Study of the ^{6}He+^{9}Be and ^{7}Be+^{9}Be collisions

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Abstract. We present elastic scattering angular distributions of the ^{6}He+^{9}Be and ^{7}Be+^{9}Be reactions at E_{lab} =16.2 MeV and E_{lab} =23.7 MeV respectively. The ^{6}He+^{9}Be measurements have been performed at the Pelletron Laboratory of the Institute of Physics of the University of Sao Paulo, Brazil, using the *Radioactive Ion Beams in Brasil* (RIBRAS) facility and the ^{7}Be+^{9}Be system has been measured at CRC Radioactive Beam Facility at Louvain-la-Neuve, Belgium. An Optical Model analysis has been performed to obtain the nuclear potentials for both systems. A coupled-channel calculation was performed for the ^{7}Be+^{9}Be system taking into account the coupling to the first excited state and breakup channels of the ^{7}Be nucleus.

Keywords: Radioctive Beams. Exotic Nuclei. Nuclear Halo. Long range absorption. Elastic Scattering. Optical potential. Coupled channels calculations.
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INTRODUCTION

Until presently, several studies of reactions induced by the ^{6}He exotic nuclei at low energies have been performed using medium and heavy mass targets, eg. ^{6}He+^{208}Pb and ^{6}He+^{64}Zn [1, 2, 3, 4, 5]. For those systems it has been observed a large reaction cross section compared to other systems of comparable masses and with weakly bound stable projetiles [6] like ^{6,7}Li, ^{9}Be and others. More recently, measurements of the ^{6}He+^{27}Al collision indicated that this enhancement in the reaction cross section could be much smaller or even disappear for lighter targets [7]. An explanation for this behaviour could be in the fact that the Coulomb interaction becomes less important for lighter systems thus decreasing the relative effect of the Coulomb breakup of the projectile. This motivated us to investigate the collision between exotic projectiles and still lighter targets where the nuclear breakup is dominant.

EXPERIMENTAL SETUP

The ^{6}He+^{9}Be system

The ^{6}He+^{9}Be measurements have been performed using the ^{6}He beam produced by the RIBRAS system [8, 9]. This system is mounted in the experimental room of the São Paulo Pelletron Accelerator Laboratory and consists of a superconducting solenoid which is able to select light secondary beams as ^{6}He, ^{7}Be, ^{8}B, ^{8}Li at low energies. The RIBRAS system has in fact two identical solenoids in line however the present experiment was performed using only the first one. The solenoids have 6.5T maximum central field and a 30 cm clear warm bore, which corresponds to an angular acceptance in the range of $2 \leq \theta \leq 6$ degrees in the laboratory system. A picture and a scheme of this system is shown in the Fig. 1.

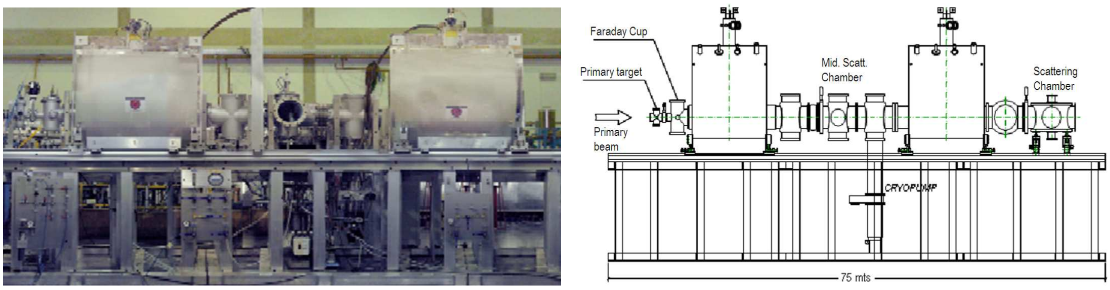

FIGURE 1. RIBRAS facility installed in the 45B Pelletron beam line.

The ^{6}He beam was produced using the ^{9}Be(^{7}Li,^{6}He)^{10}B reaction. The primary target consists of a 12μm ^{9}Be foil followed by a tungsten Faraday cup which suppress the primary beam and measures its current. We used only the first solenoid and the ^{6}He particles were focused in the midway scattering chamber located between the two solenoids. The intensity of the 22 MeV primary ^{7}Li beam on the primary target was of about 300 nAe corresponding to a secondary ^{6}He beam of 2.4×10^{4} pps. The detection system consisted of four ΔE-E telescopes formed by silicon detectors with tickness of 20μm and 1000μm respectively. Initially the secondary beam was observed directly in a telescope placed at zero degrees using a faint primary beam ($\approx$ 0.1 - 0.5 nAe) (see Fig. 2).

