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A cluster model for the ${}^6\text{He}+{}^9\text{Be}$ interaction

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Abstract. An optical model analysis of ${}^6\text{He}+{}^9\text{Be}$ elastic scattering angular distributions at two energies above the Coulomb barrier is presented. A cluster model is used for the projectile-target optical potential which is decomposed into two components, the alpha-target and the 2n-target interactions. The 2n-target is adjusted to fit the data and a long range imaginary part is obtained.

1. Introduction

The study of nuclei out of the line of stability is one of the most active fields in low energy nuclear physics nowadays. Most of the research in this area has been performed in large laboratories all over the world, and at intermediate energies, from 30-200 MeV/A or higher. In São Paulo, we have an accelerator of 3-5 MeV/A, connected with the RIBRAS (Radioactive Ion Beams in Brasil) system [1], which allows the production of secondary beams of light exotic nuclei such as ${}^6\text{He}$, ${}^8\text{Li}$ and others at low energies. Some of such light exotic nuclei are important for several reasons, for instance, in studies of the neutron halo and the 3-body structure of ${}^6\text{He}$ and in the possible role they could play in some astrophysical environments. The ${}^6\text{He}$ nucleus has a pronounced cluster structure formed by a double magic alpha core surrounded by two neutrons. Those two neutrons are bound to the α -core by only $E_{lig} = 0.973$ MeV, forming a 3-body system, which is bound only if the core plus the two neutrons are present. Due to the small binding energy and low angular momenta of the neutrons, they form a kind of low density neutron halo, which extends over large distances from the alpha core. As a consequence the ${}^6\text{He}$ nucleus can be easily dissociated in the collision with a target, affecting both, the elastic scattering angular distribution and the total reaction cross section. Over the last 10 years we have developed an extensive research program in RIBRAS [2], involving mostly low energy scattering measurements of ${}^6\text{He}$ on targets of different masses, from light to heavy ones. This kind of study allows for instance to determine the total reaction cross sections of reactions induced by the neutron rich projectile ${}^6\text{He}$ on several targets and compare it with stable systems.

This contribution presents results of a new analysis of ${}^6\text{He}+{}^9\text{Be}$ elastic scattering angular distributions measured in RIBRAS at two energies above the Coulomb barrier, $E_{lab} = 16.2$ and 21.3 MeV [3]. The analysis has been performed in the context of a cluster optical model, where the ${}^6\text{He}+{}^9\text{Be}$ optical potential has been decomposed into two components, one due to the interaction of the alpha cluster with the target and another, unknown, due to the interaction between the two neutrons and the target. The latter has been adjusted to reproduce the data.



2. The model

Scattering and reactions induced by neutron rich exotic projectiles such as ${}^6\text{He}$ are strongly affected by the fact that the continuum is so close to the ground state. For this reason the elastic scattering description at low energies has to take explicitly into account the effect of the coupling with the continuum. This is normally done by Continuum Discretized Coupled Channels description (CDCC) where the continuum of the projectile is discretized in bins of a given width up to a maximum excitation energy and a maximum angular momentum. The CDCC model has been successfully applied to a number of cases [4–8] involving the scattering of ${}^6\text{He}$ on targets of different masses. However, for the ${}^6\text{He}+{}^9\text{Be}$ light system the situation is not so simple. Due to the fact that, in this case, both projectile and target are easily broken, a complete calculation would require the inclusion of both processes simultaneously, which is not possible with the present techniques. Four and three-body CDCC calculations have been presented in Ref. [9] for the ${}^6\text{He}+{}^9\text{Be}$ scattering considering the projectile breakup only. In the three-body CDCC description the projectile-target optical potential is obtained from a cluster model, whose ingredients are the fragment-target (α -t) and the neutron-target interactions as shown below.

$$V_{opt} = \langle \phi_{6He} | V_{[2n+{}^9\text{Be}]} + V_{[\alpha+{}^9\text{Be}]} | \phi_{6He} \rangle \quad (1)$$

In principle the optical potential $V_{[\alpha+{}^9\text{Be}]}$ can be obtained experimentally from previous $\alpha+{}^9\text{Be}$ scattering experiments. Such optical potential has an imaginary part, which takes into account the overall $\alpha+{}^9\text{Be}$ absorption, and consequently, partially includes the ${}^9\text{Be}$ breakup process, induced by the alpha particle. The $V_{[2n+{}^9\text{Be}]}$ interaction on the other hand is unknown. It is impossible to be directly measured since the di-neutron is unbound. In a four-body CDCC description it can be obtained from the known neutron-target interaction, as was done in Ref. [9].

Here we present a different approach [3]. An optical model calculation was performed but using Eq. 1 to obtain the ${}^6\text{He}+{}^9\text{Be}$ optical potential. It is important to make clear that the results presented here are not from a CDCC calculation, since no coupled channels calculations were performed, but a simple optical model, whose optical potential was obtained from Eq. 1. Both potentials appearing in Eq. 1 have been parameterized by a Wood-Saxon shape. The parameters for the $\alpha+{}^9\text{Be}$ system have been obtained from previous experiments [11] and, the $2n+{}^9\text{Be}$ component was varied to best fit the angular distributions.

