# Study of the $^{120}Sn(^{6}He,\alpha)X$ reaction using $\gamma$-particle coincidences.

**Experiment previously approved as E-106 in the 2013 PAC**

**PS. we used the days granted in the E106 experiment (see paper attached)**

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**Summary:**

The project consists in measurements of the alpha particles produced in the $^{120}Sn(^{6}He,\alpha)X$ reaction in coincidence with the gamas from the decay of the residual nucleus $^{121}Sn$. The double solenoid RIBRAS [1] system will be used to produce the $^{6}He$ secondary beam. The idea is to investigate the reaction mechanism responsible for the production of alpha particles in the $^{6}He+^{120}Sn$ collision, observed in previous experiments performed in RIBRAS [2,3,4,5].

**Introdução:**

The possibility of producing secondary beams of unstable nuclei open a huge field of research in Nuclear Physics.

Since 2004 the Radioactive Ion Beams in Brazil (RIBRAS) system is in operation producing secondary beams of light exotic nuclei such as $^{8}Li$, $^{6}He$, $^{7}Be$, $^{8}B$ and others. A systematic study of elastic scattering of these beams on targets of different masses has been performed since then [1]. In particular the $^{6}He+^{120}Sn$ scattering was the PhD thesis of Pedro Neto de Faria in 2008 [4]. In this work, elastic scattering angular distributions have been measured at four energies above the Coulomb barrier using the central RIBRAS chamber, between the two solenoids. It was found in the E-DE spectra that a large yield of alpha particles has been produced, with energies around and a little lower than the $^{6}He$ projectile energy. The energy distributions have been analysed by DWBA [3] and it was found that, probably, a two neutron transfer reaction from projectile to highly excited states of the $^{122}$Sn was taking place. Alpha particle production cross sections of hundreds of millibarns have been reported in those experiments indicating a much larger reaction cross section compared to usual transfer reactions involving stable nuclei and, considerably larger than the projectile breakup cross sections predicted by CDCC calculations [3].

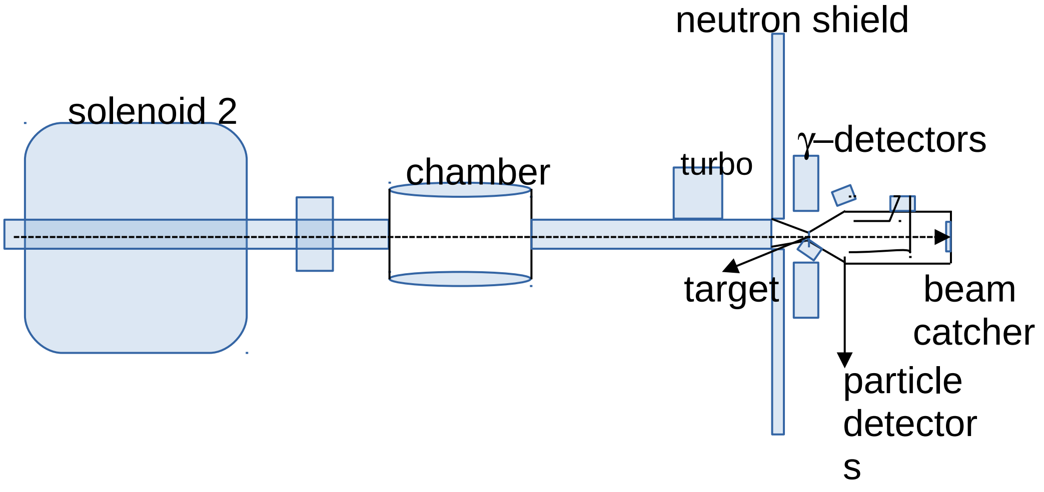
More recently [5] a new $^{6}$He+$^{120}$Sn experiment was done in the RIBRAS secondary scattering chamber using the double solenoid system, where the secondary beam is much more pure, and all the previous results have been confirmed.

Further, We want to extend the RIBRAS research program for the measurements of gamma-ray spectra in coincidence with the charged particles, in order to measure the fusion cross sections for specific reaction channels (transfer/break-up and complete fusion). We propose new measurements of the $^{120}$Sn($^{6}$He,a)X reaction detecting the alpha particles in coincidence with the gammas emited by the decay of the residual nucleus $^{121}$Sn. With this purpose an extension of the RIBRAS beam line has been mounted and a new scattering chamber for the γ-particle coincidence measurements is being projected.

