Recent results from RIBRAS (Radioactive Ion Beams in Brasil)

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Abstract. An overview of the experiments performed at RIBRAS over the last year is presented. Elastic scattering and breakup reactions induced by light exotic projectiles on different targets have been measured and some results are presented here for the $^{120}\text{Sn}(^6\text{He},\alpha)$ reaction. Resonant scattering experiments have been performed with $^{10}\text{Be}$ and $^{12}\text{C}$ secondary beams on a CH$_2$ thick target and the well known $^{12}\text{C}+\text{p}$ resonance was identified. A gamma-particle experiment using a new system of LYSO scintillators to detect gammas was done.

1. Introduction

Light nuclei far from the line of stability usually present a cluster like structure formed by a core surrounded by one or more weakly bound nucleons. Several examples, such as $^6\text{He}(\alpha+2n)$, $^{11}\text{Li}(^9\text{Li}+2n)$, $^{11}\text{Be}(^{10}\text{Be}+n)$, $^{14}\text{Be}(^{12}\text{Be}+2n)$ and others have been found mainly in the neutron rich side of the nuclide chart. Owing to their small breakup energies and the low angular momentum of the valence neutrons, their wave functions extend to large distances from the core, forming a kind of neutron halo [1]. As a result, reactions such as projectile breakup and neutron transfer may be strongly favored in the interaction between these projectiles and different targets, which enhances their total reaction cross sections [2–11].

RIBRAS (Radioactive Ion Beams in Brasil) system is capable to produce low energy secondary beams of some of these light exotic nuclei [12–14].

Here we present results for the $^{120}\text{Sn}(^6\text{He},\alpha)$ reaction as well as several other scattering and resonant scattering experiments performed over the last year. A new setup for gamma-particle measurements using LYSO cristals was tested.

2. RIBRAS system

The RIBRAS (Radioactive Ion Beams in Brasil) consists of two superconducting solenoids in line [12–14]. A scheme of the RIBRAS setup is shown in Fig. 1. The secondary beams of $^6\text{He}$, $^8\text{B}$, $^8\text{Li}$, $^7\text{Be}$, $^{12}\text{B}$ and others are selected in-flight by the double solenoid system. The primary beams of the SUD-Pelletron accelerator impinge on production targets such as $^9\text{Be}$, LiF, $^3\text{He}$. Nucleon transfer and fusion-evaporation reactions produce the secondary beams with
intensities ranging from $10^4$ to $10^6$ pps for primary beam intensities around 300 – 500 enA. The large acceptance of the first solenoid (30 msr) allows to collect most of the secondary particles produced at forward angles which partially compensates the low production cross sections due to the low primary beam energies.

Figure 1. Scheme of RIBRAS.

The secondary particles from the primary target are selected by the first solenoid and focused in the scattering chamber 2 located just after the first solenoid. The secondary beam at this position is contaminated with p,d,t,α and degraded primary beam particles. A degrader foil can be placed in the scattering chamber 2 in order to provide differential energy loss and subsequent purification of the secondary beam by the second solenoid. In this way, a secondary beam with purity better than 92% can be achieved in the secondary scattering chamber 3.

The secondary beam production rates are maximized in the beginning of the experiment by varying the currents of the solenoids and monitoring the elastic scattering on a $^{197}$Au target.

The measurements are usually carried out by using $\Delta E(25-50 \, \mu m)$-$E(1000 \, \mu m)$ silicon detector telescopes mounted on a rotating plate inside the secondary chambers 2 or 3, to perform angular distribution measurements.

Absolute cross sections are obtained by normalizing the elastic scattering data by using a Gold target, for which the scattering is pure Rutherford.
2.1. The $^{120}$Sn($^6$He,$\alpha$) reaction.

Fig. 2 shows a bi-dimensional $\Delta$E-E spectrum of the $^{120}$Sn($^6$He,$\alpha$) reaction at $E_{lab} = 24.5$ MeV in scattering chamber 2.

![∆E-E spectrum](image)

Figure 2. $\Delta$E-$E_{total}$ spectrum for the reaction $^6$He + $^{120}$Sn at $E_{6He} = 24.5$ MeV ($\theta_{lab} = 60^0$) [15].

