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PROCEEDINGS OF SCIENCE

Low Energy Measurement of the ^{18}F(p,α)^{15}O Cross Section at TRIUMF

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An experiment to measure the ^{18}F(p,α)^{15}O cross section at low centre of mass energies has been performed with the TRIUMF-UK Detector Array (TUDA) facility at TRIUMF.
Measurements of the ^{18}F(p,α)^{15}O reaction rate at four separate centre of mass energies; 665 keV, 430 keV, 330 keV and 250 keV, were carried out. The main goal of the experiment was the measurement of the ^{18}F(p,α)^{15}O cross section between 250 keV and 300 keV to help constrain the contribution to the reaction rate from nearby states and determine the effect of interference on the overall ^{18}F(p,α)^{15}O reaction rate from the proposed low lying 3/2$^+$ states with the higher 664.7 keV 3/2$^+$ state. A high intensity ^{18}F beam ($\sim$5x10^6 pps) was used to bombard a 31.6$\pm$1.9 μg.cm^{-2} polyethylene target within the TUDA scattering chamber at the four centre of mass energies. Four highly segmented silicon strip detector arrays were used for coincident detection of the reaction products. Preliminary results will be presented.

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1. Introduction

The third most violent and most common type of explosion to occur within the galaxy is a classical novae explosion, with output energies of the order of 10^{38} Joules, exceeded in magnitude only by supernovae and X-ray bursts. The thermonuclear runaway at nova temperatures (T= 0.1-0.4 GK) is thought to proceed via the hot carbon-nitrogen-oxygen (HCNO) cycles [1]. The radioactive isotopes synthesised in classical novae vary depending on the novae type which in turn depends on the type of the underlying white dwarf. Current hydrodynamic models show that CNO group nuclei are dominant in the ejecta of novae from carbon-oxygen (CO) white dwarfs, whereas novae occurring on the more massive oxygen-neon (ONe) white dwarfs also predict an enrichment of neon, sodium, aluminium or other medium mass elements [2]. The composition therefore of the ejected mass from a nova explosion contains key information on the type of underlying white dwarf and information on the explosion itself, such as the peak temperature and characteristic time scale [2]. It is hoped that observing gamma rays emitted by novae, further constraints could be placed on input parameters of nova models, such as the isotopic abundances as well as mixing of the core and accreted material, to achieve better predictions of output parameters, such as the ejected mass.

The gamma-ray emission from novae after the first few hours (when the envelope begins to become transparent to radiation) is predicted to be dominated by a 511 keV line and a continuum at lower energies due to comptonisation of the emitted photons. The majority of this photon emission is caused by positron annihilation resulting from the β^+ decay of the ^{18}F (τ = 158 mins) nuclei. Synthesis of ^{18}F in novae is thought to be mainly through the ^{16}O(p,γ)^{17}F reaction followed either by the ^{17}F(p,γ)^{18}Ne(β^+)^{18}F or the ^{17}F(β^+)^{17}O(p,γ)^{18}F reactions [3]. The rate of the ^{17}O(p,γ)^{18}F reaction has been measured recently and the uncertainty in its value is fairly well constrained [4]. The major uncertainty in the final abundance of ^{18}F, therefore, comes from its destruction. At nova temperatures the majority of the ^{18}F is destroyed in the ^{18}F(p,α)^{15}O reaction and to a lesser extent the ^{18}F(p,γ)^{19}Ne reaction. The combined effect of the uncertainties in the two reaction rates that destroy ^{18}F correspond to significant uncertainties in the expected ^{18}F abundances in the ejected material from nova, up to a factor of $\sim$10 variation in ^{18}F abundance. The ^{18}F contributes directly to the expected emitted photon fluxes and this places an upper limit on the maximum detection distances of novae [3]. Therefore a measurement of the ^{18}F(p,α)^{15}O reaction rate at nova temperatures to constrain nova models and predict detectability distances would be timely.

2. Experimental Method

A direct measurement of the ^{18}F(p,α)^{15}O reaction in inverse kinematics has been performed at four different centre of mass energies in the range E_{cm} = 250-665 keV. The experiment was performed at the ISAC I, TUDA facility [5], at the TRIUMF Laboratory, Vancouver, Canada.

Production of the ^{18}F radioactive beam was achieved using the ISOL method. An accelerated 500 MeV beam of protons from the main cyclotron were directed onto a high power silicon carbide target to produce the ^{18}F, which was then extracted and ionised using a FEBIAD ion source. The extracted beam was further accelerated to a pre-separator and then the mass separator where the ^{18}F and isobaric elements were selected. From here the beam was post accelerated to the TUDA experiment.