**Method:**

In the scheme above it is shown the RIBRAS system and the extension beyond the secondary scattering chamber.

Below an scheme of the new γ-particle coincidence chamber:




The system will consist of four E-ΔE silicon telescopes placed at a distance of about 7 cm from the target to detect the alpha particles. The target will be surrounded by two

HpGe detectors to detect the gamma rays and these gamma rays will be detected in coincidence with the charged particles. Since, the secondary beam (6He) is produced in-flight by using the tranfer reaction 9Be(7Li,6He)10B, a very large number of neutrons will be produced from this reaction. In order to protect the HpGe detectors from the neutron damage, we plan to build a neutron shield (wall, see the picture) of thickness around 50 – 60 cm using borated de-ionized water. Additonally, we also plan to use paraffin bars to shield the detectors. To stop the neutrons coming in the zero degrees (beam pipe), we plan to place blockers at stratergic positions made of high density materials. Further, due to the high vulnurability of HpGe detectors to high neutron background, we plan to replace them by LYSO(Ce) (Cerium-doped Lutetium Yttrium Orthosilicate) detectors in future (we already bought a couple of detectors for preliminary tests). LYSO(Ce) detectors have the advantages of high light output and density (very high photopeak detection efficiency), fast decay time along with a reasonable energy resolution (about 10%) and low cost. These detectors are also compact and can be used with large neutron background.

**Estimation of the γ-p counting rate:**

Assuming, I($^6$He)=$10^5$ pps (from the last experiment), HpGe detectors are placed at a distance of 10 cms and E-ΔE detectors are palced at a distance of 7 cms from the target, 400 mb α-production cross section (measured) we predict 50 γ-particles coincidences/day.

**Requested beam time: 15 days.**

**References:**

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*[4] P.N. De Faria, Tese de doutoramento, IFUSP (2008).*

*[5]Appannababu Selaboina, private communication, see paper attached.*

*[6]*R. Lichtenthäler et al, Few-Body Syst. (2016) 57:157–163

# Elastic scattering and $\alpha$ particle production in $^6$He + $^{120}$Sn reaction at 22.5 MeV

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## Abstract

Elastic scattering and $\alpha$ particle production were studied for the reaction $^6$He + $^{120}$Sn at 22.5 MeV. The elastic scattering angular distribution have been analyzed with the optical model calculations and the alpha production cross sections have been compared with Q-optimum considerations. The present results are compared with the existing reports and found that, even though the Q-optimum value is negative for 2n transfer channels, the $\alpha$ particle production cross section is very large indicating the presence direct reaction process.

PACS numbers: :

## I. INTRODUCTION

With the availability of unstable beams, the study of nuclei far from stability has been improved considerably [1]. The elastic scattering and transfer reactions induced by low-energy neutron-rich and proton-rich projectiles on several targets have been studied over the recent years and a large total reaction cross section has been reported. Further these results are compared with the reactions with stable beams. An important step in the study of reactions with radio active ion beams, is to identify the reaction channels responsible for the increase of the reaction cross sections, such as breakup and transfer. The interesting aspect of elastic-scattering studies involving $^{6}$He, is that the projectile consists of an $\alpha$ core plus two neutrons forming a bound three-body Borromean system, which may effect the reaction mechanism by the rearrangement of neutrons. In the past a large yield of $\alpha$ particles has been observed for the reaction $^{6}$He+$^{120}$Sn around the Coulomb barrier and it is found that neutron stripping transfer reactions are probably the dominant reaction mechanism contributing to the observed $\alpha$ yields [2]. Further the theoretical cross sections and experimental cross sections differ by a factor of 10, indicating that two neutron transfer plays a vital role in reproducing the experimental cross sections. In this context, we performed an experiment to extend the data for elastic scattering, as well as $\alpha$ production cross section for the reaction $^{6}$He+$^{120}$Sn at $E_{lab}$ = 22.5 MeV.

