The \((n,2p)\) Reaction as a Probe for the Pre-existing Nuclear \(\Delta^{++}\) Component

Daniel Haas, Bethany Little, Steve Thomson, Steve Wallace, June Matthews and Mark Yuly.
Department of Physics, Houghton College, One Willard Avenue, Houghton, NY 14474

1. Abstract

The \((He(n,2p)\Delta)\) and \((He(n,2p)\pi)\) cross-sections are being measured in a two-step \((\Delta^++p)\) reaction of the nuclear wave function. The incident neutron beam ranges between 250 and 800 MeV. Scattered protons on beam right pass through magnetic spectrometers which measure the momentum of the proton. The spectrometers consist of a thin \(\Delta^+\) scintillator, two drift chambers, and permanent magnets and finally two thin scintillators. On beam left, a horizontal \(\Delta^+\) scintillator array in front of a vertical proton scintillator array also detects scattered protons.

2. Motivation

Traditional models of the nucleus, which mix it as a non-relativistic system of nucleons, do not completely explain the binding energies and the electromagnetic properties of nuclei. By the 1930s, theorists suggested the presence of a pre-existing \(\Delta^+\) particle in the ground-state nuclear wave function and that this \(\Delta^+\) resonance might be important in nuclear structure. The \(\Delta\) has a mass of about 1232 MeV/c^2 and isospin of \(0/2\) and \(1/2\). To investigate the \(\Delta\) component of the nucleus, the \((He(n,2p)\Delta)\) and \((He(n,2p)\pi)\) cross-sections are being measured at the Washington Research Nuclear \(\pi\) facility, a division of the Los Alamos National Laboratory (LANSE) in Los Alamos, New Mexico.

3. Experimental Apparatus

The experimental apparatus is shown below. The neutron beam passes through the fission chamber and is incident on the helium target. Left and right detector arms are designed to detect the two scattered protons in coincidence.

3.a. Neutron Beam

The neutron beam used in this experiment is produced by spallation using the half-mile long Clinton P. Anderson proton accelerator at LANSE. Proton beam energy is selected before hydrogen ions \((H^+\text{ or } H^-)\) are accelerated through the linear accelerator, which consists of drift tubes that accelerate protons in stages. Each stage sets up an accelerating potential across a region of space, giving the proton energy. Eventually, the lengths of the drift tubes increases such that each proton spends an equal amount of time inside each drift tube. In this manner, the protons are accelerated to about 800 MeV. This high-energy proton beam is incident upon a Tungsten spallation target. Neutrons scatter from the target and travel towards various experimental areas.

3.b. Fission Chamber

The flux of incident neutrons on the target must be measured so that any changes in the beam can be detected. Measured cross sections from the \((He(n,2p)\Delta)\) and \((He(n,2p)\pi)\) reactions are compared to the neutron flux to determine a ratio between the total number of neutrons striking the target and the number of particles detected. Neutron flux is measured by the fission chamber.

The fission chamber is a cylinder \((25.4\text{ cm in diameter})\) and contains \(^{235}\text{U}\) deposits which lie in the beam’s path. Neutrons pass through the fission chamber, some of which are absorbed by the \(^{235}\text{U}\). The newly formed, radioactive \(^{239}\text{Pu}\) nucleus splits into two isotopes which mix the gas mixture. The resulting fission fragments are collected by an anode and the resulting signal is processed. Neutrons can be measured in this way since the fission rate is proportional to the number of neutrons passing through the chamber.

3.c. Target

Both \(He^+\) and \(He^\pi\) targets are used for this experiment. Generally, there are two protons in a \(He^+\) or \(He^\pi\) nucleus. However, \(\Delta^+\) particles can also exist in the nucleus, and the \(\Delta^+\) is predicted to be the most probable of all the \(\Delta\) states found in the \(He^+\) and \(He^\pi\) nuclei.