We observe the ^{7}Li^{+2} contaminant and the ^{6}He peak clearly separated. In this spectrum there are $\approx$ 1800 counts for the ^{6}He, $\approx$ 10000 counts for the ^{7}Li and $\approx$ 16000 counts for the total, including other lighter particles as α, p, d, t. The energy resolution of the ^{6}He beam was of FWHM $\approx$ 1MeV consistent with the energy straggling in the

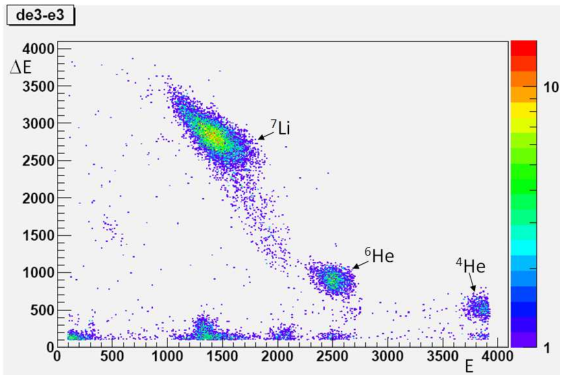

FIGURE 2. Biparametric spectrum obained with ^{6}He beam without target at θ_{lab}=0°.

primary target. During the experiment we used a 1.93 mg/cm^2 ^{9}Be and a 2.95 mg/cm^2 ^{197}Au secondary targets for normalization purposes since the ^{6}He+^{197}Au collision is pure Rutherford at the energy and angles of this experiment. Runs using the gold target were performed before and after every run with berilium target in order to monitor the ^{6}He production rate. In Fig. 3 we present also spectra measured with berilium and gold targets at 15 deg. It is interesting to observe that a large yield of alpha particles are produced in the berilium target which are not present with the gold target. This is an indication that the breakup of the projectile and target could be an important reaction channels.

The ^{6}He+^{9}Be elastic angular distribution was measured between 15° and 75° in steps of 3° in the laboratory system (see Fig. 5).

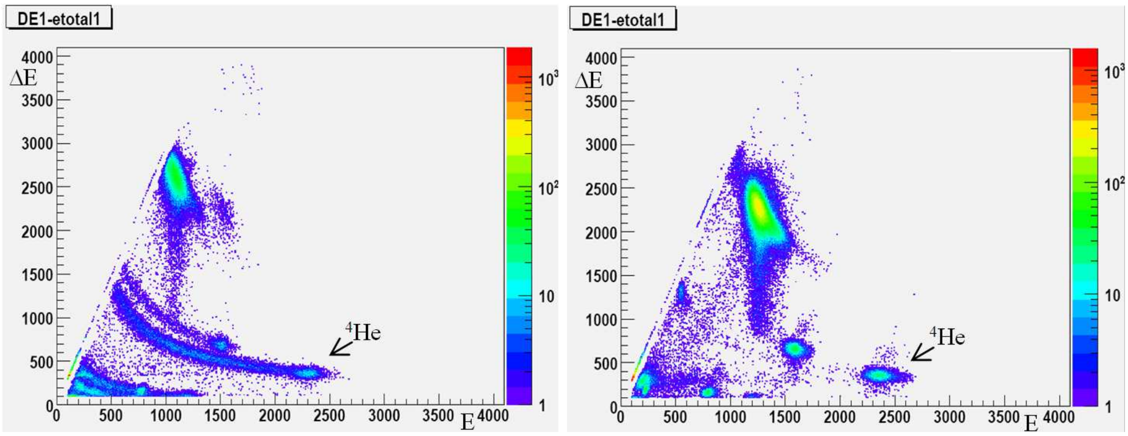

FIGURE 3. Biparametric spectrum $\Delta E \times E_{TOTAL}$ obtained with the ^{6}He beam at θ_{lab}=15° using the ^{9}Be (left) and ^{197}Au (right) targets.

The ^{7}Be+^{9}Be system

The ^{7}Be+^{9}Be angular distribution was measured using CYCLONE110 cyclotron at CRC (Centre de Research du Cyclotron) Radioactive Beam Facility at Louvain-la-

Neuve, Belgium and is presented in Fig. 7. This system makes it possible to explore light nuclei with a high quality beam of ^{7}Be. The ^{7}Li(p,n)^{7}Be was used as the production reaction to produce the ^{7}Be beam with 3×10^{7}pps intensity on the target. A detailed description of the production of the radioactive ^{7}Be beam can be found in Ref. [10].

