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Study of the ^{22}Ne(α, γ)^{26}Mg reaction at LUNA

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Abstract. The ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction competes with the ^{22}Ne$(\alpha, \mathrm{n})^{25}$Mg reaction which is the main source of neutrons for the s-process in low-mass Asymptotic Giant Branch (AGB) and massive stars. The ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction rate is affected by a high uncertainty mainly due to the poorly constrained 395 keV resonance which has been studied only indirectly leading to a wide range of possible values for its resonance strength (10^{-14} - 10^{-9} eV). The present study represents the direct measurement of the 395 keV resonance of the ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction at LUNA (Laboratory for Underground Nuclear Astrophysics), located at Gran Sasso National Laboratory. Here, the experimental campaigns, setup and some very preliminary results are presented.

1 Astrophysical Motivation

The ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction (Q_{value} = 10.6 MeV) is the main competitor of the ^{22}Ne$(\alpha, \mathrm{n})^{25}$Mg reaction which is the main source of neutron for s-process in low-mass asymptotic giant branch (AGB) stars and in massive stars [1]. Recently it has been found that the uncertainty of the ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction rate affects also the nucleosynthesis of isotopes between ^{26}Mg and ^{31}P in intermediate-mass AGB stars [2]. The ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction rate at astrophysical energies of interest (0.25≥ T ≤ 0.5) is dominated by the 395 keV resonance which has been studied only indirectly leading to a wide range of possible values for its resonance strength (10^{-14} - 10^{-9} eV), see Table 1. A direct measurement of the 395 keV resonance will reduce the wide range of resonance strength values and will be essential to clarify the role of the 395 keV resonance in the ^{22}Ne$(\alpha, \gamma)^{26}$Mg reaction rate.

Lower Limit [eV]	$\omega\gamma[eV]$	Upper Limit [eV]	Reference
1.4 10^{-14}	1.7 10^{-13}	1.6 10^{-12}	Giesen et al. 1993 [3]
-	4.7 10^{-13}	-	Giesen et al. corrected
-	1.4 10^{-13}	1.3 10^{-12}	NACRE 1999 [4]
-	-	3.6 10^{-9}	Iliadis et al. 2010 [5]
-	-	8.7 10^{-15}	Longland et al. 2012 [6]
-	-	3.6 10^{-9}	STARLIB 2013 [7]

Table 1. Values of E_α = 395 keV resonance strength reported in literature

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2 Experimental Setup

The study of the 395 keV resonance of the ^{22}Ne(α,γ)^{26}Mg reaction is already completed at LUNA 400 kV accelerator [8] installed in the underground Gran Sasso Laboratory, where the rock overburden of about 1400 m (3800 m water equivalent) reduces the muon component of the cosmic background by a factor of 10^6 and the neutron component by a factor of 10^3 [9]. The last component remains the most important source of background in the region of interest for the ^{22}Ne(α,γ)^{26}Mg reaction. Two different campaigns were performed at LUNA for the study of the 395 keV resonance. The first one took place during the summer of 2016 and the second one with some improvement in the setup during the spring - summer of 2019.

Both campaigns were performed exploiting the gas target filled with neon gas enriched in the ^{22}Ne isotope to 99.99 %, combined with a high efficiency detection system, the same one used for the study of the ^{22}Ne(p, γ)^{23}Na reaction [10] (See Figure 1).

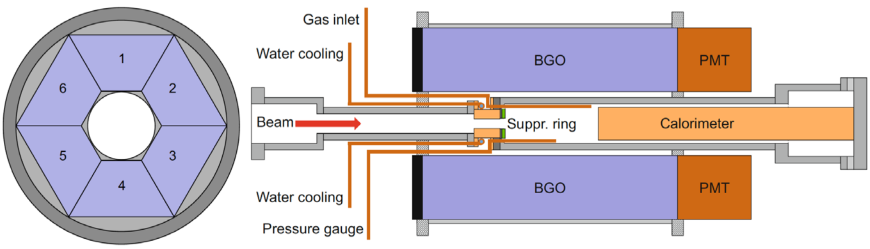

Figure 1. Experimental setup used at LUNA for the study of the ^{22}Ne(α,γ)^{26}Mg reaction with BGO detector.

