

Low Energy Proton Capture in Light Nuclei

Progress Report

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1. Introduction

Radiative capture reactions with light nuclei are of special interest in nuclear astrophysics because of their importance in the formation of the various elements. In many cases a simple direct-capture model that considers only the electromagnetic interaction is sufficient to reproduce experimental results. A direct-semidirect process may be used in which the transition amplitude is the sum of a direct term and another term representing the excitation of the target nucleus into a collective state. In cases where these approaches are not sufficient, the relative simplicity of nuclear systems with small numbers of fundamental particles allows microscopic calculations of measurable quantities from nucleon-nucleon potentials, using the multichannel resonating group model or, in some cases, Faddeev calculations.

In the summer of 1990, the PI began a collaboration with Professor Henry Weller's group at the Triangle Universities Nuclear Laboratory (TUNL). Weller's group has studied radiative capture reactions with polarized beams at TUNL for over a decade, developing considerable expertise in the detection of high energy gamma rays and for the analysis of the measurements. The PI has been involved in the development of a new series of experiments at beam energies below 100 keV, using the positive beam directly from the high intensity atomic beam polarized ion source. This work is the topic of the present grant, which began September 1, 1993.

The main activity in the grant occurs during the summer months. Since this is the first year of the grant, most of that activity will be during the upcoming summer months. The PI will travel to TUNL in mid-June and will spend most of his time from then through August either at TUNL or working on data reduction and other calculations at West Georgia College.

The PI is moving from West Georgia College (WGC) to North Georgia College (NGC) in September, 1994. He will be Professor and Chair of Physics there as he has been at WGC. His research activities will be continued there. NGC offers increased opportunities for the PI. There are about twice as many undergraduate physics majors at NGC as at WGC, and NGC is about two-hours driving time closer to TUNL. A two-month, no-cost extension on the current year's grant has been requested in order to facilitate the change of the PI's home institution.

2. Work Completed and in Progress

Some of the work reported here was begun before the beginning of the grant period on September 1, 1993. However, the PI was involved with these projects last summer and also during the current grant year. Along with studies of polarized-proton induced reactions at low energy, related applied projects involve the development and construction of a polarimeter for low-energy protons and extraction of energy-dependent data from spectra from a HPGe detector. The experiments are discussed individually below.

${}^7\text{Li}(p,\gamma){}^8\text{Be}$ Recent measurements at TUNL of the analyzing power of the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ reaction with a large, anticoincidence-shielded NaI detector have shown large analyzing powers over a range of angles for 80-0 keV protons. Analysis of these measurements with a model-independent transition element analysis indicates a large p-wave contribution in order to produce the large analyzing powers. Calculations with the direct capture model indicate that the unexpected p-wave (non-E1) contribution could reduce the extrapolated astrophysical S-factor by as much as 40%.

The ${}^7\text{Be}(p,\gamma){}^8\text{B}$ is of special importance in the solar neutrino problem since it produces ${}^8\text{B}$ which decays, producing the high energy neutrinos that are detected in the solar neutrino experiments. In ${}^8\text{Be}$ there are a pair of closely spaced $J^\pi = 2^+$, $T = 0,1$ (isospin mixed) states which are the analog to the ground state of ${}^8\text{B}$. These states can be populated by the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ reaction, producing 0.40 MeV and 0.70 MeV gamma rays. The lower state is proton-like and the upper is neutron-like so that the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ should preferentially populate the lower state. Despite the low cross section at low energy, it is felt that these gamma rays can be observed

