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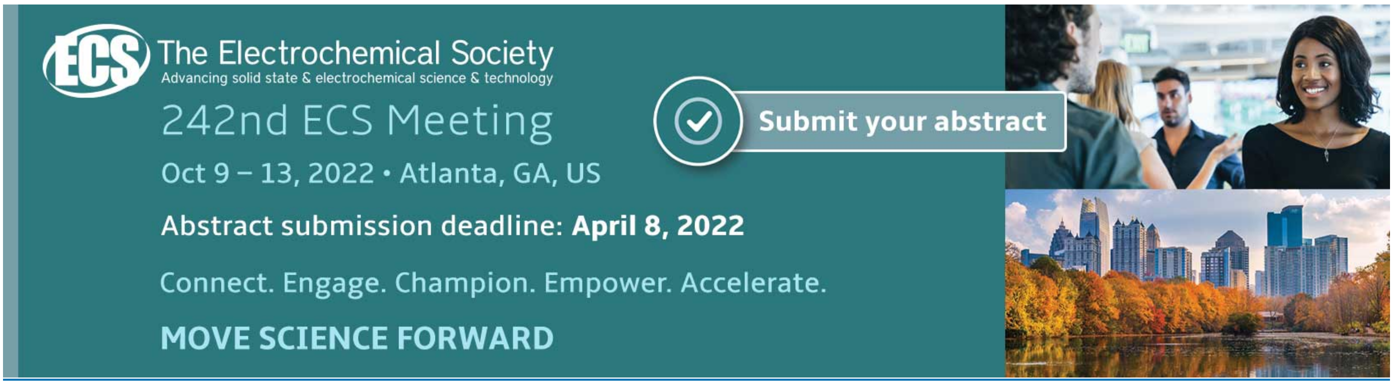

^{22}Ne(p, γ)^{23}Na cross section measurement at astrophysical energies.

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Abstract. A large number of uncertain resonances in the Gamow window make the ^{22}Ne(p, γ)^{23}Na reaction rate the most uncertain in the NeNa cycle. A new direct measurement of the ^{22}Ne(p, γ)^{23}Na reaction has been performed at LUNA (Laboratory for Underground Nuclear Astrophysics), with a windowless gas target. Two complementary setups have been used, to obtain both high resolution and high efficiency measurements. Three new resonances have been discovered at 156.2, 189.5 and 259.7 keV and their decay scheme has been determined. Two tentative resonances at 71 and 105 keV have not been detected and improved upper limits have been put on their strength. Thanks to the high-efficiency setup, it was possible to measure the non-resonant cross section at unprecedented low energies.

1. Introduction

In the innermost regions of asymptotic giant branch (AGB) stars, the temperature can be as high as 0.1 GK and the Hot Bottom Burning Process (HBB) takes place [1]. Advanced hydrogen burning cycles such as the neon-sodium (NeNa) and magnesium-aluminum (MgAl) cycles can significantly contribute to nucleosynthesis in massive stars [2, 3]. The ^{22}Ne(p, γ)^{23}Na reaction, which is part of the NeNa cycle, links ^{22}Ne to ^{23}Na, the only stable isotope of sodium.

In stars on the red giant branch in galactic globular clusters, where the ^{22}Ne(p, γ)^{23}Na is crucial for the synthesis of sodium [4, 5], a neon-sodium anti-correlation was observed. The ^{22}Ne(p, γ)^{23}Na reaction rate affects the result of stellar models intended to reproduce such anticorrelation [2, 6]. A difference as large as three orders of magnitude exists between the rates from the NACRE [7] compilation, and following evaluations by Hale et al. [8], Iliadis et al. [9], and STARLIB [10] in the relevant temperature interval.

A recent measurement [11] in a surface laboratory showed the importance of direct measurements of low-energy resonances and their impact on the thermonuclear reaction rate. LUNA [12] recently studied the ^{22}Ne(p, γ)^{23}Na reaction, observing three new low-energy resonances with two high-purity germanium (HPGe) detectors [13, 14, 15, 16]. The existence of the two lowest out of the three new resonances at E_p = 156.2, 189.5, and 259.7 keV (E_p is the proton energy in the laboratory system) was later confirmed at the Triangle Universities Nuclear Laboratory (TUNL) [17].

