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Activation measurement of the ^{19}F$(n,\gamma)^{20}$F cross section at kT=25 keV

Ethan Uberseder[*][†]**, Michael Heil, and Franz Käppeler**
Forschungszentrum Karlsruhe, Institut für Kernphysik, 76021 Karlsruhe, Germany

Joachim Görres and Michael Wiescher
University of Notre Dame, Department of Physics, Notre Dame, IN 46556, USA

Much progress has been made in the study of the production and destruction mechanisms of ^{19}F. Recent model simulations indicate that the ^{19}F$(n,\gamma)^{20}$F reaction could be the primary destruction channel for fluorine during the thermal pulses of AGB stars, therefore an accurate determination of the neutron capture cross section is of great importance. An activation measurement of the neutron capture cross section of ^{19}F has been performed at a stellar temperature of $kT = 25$ keV using the Karlsruhe 3.7 MV Van de Graaff accelerator. The short half life of ^{20}F ($t_{1/2} = 11$ s) required the employment of the fast cyclic activation technique. A preliminary analysis indicates a significantly lower neutron capture cross section at $kT = 25$ keV than is suggested in the current literature. The new mesurement also greatly reduces the quoted uncerainty of 20%.

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[*]Speaker.
[†]Email: Ethan.Uberseder.1@nd.edu

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1. Introduction

The possible contribution of asymptotic giant branch (AGB) stars to the origin of fluorine has been a topic of much interest in astrophysics since the observation of a ^{19}F overabundance on the surfaces of these objects [1]. A reaction sequence was proposed to operate within the He intershell of thermally pulsing asymptotic giant branch (AGB) stars, when ^{14}N acts as a proton source via ^{14}N$(n,p)^{14}$C. ^{18}O is also created in these zones via ^{14}C(α,γ) and ^{14}N$(\alpha,\gamma)^{18}$F$(\beta^+\nu)$, and uses the liberated protons to form ^{15}N which is then processed through α-capture to produce ^{19}F [2]. The destruction of fluorine can occur via ^{19}F(α,p), though this reaction rate has been reduced by recent measurements [3]. The neutrons that are required to initiate the reaction chain producing ^{19}F can also act to destroy fluorine. Thus, an accurate neutron capture cross section is needed at thermal energies relating to the the He intershell of AGBs. In the current literature [4], the value of the Maxwellian averaged cross section (MACS) at $kT = 30$ keV is uncertain by 20%, far too great for reliable use in stellar models. This work aims to quantify the MACS at $kT = 25$ keV, a thermal energy closely corresponding to the temperature of the He flash in AGB stars, with a great reduction in uncertainty.

2. Experiment

The activation technique is known for its accuracy and sensitivity [5]. The present series of measurement utilised the cyclic activation technique, applicable when the half life of the product nucleus is very short as in the case of ^{20}F ($t_{1/2} \sim 11$ s) [6]. Disks of CF_2, SrF_2, and NaF, 10 mm in diameter, were exposed to a $kT = 25$ keV thermal neutron spectrum created via the ^{7}Li(p,n) reaction at $E_p = 1911$ keV. In this reaction, the neutrons are kinetimatically collimated to form a cone with an opening angle of 120 degrees. Angular integration over the cone yields the energy spectrum shown in Fig. 1. For the cyclic activation, a HPGe detector was placed adjacent to

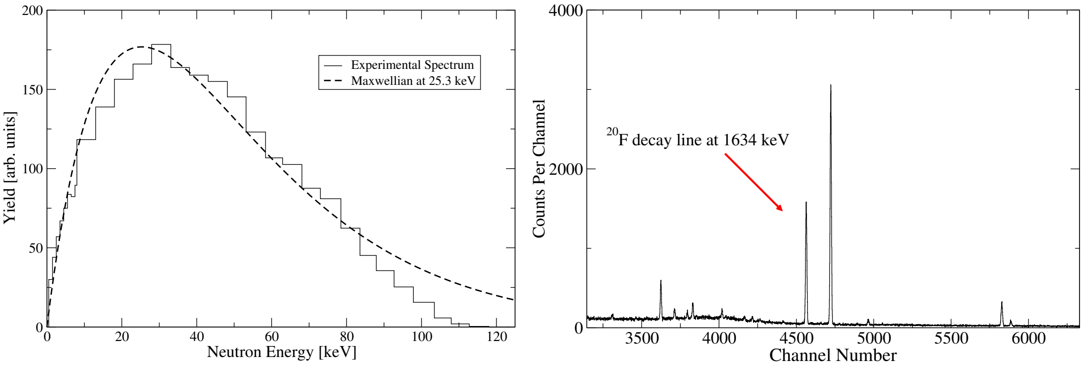

Figure 1: Left: Experimental neutron spectrum show in comparison with a $kT = 25$ keV Maxwell-Boltzmann distribution. Right: Sample γ spectrum obtained from the HPGe detector during a cyclic irradiation. The 1634 keV decay line is indicated. The significant line appearing to the right results from the decay of ^{124}Sb produced in the lead shield.

the neutron production target, and the sample was transported between the two positions by means