The detection system consisted of four 64x64 mm^{2} double-side-strip detectors (DSSD) containing 16 strips on each side were positioned around the ^{7}Be beam direction. The DSSD 1 mm-thick detectors were equivalent to 1024 conventional Si detectors with solid angle of 0.00015 sr each. A sketch of the experimental setup is shown if Fig. 4.

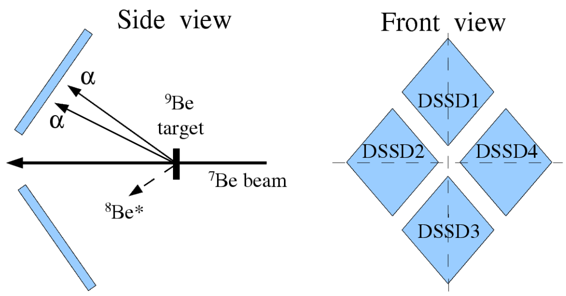

FIGURE 4. A schematic view of the experimental setup for the proposed reaction ^{9}Be(^{7}Be,X). Scattered ^{7}Be ions and decay α particles from the reaction ^{9}Be(^{7}Be,^{8}Be)^{8}Be* were detected by four large DSSD detectors.

The ^{7}Be+^{9}Be angular distribution was measured at E_{lab}=23.7 MeV between 12.3 and 38.8 degrees in the laboratory system. A channel of elastic scattering of ^{7}Be on a ^{9}Be target was identified by using a kinematic angular and energy dependence of products from reactions with two particles in exit channel. The absolute normalization of the data was not obtained in this experiment. This factor was obtained from the theoretical analysis as explained below.

Alpha particles from the ^{9}Be(^{7}Be,^{8}Be(g.s.))^{8}Be* neutron transfer reaction have been measured allowing an spectroscopic study of the ^{8}Be nucleus, however, in this work, we concentrate on the analysis of the elastic scattering process. The analysis of the one-neutron transfer channel with a more detailed description of the experiment will be given in a separate publication [11].

THEORETICAL CALCULATIONS

The ^{6}He+^{9}Be System

The ^{6}He+^{9}Be elastic scattering angular distributions has been analyzed within the optical model using Wood-Saxon shapes, whose parameters have been obtained from analysis of the similar systems ^{6}Li,^{7}Li+^{9}Be taken from the literature [12, 13, 14]. An optimal fit analysis was carried out to adjust the parameters of the potential in order to reproduce the experimental data. These calculations were done using the subroutine SFRESCO, that it part of the FRESCO code [15]. The preliminary parameters of the fit and the total reaction cross section obtained using the OM formalism are: V_0=41.98±0.45 MeV, r_0=1.36±0.08 fm, a_0=0.70 fm, W_i=2.89±0.09 MeV, r_i=2.47±0.03 fm, and a_0=0.91±0.02 fm, which leads to a reaction cross section of σ_{reac}=1660±40 MeV. The result is shown on Fig. 5. The calculated angular distribution was smeared in angle in order to take into account the angular resolution of the experiment which was of about ±3° in the laboratory that corresponds to ±5° in the CM frame. During this analysis we observed a wide range of the parameters of the real part of the potential which fit the data equally well. This means that a large ambiguity in the parameters of the real potential is present. However the imaginary part always displays a long range absorption tail. This behaviour seems to be a constant in all data involving halo projectiles and was observed in [5, 16, 17]. The total reaction cross sections obtained from different sets of parameters show small variations around the above quoted value.

As the ^{6}He is a weakly bound halo nucleus, the coupling to the breakup channel is expected to have importance and a CDCC calculation is in progress to take into account this effect.

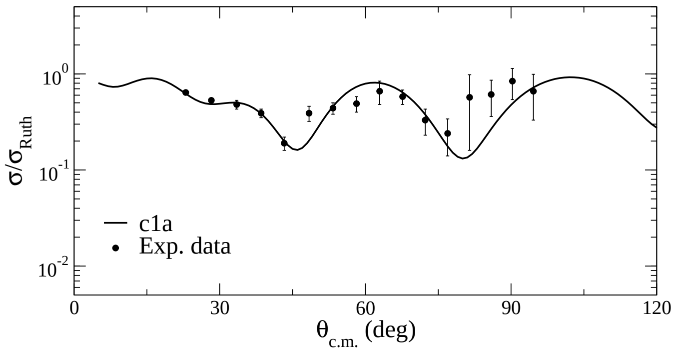

FIGURE 5. ^{6}He+^{9}Be elastic scattering angular distribution measured at E_{lab} =16.2 MeV (circles) and optical model calculation (solid line).