The $^6$He beam is produced by the $^9$Be($^7$Li,$^6$He) reaction and scattered on a $^{120}$Sn target placed in the center of chamber 2.

We can clearly see that the elastically scattered $^6$He peak is well separated from the $\alpha$-particles. A broad $\alpha$-particles energy distribution lie around and below the elastic peak energy. These $\alpha$-particles are produced in the $^6$He + $^{120}$Sn collision and are not seen in the runs with Gold target. One can also observe in Fig. 2 the light particles tritons, deuterons and protons well separated from the $\alpha$.

In Fig. 3 we show the energy distribution corresponding to the projection of the $\alpha$-cut of Fig.2. One can also see that the $\alpha$ distribution has a centroid located around 18 MeV, above the expected energy for a pure breakup at $\frac{3}{4}E_{6He}$ with $E_{6He}=24.5$ MeV, which would be around 16.3 MeV.

![Energy distribution](image)

Figure 3. Energy distribution of the $\alpha$-particles emitted from the $^{120}$Sn($^6$He,$\alpha$)X reaction at 24.5 MeV ($\theta_{lab} = 60^0$).
$\alpha$-particle energy distributions were measured at eight different bombarding energies from 17.4 MeV up to 24.5 MeV, the Coulomb barrier being around 13 MeV. An analysis as a function of the Q-value for the $^{120}$Sn($^6$He,$\alpha$)$^{122}$Sn$^*$ reaction was performed. The $E_{\alpha} \rightarrow Q_{\alpha}$ transformation was performed by considering the two-body kinematics of the 2n-transfer reaction and adjusting the total reaction Q-value to reproduce the measured $E_{\text{trans}}$. For $^{120}$Sn($^6$He,$\alpha$)$^{122}$Sn$^*$ transformation was performed by considering the two-body kinematics of the 2n-transfer reaction and adjusting the total reaction Q-value to reproduce the measured $E_{\text{trans}}$. As a result, an interesting effect was observed in the behavior of the centroid of the Q-distributions with the bombarding energies. The centroid of the Q-value distribution decreases from slightly positive values ($Q_{\text{reac}} \approx 0.3$ MeV) up to negative values around $Q_{\text{reac}} \approx -5.5$ MeV, as the incident energy increases from 17.4 to 24.5 MeV. Since $Q_{gs} = +14.01$ MeV is highly positive for this reaction, the residual nucleus $^{122}$Sn must be formed in a highly excited state around $E_{\text{exc}} \approx 14$ MeV and above. At these high excitation energies, the 2n-transfer reaction populates states in the continuum of $^{122}$Sn, well above the one-neutron emission threshold at $E_{\text{exc}} = 8.81$ MeV. More details of this analysis can be found in Ref. [15].

3. Elastic scattering measurements.
Several elastic scattering experiments have been performed in RIBRAS over the last year which will be described below. These experiments have been performed in scattering chamber 2 using only the first solenoid. Most of these experimental data is under analysis and no results will be presented here. More details about the experiments and results can be found in the other contributions to this proceedings.

3.1. The $^{12}$B + $^{58}$Ni scattering
The elastic scattering $^{12}$B + $^{58}$Ni have been measured at $E_{\text{lab}} = 30$ and 33 MeV, above the Coulomb barrier ($V_B \approx 24$ MeV). The secondary beam has been produced by the $^9$Be($^{11}$B,$^{12}$B)$^{10}$Be transfer reaction using $^{12}$B primary beam produced by the Pelletron accelerator at 37 and 40 MeV with intensities of 300 enA. The intensity of the $^{12}$B secondary beam was of $2 \times 10^5$ pps. The secondary target was a 2.1 mg/cm$^2$ isotopically enriched $^{58}$Ni foil. The detection system consisted of two E-$\Delta$E telescopes of 1000 $\mu$m and 25 $\mu$m in thickness and one 1000 $\mu$m single detector at backward angles. The detection solid angles ($\sim 16$ msr) were defined by circular collimators placed in front of the detectors. More details can be found in one of the contributions (E. Zevallos) in this proceedings.