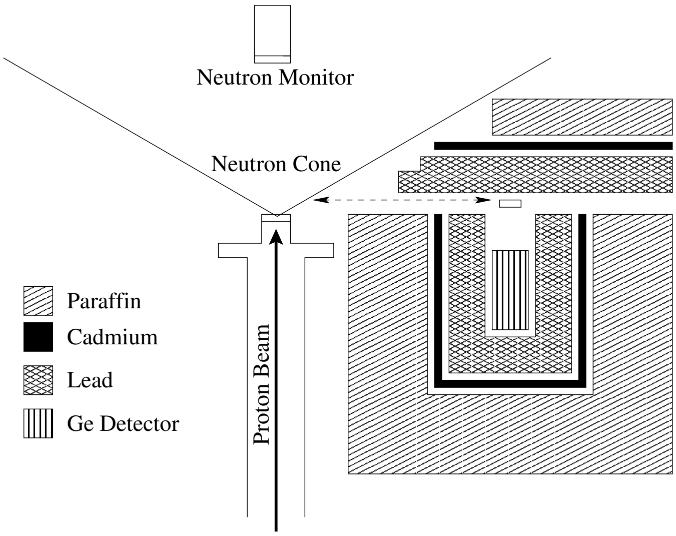

Figure 2: Cyclic activation setup used in the ^{19}F$(n,\gamma)^{20}$F cross section measurement.

of a pneumatic slide. Samples were irradiated and counted for equal time intervals of 30 s. The experimental setup is sketched in Fig. 2. To reduce neutron damage and background events, the detector was surrounded by a thick paraffin shield lined on the inner side with cadmium sheets. Within the shield a 5 cm lead layer was placed to reduce the γ background from activated materials in the experimental hall. In addition, irradiations done without the presence of a fluorine sample showed no evidence of ambient fluorine background. During the irradiation phase, the data acquisition system was gated to prevent the registration of prompt gamma background produced in the Li target. For the same purpose, the incident proton beam was blocked with a beamstop during the counting phase. A sample γ spectrum obtained from a cyclic fluorine activation is shown in Fig. 1. The 1634 keV decay line of ^{20}F was used in the analysis, and can be seen appearing prominently above background.

3. Analysis

The induced activity in the sample, A, can be written as a function of the cross section (σ), the number of nuclei in the sample expressed in atoms/barn (N), the time integrated neutron flux (Φ_T), and a correction factor [$f_b = \frac{1}{t_b\lambda}(1-exp(-\lambda t_b)$] for the decay of the product nuclei during irradiation as a function of irradiation time, t_b:

$$A = \sigma N \Phi_T f_b. \tag{3.1}$$

The quantity Φ_T is determined from the induced activity in two gold foils placed on either side of the sample [7]. Given a sample activity represented by the above formula, the number of counts expected in the HPGe detector can be written as

$$C = A\varepsilon_\gamma K_\gamma I_\gamma exp(-\lambda t_w)[1-exp(-\lambda t_m)], \tag{3.2}$$

where ε_γ is the detector photopeak efficiency, K_γ is a correction for self absorption of the photon in the sample, I_γ is the absolute intensity per decay of the given line, t_w is the time elapsed between the end of irradiation and the beginning of counting, and t_m is the counting time. As this formula describes the counts accumulated in one cycle, it must be slightly adapted for use in the case of a cyclic activation. The counts registered in the detector after n cycles can be given by

$$\begin{aligned}\sum_{i=1}^{n} C_i &= \frac{\sigma N \varepsilon_\gamma K_\gamma I_\gamma e^{-\lambda t_w}(1-e^{-\lambda t_m})(1-e^{-\lambda t_b})}{\lambda t_b (1-e^{-\lambda t_c})} \sum_{i=1}^{n} \Phi_T^i (1-e^{-\lambda(n-i+1)t_c}) \\ &= \frac{\sigma N \varepsilon_\gamma K_\gamma I_\gamma e^{-\lambda t_w}(1-e^{-\lambda t_m})(1-e^{-\lambda t_b})}{\lambda t_b (1-e^{-\lambda t_c})} (1-f_c e^{-\lambda t_c}) \Phi_T, \end{aligned} \tag{3.3}$$

where,

$$f_c = \frac{\sum_{i=1}^{n} \Phi_T^i e^{-\lambda(n-i)t_c}}{\sum_{i=1}^{n} \Phi_T^i}.$$

The complexity of this equation arises from its ability to correct for the activity present during each counting phase remaining from successive irradiation intervals. This equation also makes the assumption that the variation in neutron flux is relatively low over the irradiation time. For the present series of measurements, with an irradiation time of 30 s, this assumption is valid. For use in an astrophysical context, the cross section must be given in terms of the MACS. While the experimental spectrum closely simulates a Maxwell-Boltzmann distribution at $kT = 25$ keV, a minor correction for the deviation must be applied. This was done by first normalising the energy dependent cross section data given in JEFF, JENDL, and ENDF/B to reproduce the experimental cross section when folded with the experimental neutron spectrum. This normalised energy dependent cross section was then used to calculate the true MACS at $kT = 25$ keV with the relation

$$\langle\sigma\rangle_{kT} = \frac{\langle\sigma v\rangle}{v_T} = \frac{2}{\sqrt{\pi}} \frac{\int_0^\infty \sigma(E_n) E_n e^{-E_n/kT} dE_n}{\int_0^\infty E_n e^{-E_n/kT} dE_n}, \tag{3.4}$$

and averaged over the three databases.

4. Preliminary Results and Conclusions

The preliminary cross section obtained from the data indicates a decrease in the MACS at $kT = 25$ keV by approximately 44% with respect to the literature [4]. The uncertainty in the measurement is also improved by a factor of six due to the sensitivity of the present experimental technique. Such a significant reduction of the MACS in a thermal neutron distribution relevant to the AGB He flash indicates increased survival of fluorine through this stage of AGB evolution. After dredge-up, fluorine is again in danger of destruction near the base of the convective envelope through proton induced reactions. Recent work has also indicated a lowering in the cross sections relevant to this mechanism [8]. The systematic reduction of cross sections corresponding to destruction mechanisms of fluorine in AGB stars will have a significant impact on the modelled efficiency of these objects for ^{19}F production. A comprehensive reevaluation of AGB fluorine production considering the new cross sections is needed to quantify this effect.

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