## II. EXPERIMENT

The experiment was performed by using the RIBRAS (Radioactive Ion Beams in Brazil) facility at Sao Paulo University [1, 3]. A primary beam of $^{7}Li^{3+}$ at 27.84 MeV was used to produce a 22.5 MeV $^{6}$He beam by using the transfer reaction $^{9}$Be($^{7}$Li,$^{6}$He)$^{10}$B. The $^{6}$He beam was focused on the secondary target $^{120}$Sn of thickness 3.8 mg/cm$^{2}$ by using the twin solenoids [1]. The production rate of $^{6}$He was maximized in the beginning of the experiment by varying the currents of the solenoids and monitoring the elastic scattering cross section on a $^{197}$Au target after the first solenoid as well as the second solenoid. A lollipop was used after the first solenoid to suppress the elastically scattered $^{7}Li^{3+}$ scattered from the primary target. A gold foil was used as a degrader in the central chamber in order to change the charge state of the scattered primary beam. Another lollipop was placed after the second solenoid in order to suppress elastically scattered $^{7}Li^{2+}$ particles. A gold target of thickness 4.0 mg/cm$^2$ was used in the secondary chamber for normalization, as $^{6}$He + $^{197}$Au scattering is from pure rutherford scattering. The elastic scattering and $\alpha$ production measurements were carried out by using four E (25 - 50 $\mu$m)-E(1000 $\mu$m) silicon telescopes. These detectors were mounted on a rotating plate inside the 1.5 m long secondary chamber of the RIBRAS facility, in order to perform angular distribution measurements. The detectors were placed at a distance of 7.0 to 12.3 cms from the target. A typical $\Delta$E-E$_{total}$ spectra at forward angles is shown in the Fig: 1.

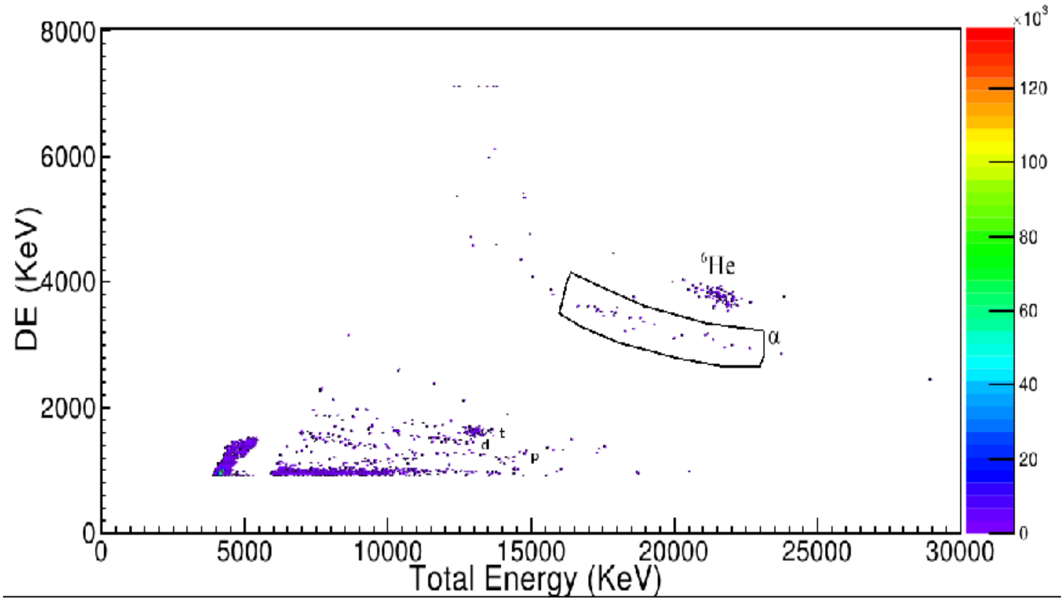


FIG. 1: (Color online) $\Delta$E - E$_{total}$ spectra with $^{120}$Sn target.

We can clearly see the $^{6}$He, $\alpha$, t, d, p peaks separated and there are no contaminations from the primary beam. The elastic-scattering cross section was extracted by using the expression

$$\sigma^{Sn}_{cm}(\theta) = \frac{N^c_{Sn}}{N^c_{Au}} \frac{N^b_{Au}}{N^b_{Sn}} \frac{N^t_{Au}}{N^t_{Sn}} \frac{J^{Sn}}{J^{Au}} \sigma^{Au}_{cm}(\theta) \tag{1}$$

where N$^c$ is the number of counts under the peak of interest, N$^b$ is the total number of $^{6}$He beam particles during the run, J is the Jacobian which transforms from laboratory to the center-of-mass and N$^t$ is the surface density of the target in number of atoms/cm$^2$ . The ratio $N^b_{Au}/N^b_{Sn}$ is the ratio of the current integrators of the runs with Au and Sn. In order to monitor the production rate of the secondary beam, we take a Au run before and after taking a run with the Sn target. The advantage of the above expression is that, it is independent of the solid angle of the detectors.