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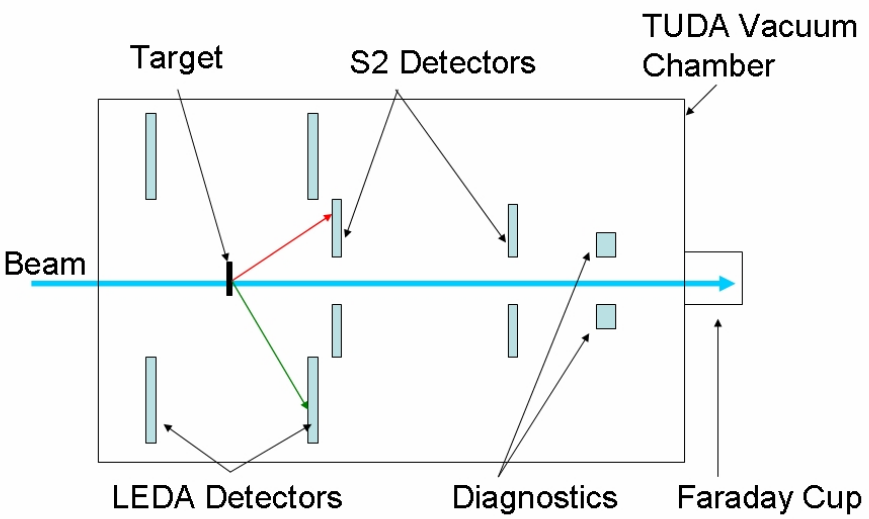

Figure 1: The experimental arrangement used for the ^{18}F(p,α)^{15}O reaction measurement.

A strong beam contamination of ^{18}O was found to exist in varying magnitudes throughout the experiment. To determine the amount of ^{18}F present in the beam, the beam purity was monitored downstream of the target location by measuring the scattered ^{18}F and ^{18}O beam particles from carbon in the target. The measurement of the scattered beam particles was achieved using a DE-E monolithic detector and a 2μm aluminium shielded silicon photodiode, positioned between 2-3 degrees above and below the beam axis respectively. This method also provided an additional measurement of the beam intensity.

An average 8x10^6 ions per second of ^{18}F and ^{18}O were delivered onto a 31.6$\pm$1.9μg.cm^{-2} polyethylene $(CH_2)_n$ target, with an average ^{18}F beam content of 60%. The products of the ^{18}F(p,α)^{15}O reaction were detected in coincidence using an array of two Micron LEDA type silicon strip detectors [6] and two Micron S2 double sided silicon strip detectors [7]. The positions of the detectors within the TUDA scattering chamber were determined using Monte Carlo simulations to achieve optimum coincidence efficiency between the reaction products for the E_{cm}= 250 keV measurement. The S2 detectors were used to detect the ^{15}O nuclei, which were emitted in a forward cone out to a maximum of 26 degrees at the E_{cm}= 250 keV reaction energy. The S2s and were positioned at 63 mm (S2_2) and 165 mm (S2_1) downstream of the target covering the lab angles between 3.8 and 29.0 degrees. The positions of the LEDA detectors were such that one was placed upstream of the target covering lab angles of 120 to 146 degrees (LEDA_2), the other LEDA detector (LEDA_1)was positioned 50 mm downstream of the target, covering lab angles between 45 and 69 degrees, see figure 1. for a schematic representation of the experimental arrangement.

The data was recorded in an event-by-event mode, allowing an offline analysis of both the single and coincidence events. Energy calibration of the detectors was performed using a triple alpha source (^{239}Pu, ^{241}Am and ^{244}Cm). Time of flight data were obtained from the hardware, zero-times were aligned using a precision pulse generator.

