Shedding light on $^{17}O(n,\alpha)^{14}C$ reaction at astrophysical energies with Trojan Horse Method and Asymptotic Normalization Coefficient

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Abstract. Indirect methods have been established in the past as a complementary way of increasing our knowledge about nuclear structure and low-energy cross section measurements. Among these, the neutron induced reaction cross sections appear to be of particular interest because of their role both for unstable and stable beams. In view of this, we report here the combined study of the $^{17}O(n,\alpha)^{14}C$ reaction accomplished by the Trojan Horse Method (THM) and the Asymptotic Normalization Coefficient (ANC) method. The low lying resonances 8038, 8125, 8213, and 8282 keV in ^{18}O are studied and Γ_n are derived. A comparison with direct data and recent THM experimental data is presented. The independent ANC investigation corroborates our previous THM results, confirms the consistence of the two indirect investigation and shows new frontiers also in view of neutron induced reactions with RIB's.

1 Introduction

The $^{17}O(n,\alpha)^{14}C$ reaction is considered in astrophysical models for its role in the relevant "s(slow)-process" since it could act as a possible "neutron poison" for the neutron-induced nucleosynthesis thus influencing the final stellar abundances of some elements such as Ni or Sr [1]. Thus, its reaction rate must be known in the energy region of interest for astrophysics, going from few keV up to about 400 keV. At such energies, the intermediate $^{17}O+n\rightarrow^{18}O$ nucleus presents four excited levels (8038, 8125, 8213 and 8282 keV) affecting the magnitude of the ^{17}O+n cross section at astrophysical energies because of the 8044 keV threshold for the neutron emission of ^{18}O. Besides the role of the two 8213 keV ($J^\pi=2^+$) and 8282 keV ($J^\pi=3^-$) states, already investigated by the direct measurements [2], up-to-now poor information is available about the 8125 keV ($J^\pi=5^-$) resonant level, thus requiring a detailed experiment.

However, neutron-induced reaction cross section measurements are difficult to be performed due to the practical difficulties of having "easily available" neutron beams. For such a reason,

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the Trojan Horse Method (THM) has been applied to the $^{17}O(n,\alpha)^{14}C$ case and discussed in [3,4]. The THM measurements [3,4] show an evident contribution of the 8213 keV and 8282 keV ^{18}O excited states with an additional contribution of the 8125 keV resonant level, naturally suppressed in the direct measurements because of the large l=3 angular momentum required for its population in the ^{17}O+n channel. Thanks to our THM investigation, information about the corresponding neutron (Γ_n) or alpha partial widths (Γ_α) is now available. To complement such information, mainly deduced by the (modified) R-matrix formalism for THM described in [5], we proposed a new experiment dedicated to the study of these resonant ^{18}O levels, with particular regard to the measurement of the 8125 keV level by means of the corresponding ANC.

2 Method and experiment

The ANC is a fundamental nuclear characteristic of importance in nuclear reactions since it corresponds to the amplitude of the overlap function of the bound-state wave functions of the initial and final nuclei. Hence, the ANC method allows one to obtain the cross section of a peripheral direct capture reaction A(a,γ)B in terms of the radial overlap integral of the X and B nuclei of the A(X,Y)B transfer reaction , where the nuclei X and A can be considered as X = Y+a and B = A+a [6]. This method has been widely used in the last 20 years to investigate proton, neutron and α direct captures in stellar environments [7-9]. In the present case, in order to extract the ANC for the ^{18}O resonant states, the $^{17}O(d,p)^{18}O$ reaction has been studied, using the deuterium for its simple p+n configuration. The experiment was performed at the isochronus cyclotron U-120M of the Nuclear Physics Institute of the Czech Academy of Science (NPI-ASCR) in Rez (Prague). A 16.3 MeV beam was delivered onto a 90% pure ^{17}O gas target, connected to the beam line with 3µm-thick havar entrance and exit windows. The beam energy was chosen in order to maximize the peripherical contribution of the reaction (see [10] and reference therein). The detection setup, already used in many experiments [11], consisted of 8 standard point-like ΔE-E telescopes, with thicknesses of 500µm and 5000µm, respectively. Three telescopes were placed at fixed angles of 17°, 27° and 37° with respect to the beam line and have been used also as the monitors. Five telescopes were placed on the turntable plate on the opposite side with a relative angular step of 10°. The whole set of five telescopes could measure reaction products in the range of θ_{LAB} from 6° to 67°.