In this experiment, neutrons are the incident particle. A neutron can interact with two protons in the \(He\) nucleus, causing them to scatter. However, an incident neutron can also interact with a \(\Delta^+\) in the nucleus. When a \(\Delta^+\) particle is scattered from the nucleus, it decays into two protons. These two protons have a different kinematic relationship than two protons that are scattered individually from the \(He\) nucleus. When detected in coincidence, the protons from a single \(\Delta^+\) particle or from two protons in the \(He\) nucleus can be determined by looking at the position and energy of the two protons. The fact that Helium has only two protons and that it is a relatively small atom makes looking at the position and energy of the two protons relevant to this experiment.

In the \(He\) nucleus, \(\Delta^+\) particles can interact with two protons in the \(He\) nucleus, causing them to scatter. However, an incident neutron can also interact with a \(\Delta^+\) in the nucleus. When a \(\Delta^+\) particle is scattered from the nucleus, it decays into two protons. These two protons have a different kinematic relationship than two protons that are scattered individually from the \(He\) nucleus. When detected in coincidence, the protons from a single \(\Delta^+\) particle or from two protons in the \(He\) nucleus can be determined by looking at the position and energy of the two protons. The fact that Helium has only two protons and that it is a relatively small atom makes looking at the position and energy of the two protons relevant to this experiment.

3.d. Spectrometer

The permanent magnet spectrometer, pictured at left, is used for measuring protons, giving measurements of their momentum and position. It is made up of two permanent magnets with a drift chamber and scintillators on either side. Drift chambers have horizontal and vertical plates of alternating cadmium and anode wires and are filled with gas. As charged particles pass through the chamber, the gas is ionized. Electrons drift toward the anode wire and create a current in that wire, allowing the wire which was nearest the path of the proton to be identified. A delay line connects the anode wires together. Charged particles drift to the anode wires, pulses are formed that travel to each end of the delay line. The time difference between when the pulses arrive at each electrode while the wire the proton was nearest. The sum of the delay line times allows the drift time to be calculated. Using this information from the vertical and horizontal wires, the position of the proton can be found.

Cathode wires detect positively charged ions after a proton exits the gas in the chamber. Cathode wires are organized such that every other cathode wire is considered ‘odd’ while the rest of the cathode wires are considered ‘even’. By looking at the cathode wire to which the ion drifted, which side of an anode wire an event took place can be determined.

4. Energy Calculations

The energies of the detected particles must be known to obtain meaningful results from the \((n,2p)\) reaction. This experiment is used to maximize the difference in expected cross-section between the two ways the experiment can proceed, in one step or two. These cross-sections, however, can only be determined if the energies of the scattered protons are known. Thus, a system to detect scattered protons must be implemented.

On beam right, a permanent magnet spectrometer is used. When a proton passes through a magnetic field the trajectory changes. How much the proton’s trajectory is changed depends on the energy. Outside the magnetic field, the proton’s trajectory is constant. Thus, by measuring the proton’s trajectory before and after the magnetic field, the energy of the proton can be found.

On beam left, the energies of the protons detected are calculated using time of flight. The time the neutron is incident upon the target can be found, and the time that the proton that detected on beam left is known. Since energy is proportional to velocity, the energy of the proton can then be found using the time it took to reach the spectrometer after scattering from the target.

5. Wire Chamber Analysis

A histogram is then made which subtracts the even pulses from the odd pulses for each individual event. The event is then used to determine the actual path of the proton as it traveled through the chamber.

6. Electronics

The electronics read in and process the signals coming from the various detectors and send them to the computer. There are multiple triggers in this experiment, most importantly the one which determines when a charged particle on the opposite side of the beam line has been detected. In order for a trigger to occur, a signal in the beam right \(\Delta\) detector and proton detector must be shown as a signal in the beam left \(\Delta\) detectors and proton bars must be set in coincidence. This ensures that two charged particles were detected in all detectors, and suggests that the particles detected scattered from the target.

7. Conclusion

A feasibility study of the \((He(n,2p)\Delta)\) experiment is currently underway. When complete, the analysis will be focused on interpreting this dataset information to calculate the trajectories and thereby momentum of the protons in coincidence with a \(\Delta^+\) proton detected on beam left. Results from this experiment are expected to lead to a full-scale experiment during the summer of 2009. Ultimately, theoretical calculations will be compared to the analysis of these experiments and a measurement of the \(\Delta^+\) component hopefully made.