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Towards a study of ^{22}Ne(p,γ)^{23}Na at LUNA

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Abstract. The ^{22}Ne(p,γ)^{23}Na reaction is involved in the NeNa cycle of hydrogen burning. This cycle plays an important role for nucleosynthesis in the Red Giant Branch and Asymptotic Giant Branch phases of stellar evolution, as well as in classical novae and type Ia supernovae explosions.
The ^{22}Ne(p,γ)^{23}Na reaction rate is highly uncertain because of a large number of resonances lying in the energy region of the Gamow peak. Several of these resonances have never been studied in either direct or indirect experiments, and only upper limits exist for their strengths. A measurement of the ^{22}Ne(p,γ)^{23}Na cross section is on-going at the Laboratory for Underground Nuclear Astrophysics (LUNA) in Gran Sasso. With the LUNA setup, it will be possible to study the ^{22}Ne+p reaction inside the Gamow window.
The results of a feasibility test, as well as the measurement strategy and the setup for the first experimental campaign are discussed.

1. Introduction

The ^{22}Ne(p,γ)^{23}Na reaction takes part in the neon - sodium cycle of hydrogen burning (fig. 1). This cycle is active in the Red Giant and Asymptotic Giant Branch phases of stellar evolution [1], as well as in classical novae [2] and type Ia supernovae explosions [3]. In these scenarios, the NeNa cycle is particularly important for the synthesis of the elements between ^{20}Ne and ^{27}Al.

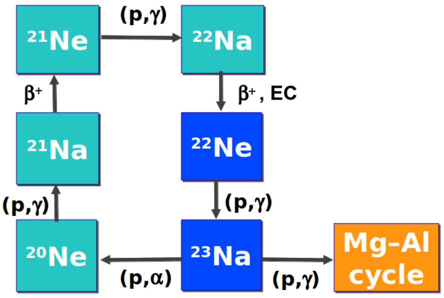

Figure 1. Schematic view of the neon - sodium cycle.

Among the reactions of the NeNa cycle, the ^{22}Ne(p,γ)^{23}Na has the most uncertain reaction rate.
Inside the Gamow window, the reaction cross section is dominated by the contribution of a

large number of resonances (fig. 2). So far, none of the resonances between 50 and 400 keV has been directly observed, and only upper limits exist for the resonance strengths. Moreover, three resonances at 68, 100 and 206 keV, respectively, have been reported as tentative by Powers et al. [4], but not observed in a similar experiment by Hale et al. [5].

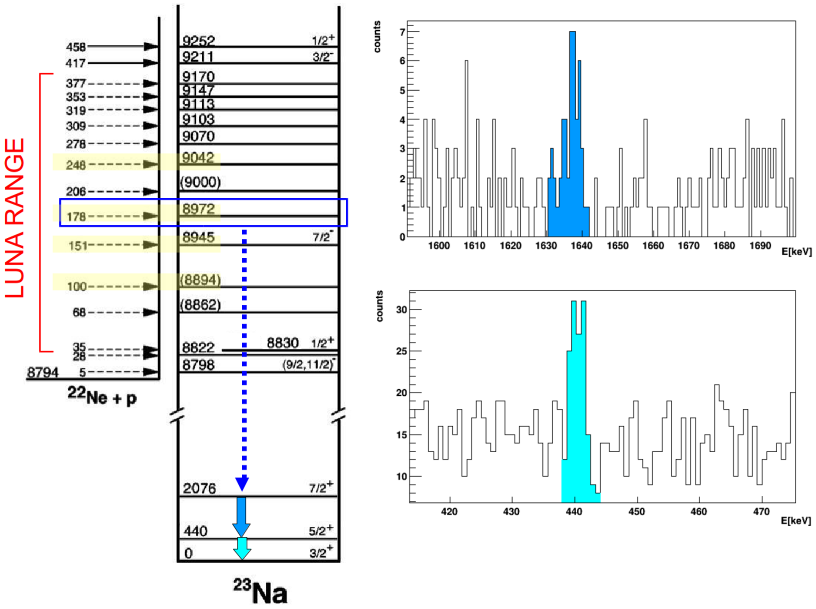

Figure 2. Left: partial level scheme of ^{23}Na. For each excited state, the corresponding resonance enrgy is reported. Right: 178 keV resonance peaks observed in the gamma - ray spectrum. The peaks correspond to the decay of the first (bottom) and second (top) excited states of ^{23}Na.

Because of this lack of information, the reaction rate reported in the NACRE compilation [6] and the one adopted by Iliadis and collaborators [7] differ by a factor of 2000.
In order to improve the experimental knowledge on the ^{22}Ne(p,γ)^{23}Na reaction, a new direct measurement will be performed at the Laboratory for Underground Nuclear Astrophysics (LUNA).

