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Introduction

Oxygen is found in many natural and human-made structures and materials, including water, concrete, or any oxide. The severe lack of data on the cross section of ^{16}O(n,α), a reaction that can be found in any material containing oxygen, is detrimental to a complete understanding of the natural or induced behavior of these materials [HYL16]. Additionally, study of this particular reaction and other neutron-induced reactions involving oxygen are useful in the design of naval light water reactors and applications in radio-biology [HYL16]. A detailed understanding of the ^{16}O(n,α) reaction is vital to the safe and efficient study, design, and development of applications such as these.

My consequent work at the Los Alamos National Laboratory (LANL), under the supervision of my mentor, Dr. Hye Young Lee, concerned an experiment to measure the reaction rate of ^{16}O(n,α) with unprecedented precision, using a method of experimentation known as the ”forward propagating approach.” What separates this method from traditional experimentation is in the use of computer simulations; in essence, this method entails the development of a computer-simulated experimental environment that behaves similarly to a corresponding physical experimental environment (the word ”similar” is used here to convey an equivalence in properties of materials, like geometry or density, and characteristics of certain nuclear processes between the simulated and physical environments). The simulated environment receives inputs, like detector resolution and efficiency, beam resolution, or theoretical calculations of cross sections, that are determined from physically measured results, and then output data that – provided the simulation was prepared and executed properly – closely resemble the results expected from physical execution of the experiment. By comparing data from the simulated experiment and the physical experiment, the relevant results can be constrained to achieve a high precision measurement. The goal of my mentor’s experiment–the experiment that I helped build and simulate–was to achieve a high precision measurement of the cross section of ^{16}O(n,α) using the forward propagating approach technique.

Procedure

The experiment was to be executed at the LANSCE Weapons Neutron Research (WNR) facility, using a newly constructed detector called the Low Energy NZ (LENZ) chamber (”NZ” meaning low energy, neutron-induced charged particle reactions). The LENZ chamber is an instrument consisting of a telescope array of three silicon detectors and an ionization chamber. The telescope array allows for a higher resolution of charged particle energy deposit by measuring the deposit through multiple facets. My task was to develop code with the ability to simulate the geometry of the chamber and the efficiency of a Micron Semiconductor S1 silicon detector [Sem] within the chamber, based on physical Computer Aided Design (CAD) drawings and measurements of detector resolution. This class of detector is exceptionally accurate in alpha particle detection, which is the product of the ^{16}O(n,α) reaction, and detecting them is fundamental to proper analysis of reaction rate. My simulation was compared to a previous S1 silicon detector calibration experiment using Th-229, the decay scheme of which provides an excellent source of alpha particles. This comparison offered a means to verify that the structure and output of my simulation would be appropriate for future experiments and data analysis. In addition to the code development, I aided in the physical construction, configuration, and calibration of the LENZ instrument.

I used a collection of software known as Geant4 to develop the code for my LENZ simulation. Geant4 is an object-oriented C++ programming toolkit designed to offer developers the tools necessary to create applications simulating the passage of particles through matter [CER]. To construct the LENZ geometry, I used a series of CAD drawings depicting the design of the LENZ chamber, including the aluminum outer container and the structure of the target wheel and translated them into Geant4 geometry objects. The most complex piece of the geometry was the S1 detector, which consisted of 32 separate channels, split into sixteen rings and four quadrants (referred to in the results as ”wedges”). The next step was to design the simulation's detector response, which involved a few simple algorithms to, first, simulate the decay of Th-229 (which implemented a process to simulate detector resolution) and then record a hit (alpha particle collision) within a channel on the detector. Detector resolution, which was important in simulating the alpha decay spectrum of Th-229, was implemented into the code by ”smearing” the energy deposit of an alpha particle in the detector, using a Gaussian distribution seeded with a constant value determined from the Full Width at Half the Maximum (FWHM) of known centroid peaks in a measurement of the spectrum.

