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Determination of the Stellar Reaction Rates of ^{17}O(α,n)^{20}Ne and ^{17}O(α,γ)^{21}Ne

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A. Best*
University of Notre Dame
E-mail: abest1@nd.edu

J. Görres
University of Notre Dame
E-mail: jgoerres@nd.edu

M. Wiescher
University of Notre Dame
E-mail: Michael.C.Wiescher.1@nd.edu

S. Falahat
Johannes Gutenberg Universität Mainz
E-mail: s.falahat@mpic.de

K.-L. Kratz
Johannes Gutenberg Universität Mainz
E-mail: klkratz@uni-mainz.de

The reaction ^{16}O(n, γ)^{17}O acts as a neutron poison in the weak s process by reducing the number of available neutrons in the stellar burning environment. The captured neutrons can be re-emitted into the stellar environment by the reaction ^{17}O(α,n)^{20}Ne, weakening the poisoning effect of ^{16}O. This branch competes with the reaction ^{17}O(α,γ)^{21}Ne. In order to determine the strength of ^{16}O as a neutron poison one needs to know the ratio of the stellar reaction rates of both channels. Both reactions have been recently measured at the Nuclear Science Laboratory of the University of Notre Dame and preliminary results are presented.

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*Speaker.

1. Introduction

The efficiency of ^{16}O as a neutron poison in the weak s process depends strongly on the ratio of the reaction rates of the reactions ^{17}O(α,n)^{20}Ne and ^{17}O(α,γ)^{21}Ne [1, 2]. At the moment there exist two estimates for the reaction rate of the ^{17}O(α,γ)^{21}Ne channel [3, 4]. They differ by up to five orders of magnitude, which has a large impact on the outcome of s process calculations: A very low rate for the ^{17}O(α,γ)^{21}Ne reaction results in full recycling of the neutrons that were originally captured by ^{16}O(n, γ)^{17}O, thereby neutralising the poisoning effect of ^{16}O.

The ^{17}O(α,n)^{20}Ne channel has been measured previously [5, 6, 7] in the energy range 1 - 12.5 MeV. No experimental data exist on the ^{17}O(α,γ)^{21}Ne reaction. The lower energy measurements of the neutron channel were done using a mixture of ^{17}O and ^{18}O in the target material, resulting in a large contribution to the detected neutrons from the strong ^{18}O(α,n)^{21}Ne reaction. The subtraction of this contribution and some uncertainty in the efficiency of the used ^{3}He detector leads to the lower energy data being less reliable than desired. In order to overcome these uncertainties both reactions have been measured using the KN Van de Graaf accelerator at the University of Notre Dame Nuclear Science Laboratory.

2. Experimental Setup

2.1 Target preparation

Using highly enriched (90.1%) $H_2{}^{17}O$ water[1] a batch of similarly thick targets were produced by the anodization of 0.3 mm thick tantalum backings. This process is well studied and known to reliably yield homogeneous Ta_2O_5 films of reproducible thickness [8, 9]. A constant current power supply was connected to a water reservoir filled with the enriched water and to the back side of a tantalum backing. The voltage drop across the setup is proportional to the thickness of the anodized film and the power supply automatically reduced the current to zero when a preset voltage (e.g. 9.5-9.8 V) was reached. This resulted in a target thickness of 7 keV at an α-energy of 1.35 MeV.

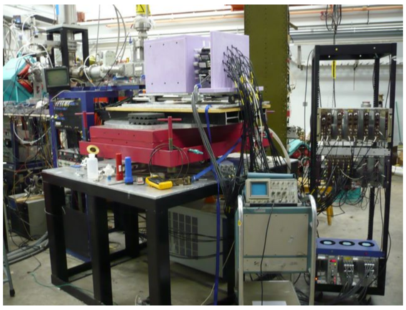

Figure 1: Experimental setup of the ^{17}O(α,n)^{20}Ne measurement. The beam is coming from the left. Surrounding the target is a polyethylene block with 20 ^{3}He counters in two concentric rings around the beamline.

[1]Purchased from isotech, Miamisburg, OH

2.2 Neutron measurements

The ^{17}O(α,n)^{20}Ne reaction was measured using a polyethylene moderated neutron detector. It consists of 20 ^{3}He proportional counters which are arranged in two concentric rings around the beamline. In order to reduce signals from natural neutron background the detector is shielded by a 2 in thick layer of borated polyethylene. The detector is characterised in [10], including efficiency measurements, Geant4 and MCNP simulations. The counting efficiency for neutrons below 1 MeV is found to be 45%.

2.3 Gamma measurements

Figure 2: Setup used for the ^{17}O(α,γ)^{21}Ne measurement.

A single germanium detector with $\sim$ 55% relative efficiency was placed at an angle of 45 degrees with respect to the beam. Detector and end piece of the beamline were surrounded by at least 4.5 cm of lead on all sides. In order to reduce neutron damage to the detector and the background from neutron induced signals a 1.94 cm thick polyethylene disk was placed between target holder and front cap of the detector. This setup was also used to measure an excitation curve of ^{18}O(α,n$_1$)^{21}Ne in order to understand the background due to a small ^{18}O contamination of the targets. The ^{17}O(α,n$_1\gamma$)^{20}Ne channel was measured using a smaller germanium detector with $\sim$ 20% relative efficiency and no lead shielding.