The ^{7}Be+^{9}Be System

The ^{7}Be+^{9}Be elastic scattering angular distribution was first analyzed in terms of phenomenological optical potentials. We started from differents optical potential parameters obtained from the literature for the system ^{7}Li+^{9}Be at energies between 24 MeV and 34 MeV [12, 13]. All these potentials use standard Woods-Saxon shapes. An optimal fit analysis was carried out in order to obtain the parameters that best reproduce the data. We vary the depths of the real (V_0) and imaginary (W) parts, as well as the normalization of the experimental data (N). These calculations were done with the subroutine SFRESCO [15]. The parameters of the fit obtained with this procedure are: V_0=48.6 MeV, r_0=1.28 fm, a_0=0.88 fm, W_i=13.13 MeV, r_i=1.86 fm, a_0=0.78 fm. In order to check the obtained normalization we have compared our data with those reported by Verma *at al.* [18] for the same system at E_{lab}=21 MeV. This comparison is shown in Fig. 6. We can see that the magnitude of the experimental data from [18] (squares) is fully consistent with the present data (circles) using the normalization obtained with the optical model analysis, providing further confidence on this normalization.

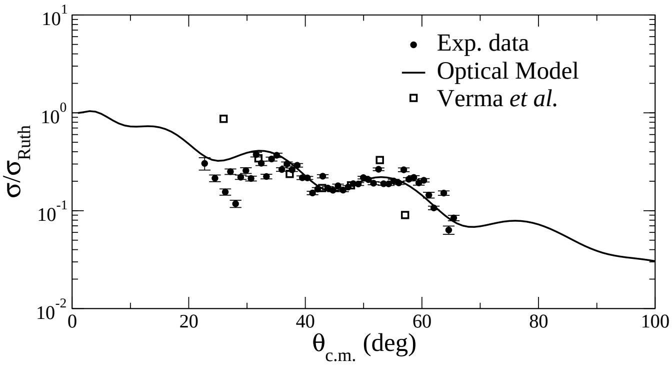

FIGURE 6. Experimental data for the ^{7}Be+^{9}Be elastic scattering from Ref. [18] (squares) and from the present work (circles), measured at 21 and 23.7 MeV, respectively. The latter have been normalized according to the prediction of the optical model calculation (solid line). See text for details.

Due to the fact that the ^{7}Be nucleus is only bound by 1.59 MeV, this nucleus may have a significant probability to break up in the nuclear and Coulomb field of the target nucleus. To study the effect of breakup channels on the elastic scattering, we have performed CDCC calculations using a few-body model of the ^{7}Be nucleus. In this calculation, the ^{7}Be nucleus was considered as a two-body system (^{4}He+^{3}He) and the projectile-target interaction was described in terms of the sum of the interactions of each fragment with the target. Since the experimental resolution did not allow to separate the data of elastic scattering from the data of inelastic scattering (1st excited state of ^{7}Be at E_x= 0.429 MeV), we included this state in the calculations.

In Fig. 7 we compare the optical model (dashed) and CDCC (dot-dashed) calculations. We include also the CDCC calculation removing the coupling to continuum states (solid line). We found that these three calculations provide similar results, providing further support on our results in the angular region where data exist.

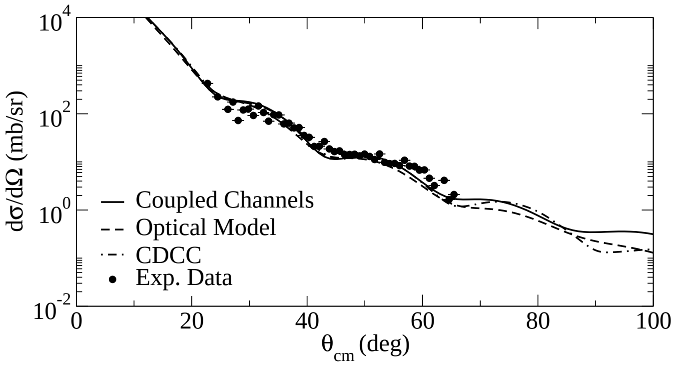

FIGURE 7. Comparison between experimental ^{7}Be+^{9}Be angular distribution and the optical model, coupled channels and CDCC calculations (see text for details).

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