## III. ANALYSIS OF THE ELASTIC SCATTERING THROUGH OPTICAL MODEL (OM)

We have performed optical model calculations based on the Sao Paulo Potential (SPP) using the global code. We have used Woods-Saxon potential as well as the the imaginary part of the optical potential in the calculations. The fit for the angular distributions by using the global code is shown below in Fig: 2. Further, the experimental data from the present

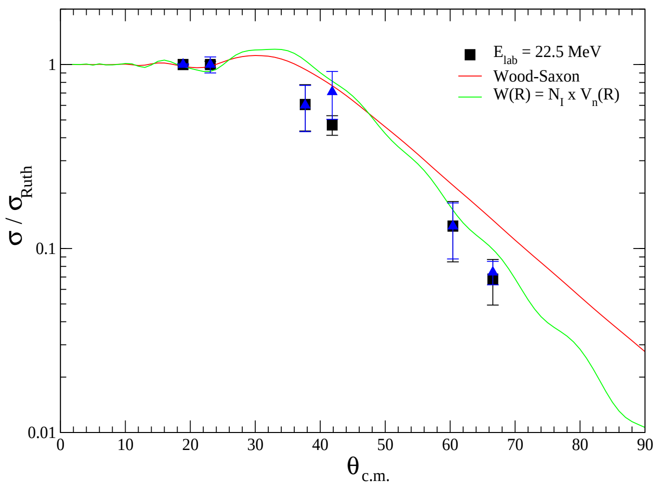


FIG. 2: (Color online) $^6$He + $^{120}$Sn elastic angular distributions (circles) along with the optical model fits.

experiment along with the previous experiment [4] was analyzed by using OM calculations using the SFRESCO code [5]. Initially, we used a Woods-Saxon potential shape and the six parameters (see Ref. [4] for more details) were varied freely to fit the experimental data, which reproduces our data exactly. It is observed in previous analysis that different potential parameters reproduced the experimental data, indicating that there may be a presence of a large ambiguity in the Woods-Saxon parameters [4]. In order to answer this ambiguity, We further analyzed the data by searching all the parameters, including V and W (real and imaginary potentials) for each energy, by using sfresco code, which independently adjust all the parameters depending on the experimental data. The fits are shown in Fig. 4 by continuous lines, where one can observe that our data along with the previous experimental data are reproduced well with independent search. We are in a process to extract OM total reaction cross sections by $\chi^2$ minimization by leaving all the fit parameters independent (or by fixing at least one parameter).

