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Two-neutron transfer as a tool to study pairing correlations in nuclei

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Abstract. A feasibility study of two-neutron transfer reactions, using ^{12}C and ^{19}F targets, was performed. In this experiment, a ^{6}He beam at 20 MeV incident energy was delivered by the RIBRAS facility. The main goal of this work was to test the RIBRAS system, operated in a single-solenoid mode, to investigate (^{6}He,α) reactions in light nuclei. The excitation function of the ^{14}C nucleus, populated by the ^{12}C(^{6}He,α) reaction, was extracted from the data. Evidence of nn-transfer reactions populating the ground state and the first 0^+_1 state in ^{14}C were observed. However, the present spectrum might have contribution from other reaction channels such as the ^{6}He breakup. Future experiments with the RIBRAS dual-solenoid mode will improve the quality of the data by reducing a significant amount of background.

1. Introduction

Pairing correlations in nuclei play a fundamental role in describing nuclear properties such as masses, binding energy and other quantities that depend on the microscopic structure of the nucleus [1]. Pairing is also essential to understand the exotic structures exhibited by nuclei far-from-stability, for example the two-neutron halo configuration in ^{6}He and ^{11}Li. Although the importance of pairing for describing nuclear phenomena is well accepted, the reaction probes used to measure pairing are still poorly understood. Two-nucleon transfer reaction is an usual probe to study pairing effects. However, the description of the reaction mechanism associated with the transfer of a pair of particles in heavy-ion reactions has always been a rather complex problem. Usually, (t, p) or (p, t) reactions have been used to investigate two-neutron correlation [2, 3]. An advantage of using these probes is the possibility to study not only the ground state of the recoiling nucleus but also its excited states, which are accessible through energy and angular momentum matching. For example in Ref. [4], low-lying states of ^{21}F were investigated via $(t, p+\gamma)$ reactions. Coincidence measurements of proton and γ-rays were used to identify several excited states populated by the two-neutron transfer reaction. As the structure of the tritium nucleus is well established, reaction calculations can be relatively simple, but still the cross sections in these experiments require large normalization factors (between 2 and 3) to describe the experimental data [5]. Other possible probe that can be used to study two-neutron transfer is the (^{6}He,α) reaction. The Borromean nature of the ^{6}He structure and its very low two-neutron separation energy (S_{2n} = 0.97 MeV) makes it a very attractive candidate for two-neutron transfer reactions studies. A large dominance of the two-neutron over the one-neutron transfer cross section has been observed in several experiments [6]. In a recent work in São Paulo, the reaction mechanism of two-neutron transfer with ^{6}He+^{120}Sn was investigated and analyzed using 4-body Continuum Discretized Coupled Channels (CDCC) calculations [7]. This work indicates the importance of considering the ^{6}He as a 3-body system ($\alpha + n + n$) to describe the elastic scattering cross sections. Also, studies with light targets have been used to understand the reaction mechanism of two-neutron transfer with ^{6}He, for instance in Ref. [8]. In this context, it might be very interesting to study two-neutron transfer mechanism with light targets (due to the small Coulomb barrier) such as ^{12}C and ^{19}F, with this last one being a good candidate for such an investigation since it is an asymmetric nucleus and nn correlations appear in almost all $N > Z$ nuclei. In this work, we report about a feasibility study performed at the São Paulo RIBRAS facility, using a ^{6}He beam at 20 MeV. The details of the experimental procedure, some initial data analysis, as well as some future perspectives are presented below.

2. Experiment

Angular distributions of elastic scattering and transfer reactions using a ^{6}He beam at E_{lab} = 20 MeV on CH_2 and Teflon (C_2F_4) targets were measured. The angular distributions were obtained using a secondary radioactive beam produced in the RIBRAS facility [9] at the Universidade de São Paulo, Brazil. A sketch of the RIBRAS facility is presented in Fig. 1. In this facility, radioactive ion beams are produced in-flight by a few-nucleon transfer reactions between a stable accelerated beam and a light target. The secondary radioactive beam is then selected and focused by a strong magnetic field from a superconducting solenoid with angular acceptance ranging from 2^o to 6^o. The secondary ^{6}He ion beam was obtained by the ^{9}Be(^{7}Li,^{6}He)^{10}B reaction, with a 100 enA ^{7}Li beam of 24.4 MeV and a ^{9}Be target of 2.2 mg/cm^2 thick. After passing through the production target, unreacted particles from the primary beam are stopped in a Faraday cup, which integrates the charge and allows to obtain an online beam intensity readout (chamber 1 in Fig. 1). For each 1 μA of primary beam, the secondary beam intensity of ^{6}He was about 10^5 pps. The secondary beam was selected by its magnetic rigidity and focused on the reaction target [CH_2 (1 mg/cm^2 thick) and C_2F_4 (3.0 mg/cm^2 thick)] located in the center of the middle scattering chamber [9] (chamber 2 in Fig. 1). A gold target of 1.59 mg/cm^2 thickness was also used in separate runs to obtain the overall normalization. The particles were identified by three ΔE-E (telescope) silicon detectors and one E silicon detector, placed at different angles. The ΔE detectors of 50 μm in thickness and 300 mm^2 in area were backed by the E detectors of 1000 μm in thickness. These telescopes had collimators with apertures that subtended solid angles of about 12 msr. The angular distributions were measured over an angular range of 15 to 60 degrees in the laboratory system.