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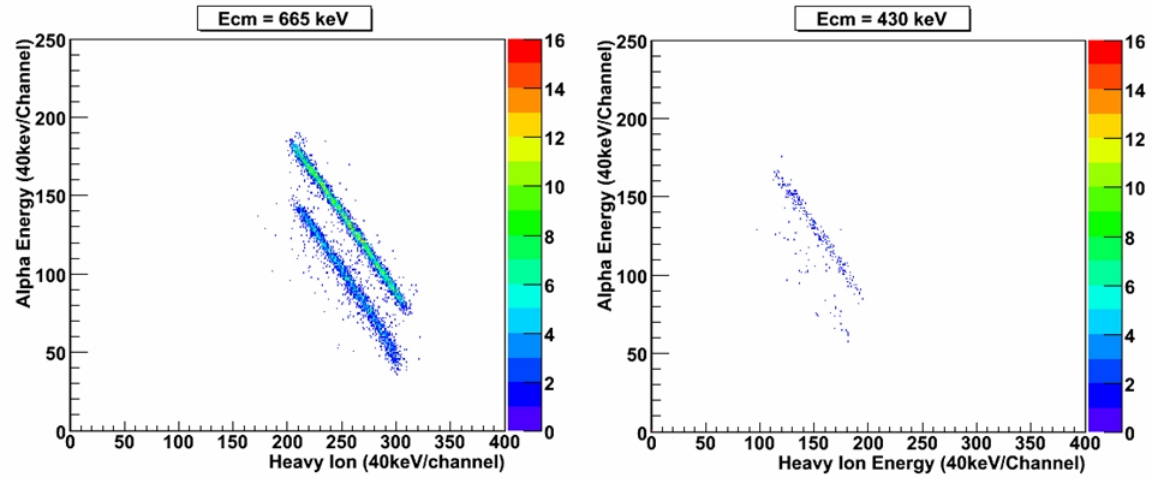

Figure 2: Cleaned Energy vs Energy Spectra for E_{cm} = 665 keV and 430 keV.

3. Results and Discussions

Preliminary results have been obtained for two of the centre of mass energies measured, E_{cm} = 665 keV and E_{cm} = 430 keV. To obtain coincident α particle yields for the ^{18}F and ^{18}O (p,α) reactions, energy vs energy coincidence spectra between LEDA_1 and S2_2 were used. The E_{cm} = 665 keV and 430 keV energy vs energy coincidence data were cleaned using several conditions; sum energy, coplanarity (dϕ), timing (dt), and α particle kinematics. Due to the difference in Q-value between the ^{18}F(p,α)^{15}O and the ^{18}O(p,α)^{15}N reactions (2.882 MeV compared to 3.981 MeV respectively), the coincident α particles and heavy ions produce easily distinguishable loci in the energy vs energy spectra. The locus for the ^{18}F(p,α)^{15}O reaction is lower in energy than the ^{18}O(p,α)^{15}N due to the lower reaction Q-value. Figure 2 shows the clean energy vs energy coincidence spectra between LEDA_1 and S2_2 for the E_{cm} = 665 keV and 430 keV measurements.

Differential cross sections were determined using a ratio calculation, equation 3.1. The value used for the ^{18}O(p,α)^{15}N differential cross section at the E_{cm} = 665 keV measurement was 20$\pm$3 mb/sr [8], for the E_{cm} = 430 keV measurement, an average ^{18}O(p,α)^{15}N differential cross section of 0.75$\pm$0.3 mb/sr [9] was used.

$$\left[\frac{d\sigma}{d\Omega}\right]_{^{18}F} = \frac{Y(E)_{^{18}F}}{Y(E)_{^{18}O}} \frac{I_{^{18}O}}{I_{^{18}F}} \left[\frac{d\sigma}{d\Omega}\right]_{^{18}O} \tag{3.1}$$

Where Y(E) is the yield of α particles in coincidence with the corresponding heavy ion and I is the beam intensity. The ratio $I_{^{18}O}/ I_{^{18}F}$ for each run was determined from the measurements made by the monolithic and photodiode diagnostics. It was found that the fraction of ^{18}O contamination in the beam decreased significantly during extended periods of beam use. During the E_{cm} = 330 keV and 250 keV measurements, there were runs where the beam content was recorded to be more than 85% ^{18}F, with beam intensities of 8x10^6 ions per second.

A preliminary value for the differential cross section of the ^{18}F E_{cm}=665 keV resonance has been calculated to be 34.2 $\pm$6.8 mb/sr. This value is within error of a previous measurement of

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42.6 $\pm$ 2.4 mb/sr, performed using a 35$\pm$4 μg.cm^{-2} CH_2 target by Bardayan et al. [8].

The ^{18}F total cross section for the E_{cm}=430 keV measurement was calculated to be 1.0$\pm$0.9 mb assuming an isotropic distribution in the centre of mass. The motivation for the E_{cm}=430 keV cross section measurement was to determine whether a predicted $J^{\pi} = 3/2^{-}$ resonance exists in the compound ^{19}Ne nucleus. Currently, it is not clear whether the resonance at E_{cm}=430 keV exists from comparison of the preliminary cross section from this work with work done by N. de Séréville [10], and a more rigorous analysis of the data is currently being pursued.

Yields at the lower energy measurements of E_{cm} = 330 keV and 250 keV have been observed. The analysis of the data for these lower energy ^{18}F(p,α)^{15}O measurements is ongoing.

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