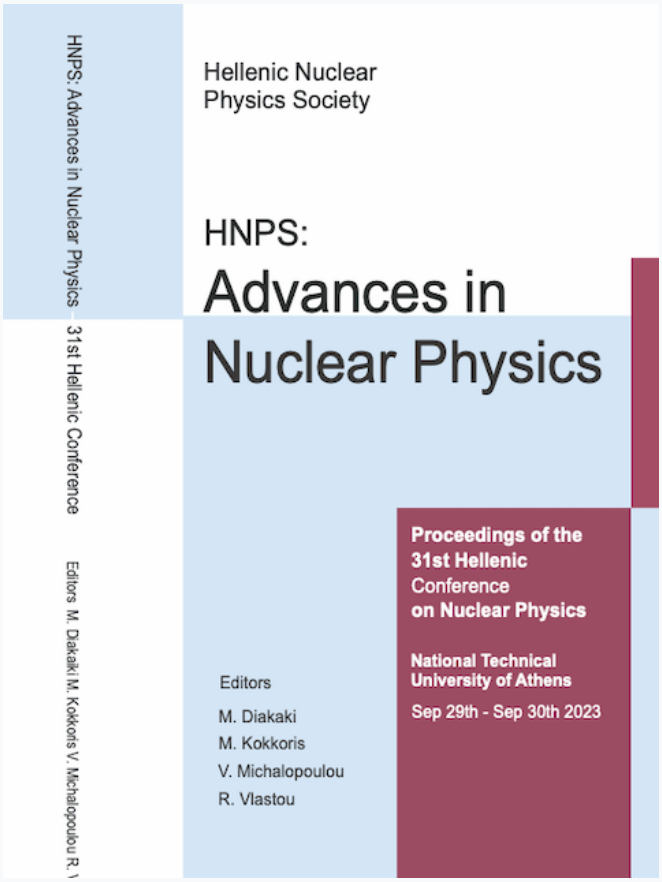
**HNPS Advances in Nuclear Physics**

Vol 30 (2024)

HNPS2023




# Differential cross section measurements of the 18O(p, a0)15N reaction at 170º and 160º, in the energy range Ep=1-2MeV

*A. Kotsovolou, M. Axiotis, A. Karakaxi, M. Kokkoris, A. Lagoyannis, E. Taimpiri, A. Ziagkova*

doi: 10.12681/hnpsanp.6664



**To cite this article:**

Kotsovolou, A., Axiotis, M., Karakaxi, A., Kokkoris, M., Lagoyannis, A., Taimpiri, E., & Ziagkova, A. (2024). Differential cross section measurements of the 18O(p, a0)15N reaction at 170º and 160º, in the energy range Ep=1-2MeV. *HNPS Advances in Nuclear Physics*, *30*, 211–214. https://doi.org/10.12681/hnpsanp.6664

# Differential cross-section measurements of the $^{18}O(p,\alpha_0)^{15}N$ reaction at 170º and 160º, in the energy range $E_p$=1-2 MeV

A. Kotsovolou[1,2], M. Axiotis[2], A. Karakaxi[1], M. Kokkoris[1], A. Lagoyannis[2], E. Taimpiri[1,2], A. Ziagkova[1,2]

[1] *Department of Physics, National Technical University of Athens, Zografou campus, 15780 Athens, Greece*
[2] *Tandem Accelerator Laboratory, Institute of Nuclear Physics, N.C.S.R. "Demokritos", Aghia Paraskevi, 15310 Athens, Greece*

**Abstract** In the present work, the differential cross-sections of the $^{18}O(p,\alpha_0)^{15}N$ reaction were determined using the absolute measurement technique, in the proton energy range $E_p$=1–2 MeV for NRA purposes. The experiment was carried out in energy steps of 10 or 20 keV. Two detection angles, 170° and 160°, were measured, employing 500 μm thick Surface-Barrier-Back-Scattering detectors in a high-precision goniometric chamber. The target, a thin layer of $Ta_2O_5$ highly enriched in $^{18}O$, was deposited on a thick tantalum foil via anodization. Its thickness was provided by the manufacturer and independently verified experimentally using the $^{18}O(d,\alpha_0)$ reaction. SIMNRA simulations were performed to determine the Q•Ω value, incorporating a pile-up calculation routine. The obtained results were compared with previously published data, allowing for a comprehensive analysis of both similarities and discrepancies. The reaction's differential cross-section was determined using the absolute measurement technique. The final results revealed larger cross-section values compared to the existing literature ones. Some of the observed discrepancies were attributed to inaccuracies in the database entries. These coherent differential cross-section datasets are expected to facilitate the extension of the existing SigmaCalc evaluation of the $^{18}O(p,\alpha_0)$ reaction to higher energies in the near future.

