Using Rutherford backscattering spectroscopy to characterize targets used for nuclear reaction cross section measurements performed with laser-accelerated ions

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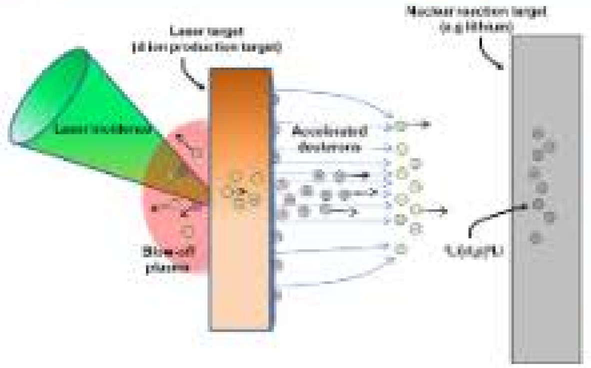
Abstract

A project is underway to develop a platform for measuring low energy nuclear reaction cross sections using light ion beams accelerated from the rear side of targets illuminated with an ultra-intense laser. These ions, accelerated via the target-normal sheath acceleration (TNSA) mechanism, strike a nuclear production target placed behind the laser-illuminated target. The reaction products are collected, and their activity is measured to determine the nuclear cross section. We report on a set of experiments designed to characterize the nuclear production targets. These targets consist of lithium deposited on a substrate and coated with a thin metal film in a deposition chamber. The thin metal film must be thick enough to prevent the lithium from reacting with air during handling but thin enough to allow the projectile TNSA ions to pass through. The thickness of the metal overcoat has been measured using Rutherford backscattering spectroscopy (RBS) at the SUNY Geneseo 1.7 MV Pelletron accelerator. In RBS, an MeV proton or alpha particle beam strikes the target at normal incidence and the energy spectrum of the backscattered ions is measured with a silicon detector. The elemental composition of the target and its thickness can be inferred from the resulting spectrum. (This project is funded in part by a grant from the DOE through the Laboratory for Laser Energetics and by SUNY Geneseo.)

Motivation

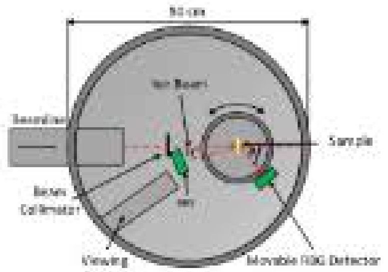


A light ion beam (e.g., deuterons) is accelerated from the rear side of a laser target illuminated with an ultra-intense laser (MTW or OMEGA). The light ion beam then strikes a nuclear reaction target (e.g., lithium) and initiates nuclear reactions. By counting the activity of the reaction products, the nuclear reaction cross section can be determined.

Target characterization

A set of nuclear reaction targets were made at Houghton University. These targets consist of a layer of lithium deposited on a substrate of stainless steel. The thickness of the lithium layer needs to be measured to determine the nuclear reaction cross sections. We used ion beams from the SUNY Geneseo 1.7 MV Pelletron accelerator laboratory to measure the thickness and composition of these targets.

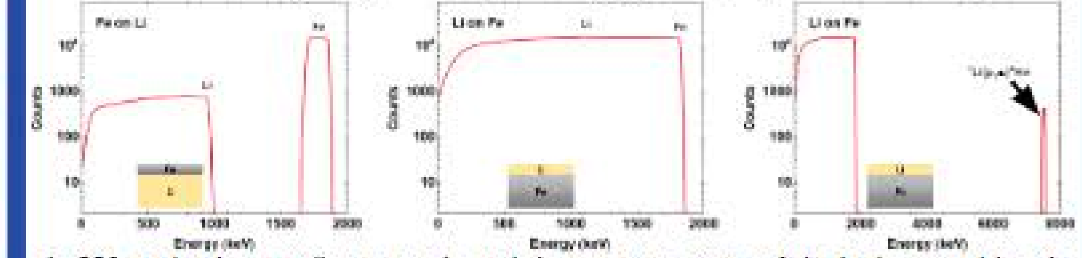
The Geneseo Pelletron Accelerator



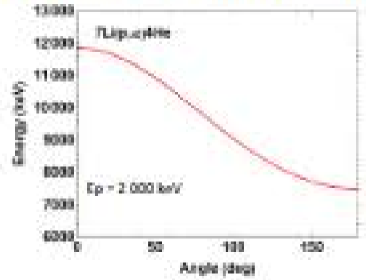
$$\frac{d\sigma}{d\Omega} = \frac{1}{16}\left(\frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 E_0}\right)^2 \sin^{-4}(\theta/2)$$

Rutherford Backscattering Spectroscopy

Proton bombarding energy = 2000 keV, scattering angle 165°, layer thickness 10^{19} at/cm^2

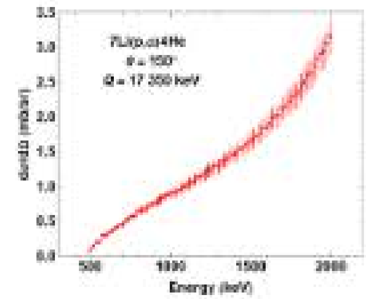


In RBS, an ion beam strikes a sample, and the energy spectrum of the backscattered ions is measured with a silicon detector. RBS works best when the sample consists of a thin film of heavy elements on top of a light substrate. Our targets consist of the opposite—a thin film of light elements (Li) on top of a heavy substrate (stainless steel). Fortunately, we can clearly detect the presence of lithium in our targets due to the high energy alpha particles produced in the 7Li (p,α) reaction (*Q* value 17,350 keV).

