PROCEEDINGS OF SCIENCE

STUDY OF THE RESONANCES AT 417, 611, AND 632 keV IN THE ^{22}Ne(p,γ)^{23}Na REACTION

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The ^{22}Ne(p,γ)^{23}Na reaction is part of the NeNa cycle of hydrogen burning. This cycle plays a key role in the nucleosynthesis of the elements between ^{20}Ne and ^{27}Al in red giant stars, asymptotic giant stars and classical nova explosions. The strengths of the resonances at proton energies above 400 keV are still affected by high uncertainty.In order to reduce this uncertainty, a precision study of the most intense resonances between 400 keV and 700 keV has been performed at the HZDR 3 MV Tandetron. The target, made of ^{22}Ne implanted in a 0.22 mm thick *Ta* backing, has been characterized using the 1222 keV and 458 keV resonances, well known in literature.Subsequently, the strengths of the resonances at 417, 611, and 632 keV were determined. Two HPGe detectors equipped with active anti-Compton shielding have been used. The uncertainty on the measured resonance strengths has been significantly lowered compared with previous values.

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1. The NeNa cycle of hydrogen burning and the ^{22}Ne(p, γ)^{23}Na reaction.

For those nuclei with mass number A between 20 and 40, in several cases the (p,α) and (p,γ) reactions are in competition with one another. If the branching ratio between the reaction rates $B_{(p,\alpha)}/B_{(p,\gamma)}$ is greater than one, it is possible for a cycle to develop. This is the case of the NeNa cycle, which has a $B_{(p,\alpha)}/B_{(p,\gamma)}$ greater than one in a large temperature interval [5].

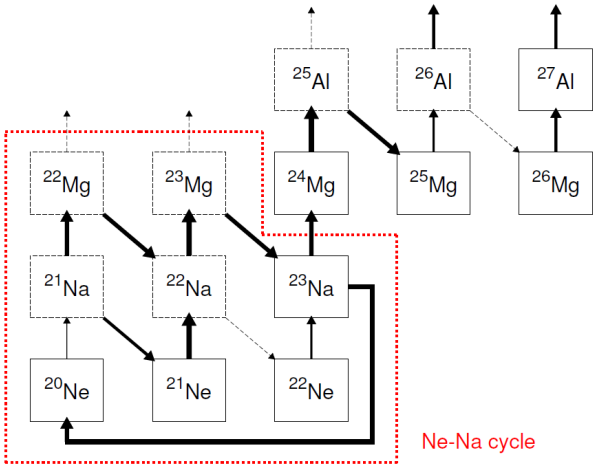

Figure 1: The NeNa cycle and its link to the MgAl cycle.

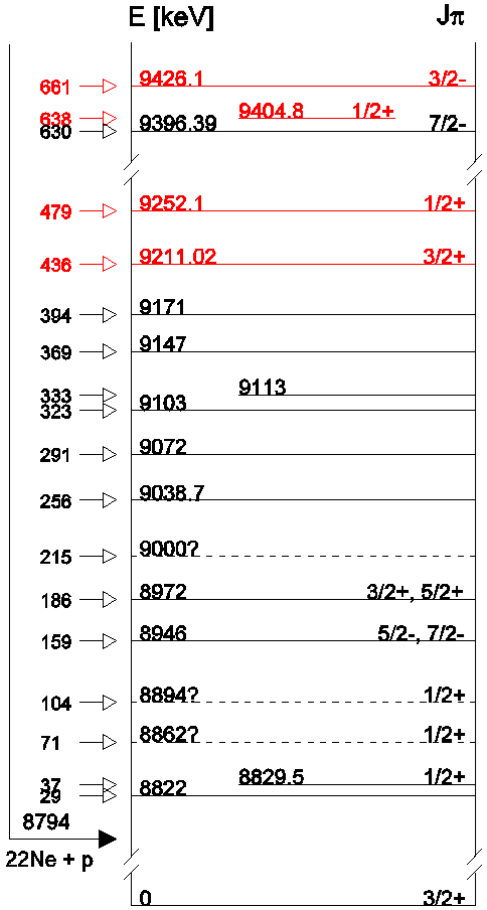

Figure 2: ^{23}Na excited states. On the left are indicated the resonance energies in the laboratory frame of reference.