**Keywords** IBA, NRA, Differential cross section, $^{18}O$

## INTRODUCTION

Oxygen is Earth's most abundant element, and the third-most abundant element in the universe. Diatomic oxygen gas currently constitutes 20.95% of the Earth's atmosphere, while oxygen makes up almost half of the Earth's crust in the form of oxides. As it is a highly reactive element, it finds various applications in the semiconductor industry, biological systems, solid state electrochemistry and even metallurgy. It is comprised of three natural stable isotopes, namely $^{16}O$ (99.76%), $^{17}O$ (0.04%) and $^{18}O$ (0.2%). The predominance of $^{16}O$, along with the high abundance of natural oxygen in nature, renders $^{18}O$ particularly valuable for isotopic tracing purposes, especially when the diffusion or deep penetration of oxygen in material surfaces needs to be carefully quantified. This procedure can be best monitored using oxygen gas or compounds highly enriched in $^{18}O$.

For the study of $^{18}O$ depth profile concentrations in various matrices Ion Beam Analysis (IBA) techniques have proven to be ideal and particularly Nuclear Reaction Analysis (NRA), mainly based on the $^{18}O(p,\alpha_0)$ reaction. This reaction was among the very first to be studied historically and the pioneer measurement carried out by G. Amsel [1] in 1964 set the ground for the further development and evolution of NRA and all the other related IBA techniques. However, as evidenced in the Ion Beam Analysis Nuclear Data Library (IBANDL) [2], some inconsistencies exist between this initial study and differential cross-section data reported by the same author three years later, in 1967 [3], over a partially overlapping proton beam energy range. These discrepancies currently limit the energy range of the theoretical evaluated datasets that can be obtained via the online SigmaCalc code. In order to address these discrepancies, the differential cross-section of $^{18}O(p,\alpha_0)^{15}N$ reaction was measured using the absolute measurement technique.

## EXPERIMENTAL DETAILS

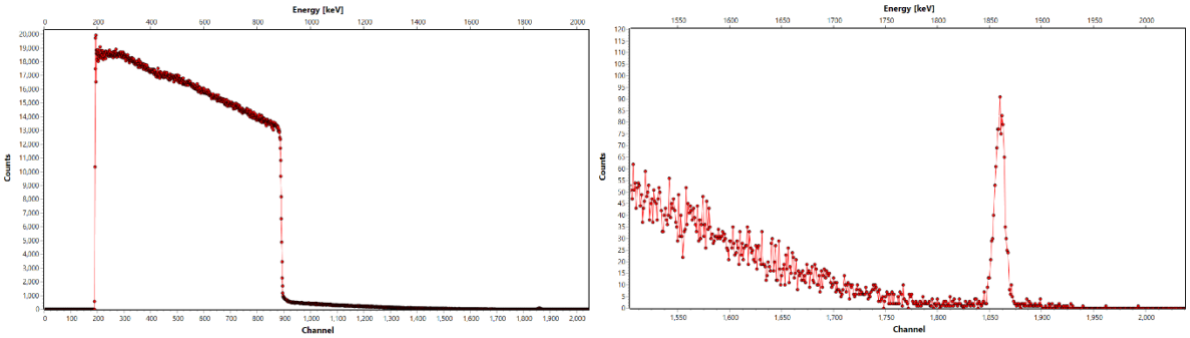
The experiment was carried out at the HV TN-11 5.5 MV Tandem Accelerator of the Institute of Nuclear and Particle Physics (INPP), at the National Center of Scientific Research (NCSR) "Demokritos", in Athens, Greece. The proton beam energy range was $E_p$=1–2 MeV, in energy steps of 10 or 20 keV. The characteristic resonance at $E_p$=991.89±0.1 keV from the $^{27}Al(p,\gamma)^{28}Si$ reaction was employed, determining the energy offset of the beam at 2 keV. The beam intensity did not exceed 100 nA to keep the ADC dead time below 5% and to mainly reduce the pile-up effects due to the thickness of the target. The implemented target consisted of a thin layer of $Ta_2O_5$ highly enriched in $^{18}O$, created on the surface of a thick tantalum foil via controlled, progressive anodization. The thickness of the thin oxidized layer with $^{18}O$ was provided by the manufacturer ($3.26\cdot 10^{17}$ $^{18}O$ at./cm$^2$), and was also checked independently using experimental differential cross-section data of the $^{18}O(d,\alpha_0)$ reaction ($2.207\cdot 10^{17}$ $^{18}O$ at./cm$^2$). The target was mounted in the middle of a high-precision goniometric chamber where two backscattering detection angles, namely 170$^o$ and 160$^o$, were examined using 500 μm thick SSB detectors both placed at distance of 12 cm from the target.