ϕ_{6He} is the ground state ${}^6\text{He}$ wavefunction and was calculated in the single particle model considering the two neutrons as a single particle bound to the α core. The $2n+\alpha$ binding energy was set to 1.6 MeV to reproduce 3-body effects of the ${}^6\text{He}$ wave function as described in Ref. [10].

The fits are shown in Figure 1 and the resulting parameters are in Table 1. In the first line of Table 1 we present the parameters of the $\alpha+{}^9\text{Be}$ potential taken from the literature [11]. In the second line we present the parameters of the $2n+\alpha$ bound state potential used here. In the third and fourth lines the resulting $2n+{}^9\text{Be}$ parameters for the real and imaginary parts at the two energies analysed are presented.

The effect of the experimental angular resolution is important in this case and was taken into account by performing an average of the theoretical curves over the angular acceptance of the detectors. Its effect is displayed by the two curves (dotted and solid) in Figure 1 (see Ref. [9] for more details).

3. Conclusions

A cluster model was applied to obtain the optical potential that best reproduces the ${}^6\text{He}+{}^9\text{Be}$ scattering. The model considers the ${}^6\text{He}+{}^9\text{Be}$ interaction as the folding between the $\alpha+{}^9\text{Be}$ and the $2n+{}^9\text{Be}$ interactions with the ground state ${}^6\text{He}$ wave function. The $\alpha+{}^9\text{Be}$ interaction was obtained from the literature and is known from previous experiments. The di-neutron- ${}^9\text{Be}$

Table 1. Parameters obtained from the Optical Model calculations. The calculation was performed with the folded potential (Eq. 1) using the parameters given below. Table taken from Ref. [3].

E_{lab}	Potencial	V_0 (MeV)	r_0 (fm)	a_0 (fm)	W_0 (MeV)	r_i (fm)	a_i (fm)	σ_{reac} (mb)	Ref.
	$\alpha+{}^9\text{Be}$	50.00	1.85	0.55	2.50	1.85	0.55	-	[11]
	$2n+\alpha$	96.06	1.90	0.25	-	-	-	-	[10]
16.2	$2n+{}^9\text{Be}$	61.01	1.51	0.55	20.00	1.20	1.01	1513	-
21.3	$2n+{}^9\text{Be}$	21.41	1.51	0.54	10.02	1.35	1.56	1944	-

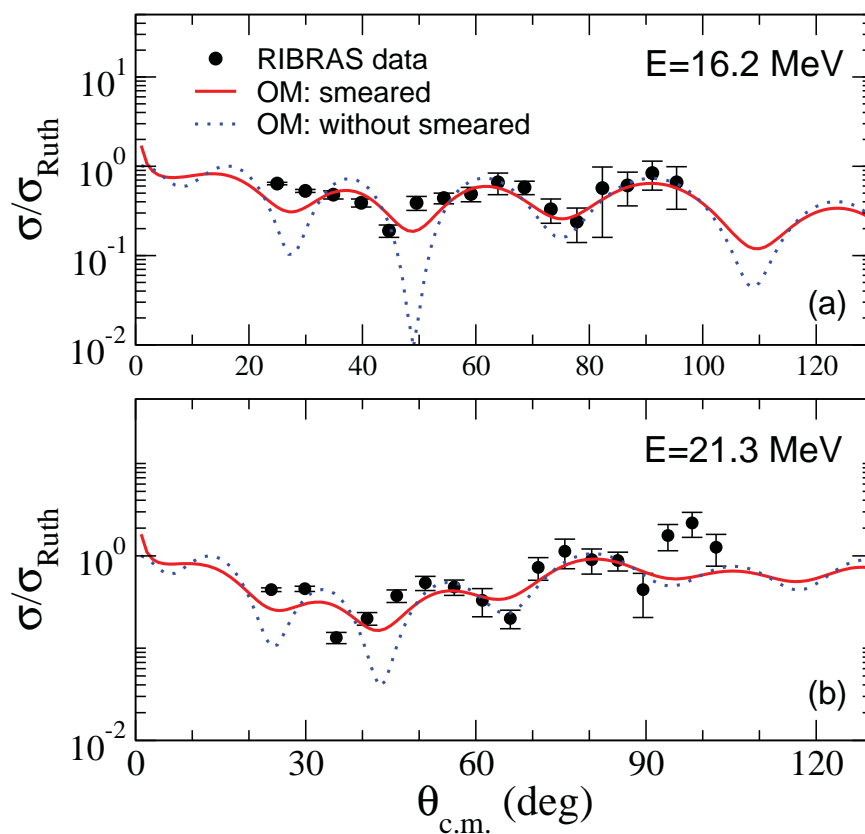


Figure 1. ${}^6\text{He}+{}^9\text{Be}$ Elastic angular distributions at 16.2 and 21.3 MeV compared with optical model calculations. This Figure has been taken from Ref. [3]

interaction is unknown and was adjusted to best reproduce the ${}^6\text{He}+{}^9\text{Be}$ angular distributions. The $2n+{}^9\text{Be}$ potential obtained from the present analysis shows a remarkably large imaginary diffuseness in comparison to the $\alpha+{}^9\text{Be}$ potential, indicating an effect of a rather extended neutron halo in the ${}^6\text{He}+{}^9\text{Be}$ scattering. The total reaction cross sections are also large and an enhancement has been observed with respect to the cross sections for similar stable systems.

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