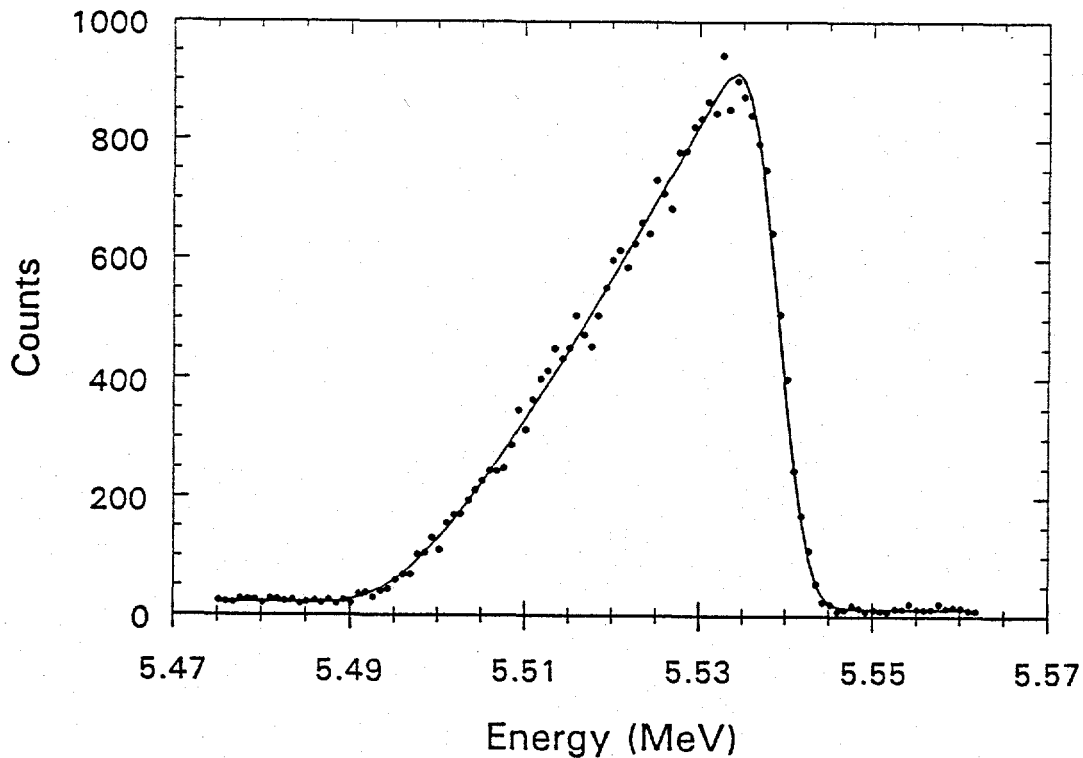
with the high efficiency HPGe detector which was recently acquired at TUNL. Preliminary measurements have been made and another run is scheduled for July, 1994. This experiment has recently been assigned to one of Professor Weller's graduate students as a dissertation project.

Polarimeter Because of the large analyzing powers for ${}^7\text{Li}(p,\gamma){}^8\text{Be}$, this reaction is a good candidate for use in a low-energy proton polarimeter. Data have been taken testing this idea. These measurements use an unshielded 25 cm x 25 cm NaI detector placed at 90° very near a ${}^7\text{Li}$ target. Spectra were sufficiently simple to be analyzed by subtracting the cosmic-ray-induced background and then summing over the region of interest. An analyzing power of 0.39 ± 0.02 was determined. Utilization of this result in the design of a polarimeter is being pursued. Using two NaI detectors, increasing the beam energy by 25% and increasing the beam on the ${}^7\text{Li}$ target will increase the performance of a polarimeter and allow the two beam polarization states to be determined to within 10% in a one-hour run. The PI will be working on the polarimeter during his time at TUNL this summer.

HPGe Detector A new high efficiency germanium detector at TUNL will be used in the future for a number of low-energy experiments, including polarized proton capture on ${}^6\text{Li}$, ${}^7\text{Li}$, ${}^9\text{Be}$ and ${}^{10}\text{B}$. It is currently being used for ${}^2\text{D}(p,\gamma){}^3\text{He}$ as a part of the dissertation project of Mr. G. J. Schmid, one of Professor Weller's graduate students. Because of the low energies of the particles and the very low counting rates, the targets are thick, and the beam stops in the target. The resulting gamma ray peak in the HPGe spectrum is wider than the intrinsic energy

resolution of the detector because of the range of gamma energies corresponding to the range of incident particle energies. The PI has written a computer code to calculate the peak shape, taking into account the variation of the proton (and gamma ray) energy as the beam slows in the target, the detector resolution, and the gamma energy spread due to the finite angular size of the detector. The variation of the cross section with incident particle energy is taken into account by expressing the cross section in terms of the astrophysical S-factor, which is assumed to have a linear energy dependence. The program fits the spectrum shape and extracts the parameters of the S-factor.