## METHODOLOGY AND DATA ANALYSIS

The determination of the differential cross-section values was accomplished using the absolute-measurement technique and the following well-known formula [4]:

$$\left(\frac{d\sigma}{d\Omega}\right)_{E,\theta} = \frac{Y(E,\Theta)}{Q\cdot\Omega\cdot N_t}$$

where, Y(E,θ) corresponds to the experimental yield determined by integrating the (p,$a_0$) peak at each spectrum using the SPECTRW code [5] with an average statistical error of 3%, Q•Ω corresponds to the charge multiplied by the solid angle and $N_t$ corresponds to the number of atoms in the target (layer thickness).




*(a)* *(b)*

**Figure 1**. *Typical spectrum of the $^{18}O(p,\alpha_0)^{15}N$ reaction at 170$^o$. In (a) it is shown in full scale, where only the heavy Ta backing is visible. By zooming- in in (b), the analysis of the a-peak, is possible.*

Due to the absence of an ultra-thin, self-supporting target for the differential cross-section measurements, a gold-coated aluminum chopper was set in the entrance of the high-precision goniometric chamber, in order to facilitate the accurate determination of the Q•Ω product.. Additionally, SIMNRA simulations using the incorporated-in-the-code analytical pile-up calculation routine were performed for the same purpose, aiming at reproducing the proton elastic-backscattering spectrum of the thick Ta backing, offering more reliable results.

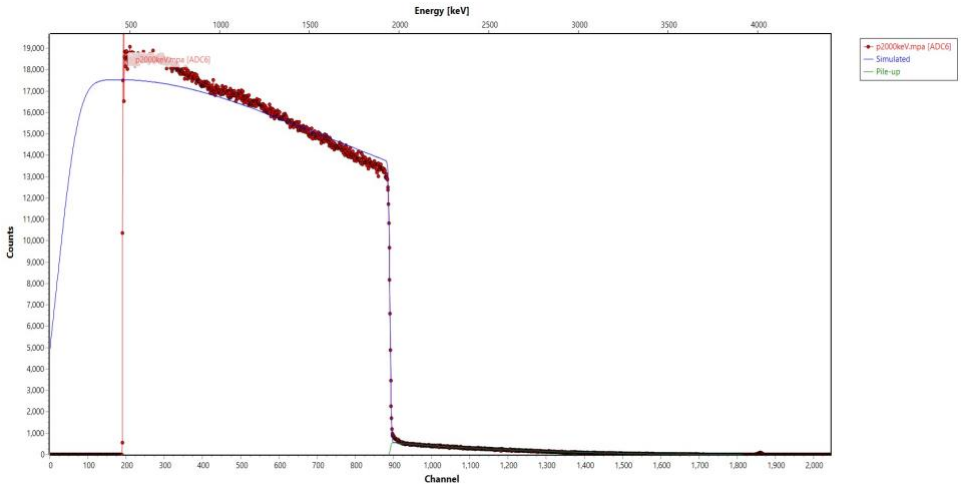



**Figure 2**. *Example of SIMNRA simulation, including experimental data (red line), basic target-simulation (blue line) and pile-up calculations (green line), for the 2 MeV spectrum*

## RESULTS AND DISCUSSION

According to the methodology discussed above, the following results occurred as shown in Figs. 3 and 4.