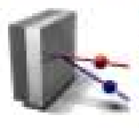


$$E_1 = E_0\frac{M_1^2}{(M_1+M_2)^2}\left\{\cos\theta \pm \left[\left(\frac{M_2}{M_1}\right)^2 - \sin^2\theta\right]^{1/2}\right\}^2$$

The plot shows the energy of the alpha particles produced in the 7Li(p,α) reaction as a function of angle. The proton bombarding energy was set to 2000 keV. Our detector is placed at approximately 165°, yielding an alpha particle energy of 7542 keV.



The 7Li(p,α) reaction cross section has been measured as a function of proton energy by Dieumegard, Nucl. Instrum. And Methods in Phys. Res., Vol 168, p. 93 (1980). These cross-section measurements are included in the ion beam analysis program SIMNRA.

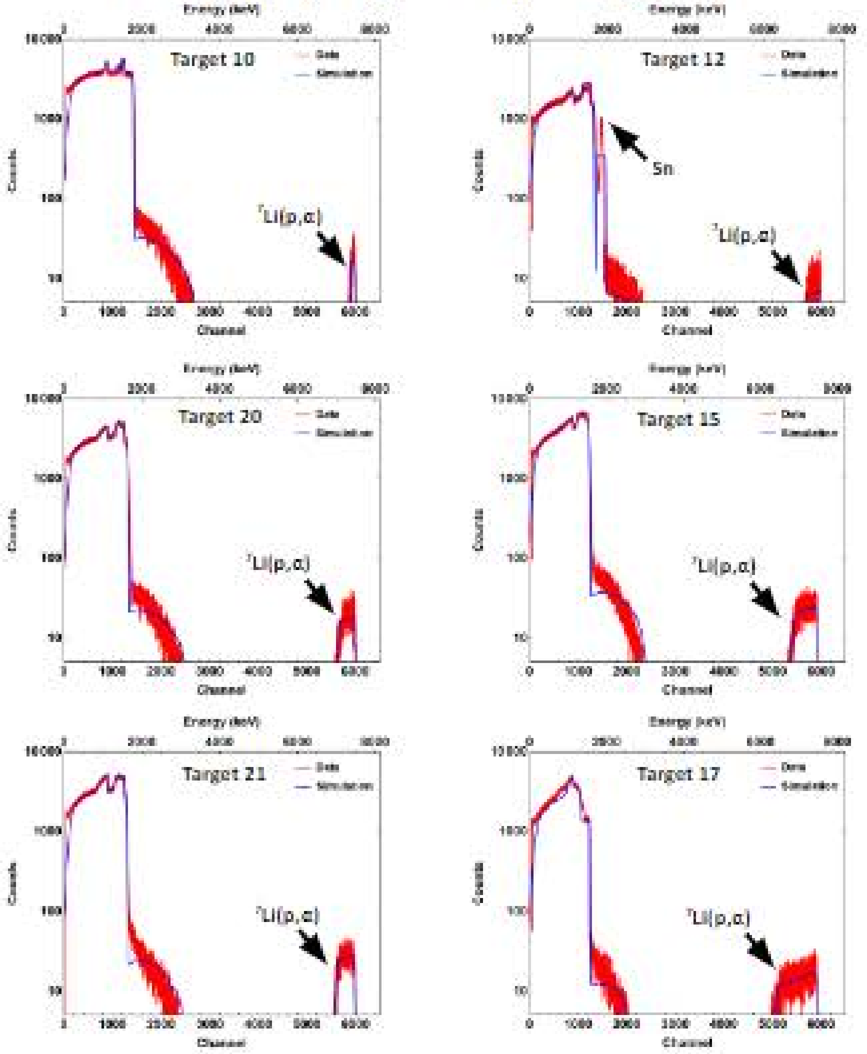


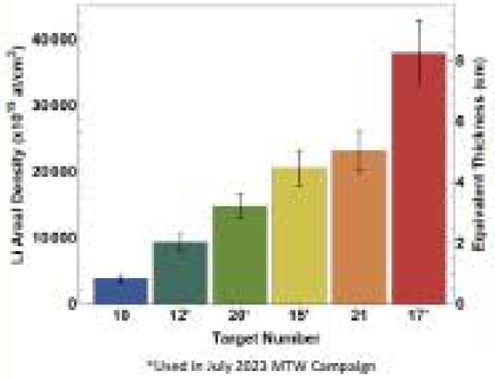
SIMNRA

For more on SIMNRA and its calculations, please refer to the SIMNRA User's Manual: https://mam.home.ipp.mpg.de/SIMNRA-Users-Guide.pdf

Analysis

Proton bombarding energy = 2014 keV, scattering angle 165.6°





*Used in July 2023 MTW Campaign

We have shown that ion beam analysis can be used to measure the thickness and composition of nuclear reaction targets. These measurements are important for calculations of light-ion cross sections. In the future, we will investigate the contaminants in the lithium layer, including oxygen and carbon. We can also perform these measurements at different proton bombarding energies to confirm that the thicknesses are consistent. The uncertainty in thicknesses is due to the 7Li(p,α) cross section uncertainty (8%) and a statistical uncertainty of approximately 10%, resulting in overall uncertainty of ~13%