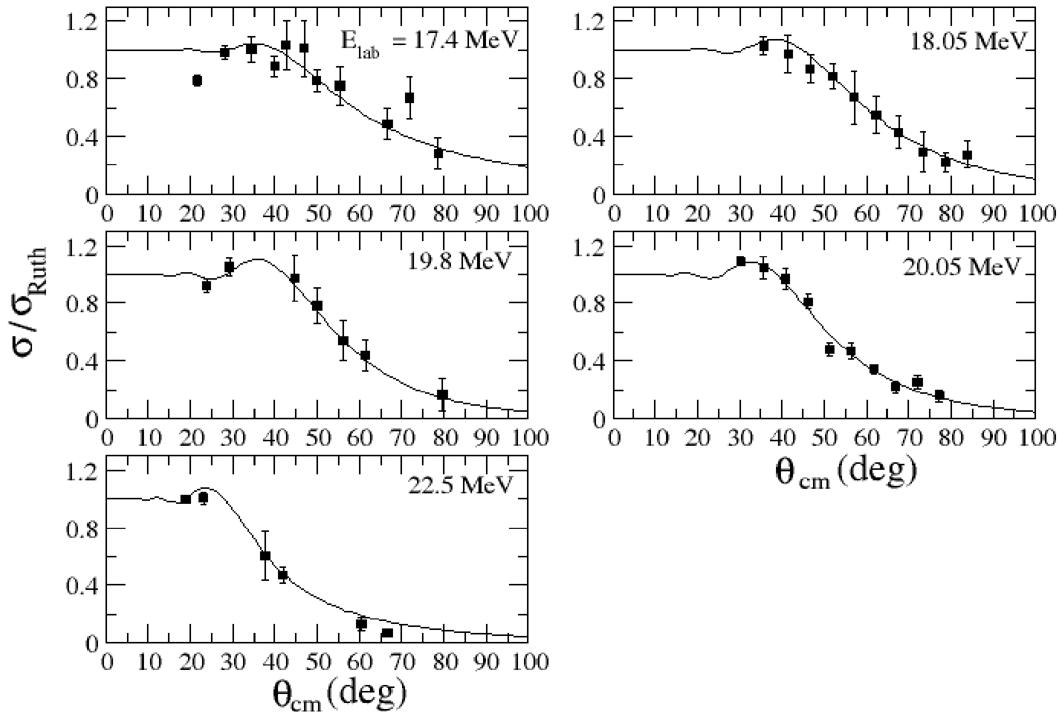


FIG. 3: (Color online) $^6$He + $^{120}$Sn elastic angular distributions. The present and previous experimental data [4] (solid circles) are compared with OM (solid lines calculations. See text for further details.

Further, We extracted the energy spectra and the corresponding angular distributions of the $\alpha$ particles produced in the reaction $^6$He + $^{120}$Sn, as mentioned in the Ref[2]. The extracted results are plotted in Fig. 3.

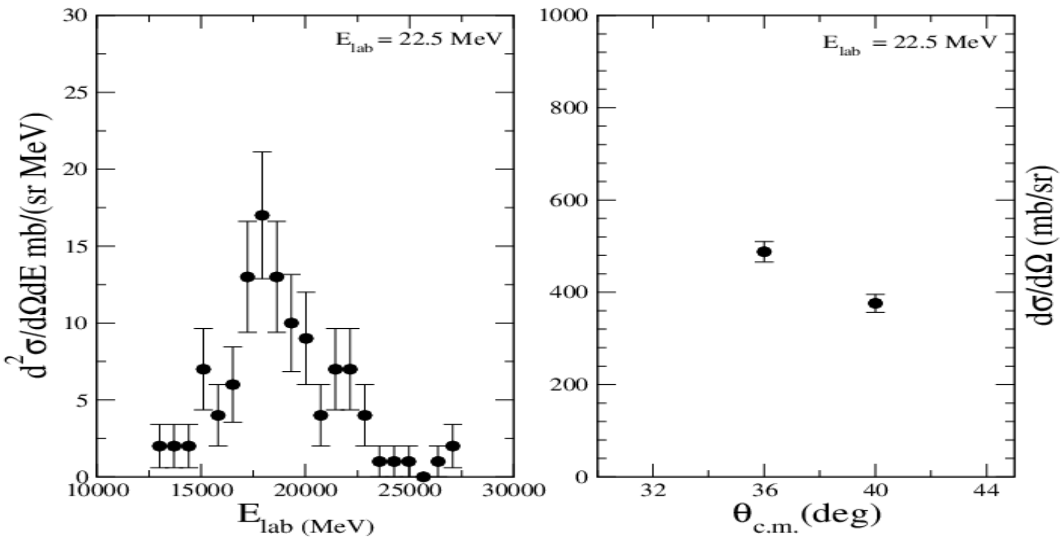


FIG. 4: (Color online) Energy spectra (left) and the corresponding angular distributions (right) of the $\alpha$ particles produced in the reaction $^{6}$He + $^{120}$Sn at 22.5 MeV.