The efficiency of the detectors was determined using calibrated sources (^{133}Ba, ^{137}Cs and ^{60}Co) and with the well-known E_p = 992 keV resonance in ^{27}Al(p,γ)^{28}Si [11].

3. Results

Yield curves of the ^{17}O(α,n)^{20}Ne and ^{17}O(α,n$_1$)^{20}Ne reactions are shown in fig. 3. Above the n$_1$ threshold at $E_\alpha = 1.3$ MeV the (α,n) yield consists of a mixture of neutrons with two different energies. As the detection efficiency depends on the energy of the incident neutrons we independently measured the (α,n$_1$) channel to more reliably determine the efficiency of the setup. The line through the (α,n$_1$) data points is the result of a calculation with the R-Matrix code AZURE [12]. Target integration routines were implemented into the code in order to directly fit the experimental yield.

Fig. 4 shows an excitation curve of the ^{17}O(α,γ)^{21}Ne reaction. It was generated by looking at the dominant 351 keV transition to the ground state of ^{21}Ne. Resonances were found at

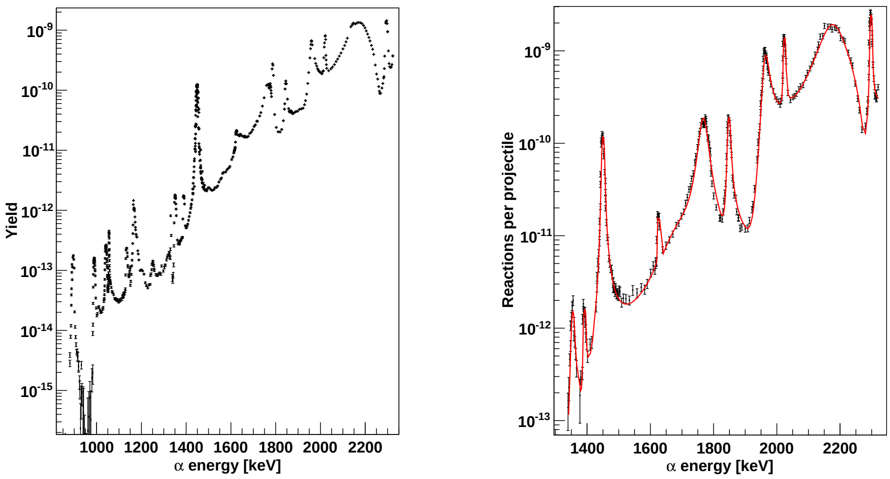

Figure 3: Yield of the reactions ^{17}O(α,n)^{20}Ne (left) and ^{17}O(α,n$_1$)^{20}Ne (right). The line through the n$_1$ data represents an R-Matrix fit with the code AZURE.

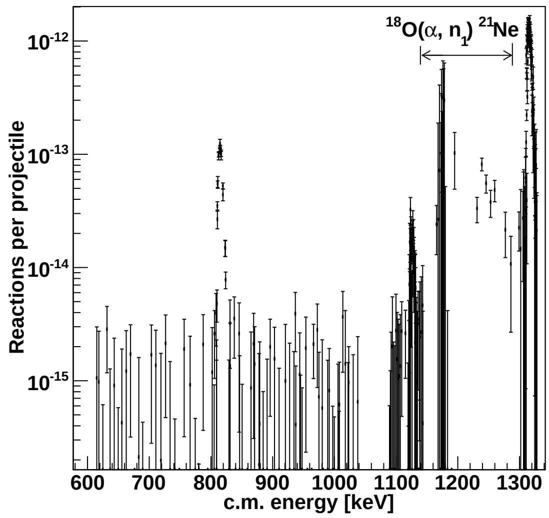

Figure 4: Excitation curve of ^{17}O(α,γ)^{21}Ne using the 351keV $\rightarrow$ g.s. transition in ^{21}Ne. As this state is also populated through the strong ^{18}O(α,n$_1$)^{21}Ne reaction, there is a contribution to the measured yield due to the small ^{18}O contamination of the targets. The high yield region above 1450 keV corresponds to a strong resonance in ^{18}O(α,n$_1$)^{21}Ne.

the energies $E_\alpha = 1001$, 1386 and 1619 keV. The high yield above 1450 keV is due to the reaction ^{18}O(α,n$_1$)^{21}Ne. Analysis is in progress to determine the γ-branching ratios and the absolute resonance strengths of these newly detected resonances.

In order to extend the (α,n) measurements to lower energies significant reduction of the beam-induced background, mainly due to the reaction ^{13}C(α, n)^{16}O needs to be achieved. The γ measurements will be continued using a new setup consisting of an array of 5 high efficiency germanium

detectors (GEORGINA).

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