3. Preliminary results

As mentioned before, the present experiment was a feasibility study of two-neutron transfer with a secondary beam at RIBRAS using CH_2 and C_2F_4 targets. A limited amount of beam-on target data was obtained for this study. However, the overall result provided very good ideas on how to improve the next experiments and possibilities to extend the current setup for coincidence measurements.

A typical ΔE-E particle-identification spectrum obtained in the experiment can be seen in Fig. 2 (left). As can be noticed, ^{6}He particles are well separated from the α particles produced mainly by breakup and transfer reaction channels. It is also important to mention that a

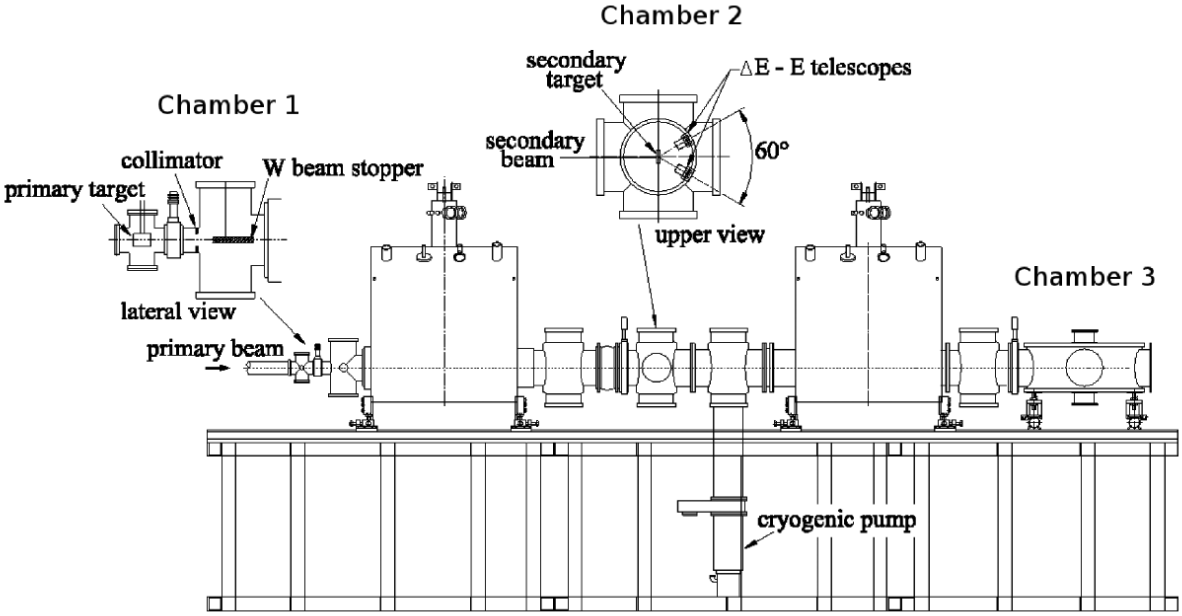

Figure 1. The Ribras system [9]. The primary beam comes from the left. The production target is located in chamber 1, where it can also be seen the Tungsten Faraday Cup. The secondary unstable beam was produced and focalized, by the first solenoid, in the center of chamber 2. The reaction targets and detector setup were mounted in chamber 2.

significant amount of a scattered ^{7}Li beam and ^{4}He are also selected with the same magnetic rigidity with the present setup. The next experiments are planned to use the dual-solenoid mode of RIBRAS, which allows a beam purity above 90%. The two-neutron reaction channel can be extracted from a projection of the α particles band. Fig. 2 (right) shows a projection in the ^{14}C excitation energy. The excitation energy in the spectrum was obtained considering a two-body kinematics and the missing mass technique [10]. As can be seen, the spectrum is dominated by the breakup channel and also reactions with the ^{7}Li scattered beam. This also indicates that background measurements with only ^{7}Li beam are needed to remove a few reaction components in the spectra. Nevertheless, two bumps around excitation energies of 0 and 6.6 MeV can be observed. These peaks correspond to the transitions to the ground state and first 0_1^+ state in ^{14}C that are expected to be populated via nn-transfer reaction in ^{12}C.