This cycle greatly affects the abundances of the elements between ^{20}Ne and ^{27}Al produced in red giant branch (RGB) and asymptotic giant branch (AGB) stars and classical novae [6, 7]. The reaction rates for the reactions involved is affected by a large uncertainty due to the lack of knowledge we have about the low-energy resonances in the energy region of interest [8, 3]. In this context, the ^{22}Ne(p, γ)^{23}Na rate is the most uncertain. For temperatures $T_9 \leq 0.5$, the resonances that contributes most to the ^{22}Ne(p, γ)^{23}Na reaction rate are in the energy range between 70 keV and 640 keV and the uncertainty on the reaction rate due to those resonances is as high as 30% [3], if they are known at all.

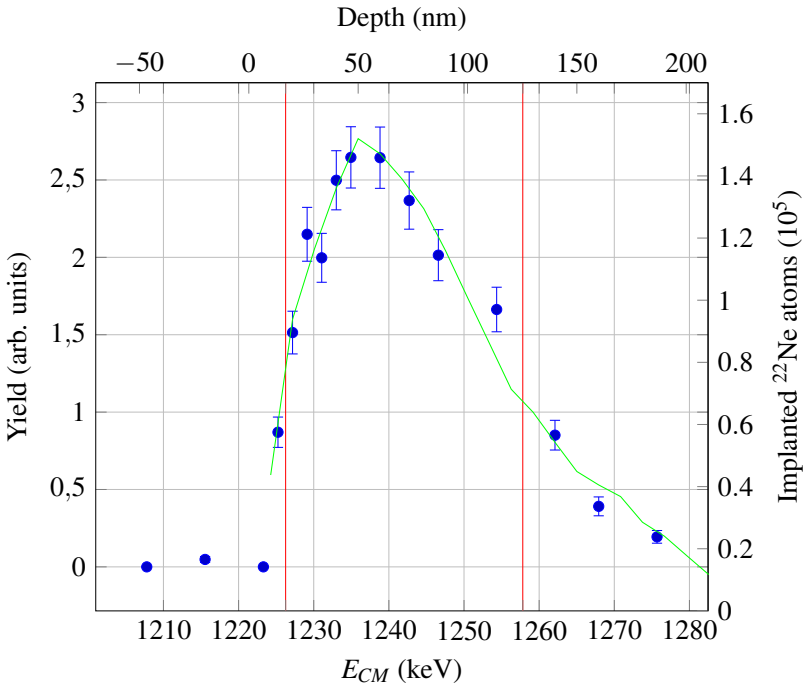

Figure 3: Yield curve ($E_\gamma = 9575.3$ keV) for the $E_{CM} = 1222$ keV resonance at the beginning of the experiment (blue) and simulated implantation profile (green).

2. Experimental method

The measurements of the resonance strengths have been carried out at the 3MV Tandetron accelerator of Helmholtz-Zentrum Dresden-Rossendorf in Dresden, Germany. We used a solid target made of ^{22}Ne implanted in a 0.2 mm thick Tantalum backing, bombarded with a 10 μA proton current. The target was positioned so that the direction orthogonal to its surface makes an angle of 55° with the direction of the beam. The target has been water-cooled and the suppression of secondary electrons has been realized by means of a copper tube connected to a voltage of -100 V. This permitted to measure the charge collected on the target for each run with an uncertainty of 1%.

Two high-purity Ge detectors equipped with active BGO shielding and surrounded by Pb have been placed at 90° and 55° to the beam axis in order to detect γ-rays emitted by the ^{23}Na excited levels. A Pb collimator has been placed in front of each detector to better define the solid angle subtended by the target. The anti-coincidence technique permitted to reduce the background by a factor of ≈ 3 without greatly affecting the full energy peak efficiency. The target scans, performed by using the 1222 keV resonance (energy in the CM frame), permitted to monitor the target stability over the time and to measure the implantation profile. Standard radioactive sources (^{137}Cs, ^{60}Co and ^{88}Y) have been used for the energy and efficiency calibration from 662 keV to 1836 keV, together with the well known ^{27}Al(p,γ)^{28}Si reaction, which permits to extend the energy and efficiency measurements up to 10763 keV. A target scan has been carried out for each resonance and the yield curve has been studied. Subsequently, a long run on the top of the yield curve permitted to measure the reaction yield accurately and determine the strength of each resonance.