3 Data analysis and conclusions

After the performed detector calibrations and uncertainties evaluations, the next stage of the present analysis has been the extraction of the angular distribution for both, the elastic scattering ^{17}O+d and the reaction $^{17}O(d,p)^{18}O$. This is a standard procedure followed elsewhere [12] and focuses first on extracting the optical parameters from DWBA calculation on the ^{17}O+d elastic scattering angular distributions and then the ANC for the resonant ^{18}O levels populated in the $^{17}O(d,p)$ reaction.

Once extracted, each ANC value ($|C_l|^2$) can be connected to the corresponding Γ_n of the ^{18}O level state by the following formula [13]:

$$\Gamma \approx \frac{k_r \hbar c^2 C_l^2}{\mu_{ab}} = \frac{\sqrt{2\mu_{ab}E_r}\hbar c C_l^2}{\mu_{ab}} = \sqrt{\frac{2E_r}{\mu_{ab}}}\hbar c C_l^2 \qquad (1)$$

where E_r is the resonance energy (in MeV), μ is the reduced mass (in MeV), ħc=197 MeV fm and $|C_l|^2$ is in fm^{-1}.

Then, considering also the Γ_α as reported in [4], it is possible to calculate the cross section and compare it with the direct and inverse data [2,14,15]. This comparison is reported in Fig. 1 where the red line represents the cross section calculated as described before while the red band is the error associated to the Γ_n of about 20%. Light blue points are data taken from the work of [2], blue points from [14] while black points are the inverse data of [15] converted using the detailed balance. From Fig.1 it is clear the presence of a quite good agreement between the ANC calculation and the direct data at the energy region above 150 keV. Below this region the direct measurements present a very big scatter distribution, while the ANC calculation decrease a lot due to the absence of a proper evaluation of the subthreshold level.

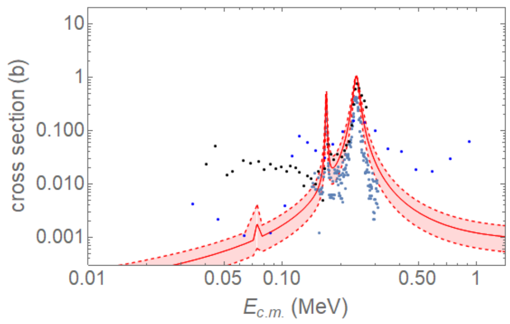

Figure 1 - ANC cross section compared with available direct data (see text for details)

Moreover, with the same parameters it is possible to compare also the THM data [4], as reported in Fig. 2. Again, red line and red band are used to highlight the cross section calculated from the Γ_n derived from the ANC data while the black points represent the THM data.

Not yet included is the subthreshold level centered at -7 keV since for this level the analysis is still ongoing. In both cases the results are in good agreement, confirming the possibility to use independent ANC investigation to corroborate THM results and thus opening new frontiers also in view of neutron induced reactions with RIBs, where there is still a lack of direct measurements due to practical problems in the simultaneous production of neutron and radioactive beams.

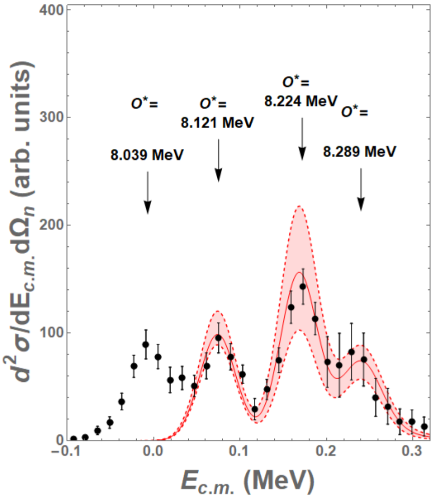

Figure 2 - ANC cross section compared with available THM data

As a final remark, Table I compare the Γ values for the ^{18}O level state available in the literature, as a final cross-check of the good agreement between the methods and to underline once more that the combined study presented here allows us to measure for the first time the resonance parameters of the 8125 keV ($J^{\pi}=5^{-}$) level state, suppressed in direct measurement due to the centrifugal barrier.

Table 1 - Total level width available in literature compared with the present measurement.

$E_{c.m.}$ (keV)	Γ (eV) Ref. [2]	Γ (eV) Ref. [4]	Γ (eV) This work
75	----	36±5	33±6
178	2258±135	2260±300	2150±420
244	14739±590	14700±3800	16670±3350

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