Towards an activation cross section measurement of the $^{17}\text{O}(p,\gamma)^{18}\text{F}$ reaction in a wide energy range

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Abstract.

The CNO cycles are fusion processes in stars that convert hydrogen to helium. These hydrogen burning processes occur in several sites and stages of stellar evolution, such as red giants, asymptotic giant branch (AGB) stars, massive stars, and classical novae. One of the important reactions in the CNO-III and CNO-IV cycles is $^{17}\text{O}(p,\gamma)^{18}\text{F}$. The only available total cross section measurement in a wide energy range for this reaction dates back to several decades ago [2] which makes the theoretical extrapolation to astrophysical energies more difficult and introduces uncertainty.

The aim of the present work is to provide precise total cross section data in the energy range between about 500 keV and the 2 MeV using the activation method. The experimental campaign at the new tandemron accelerator of Atomki is in progress.

1. Introduction

The $^{17}\text{O}(p,\gamma)^{18}\text{F}$ reaction competing with the $^{17}\text{O}(p,\alpha)^{14}\text{N}$ process opens the way to the third and fourth CNO cycles of hydrogen burning which take place at elevated temperatures in several different stellar environments. This reaction plays therefore an important role in e.g. the nucleosynthesis of the rare oxygen isotopes and the important radionuclide $^{18}\text{F}$.

In order to provide the precise reaction rate, the low energy cross section of the $^{17}\text{O}(p,\gamma)^{18}\text{F}$ reaction has been measured by several groups recently ([4], and references therein). The only available total cross section data in a wide energy range, however, dates back to several decades ago [2] and the validity of the low energy part of these data was already questioned [5]. The aim of the present work is therefore to measure the cross section of the $^{17}\text{O}(p,\gamma)^{18}\text{F}$ reaction in the energy interval between $E_p=500$ keV and $E_p=2000$ keV.

2. Experimental approach

The reaction cross section is determined using the activation method as the reaction product $^{18}\text{F}$ is radioactive, decays by positron emission which can be measured by detecting the 511 keV annihilation radiation. The activation method provides directly the astrophysically important total cross section independently from the various transitions in the residual nucleus.

The present experiment is the first scientific project to be performed at the new 2 MV tandem accelerator installation in the Atomki institute in Debrecen, Hungary. The proton beam energy
of the new accelerator was thus calibrated first using some of the well known resonances in the
\( ^{27}\text{Al}(p,\gamma)^{28}\text{Si} \) reaction.

The \( \text{Ta}_2\text{O}_5 \) targets were prepared by anodic oxidation of tantalum backings in isotopically
enriched water [6]. To determine the target thickness and stoichiometry, the targets were studied
with the RBS technique, using an alpha beam of 1.6 MeV at the microprobe facility of Atomki. The
target thickness was then calculated using the SIMNRA code to fit the obtained spectra
(see Fig. 1).

Target stability was periodically monitored with \( ^{17}\text{O}(p,\gamma) \) and \( ^{18}\text{O}(p,\gamma) \) resonance scans
detecting the prompt gamma radiations.

For the cross section measurements the targets were irradiated by proton beams of several
\( \mu\)A intensity for a few hours, after which they were transported to a calibrated offline low
background detector for the measurement of the \( ^{18}\text{F} \beta^+ \) decay (Fig. 2).

![RBS Spectrum](image)

**Figure 1.** Measured and simulated RBS spectrum of a \( \text{Ta}_2\text{O}_5 \) target taken at \( E_\alpha = 1.6 \text{ MeV} \)
with the detector at 135°.

### 3. Analysis

The main decay mode of \( ^{18}\text{F} \) is the \( \beta^+ \) emission (96.7%) with half-life of 109.77 minutes. To
track this \( \beta^+ \) decay curve, several 10-minute gamma-spectra were taken to measure the 511
keV annihilation radiation, allowing the calculation of the activity after the activation of the
\( \text{Ta}_2\text{O}_5 \) target.

In Fig. 2 a typical \( ^{18}\text{F} \beta^+ \) decay curve is shown fitted with an exponential decay curve
superimposed on a constant 511 keV background.
4. Status of the experiments and outlook
A few test irradiations were carried out between $E_p = 580$ keV and $E_p = 1800$ keV in order to study the feasibility of the measurement. It is found that the decay of the 511 keV $\gamma$-radiation can be well described by the half-life of $^{18}$F and therefore no disturbing short-lived positron emitter is present in the target.

The analysis of the obtained data as well as the experimental campaign are still in progress and the final results will be given in a forthcoming publication.

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