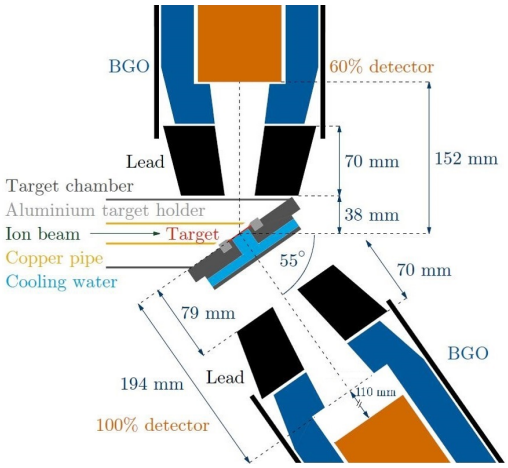

Figure 4: Setup drawing. BGO detectors are used as anti-Compton veto. The lead collimators in front of each detector define the subtended solid angle and shield the BGO from photons emitted by the target.

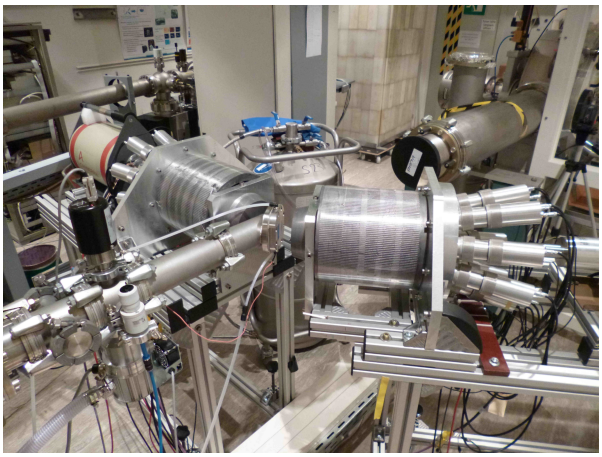

Figure 5: Setup picture. On the left side the target chamber is visible, together with the 60% detector placed at 90° to the beam direction and the target water-cooling pipes. On the right side the 90% detector placed at 55° to the beam direction.

3. Data analysis

The spectra acquired have been analysed and the characteristic peaks of ^{23}Na have been identified. Indicating the resonance energies in the CM reference frame, the Ta/^{22}Ne ratio was determined by normalizing our results to the 1222 keV and 458 keV resonance strengths [3, 4], thus reducing the uncertainty on the stoichiometry, wich turned out to be Ta/^{22}Ne=$7.8 \pm 0.06_{\text{stat}} \pm 0.6_{\text{sys}}$.
All the primary transition peaks have been recognised for the resonances at E_{CM}=417, 611, and 632 keV. The background subtraction was done for each primary transition peak and the total yield have been calculated, using the information on the efficiency and the angular distribution, thanks to the equation

$$Y_{tot} = \frac{e}{Q} \sum_i \frac{N_{\gamma_i}}{W_{\gamma_i} \eta_{\gamma_i}} \tag{3.1}$$

where $\frac{e}{Q}$ is the reciprocal of the total number of incident particles, N_{γ_i}, W_{γ_i} and η_{γ_i} are respectively the number of counts, the angular correlation coefficient and the efficiency of the i^{th} primary transition photon.
The stopping power in ^{22}Ne and *Ta* has been calculated with SRIM and the resonance strengths were determined using the equation

$$Y_{max} = \frac{\lambda^2}{2} \omega\gamma \frac{M+m}{M} \frac{1}{\varepsilon} \tag{3.2}$$

where λ is the De Broglie wavelength, $\omega\gamma$ is the resonance strength, M and m are respectively the masses of the target and the projectile and ε is the effective stopping power in the *Ta* - ^{22}Ne compound.

4. Results

In conclusion, we measure ^{22}Ne(p,γ)^{23}Na resonance strengths for E_{CM}=417, 458, 611, 632, 1222 keV. The final strengths are still under analysis.
This experiment, with the measured resonance strengths, is complementary to the measurements made by LUNA on the same reaction at lower energies [9, 10] and will improve our knowledge of the thermonuclear reaction rate.

Acknnowledgments

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