Vol. 40 (2009) ACTA PHYSICA POLONICA B No 3

MEASUREMENT OF THE 330 keV RESONANCE IN $^{18}F(p,\alpha)^{15}O$*

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(Received October 30, 2008)

While recent measurements have substantially improved our understanding of the $^{18}F(p,\alpha)^{15}O$ reaction that is important in novae, the production of ^{18}F is still uncertain by more than 2 orders of magnitude, due in large part to the contribution of a resonance located at $E_{\rm cm} = 330$ keV. We developed a new technique to study resonant (p,α) reactions and employed it to measure properties of the $E_{\rm cm} = 183$ keV resonance in $^{17}O(p,\alpha)^{14}N$ which had been previously reported to decrease ^{18}F production in ONeMg novae by as much as a factor of 10. The previous results were confirmed using the new technique and we now propose to use this technique to study the $^{18}F(p,\alpha)^{15}O$ reaction.

PACS numbers: 26.50.–k, 25.70.Ef, 26.20.Cd, 27.20.+n

1. Introduction

To model the nucleosynthesis in novae, the accurate determination of reaction rates is required. Of particular importance are the reactions which lead to the production and destruction of ^{18}F, whose β-decay is believed to be the most important source of 511 keV γ-ray emission after the initial nova envelop becomes transparent and thus this decay has become a target of γ-ray astronomy [1, 2].

* Presented at the Zakopane Conference on Nuclear Physics, September 1–7, 2008, Zakopane, Poland.

Three direct studies of the $^{18}F(p,\alpha)^{15}O$ reaction cross section have been conducted at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory thus far. The combined results from these measurements are shown in Fig. 1. In the first measurement, the properties of a resonance at $E_{\rm cm} = 665$ keV were accurately measured [3]. In the second, the strength of what may be the single most important resonance $(3/2^-)$ for novae at $E_{\rm cm} = 330$ keV was measured with about 30% precision [4]. The most recent measurements at energies above the 665 keV resonance set the first constraints on the sign of interference between the $3/2^-$ states in the region [5]. These measurements represent great progress in our understanding of novae and resulted in the reduction of the uncertainties in ^{18}F production between 1 and 2 orders of magnitude. However, large uncertainties still remain in the $^{18}F(p,\alpha)^{15}O$ reaction rate due to uncertain properties of a narrow resonance near 330 keV.

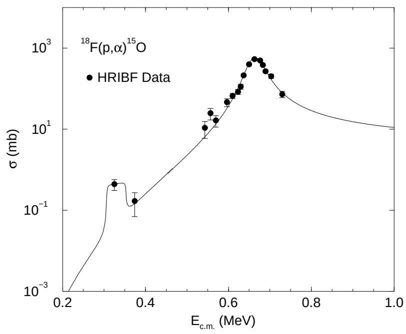

Fig. 1. Previous work done at the HRIBF on the $^{18}F(p,\alpha)^{15}O$ reaction [3–5].

All the previous studies mentioned used CH_2 targets, which are not ideal for narrow resonances where the energy loss in the target is much larger than the resonance width. The total width of the 330 keV resonance is believed to be about 3 keV (CM) [4], much smaller than thinnest CH_2 targets which typically produce 50 keV energy loss (CM) or more. Another problem with the use of CH_2 targets is that they reduce the resonance yield by about a factor of 3 for a given thickness due to inactive carbon atoms in the target.

To study low energy resonant (p,α) reactions, we developed a new technique which involved filling a large scattering chamber with hydrogen gas at pressures of up to 4 Torr [6]. An advantage of this technique is that the pure nature of target maximizes the yield from narrow resonances. Since the target stoichiometry is well known, uncertainties that are encountered by using mixed targets are decreased. The target areal density can also be adjusted to match the expected resonance width by adjusting the pressure inside the chamber. Using this technique, we are able to achieve increased sensitivity to narrow resonances over that of CH_2 targets.

2. Experimental setup

A schematic illustration of the experimental setup is shown in Fig. 2. A heavy ion beam bombards a differentially pumped scattering chamber filled with hydrogen gas. The alpha particles and heavy recoil particles are detected in coincidence by an array of silicon strip detectors located inside the scattering chamber. The SIDAR silicon array has an inner(outer) radius of 50 mm (130 mm) and is segmented into 8 wedges of 16 strips [3], providing a large solid angle for the detection of alpha particles. Heavy recoils pass through the center of the SIDAR array and are detected by an annular type S1 detector with an inner (outer) radius of 24 mm (48 mm).

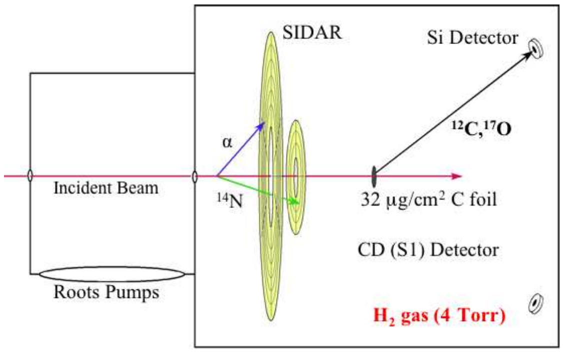

Fig. 2. Schematic of the experimental setup for the ^{18}F$(p,\alpha)^{15}$O and ^{17}O$(p,\alpha)^{14}$N studies.