Results for ${}^2\text{D}(p,\gamma){}^3\text{He}$ give a slope for the S-factor in agreement with the one previous measurement of its energy dependence. This technique will be used in reduction of the data for other measurements in the future. An experimental spectrum for the HPGe full-energy peak for ${}^2\text{D}(p,\gamma){}^3\text{He}$ and the fit are shown in the figure below.



${}^6\text{Li}(p,\gamma){}^7\text{Be}$ First measurements on the ${}^6\text{Li}(p,\gamma){}^7\text{Be}$ are scheduled to be made in mid-June, 1994. The principal TUNL collaborator with the PI on this experiment is Dr. Charles Laymon, a postdoctoral research associate at TUNL. Unlike the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ reaction which produces 17.3 MeV gamma ray and requires the use of a large NaI detector, this reaction produces gamma rays up to 6.3 MeV in energy. This makes the use of the large HPGe detector feasible. It will be used with an annular NaI shield to reduce backgrounds. Spectra from the HPGe detector will be extracted using the method described above to obtain energy dependence of the cross section and analyzing power.

This will be the first experiment at TUNL in which undergraduate student assistants from WGC will participate. They will spend approximately two weeks at TUNL helping to set up the experiment and helping with data acquisition and reduction. During the academic year the student assistants worked with various aspects of data reduction, using PCs at WGC and the VAX cluster at TUNL via Internet.

3. Publications and Abstracts

Submitted for Publication

Chasteler, R. M., H. R. Weller, D. R. Tilley and R. M. Prior, Observation of substantial p-wave capture strength in the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ reaction at $E_p = 80\text{-}0$ keV and implications on astrophysical S-factors, submitted to Phys. Rev. Lett. (1994).

In Preparation

Prior, R. M., R. M. Chasteler and H. R. Weller, A polarimeter for low-energy protons, to be submitted to Nucl. Instr. and Meth.

Abstracts

Prior, R. M., R. M. Chasteler and H. R. Weller, A polarimeter for proton energies below 100 keV, Bull. Am. Phys. Soc. **39**, 1041 (1994).

Chasteler, R. M., H. R. Weller, D. R. Tilley and R. M. Prior, Observation of substantial p-wave capture strength in the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ reaction at 80-0 keV and implications on astrophysical S-factors, Bull. Am. Phys. Soc. **39**, 1253 (1994).

4. Personnel

Principal Investigator

Richard M. Prior, Professor and Chair of Physics

West Georgia College, Carrollton, GA.

Full time, July 1, 1994 - August 31, 1994.

Undergraduate Student Assistants (part time assistants)

Quentin Davis, fall, 1993, to present.

Brian Nicholas, fall, 1993, to March, 1994.

Christopher Chapman, April, 1994, to present; student assistant on other support,
September, 1993, to March, 1994.

Collaborators at TUNL

Dr. H. R. Weller, Professor of Physics, Duke University

Dr. D. R. Tilley, Professor of Physics, North Carolina State

Dr. R. M. Chasteler, post-doc, Duke University

Dr. C. Laymon, post-doc, Duke University

G. J. Schmid, graduate student, Duke University

M. Godwin, graduate student, Duke University

5. Summary

A facility for using the intense polarized beam from the TUNL polarized ion source for low-energy radiative capture reactions has been developed. Measurements of cross section and analyzing power have been made for the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ reaction at 80-0 keV. Analysis of the results indicates an unexpectedly large contribution from p-waves, which may significantly affect the value of the astrophysical S-factor. Further measurements of the ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ reaction to excited states of ${}^8\text{Be}$ are in progress. The large analyzing power and cross section of ${}^7\text{Li}(p,\gamma){}^8\text{Be}$ is being utilized to develop and build a polarimeter for low-energy polarized protons. A computer code has been written to extract the energy dependence of the astrophysical S-factor from thick-target gamma ray spectra taken with a large HPGe detector. Measurements for the ${}^6\text{Li}(p,\gamma){}^7\text{Be}$ reaction are beginning during this summer, including the participation of undergraduate student assistants from West Georgia College.