2. Experimental setup

The LUNA facility is located at Gran Sasso National Laboratories (Italy) [8]. The laboratory is shielded against cosmic radiation by 1400 m of rocks, reducing the cosmic muon and neutron flux by six and three orders of magnitude, respectively.
The LUNA setup is composed of a 400 kV electrostatic accelerator providing an high intensity ($\sim$200 μA) proton or alpha beam. The beam can be delivered to a solid or gas target system. Different gamma-ray or particle detectors can be used, depending on the characteristics of the nuclear reaction to be studied.
For the ^{22}Ne(p,γ)^{23}Na cross section measurement, a proton beam will be delivered to a windowless gas target filled with 99.9% enriched ^{22}Ne.
The gamma-rays emitted in the de-excitation of ^{23}Na will be detected by two HPGe detectors placed at 55° and 90° angle with respect to the beam direction.
In order to reduce the environmental background, the two detectors will be surrounded with a 25 cm thick lead and copper shielding (fig. 3). GEANT 4 simulations of the setup indicate that this shielding will ensure about four orders of magnitude background reduction in the γ - ray energy range below 3 MeV.

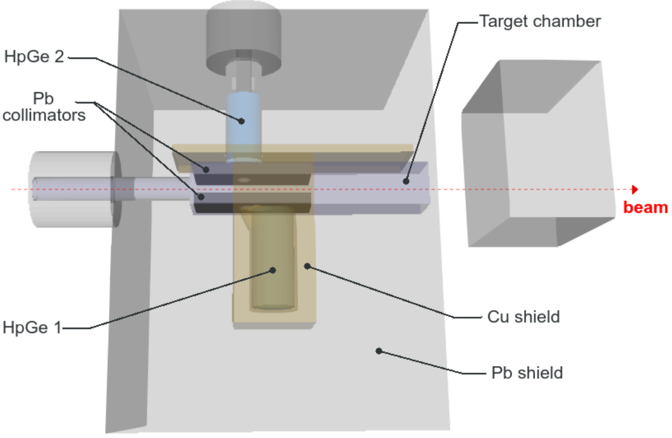

Figure 3. GEANT 4 simulation of the setup for the ^{22}Ne(p,γ)^{23}Na measurement.

3. Measurement plan

As a first step, a feasibility test was performed using the setup of the previous ^{2}H(α,γ)^{6}Li experiment [9].

For this test, neon gas with natural isotopic composition was used (90.48% ^{20}Ne, 0.27% ^{21}Ne and 9.25% ^{22}Ne). The aim of the test was to study the possible sources of beam induced background, and to have some hints on the sensitivity to the ^{22}Ne+p resonant cross section.

During the test, runs on the ^{22}Ne(p,γ)^{23}Na resonances at 100, 151, 178 and 248 keV have been performed. Despite the use of non enriched gas (only 9.25% ^{22}Ne) and a setup which was not optimized for this measurement, gamma-rays from the 178 keV resonance have been observed in a 12 h run (fig. 2). This resonance was never observed in previous experiments, and the literature upper limit for the resonance strength is $\omega\gamma < 2.6 \cdot 10^{-6}$ eV.

Following the feasibility test, the characterization of the setup for the first experimental campaign on the ^{22}Ne(p,γ)^{23}Na resonances was started.

In particular, the pressure and temperature profile of the gas inside the target chamber have been studied using a dedicated setup. Then the beam heating effect in natural neon gas has been meaured with the resonance scan technique, using the intense ^{21}Ne(p,γ)^{22}Na resonance at 271 keV beam energy.

The preparation of the final setup is currently on-going, and the data taking is planned to start in fall 2013.

4. Conclusions

An experimental study of the ^{22}Ne(p,γ)^{23}Na reaction rate is needed to understand the nucleosynthesis of the elements with mass number around 20 in many astrophysical scenarios.

A new measurement of the ^{22}Ne(p,γ)^{23}Na cross section is now starting at LUNA.

The first test run demonstrated that the sensitivity to the weak resonances lying in the Gamow window can be significantly improved thanks to the low background. This will allow to observe some resonances for the first time, or significantly lower the existing upper limits on the resonance strengths.

References

[1] N. Prantzos et al. 2007 *Astronomy and Astrophysics* **470** 179-190
[2] C. Iliadis et al. 2002 *Astrophys. Jour. Suppl. Series* **142** 105-137
[3] A. Parikh et al. 2013 *Preprint* astro-ph/1306.6007
[4] J. R. Powers et al. 1971 *Phys. Rev. C* **4** 2030-2046
[5] S. E. Hale et al. 1971 *Phys. Rev. C* **65** 015801
[6] C. Angulo et al. 1999 *Nuclear Physics A* **656**, 3-187
[7] C. Iliadis et al. 2010 *Nucl. Phys. A* **841** 1-322
[8] C. Broggini et al. 2010 *Ann. Rev. Nucl. Part. Sci.* **60** 53-73
[9] M. Anders et al. 2013 *Eur. Phys. J. A* **49** 28