The high intensity alpha beam was delivered to a diferentially pumped windowless gas target through three pumping stages separated by apertures of increasing flow impedance. The cylinder scattering chamber was partially occupied by the calorimeter on which the beam stopped. The beam current is measured by a constant - gradient calorimeter characterized by two sides, a hot side heated to 70°C by eight thermoresistors and a cold one cooled to -5 °C by a refrigerating system. The intensity of the beam is obtained using the difference in the power required to keep the hot site constant with and without beam. The target chamber and the beam calorimeter were hosted inside the borehole of BGO detector, which consist of six optically independent BGO crystals, each covering an angle of 60 degrees and read out by independent acquisition chains. A homemade software is used for the offline analysis which is able to create in general two types of spectra: First,it creates an addback spectrum using energies from all crystals summed together (events lying in 3.5 s wide window, which are considered coincident). Second, it creates a so-called singles sum spectrum obtained by simply summing the individual histograms.

Thanks to LUNA location, natural background is the main source of background below 3 MeV and in particular the background peaks are used for energy calibration of the BGO detector. Due to possible contaminants in different parts of the setup, another source of background that needs particular attention is the beam induced background, which can produce high-energy γ rays. In order to control the beam induced background for the ^{22}Ne(α,γ)^{26}Mg reaction, runs with argon gas at 0.468 mbar were performed. The pressure of 0.468 mbar of argon was chosen in order to have the same energy loss as in 1 mbar of neon.

The detection efficiency is obtained with 4% uncertainty using Monte Carlo simulations of the setup combined with radioactive sources (^{137}Cs, ^{60}Co and ^{88}Y) at low energies and the ^{14}N(p, γ)^{15}O reaction at the resonance at 278 keV proton energy [10], [11].

3 Preliminary results and future prospective

In Figure 2 the addback spectra in neon and laboratory background during the first campaign are shown [11]. Even if no evident peak in the region of interest was identified, from the first campaign a meaningful upper limit value for the 395 keV resonance strength was estimated. Unfortunately, the accumulated charge for the beam induced background was not enough to be considered in the analysis.

To improve the results from the first campaign [11], a new borated polyethylene shielding was implemented in the second one to reduce by an additional order of magnitude the neutron induced background in the region of interest. Moreover in the second campaign the accumulated charge in neon was increased and in particular a better control of the beam induced background was reached.

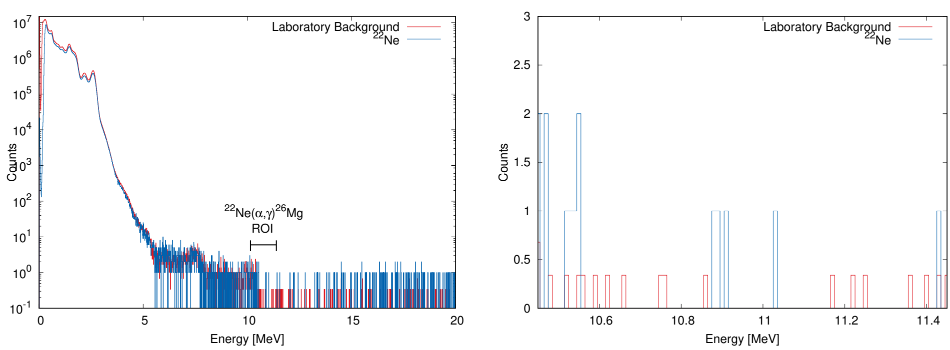

Figure 2. Number of counts as a function of gamma energy for the 395 keV resonance compared with the laboratory background is shown. Left: in blue the sum of all the BGO addback spectra for the study of ^{22}Ne(α, γ)^{26}Mg reaction. In red the laboratory background normalized for the livetime. To better visualize the whole range of energies, a logarithmic scale was chosen. Right: a zoom of the region of interest for the 395 keV resonance is given (linear scale). Both spectra were acquired during the first campaign [11].

4 Summary

The two measurement campaigns of the 395 keV resonance of ^{22}Ne(α, γ)^{26}Mg reaction at LUNA are already completed and the analysis is ongoing. The study was performed by impinging an high intensity α-beam, accelerated to 399.9 keV, on a 99.99% enriched ^{22}Ne target gas at the pressure of 1 mbar. Under these conditions the resonance was populated in the middle of the chamber which corresponds to the maximum detection efficiency. The first campaign reached a sensitivity of 10^{-10} eV on the resonance strength which excludes one of the previous upper limits in the literature making this result very promising. The second campaign will be able to reduce the upper limits by one order of magnitude and finally better constrain the role of the 395 keV resonance on the ^{22}Ne(α, γ)^{26}Mg reaction rate.

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