Results

The final code succeeded in its purpose to simulate geometry and efficiency of the silicon detector. The final simulation was easily customizable and flexible for future experiments and variations of the LENZ chamber due to the nature of the geometry construction. Figure 1 depicts the LENZ geometry translated into the Geant4 simulation. The important pieces of the target wheel support structure, as well as the silicon detectors, are brightly colored for contrast. The blue lines in the middle image of the collection of geometry images represent alpha particle tracks. Inspection of these tracks shows alpha particles stopping in the silicon, as expected.

In the context of this project, the efficiency is more of a qualitative analysis of the total number of counts gathered per channel in the silicon detector. When plotted as a histogram of counts versus channel, data collected in the physical calibration experiment should closely resemble data generated by the simulation. As can be seen in Figure 2, this expectation is verified. An interesting question arises from inspection of the calibration experiment calibrated energy histogram; why do columns seem to be missing from the data? The missing data in ring nine and fifteen is explained by the fact that these rings were dead at the time of the calibration experiment, likely due to a malfunction in the detector hardware. The wide ”dips” in the wedge channels are explained by the

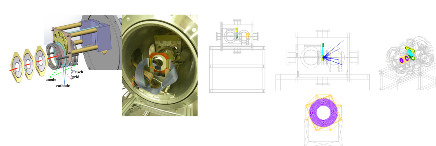

Figure 1: (left)Graphic depicting the target wheel and detector structure within the LENZ chamber, as well as photo of the physical LENZ chamber with the detectors assembled. (right) Image of Geant4 detector geometry, including closeup of the simulated S1 silicon detector.

location of electrodes placed on the detector disks (see S1 detector design [Sem]). The other missing column corresponding to ring six, which seems to have collected only half of the expected number of counts, is likely due to another malfunction. Sustaining the conviction to a realistic simulation, the causes of missing data were included in the design of my code.

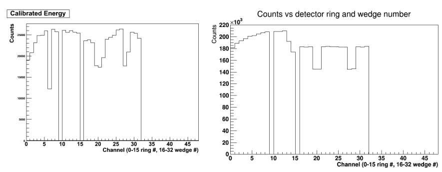

Figure 2: (left) Counts versus channel number from calibration experiment. (right) Counts versus channel plotted from data generated in LENZ simulation.

The implementation was not perfect and my time at the Laboratory had ended before I could establish a proper algorithm to simulate ring six's missing data. However, the results prove that a realistic, detailed simulation can be created and leaves room for further improvement.

The strength of the simulation is further proven by its generation of a Th-229 alpha decay spectrum. A comparison of the measured spectrum versus the simulated spectrum can be observed in Figure 3. These results suggests that the simulation properly accounts for the decay scheme of a specific isotope when generating alpha particles. Conceivably, any isotope's decay scheme could be implemented based on this comparison, which indicates a that the code could be reused for future neutron-induced charged particle reaction experiments with the LENZ instrument.

Discussion

The efficiency analysis and spectrum generation of the simulation provide compelling evidence for its strength in constraining experimental results. The simulation was not perfect in detail, but in practicality the efficiency, resolution, and geometry results demonstrate an important versatility in purpose. For application in the ^{16}O(n,α) experiment, where precise measurements of detector efficiency and resolution determine the precision of the cross section measurement, the data comparisons suggest that the simulation can be used to adequately constrain future experimental data to achieve the desired precision.

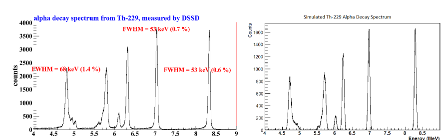

Figure 3: (left) Spectrum collected from calibration experiment. (right) Spectrum collected from LENZ simulation.

References

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[CER] CERN. *Geant4*. URL: `http://geant4.cern.ch/`.

[Sem] Micron Semiconductor. *Specialist Detectors for Nuclear Physics*. URL: `http://www.micronsemiconductor.co.uk/pdf/s.pdf`.