EPJ Web of Conferences **66**, 07004 (2014)
DOI: 10.1051/epjconf/20146607004

First test on the ^{22}Ne(p,γ)^{23}Na reaction at LUNA

Francesca Cavanna[1,a] for the LUNA collaboration[2]

[1] *Dipartimento di fisica, Università di Genova, and INFN Sezione di Genova, Genova, Italy*
[2] *http://luna.lngs.infn.it/*

Abstract.
The ^{22}Ne(p,γ)^{23}Na reaction is involved in the hydrogen burning neon-sodium cycle. In second-generation stars, where the central temperature is higher than 0.05 10^9 K, hydrogen burning can proceed also via the NeNa cycle. The ^{22}Ne(p,γ)^{23}Na cross section, dominated by a large number of resonances never measured directly, is still affected by large uncertainties.
At the Laboratory for Underground Nuclear Astrophysics (LUNA), in the Gran Sasso National Laboratory in Italy, several cross sections have been measured in the past down to the energies of astrophysical interest. An experimental study of the ^{22}Ne(p,γ)^{23}Na reaction is under preparation at LUNA, using a windowless gas target system and two HPGe detectors.

1 Introduction

The NeNa cycle determines the nucleosynthesis of the Ne and Na isotopes in the Red Giant Branch and Asymptotic Giant Branch phases of stellar evolution [1]. Moreover, the NeNa cycle affects the abundances of the elements between ^{20}Ne and ^{27}Al ejected in the interstellar medium by classical novae explosions [2].

2 Astrophysical motivations

During the carbon burning process of stellar nucleosynthesis, ^{20}Ne is created in the collision between two ^{12}C nuclei, by the reaction: $^{12}C + ^{12}C \rightarrow ^{20}Ne + ^{4}He$. In second generation stars where the central temperature T is higher than 0.05 10^9 K, from ^{20}Ne, the NeNa cycle can originate. The following reactions are involved in this cycle [3]:
^{20}Ne(p,γ)^{21}Na(β^+,ν)^{21}Ne(p,γ)^{22}Na(β^+,ν)^{22}Ne(p,γ)^{23}Na(p,α)^{20}Ne
From the astrophysical point of view, the ^{22}Ne(p,γ)^{23}Na cross section measurement is important for studying:

- the Red Giant Branch Stars surface composition (Gamow Peak 30 keV < E < 100 keV)
- the composition of ejected materials from Asymptotic Giant Branch Stars and Classical Novae (Gamow Peak 100 keV < E < 400 keV)

[a] e-mail: Francesca.Cavanna@ge.infn.it

In these energy ranges the reaction rate is dominated by a large number of narrow resonances. However, for the resonances below E_p = 0.4 MeV, only upper limits exist in the literature [3]. The rate adopted in the most recent reaction rate compilation [4] uses indirect data [5] to quantify the strength of several resonances, very often adopting upper limits. The lowest-lying resonance with a directly measured strength is the one at E_p = 479 keV [6].
The recent Iliadis et al. [4] thermonuclear reaction rate calculations show the lower and upper limit contributions to the total reaction rates, by neglecting the resonances for which upper limit only are avaliable, and by estimating a maximum possible contribution. Between the lower and the upper limit there are up to four orders of magnitude of difference in the thermonuclear reaction rate.
Therefore, a new study is highly desirable. The previous upper limits for the low-energy resonance strengths in the ^{22}Ne(p,γ)^{23}Na reaction are in the μeV range [3, 5], i.e. in the typical sensitivity of LUNA experiments.

3 LUNA: Laboratory for Underground Nuclear Astrophysics

At the Laboratory for Underground Nuclear Astrophysics (LUNA), in the Gran Sasso National Laboratory, several cross sections have been measured in the past down to the energies of astrophysical interest [7].
At low energy, the cross section of a charged particle induced reaction steeply drops with decreasing energy due to the Coulomb barrier. Generally, it has a very low value at the Gamow Peak; this prevents a direct measurement in a laboratory on the Earth's surface, where the signal to background ratio is too small because of cosmic ray interactions with detectors. This is particularly evident in the case of reactions emitting gamma rays.
The Gran Sasso underground facility is shielded against cosmic rays by a rock cover (1400 m thick) equivalent to 3800 m water, suppressing the muon and neutron flux by six and three orders of magnitude, respectively.
The measurement of the cross section and the determination of the astrophysical S - factor for thermonuclear reactions require an experimental apparatus composed of an accelerator, a target, and a detection system.
The 400 kV accelerator delivers a proton beam of 500 μA or an alpha beam of 300 μA in the energy range of E_p = 50-400 keV. The ions can be sent into one of two different, parallel beam lines, thereby allowing the parallel installation of solid and gas target setups.
Radiative capture cross section measurements require the detection of γ rays. Here the choice of the most suitable detector depends on the physical information desired. The 4π bismuth germanate (BGO) summing crystal used at LUNA can reach an efficiency as high as 70% for a 7-MeV γ ray, thus allowing the measurement of extremely low reaction yields. However, the BGO's energy resolution is very poor and does not allow measurements of cascades and branching ratios to different levels because most of the γ-ray transitions are summed in a single peak. With a germanium detector, the efficiency decreases to the level of a few per mil, but the energy resolution is much better, allowing complex γ-ray cascades to be disentangled. Moreover, angular distribution measurements can be made by placing the detector at different angles with respect to the ion beam.