Unreacted beam passes through the centers of both detectors and scatters from a 32 μg/cm^2 carbon foil. Scattered carbon is detected by two surface barrier monitor detectors at $\theta_{\rm lab} \approx 33^\circ$ and used to determine the number of incident beam particles for normalization. Since the incoming beam for the ^{18}F$(p,\alpha)^{15}$O study will be comprised of a mixture of radioactive ^{18}F and stable ^{18}O, an ion counter will be placed after the scattering chamber in order to determine beam composition.

We demonstrated this technique on a measurement of the 183 keV resonance in ^{17}O$(p,\alpha)^{14}$N that was previously shown to decrease ^{18}F production by up to a factor of 10 in ONeMg novae [6,7]. Typical beam intensities were $\approx 10^9$ ^{17}O/s. The ^{1}H(^{17}O,α)^{14}N reaction was identified from plots of the energy of particles detected by the S1 detector *versus* the energy of particles detected by SIDAR for events coincident within 0.4 μs. Shown in Fig. 3 are data taken at bombarding energies of $E(^{17}\mathrm{O})$ = 3.29 MeV (off resonance) and $E(^{17}\mathrm{O})$ = 3.27 MeV (on resonance). Events from the ^{1}H(^{17}O,α)^{14}N reaction are distinguished by a straight line with a constant sum energy indicative of the reaction Q-value.

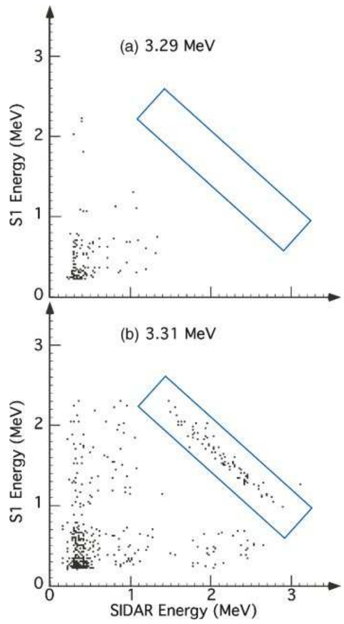

Fig. 3. Energy of the particles detected in the S1 detector plotted against the energy of coincident particles in the SIDAR detector. The box indicates where the (p,α) events fall.

The energy of each detected alpha particle defines a unique reaction angle and can be used in conjunction with the segmentation of the SIDAR array to determine the distance from the reaction vertex to the plane of SIDAR. In Fig. 4 we plot the reaction yield as a function of the distance from the

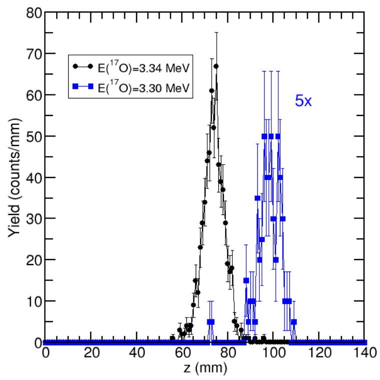

Fig. 4. The distribution of ^{1}H(^{17}O,α)^{14}N events as a function of the distance (z) from the plane of SIDAR (mm) at a pressure of 4 Torr. The 3.30 MeV yield has been multiplied by a factor of 5 for purposes of comparison.

reaction vertex to the plane of SIDAR for two comparable beam intensities. The ^{1}H(^{17}O,α)^{14}N events originate from a narrow range inside the chamber, indicating the yield is due to a narrow resonance.

3. Results and conclusions

Our results for the 183 keV resonance energy and strength ($E_{\rm r} = 183.5^{+0.1}_{-0.4}$ keV and $\omega\gamma_{p\alpha} = 1.70 \pm 0.15$ meV) are in good agreement with those reported by Chafa *et al.* ($E_{\rm r} = 183.2 \pm 0.6$ keV and $\omega\gamma_{p\alpha} = 1.6 \pm 0.2$ meV). This new technique has been shown to be a valuable method for studying narrow resonant (p,α) reactions. We now propose to use this technique to measure properties of the 330 keV resonance in the ^{18}F$(p,\alpha)^{15}$O reaction.

This work was supported in part by the U.S. Department of Energy under the contract numbers DE-FG03-93-ER40789 (UTK), DE-FG02-96ER40978 (LSU), DE-AC05-00OR2272 (ORNL), DE-FG52-03NA00143 (Rutgers, ORAU), DE-FG02-96ER40955 (TTU), DE-FG02-96ER40990 (TTU), DE-FG03-93ER40789 (Mines); the National Science Foundation; and the LDRD program of ORNL.

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