Study of the $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ reaction at LUNA

Antonio Caciolli^{1,2,*} and Sandra Zavatarelli^{3,**} for the LUNA collaboration

¹Physics and Astronomy Department, University of Padova, Via Marzolo 8, 35131, Padova (Italy)

²INFN Section of Padova, via Marzolo 8, 35131, Padova (Italy)

³INFN Section of Genova, Via Dodecaneso, 33, 16146 Genova (Italy)

Abstract. The $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ is the first reaction of the NeNa cycle and having the slowest reaction rate, it controls the speed at which the entire cycle proceeds. This reaction is important in different stellar scenarios such as red giants stars (during H shell-burning), asymptotic giant branch stars, novae, and massive stars. Existing uncertainties on the $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ are now the ones that severely affect the estimated elements production in the NeNa cycle. In particular, such uncertainties affect the amount of produced ^{22}Ne , a stellar γ -ray signature, and ^{22}Ne , an important neutron source in the s-process, via the $^{22}\text{Ne}(\alpha,n)^{25}\text{Mg}$. Here, we propose to study the resonance at $E_R = 366$ keV and to measure the $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ reaction cross section at proton energies below 400 keV, in particular the contribution from the sub-threshold state, in order to better constrain the overall astrophysical rate of this important reaction. In this contribution, the experimental setup will be described and the expected results discussed.

1 Introduction

The NeNa-MgAl cycles are involved in the synthesis of Ne, Na, and Mg isotopes. Proton capture on ^{20}Ne nuclei may occur in different stellar scenarios such as red giants stars (during H shell-burning), asymptotic giant branch stars, novae, and massive stars. These reactions can proceed in these environments if the temperature reaches $T \sim 0.05$ GK [1].

Until recently, the major uncertainty on the NeNa cycle was given by the $^{22}\text{Ne}(p,\gamma)^{23}\text{Na}$ reaction. Now, thanks to the latest LUNA measurements [2–6], it has been reduced to negligible values [7]. As a result, existing uncertainties on the $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ are now the ones that severely affect the estimated elements production in the NeNa cycle.

The $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ reaction has already been studied experimentally by several experiments with results published in referred journals [8–13] with both direct and indirect approaches. In the recent years, two PhD theses have been reported on this reaction from the TUNL and DRAGON nuclear astrophysics groups [14, 15]. Quoted data show some discrepancies on the resonance strength of the 366 keV resonance and only the data in the PhD thesis [15] report cross section data below 400 keV, the range of the LUNA accelerator [16]. For this reason, the LUNA collaboration has decided to approach the study of this reaction by using a gas target [17] with natural neon gas inside the target chamber. In this contribution we describe the setup used at LUNA for the $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ reaction study.

*e-mail: antonio.caciolli@unipd.it

**e-mail: sandra.zavatarelli@ge.infn.it

2 Experimental setup

The setup has been installed at the LUNA400 accelerator facility under the Gran Sasso Laboratories where the shielding of the 1.4 km of rock greatly reduces the cosmic rays flux [18]. The experimental approach followed in this experimental study is equal to the one already adopted in [6]. The proton beam enters the scattering chamber by passing through three apertures that regulates also the differential pumping system allowing to work without any window before the scattering chamber: a possible layer before entering the chamber could deteriorate the beam characteristics introducing problematic uncertainty in the analysis. The beam current is measured by using a calorimeter and the gamma rays emitted by the reaction are detected by two different germanium detectors fully shielded. The Q-value of the $^{20}\text{Ne}(p,\gamma)^{21}\text{Na}$ reaction is about 2.4 MeV and the emitted gamma radiation falls in an energy range dominated by the radioactive decays of the experimental room materials [19]. All systematics related to the gas characterisation and response against beam heating are already well known, since also in the previous experiment a neon gas has been used (with a different isotopical enrichment). The efficiency has been tested again using radioactive calibrated sources and by scanning the 278 keV resonance in the $^{14}\text{N}(p,\gamma)^{15}\text{O}$ reaction. With respect to the setup used in [6], in the actual experiment we have decided to remove internal collimators and to use the scattering chamber as an extended gas target. Recently, the LUNA collaboration have worked with extended gas target to constraint the d+p reaction [20, 21] with optimal results and we have observed by an extensively study with simulations that this configuration can solve the problem related with resonance strength evaluation with important straggling effect [22]. During the data taking in 2021 the resonance has been measured and the correction for beam straggling well evaluated. In this study the branching to different excited states of ^{21}Na have been also detected by combining also the results of the two detectors. A preliminary investigation of the direct capture component has been done demonstrating the feasibility of our study down to 330 keV and even below. A new experimental campaign is foreseen for February 2022 with the aim of investigating the direct capture component. During 2022, the $^{21}\text{Ne}(p,\gamma)^{22}\text{Na}$ reaction will be also studied with the same setup.

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