Reduction methodology for reaction cross sections induced by tightly bound nuclei

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Introduction

In the last two decades an inclusive study has been performed in the field of nuclear reactions using the weakly bound or short-lived nuclei [1,2]. Extensive studies from theoretical and experimental aspects has been dedicated to it. Dynamic and static effects present in neutron and proton halo structure of the projectiles play a fundamental role. The fusion cross section is strongly influenced by the static effects due to halo structure of some nuclei and by the breakup (dynamic) channels, as they are usually weakly bound, when compared to the cross sections of reactions involving tightly bound nuclei [1,2]. The elastic scattering is the simplest approach to study the reaction mechanism of the two colliding nuclei. At low energies, it is a surface process and thus very suitable to investigate surface properties such as deformations and cluster configurations. The investigation of the elastic scattering angular distributions can help to derive the optical potentials which are necessary for the entrance and final partition in the calculation of transfer cross sections, especially when the distorted wave Born approximation is used.

In the present work, we extract the total reaction cross sections by means of Optical Model calculations from already published work for ^{10}B + ^{58}Ni system [3]. The objective here is to study the overall effect of all the reaction mechanisms, but fusion, on the reaction cross section. As cross sections are influenced by the atomic and mass numbers of the colliding nuclei, to compare data of different systems it is necessary to apply some reduction procedure. The reduction is made from the collision energy and cross sections point of view to weaken, or completely eliminate (if possible), the atomic and mass numbers effect.

Optical Model analysis of elastic scattering

In this section we present the Optical Model (OM) analysis of the elastic scattering angular distribution data using the double-folding São Paulo potential (SPP) [4,5]. The OM fits to the elastic scattering data were performed using the S-FRESCO code [6]. The SPP [4,5] is a model for the heavy-ion nuclear interaction. In Figures 1(a) and (b) we show the detailed OM fitting, using SPP, with the experimental data obtained at E_{lab} = 25 MeV. The rest of the five energies will be shown in the conference. One can see that a remarkable good fit of the elastic scattering angular distribution is achieved. The more crucial region of the angular distributions are very well described, the so-called Coulomb rainbow peak and the backward angle region, where the effects of the nuclear and Coulomb – nuclear interference are relevant. In this way, the S-matrixes are derived allowing to determine the reaction cross sections with high confidence.

Reduction Methodology

Recently [7], a new reduction procedure (*N*) has been proposed and successfully applied to many systems [8] that allows to access to the quantitative effect of the direct reaction mechanism on the total reaction cross section by comparing the reduced cross section of tightly and weakly bound systems. To access to this effect the experimental reaction cross section was normalized by the total fusion (TF) derived from coupled channel (CC) calculation, using a reliable real potential, an imaginary potential term of a shorter range than the Coulomb barrier, that accounts exclusively for the fusion process. The center of mass energy was normalized by the barrier height, so that, the new dimensionless quantities are

$$E \rightarrow \varepsilon^{(N)} = \frac{E}{V_B} \text{ and } \sigma \rightarrow \sigma^{(N)} = \frac{\sigma_R}{\sigma_{TF}}. \quad (1)$$

This $\sigma^{(N)}$ is always larger than one, its lower limit, corresponding to the case of no effect of any direct reaction mechanism on the reaction cross section. This new reduction method will be used to study the effect of the direct reaction mechanisms on the reaction cross section.

We performed one-channel calculations with standard optical potentials for all the mentioned systems in the present work to obtain the total fusion cross sections. The single channel calculations were performed for the entire set of systems using the code FRESCO [6]. The present work covers the procedure applied in [8] using bare potential by the parameter-free double-folding São Paulo potential (SPP) [4,5]. Then, to avoid any absorption at the interaction surface (as mentioned above) we used a much shorter imaginary potential, a fixed Woods - Saxon shape potential with the parameters: V_i = 50 MeV, r_i = 1.06 fm, and a_i = 0.2 fm.

To be precise, the total fusion cross section serves to be a lower limit of the reaction cross section if one opts for no-coupling (one-channel) case and thus a new reduction formula could be applied where one can take a ratio of experimental total reaction cross sections to, one-channel calculated total reaction cross sections, which in principle is the total fusion cross section. The values of this ratio are expected to be larger or equal to 1 (as mentioned above), where the value 1 corresponds to the case where there is no any direct reaction channel enhancing the reaction cross section.

In fig. 2, we show the ratio of σ_R/σ_{TF} versus $E_{c.m.}/V_B$, for the both $^{10,11}B + ^{58}Ni$ systems only, where σ_R is the experimental reaction cross section obtained from OM analysis and σ_{TF} was derived from the one-channel calculation. From fig. 2, it has already justified for $^{11}B + ^{58}Ni$ system [8] that for the higher cross section ratio at below barrier energies, there could be inelastic excitation of target / projectile and also contribution from some transfer channels. The result remains the same for the $^{10}B + ^{58}Ni$ system as the projectile involved has nonzero ground state deformation.

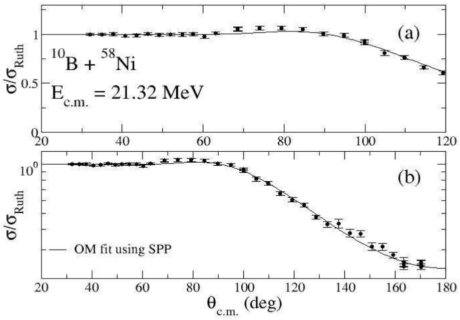

Fig. 1 Elastic scattering angular distribution for the $^{10}B + ^{58}Ni$ system at $E_{c.m.}$ = 21.32 MeV in (a) linear and (b) logarithmic scales. The curves are results of the best fits using SPP.

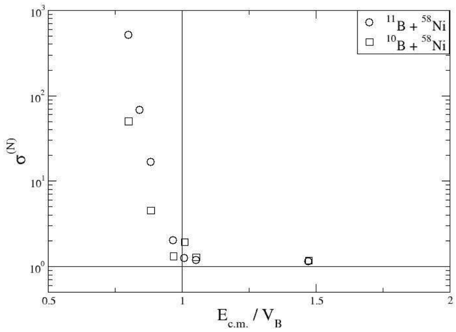

Fig. 2 Reduced total reaction cross section, for $^{10,11}B + ^{58}Ni$ system, for the case of the reduction of σ_R by σ_{TF}. See text for details.

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