## IV. INTERPRETATION OF $\alpha$-PARTICLE PRODUCTION CHANNEL

It is well known that the energies of the $\alpha$ particles produced in a reaction depends on the kinematics of the reaction and the excitation energies of the nuclei populated in the exit channel. In the previous studies on the reaction $^{6}$He + $^{120}$Sn, by using simple Q-optimum considerations, It is observed that the $\alpha$ particles are most probably produced in neutron (2n, 1n) stripping reactions to excited states of $^{122}$Sn and $^{121}$Sn [2]. Further it is found that the calculated cross sections from theoretical predictions are found to be of the order of a few tens of millibarns, where as the experimentally extracted cross sections are in the order of hundreds of millibarns. As the direct breakup mechanism alone cannot explain the observed experimental results, theoretical predictions are done for the two neutron transfer channels and found to be reproducing the experimental results. In order to compare the present results with the existing ones, we analyzed our data through Q-optimum considerations by interpreting the $\alpha$ particles are coming from the two neutron $^{120}$Sn($^{6}$He,$\alpha$)$^{122}$Sn stripping reaction. According to the kinematics, it is expected that the $\alpha$ particle energy distribution is centered at $Q_\alpha = 0$ for two neutron transfer process. The experimentally extracted energy distributions of the $\alpha$ particles along with the Q-optimum considerations are shown in Fig. 4. It can be observed, that at lower energies (near to the coulomb barrier) the $\alpha$ particle energy distributions agrees with the Q-optimum considerations ($Q_\alpha \sim 0$) indicating

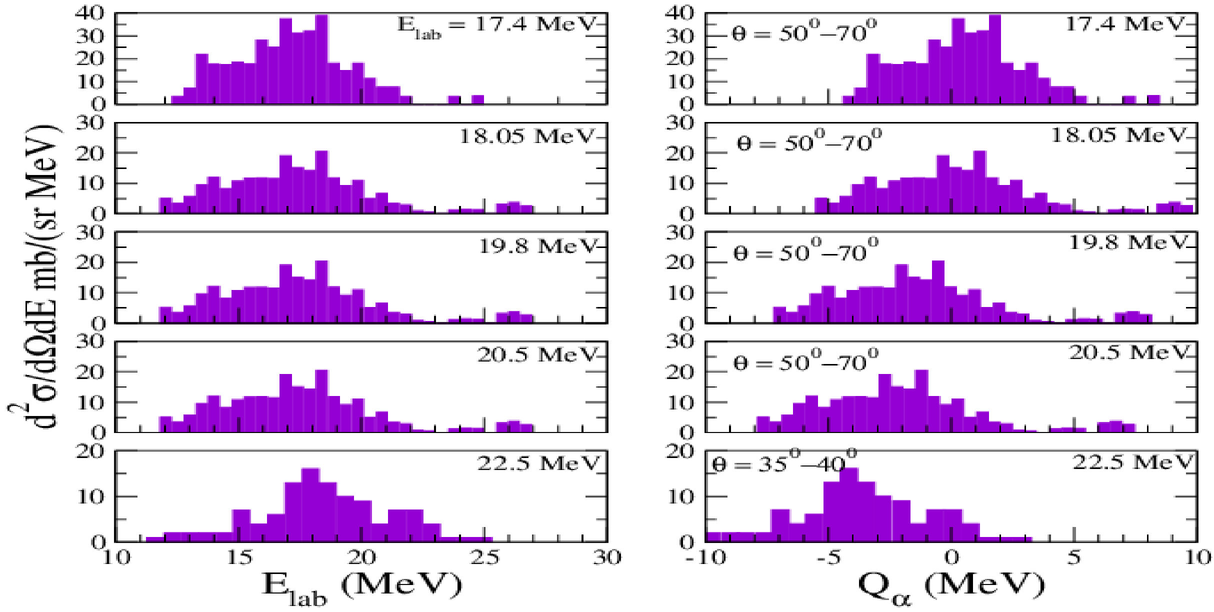


FIG. 5: (Color online) The energy distributions of the $\alpha$ particles (left) along with the Q-optimum considerations.

the dominance of 2n transfer channels. But with increasing energy, It indicates that other reaction mechanisms (inelastic breakup process) are responsible for the production of large number of $\alpha$ particles. It is interesting to observe that even though the Q-optimum value is negative at higher energies, the $\alpha$ particle production cross section is very large. Theoretical predictions are in progress, to explain this large number of $\alpha$ particles production with negative Q value.

## V. CONCLUSIONS

The experimental data for elastic scattering and $\alpha$ production cross sections were presented for the reaction $^{6}$He + $^{120}$Sn at 22.5 MeV. The elastic scattering data was analyzed using OM analysis, along with the existing experimental data. The $\alpha$ particle energy distributions are compared with the Q-optimum considerations and it is observed that even though the Q-optimum value is negative, the $\alpha$ particle production cross section is very large indicating the presence of other reaction mechanisms.

## VI. ACKNOWLEDGMENTS

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