are neglected, the results of this technique agree with the corresponding results of the DF model [21]. In order to increase the accuracy of the calculation of the potential we have used the densities of the