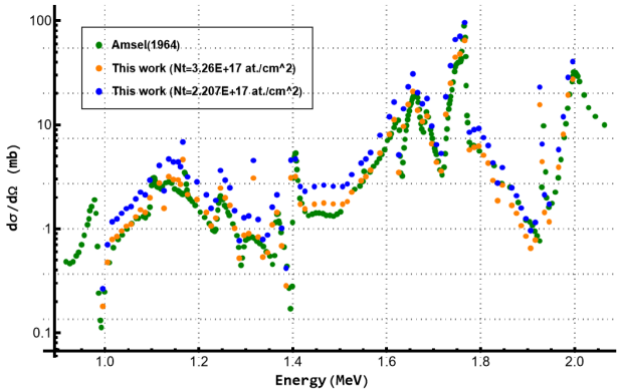



**Figure 3**. *Differential cross-sections of the $^{18}O(p,\alpha_0)^{15}N$ reaction at 170°. Comparative illustration with Amsel's (1964) [1] measurement (green).*

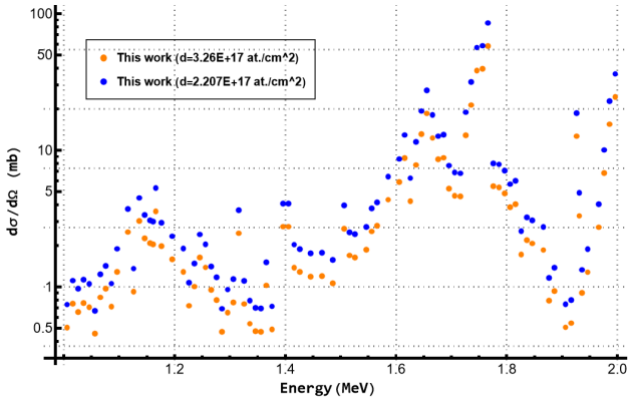



**Figure 4**. *Differential cross-section of $^{18}O(p,\alpha_0)^{15}N$ reaction at 160°*

The experimental value for the thickness of the target does not completely agree with the thickness provided by the manufacturer. Therefore, in both angles (Figs. 3 and 4), the differential cross-section values were calculated twice, using both the target thickness as given by the manufacturer (orange), and

the one calculated via the $^{18}O(d,\alpha_0)^{16}N$ reaction (blue). In figure 3, for the detection angle at 170°, the experimental data is additionally compared with the existing ones from G. Amsel [1], suggesting that the thickness of the target by the manufacturer leads to calculations closer to the bibliography. To resolve this matter, the thickness is scheduled to be measured again, employing the very narrow resonance in $^{18}O(p,\alpha_0)^{15}N$ reaction at $E_{p,lab}$=152 keV.

## CONCLUSIONS

In this scientific investigation, experimental measurements of reaction cross-sections were conducted within the energy range of 1–2 MeV, at detection angles of 170 and 160 degrees. A comparison was made with previously established data dating back to 1964, specifically for the 170-degree angle. The current findings indicate a slight increase of the measured cross-sections compared to the existing dataset. Nonetheless, the fundamental shape of the cross-section behavior remains consistent. Notably, an observed discrepancy was subsequently traced back to a series of incorrect data--entries within the database. These coherent differential cross-section datasets are anticipated to facilitate the extension of the existing SigmaCalc evaluation of the $^{18}O(p,\alpha_0)$ reaction to higher energies in the near future.

### Acknowledgments

We would like to thank M. Andrianis and A. Laoutaris for providing the proton beam during the experiment, and all the members of the Nuclear Physics Group (NTUA) for their help with the night shifts.

### References

[1] G. Amsel, Annales de Physique 13, 297 (1964); doi: 10.1051/anphys/196413090297
[2] Ion Beam Analysis Nuclear Data Library; url: https://www-nds.iaea.org/exfor/ibandl.htm
[3] G. Amsel and D. Samuel, J. Anal. Chem. 39, 1689-1698 (1967); doi: 10.1021/ac50157a027
[4] Y. Wang and M. Nastasi, Handbook of Modern Ion Beam Materials Analysis (2nd ed), Materials Research Society (2009)
[5] C. Kalfas et al, NIM A 830, 265 (2016); doi: 10.1016/j.nima.2016.05.098
[6] M. Mayer, NIM B 332, 176 (2014); doi: 10.1016/j.nimb.2014.02.056