3.2. The $^8$Li scattering on $^9$Be, $^{58}$Ni and $^{120}$Sn targets.
The $^8$Li scattering has been measured on the light $^9$Be, intermediate mass $^{58}$Ni and heavy $^{120}$Sn targets. The $^8$Li secondary beam was produced by the $^9$Be($^7$Li,$^8$Li)$^7$Li transfer reaction using the $^7$Li beam produced by the 8UD-Pelletron accelerator. Four silicon E(1000$\mu$m) -$\Delta$E(25$\mu$m) telescopes with areas of 150 mm$^2$ were used as detection system. For the $^9$Be target one angular distribution was measured at $E_{\text{lab}} = 23.7$ MeV. This corresponds to about 7 times the Coulomb barrier $V_B = 3.5$ MeV. For the $^{58}$Ni targets four angular distributions were measured at 23.9 MeV, 26.1 MeV, 28.7 MeV, and 30.0 MeV laboratory energies, the Coulomb barrier being at $V_B = 13.1$ MeV [16]. Two angular distributions on $^{120}$Sn were measured at $E_{\text{lab}} = 21.7$ and 26.8 MeV, the Coulomb barrier being at $V_B = 20.5$ MeV.

3.3. The $^{10}$Be + $^9$Be scattering.
The $^{10}$Be beam has been produced by the $^9$Be($^{11}$B,$^{10}$Be) transfer reaction with a $^{11}$B primary beam of 34 MeV. In Fig.4 we show a spectrum of the secondary beam particles produced in the reaction $^9$Be($^{11}$B,$^{10}$Be) detected in the scattering chamber 2. An angular distribution for the $^{10}$Be+$^9$Be reaction was measured at $E_{\text{lab}} = 21.7$ MeV.
4. Resonant scattering measurements
Measurements of resonant scattering of exotic beams such as $^8\text{Li}$ [17] and $^6\text{He}$ on CH$_2$ thick targets have been performed over the last year using the double solenoid system. In the thick target method one uses a CH$_2$ foil, thick enough to stop the projectile in the target. The recoil protons resulting from the interaction with the beam are detected at forward angles where silicon telescopes were mounted to identify the particles and measure their energy distributions. This technique allows the measurement of an excitation function and the identification of resonances in the $p+$projectile composed system. Over the last year, two resonant scattering experiments have been performed in RIBRAS, the $^{12}\text{C}+p$ and $^{10}\text{Be}+p$, both using CH$_2$ solid targets (thick target method). The $^{12}\text{C}+p$ reaction was measured to identify a well-known resonance [18] and use it for a precise energy calibration, see Fig. 5. In this case a primary $^{12}\text{C}$ beam scattered in the primary target foil was selected by the RIBRAS solenoids and used as the secondary beam.

![Figure 5. Proton spectrum from $^{12}\text{C}+p$ scattering measured at RIBRAS.](image)
5. Gamma-particle coincidence measurements.
One of the difficulties in performing gamma measurements in RIBRAS comes from the residual magnetic field around the solenoid and inside the scattering chambers, which prevents the operation of photo-multipliers vacuum tubes based detectors. In addition to this, an intense neutron secondary beam comes from the RIBRAS primary target causing serious damage to germanium detectors. More recently, LYSO (Lutetium-yttrium oxyorthosilicate) scintillators are being used to detect gammas in association with silicon diodes which are not sensitive to magnetic fields. We purchased LYSO crystals and four gamma detectors were mounted by J.R.B. de Oliveira group (see contribution to this proceedings). A $^8\text{Li}+^{120}\text{Sn}$ test experiment was performed in RIBRAS using these LYSO detectors. The particles were detected in four silicon telescopes fixed at forward angles and the gammas were detected in the LYSO crystals placed around the target. A TDC peak was measured from the gammas in coincidence with light particles, which gave cross sections of the order of the expected for fusion reactions.

We expect this setup to be enlarged with more LYSO detectors and plan to use it in the future for fusion and other reactions using the RIBRAS facility.

6. Summary
A summary of the experiments performed in RIBRAS over the last year is presented. Elastic scattering and reactions involving light exotic projectiles such as $^6\text{He}$, $^8\text{Li}$, $^{10}\text{Be}$, $^{12}\text{B}$ on several targets are reported. A new setup for gamma measurements using LYSO crystals is described.

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