Despite the short run measurement and after some preliminary analysis, it was possible to obtain angular distributions for ^{4}He produced and ^{6}He elastic scattering particles on ^{12}C and ^{19}F, as can be seen in Fig. 3. As part of the feasibility study, a mixed target was used, Teflon®, to investigate if the separation of the ^{4}He and ^{6}He scattering particles would be achievable in this kind of experiment. A good separation would allow to measure the reactions in two target nuclei in the same experiment. Unfortunately, the separation was not possible even for the elastic scattegkaur.phy@gmail.comring channel. Even so, the elastic scattering distributions were compared with optical model analysis using the São Paulo potential with the usual normalization coefficients ($U(R) = (1.0 + 0.78i)V_{SP}^{LE}(R)$) [11].

The results here presented are part of a project for measurements of two-nucleon transfer (nn, pp, np) to investigate pairing correlations and collective excitations like the recently observed Giant Pairing Vibration (GPV) [12]. A paper with the results of an experiment on (^{6}Li,α) reaction performed at the Tandar - CNEA facility in Argentina, also using ^{12}C and ^{19}F targets, is in preparation [13]. Also, future measurements of (^{3}He,n) reactions in inverse kinematics are

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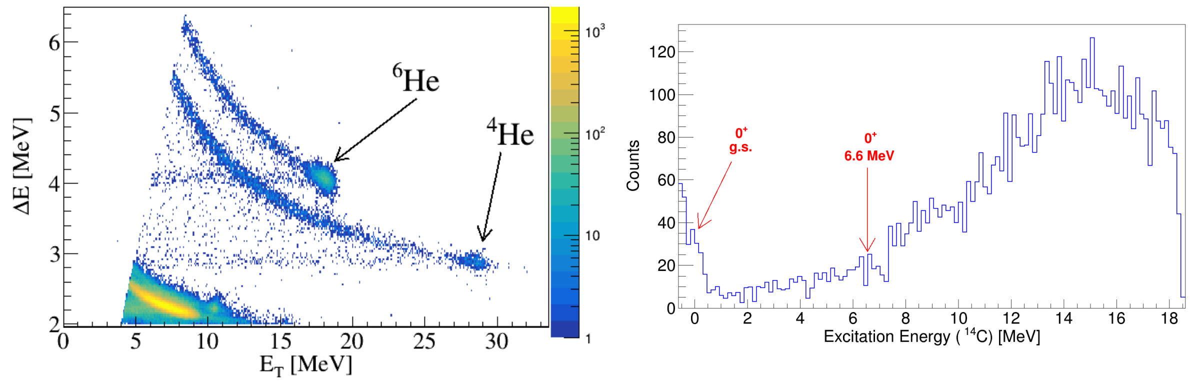

Figure 2. Left: Particle identification spectrum (ΔE–E) using a C_2F_4 target. Right: Excitation energy spectrum extracted from ^{4}He particles. Two bumps at 0 and 6.6 MeV are associated with the ground state and the first 0_1^+ state in ^{14}C.

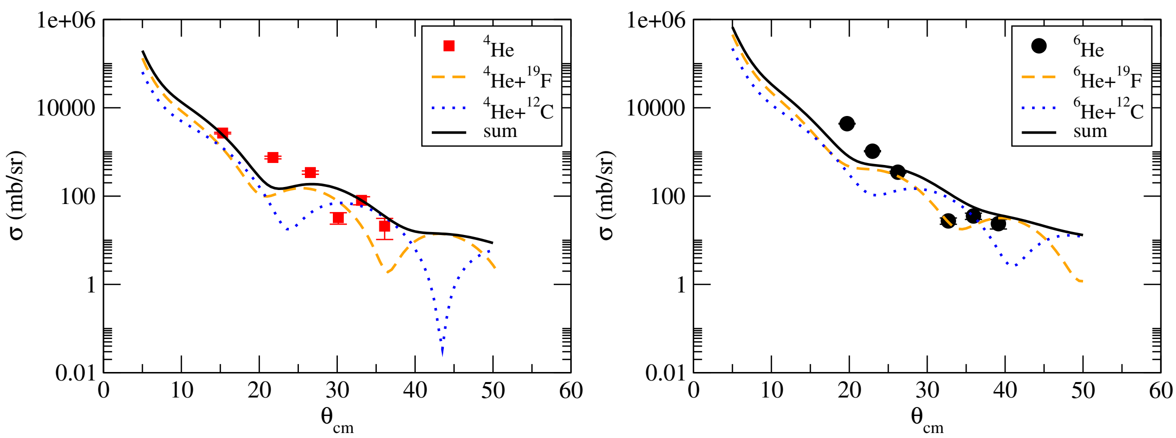

Figure 3. Angular distributions for ^{4}He and ^{6}He.

planned to study the *pp* transfer mechanism with light nuclei.

Acknowledgments

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