# LUNA:Laboratory for Underground Nuclear Astrophysics

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During most of its life, a low mass star burns H in the center via the pp chain. However, when the central H mass fraction reduces down to 0.1, the nuclear energy produced by the H-burning becomes not sufficient and the stellar core must contract to extract some energy from its gravitational field. Then, the central temperature (and the density) increases and the H-burning switches from the pp-chain to the more efficient CNO-burning. Thus, the escape from the main sequence is powered by the onset of the CNO burning, whose bottleneck is the $^{14}N(p,\gamma)^{15}O$ reaction. A modification of the rate of this reaction alters the turn off luminosity, but leaves almost unchanged the stellar lifetime, which is mainly determined by the rate of the pp reaction.

At solar energies the cross section of $^{14}N(p,\gamma)^{15}O$ is dominated by a subthreshold resonance at -504 keV and at energies higher than 100 keV by the resonance at $E_R$ = 278 keV with transitions to the excited states at energies of 5.18 MeV, 6.18 MeV and 6.79 MeV and the groundstate in $^{15}O$. According to Schröder et al. [1] the main contribution to the total S factor at zero energy comes from transitions to the ground state in $^{15}O$ and to the subthreshold state at $E_x$ = 6.79 MeV. Recently a reanalysis of the experimental data gave a different picture. The main difference concerns the S(0) factor for capture to the $^{15}O$ ground state: a factor of 19 lower S(0) factor than the value Schröder et al. suggested, reducing the total rate by about 50 %.

In summary, new measurements of the $^{14}N(p,\gamma)^{15}O$ cross section at energies $E \leq 200$ keV are necessary, in particular measurements of the transition to the ground state in $^{15}O$. The peculiarities of the 400 kV LUNA facility are particularly well suited for this study, where reaction $\gamma$-ray lines up to $\simeq$ 7.5 MeV have to be measured with very low intensities. High beam intensities and high detection resolutions have to be coupled to high target stability and purity, which leads to low beam-induced background; cosmic background is strongly suppressed by the mountain shielding and low intrinsic activity detectors are employed.

The excitation function of the $^{14}N(p,\gamma)^{15}O$ reaction (Q = 7.297 MeV) to four final states in $^{15}O$ was measured in the region of the resonance at $E_p$ = 278 keV. From a constrained fit to the observed $\gamma$-ray positions in the $\gamma$-spectrum, using as free parameters the $^{15}O$ energy levels, i.e. the energy of the secondary peaks of the spectrum, and the Q-value, we obtained: $E_1 = 5180.3 \pm 0.3$ keV; $E_2 = 6172.0 \pm 0.3$ keV; $E_3 = 6791.6 \pm 0.3$ keV and $Q = 7297.2 \pm 0.3$ keV. To determine the precise value of the resonance energy and width, we fitted the measured yield using the machine calibration to obtain the beam energy at each point. The values obtained for the resonance parametrs are: $E^R_{cm} = 259.1 \pm 0.3$ keV and $\Gamma_p = 1.07 \pm 0.05$ keV. Properly taking into account the summing effects due to the finite geometry the following values for the resonance strength and branching ratios were found: $\omega\gamma = 13.5 \pm 0.5$ meV, $b_0 = 1.6 \pm 0.1$ %, $b_1 = 16.8 \pm 0.2$ %, $b_2 = 58.2 \pm 0.3$ % and $b_3 = 23.4 \pm 0.3$ %. These values were used in order to obtain the absolute normalization of the cross section at the beam energies below and above the resonance.

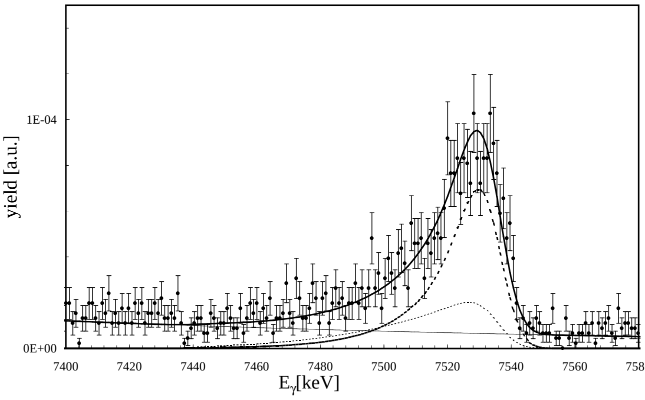

Figure 1: The figure shows the $\gamma$-spectrum for the groundstate transition at $E_{cm}$ = 270 keV.

The yield of the $^{14}N(p,\gamma)^{15}O$ reaction has been measured using deposited targets of thickness larger than 60 keV. In particular we have covered the energy range from $E_p$ = 147 to 400 keV. In order to determine the absolute cross section from the observed $\gamma$-ray spectra, we studied in detail the expected line shape. This shape is determined by the cross section behaviour in the proton energy interval spanned by the incident beam during the slowing-down process in the target. The energy loss of the protons in the thick target gives rise to a drop in the yield at the low energy tail of the capture line.

Since the above result depends on the stochiometry of the target, to obtain the absolute value of the cross section it is necessary to normalize the yield to the corresponding infinitive resonance yield measured with the same target. An example of the fit is given in figure 1, where the $\gamma$-spectrum for the ground-state transition at $E_{cm}$ = 270 keV is plotted: the thin solid line is the background, the bold and the thin dotted lines represent the non resonant and the resonant part of the cross section, respectively, and the bold solid line is the sum of these functions. It is worth to note that we obtain such a fit using as free parameters only the non resonant astrophysical S factor and the background parameters. The final analysis of the measured excitation curve is in progress.

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## References

[1] Schröder et *al*, Nucl. Phys. A 467(1987)240.