In order to measure the cross section at such low energy, new measurements have been performed at LUNA using a high-efficiency setup including a segmented Bismuth Germanate (BGO) detector. The resonances at E_p = 156.2, 189.5, and 259.7 keV have been investigated

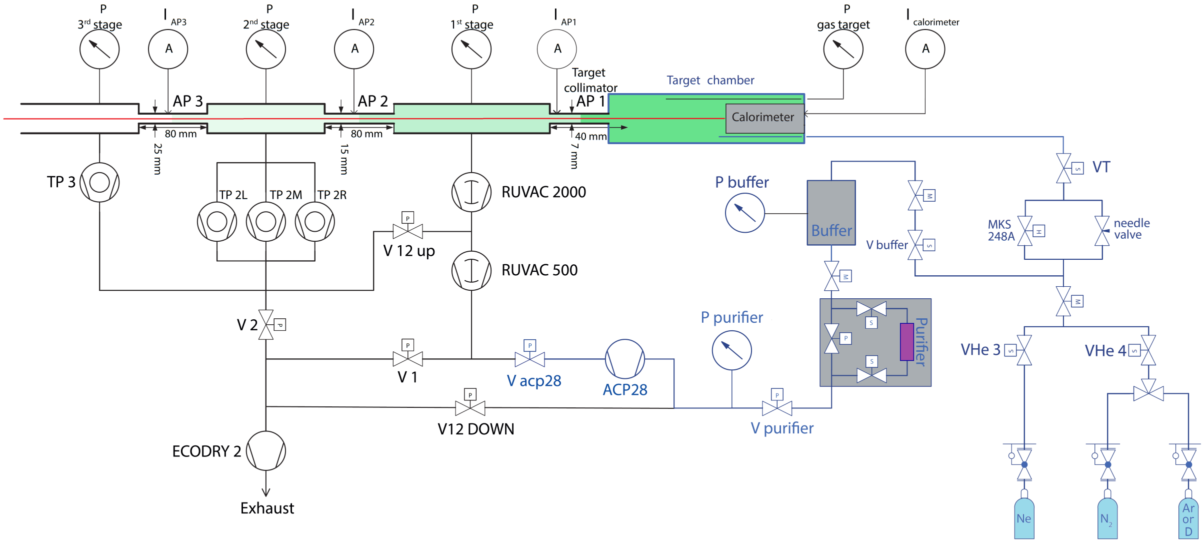

Figure 1. Scheme of the differential-pumping, extended gas target used at LUNA.

further, determining their strength and branching ratios. Two resonances at $E_p = 71$ and 105 keV, reported as tentative in an previous indirect experiments [18] and not confirmed later [8, 19] have been investigated with higher sensitivity with respect to the previous setup. The direct capture contribution, as well as the contribution from a broad sub-threshold resonance have been measured using the high-efficiency setup.

2. Experiment

2.1. Setup

A differential-pumping, extended gas target was used in combination with a $\sim 4\pi$ solid angle coverage BGO detector segmented in 6 parts [20] [21]. Enriched ^{22}Ne ($\geq$ 99.9% pure) was recycled through the pumping system and purified by a chemical getter in order to remove hydrocarbons, oxygen and nitrogen. The density profile was determined measuring pressure and temperature in several position inside the target chamber.

A power compensation calorimeter with constant temperature gradient was used to measure the beam current. Each optically insulated segment of the six-fold BGO detector was coupled to a PMT and independently digitized. Acquired events were time-stamped to allow offline coincidence analysis.

2.2. Measurements

A yield curve was measured varying the beam energy in steps of 1-3 keV for each of the three previously observed resonances [13, 14, 15, 16, 22]. Long runs were taken at a beam energy corresponding to maximum yield. Runs with argon inside the target chamber were taken to properly subtract the beam-induced background.

The beam-induced background was mainly due to the ^{11}B(p, γ)^{12}C reaction and its Compton continuum [21]. The beam-induced background spectrum was scaled for equal counting rate in the 10-19 MeV region, where the contribution of the ^{11}B(p, γ)^{12}C is dominant. Singles spectra, gated on add-back events in the region of interest of the ^{22}Ne(p, γ)^{23}Na reaction, were compared with GEANT4 and GEANT3 Monte Carlo simulations using previously measured branching ratios [15, 21]. A reasonably good agreement was found, but a new evaluation of branching ratios with the BGO detector might uncover the contribution of very weak branches.

To investigate the possible resonances at $E_p = 71$ and 105 keV, many long runs were performed around their nominal energy, in the 63-78 keV and 95-113 keV energy intervals respectively. Since these resonances were not observed, new upper limits were put on their strength. The non-resonant yield was measured at four beam energies, $E_p = 188.0$, 205.2, 250.0, and 310.0 keV to study the contribution by a broad sub-threshold resonance [23] and direct capture.

3. Conclusion

The measured strengths are slightly higher than previous values obtained at LUNA [13, 14, 15, 16, 22] but consistent within 2 σ. Because of the particular setup used in the LUNA-HPGe experiment, the difference may be due to angular distribution effects or weak branches. These effects can only play a minor role in the present LUNA-BGO experiment, thanks to the $\sim 4\pi$ solid angle coverage of the detector and its high efficiency.

The existing uncertainty on the measured strengths and the off-resonance measurements at 250.0 and 310.0 keV is mainly due to the uncertainty on detection efficiency (5% systematic uncertainty). The uncertainty on the off-resonance measurements at 188.0 and 205.2 keV, instead, is mainly due to statistics (9% statistical uncertainty).

A detailed description of the experiment is about to be published.

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