Study of the $^{17}$O(n,α)$^{14}$C reaction: extension of the Trojan Horse Method to neutron induced reactions

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Astrophysical scenario

- **Inhomogeneous Big Bang Nucleosynthesis (IBBN)**

  The reaction $^{17}\text{O}(n,\alpha)^{14}\text{C}$ represents one of the main channels for $^{14}\text{C}$ production, an ingredient for the $^{22}\text{Ne}$ production via $^{14}\text{C}(\alpha,\gamma)^{18}\text{O}(n,\gamma)^{20}\text{Ne}(\beta)^{20}\text{F}(\beta)^{20}\text{Ne}(n,\gamma)^{21}\text{Ne}(n,\gamma)^{22}\text{Ne}$.

- Temperature $\rightarrow 0.8<T_s<11$ K
- Energy range $\rightarrow \sim 0$-100 keV

Strong components - process $^{17}\text{O}(n,\alpha)^{14}\text{C}$ and $^{17}\text{O}(\alpha,n)^{20}\text{Ne}$ since they act as a neutron poison and a recycle channel during s-process nucleosynthesis in massive stars ($M>8M_{\odot}$).
Status of art of the reaction

P.E. Koehler & S.M. Graff, Ph. Rev., C44(6), 2788 (1991) (full line)


FACTOR 2 DISCREPANCY

THM
Experimental setup

- The reaction $^{17}\text{O}(n,\alpha)^{14}\text{C}$ was studied via the $^2\text{H}(^{17}\text{O},\alpha^{14}\text{C})p$, $V_{\text{coul}}=2.3$ MeV;
- The deuteron is the TH nucleus. Strong cluster $n+p$; $B=2.2$ MeV, $|p_s|=0$ MeV/c.

- Experiments performed at ISNAP at the University of Notre Dame (USA) and LNS of Catania;
- $E_{\text{beam}}(^{17}\text{O})=43.5$ MeV;
- Target thickness $CD_2 \sim 150$ µg/cm$^2$;
- IC filled with $\sim 50$ mbar isobutane gas;
- Angular position to cover the QF angular region;
- Symmetric set-up in order to increase the statistic.
Data analysis: channel selection

\[ ^2\text{H}(^{17}\text{O},^{14}\text{C})p \rightarrow Q_{\text{value}} = -0.407 \text{ MeV} \]

- Selection of the events with carbon in the final state
- Presence of a peak centered at the expected value
- Comparison between experimental and simulated kinematical locus
Data analysis: sequential mechanism

» Presence of vertical loci corresponding to $^{18}$O;
» Presence of $^{15}$N levels but far from the zone of interest;
» Absence of horizontal loci from $^5$Li.
Data analysis: QF selection

By following the PWIA approach it is possible to extract the experimental momentum distribution:

\[ |\Phi(p_S)|^2 \propto \frac{d^3\sigma}{dE_c d\Omega_c d\Omega_e} \]

Necessary condition for the presence of the QF mechanism

Comparison between the experimental data and the theoretical Hütten function

\[ \Phi(p_S^*) = \frac{1}{2\pi} \sqrt{\frac{ab(a+b)}{(a-b)^2}} \left( \frac{1}{a^2 + P_S^2} - \frac{1}{b^2 + P_S^2} \right) \]
Data results: $^{17}\text{O}(n,\alpha)^{14}\text{C}$ angular distributions

After the study of the 3-body channel and the QF selection, it is important to study the 2-body one. The angular range covered in the experiments in the c.m. system allows one to study the angular distributions.

$\ell=3$ distribution: no data present in literature (suppressed in direct measurements)

$\ell=2$ distribution: no data present in literature

$\ell=1$ distribution: will be compared with the available data
Data results: $^{17}\text{O}(n,\alpha)^{14}\text{C}$ cross section

<table>
<thead>
<tr>
<th>$^{18}\text{O}^*$ (MeV)</th>
<th>$J^\pi$</th>
<th>$E_{\text{c.m.}}$ (MeV)</th>
<th>$l_{\text{in}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8.039</td>
<td>1$^-$</td>
<td>-0.007</td>
</tr>
<tr>
<td>B</td>
<td>8.125</td>
<td>5$^-$</td>
<td>0.075</td>
</tr>
<tr>
<td>C</td>
<td>8.213</td>
<td>2$^+$</td>
<td>0.166</td>
</tr>
<tr>
<td>D</td>
<td>8.282</td>
<td>3$^-$</td>
<td>0.236</td>
</tr>
</tbody>
</table>


✓ -0.8 < $Q_{\text{value}}$ < 0 MeV
✓ |$p_s$| < 40 MeV/c
✓ 90° < $\theta_{\text{c.m.}}$ < 140°

(integrated with theoretical distribution)

Guardo et al., PRC, submitted (2016)
Data results: \(^{17}\text{O}(n,\alpha)^{14}\text{C}\) R-matrix fit

\[ \frac{d^2\sigma}{dE_{\text{cm}}d\Omega_s} = NF \sum_i (2J_i + 1) \times \sqrt{\frac{k_i(E_{\text{cm}})}{\mu_{cc}}} \sqrt{2P_i(k_{cc}R_{cc})M_i(p_{xA}R_{xA})\gamma_{cc}^i\gamma_{xA}^i} \]

<table>
<thead>
<tr>
<th>(E_{\text{cm}}) (keV)</th>
<th>(\Gamma_n) (eV)</th>
<th>(\Gamma_\alpha) (eV)</th>
<th>(\Gamma_{\text{TOT}}) (eV)</th>
<th>(\Gamma_{\text{wag.}}) (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7</td>
<td>0,01±0,001</td>
<td>2362±307</td>
<td>2362±307</td>
<td>2400</td>
</tr>
<tr>
<td>75</td>
<td>0,05±0,006</td>
<td>36±5</td>
<td>36±5</td>
<td>-</td>
</tr>
<tr>
<td>166</td>
<td>86±11</td>
<td>2171±282</td>
<td>2257±293</td>
<td>2258±135</td>
</tr>
<tr>
<td>236</td>
<td>1714±446</td>
<td>13021±3386</td>
<td>14735±3832</td>
<td>14739±590</td>
</tr>
</tbody>
</table>

Guardo et al., PRC, submitted (2016)
Data results:

$^{17}\text{O}(n,\alpha)^{14}\text{C}$ reaction rate

$$N_A \langle \sigma \nu \rangle = \frac{3,7318 \times 10^{10}}{T_{9}^{3/2}} \sqrt{\frac{A_1 + A_2}{A_1 A_2}} \times$$

$$\times \int_{0}^{\infty} E \sigma(E) e^{-11.605E/T_{9}} dE$$

Guardo et al., PRC, submitted (2016)
Conclusions

-7 keV in center of mass system corresponding to 8.039 MeV level of $^{18}$O
- SUBTHRESHOLD LEVEL

75 keV in center of mass system corresponding to 8.125 MeV level of $^{18}$O
- SUPPRESSED IN DIRECT MEASUREMENTS BECAUSE OF THE CENTRIFUGAL BARRIER

$R$-matrix fit allow us to measure for the first time the neutron and alpha partial widths.

166 keV in center of mass system corresponding to 8.213 MeV level of $^{18}$O
- FIRST ANGULAR MOMENTUM DISTRIBUTION ASSIGNMENT

New total reaction rate at astrophysical region
- POSSIBLE CONSEQUENCES IN ASTROPHYSICAL MODELS
Thank you for your attention