3.1 Experimental setup

Our experimental setup consist of a windowless gas target with three differential pumping stages and a gas recirculation system, which allow us also to purify the gas at each recirculation.
The experiment is planned in three phases:

1. test (already done) with natural neon gas performed by a germanium detector (high E_γ resolution, low efficiency $\eta \sim 1\%$): the proton energy range 120-400 keV was explored with a gas target pressure ranging from 0.6 to 2.5 mbar and natural neon gas (9.25 % ^{22}Ne).

2. measurement of the cross section, with isotopically enriched neon-22 gas using two HPGe detectors. High resolution detector and well defined solid angles allow a measurement of the different branching ratios of the resonance decay.

3. measurement of the non resonant cross section, with enriched neon-22 gas using a high efficiency ($\eta \sim 70\%$ at E_γ = 7 MeV) 4π BGO detector at the lowest energies.

3.2 Status of the experiment and future plans

The test has been performed with the pre-existing ^{2}H(α,γ)^{6}Li setup [8], with the aim of studying the laboratory and beam induced background, determining the effect of ^{20}Ne and ^{21}Ne inside the target, having hints on the resonant reaction rate.
We had already good results from this test, we could observe the 186 keV, laboratory frame, ^{22}Ne resonance: in particular the transition from the first excited state (i.e. 440 keV) to the ground state, and the transition from the second excited state to the first one (i.e. 2076 keV $\rightarrow$ 440 keV) as shown in figure 1.
In this preparatory phase we also studied the density profile of our target chamber and the beam heating effect on the gas density.
Next months we will mount the new setup for the second phase: this consist of two Germanium detectors, one at 90 degrees with respect to the beam direction, and the other one at 55 degrees (figure 2). In this way we will be able to confirm an isotropic angular distribution. The target chamber and the two germanium detectors will be well shielded with approximatively four orders of magnitude of background reduction compared with the unshielded setup.

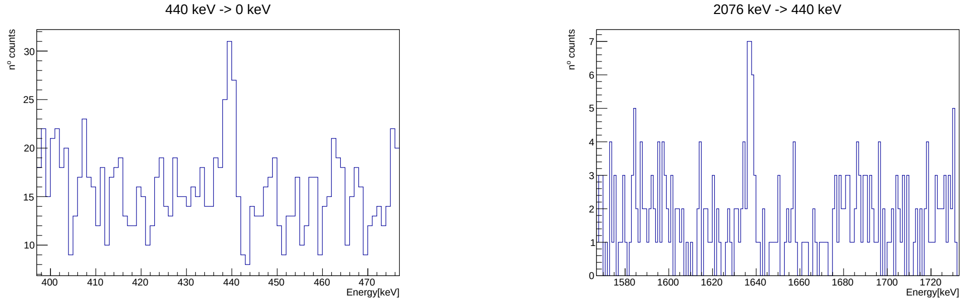

Figure 1. Energy spectrum of the 186 keV, laboratory frame, ^{22}Ne resonance: the peaks related to the transition from the first excited state (i.e. 440 keV, left one) to the ground state and from the second excited state to the first one (i.e. 2076 keV $\rightarrow$ 440 keV, right one) are shown

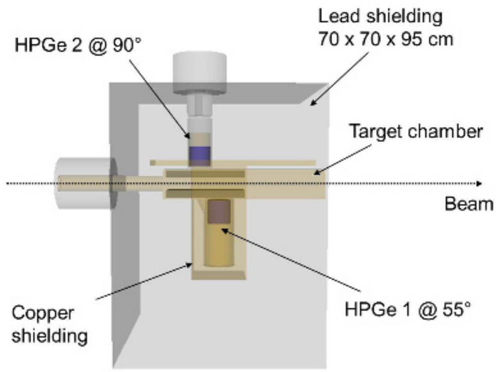

Figure 2. Setup for the resonances study with the two HPGe detectors placed at 90 and 55 degrees.

References

[1] N. Prantzos et al., A&A **470**, 179190 (2007)
[2] C. Iliadis et al., ApJSS **142**, 105-137 (2002)
[3] J. Görres et al., Nucl. Phys. A **385**, 57 (1982)
[4] C. Iliadis et al., Nucl. Phys. A **841**, 251 (2010)
[5] S. E. Hale et al., Phys. Rev. C **65**, 015801 (2002)
[6] R. Longland et al., Phys. Rev. C **81**, 055804 (2010)
[7] C. Broggini et al., Annu. Rev. Nucl. Part. Sci. **60**, 53-73 (2010)
[8] M. Anders et al., Eur. Phys. J. A **49**, 28 (2013)