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Study on low energy resonances in ^{22}Ne (α, γ) ^{26}Mg using the ^{22}Ne + ^{6}Li α-transfer reaction

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While the reaction ^{22}Ne(α,n)^{25}Mg in stellar He burning is considered the dominant neutron source for the s-process in massive stars, the competing ^{22}Ne(α,γ)^{26}Mg reaction may be of considerable strength and significantly reduce the neutron production. The branching ratio of the two reactions and resonance parameters such as levels and strengths in ^{26}Mg produced by α + ^{22}Ne should be experimentally determined with better accuracy. In this work, we studied the feasibility of the ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer reaction to investigate some low energy resonances within the Gamow window (E_α = 400 ~ 1000 keV).

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1. Introduction

Slow neutron-capture (s) process during stellar He burning contributes about half of the elemental abundances between Fe and Bi [1]. The $^{22}Ne(\alpha,n)^{25}Mg$ reaction is thought to be the main neutron source during the s-process in massive stars with $M > 8\ M_{\odot}$ (solar mass) which synthesizes the nuclides in the A = 60 ~ 90 mass range, and also to be the secondary neutron source in low-mass asymptotic giant branch (AGB) stars which synthesizes nuclides in the A= 90 ~ 209 mass range. At typical temperatures of $T_9 = 0.3$ which is relevant to these s-processes, the $^{22}Ne(\alpha,\gamma)^{26}Mg$ reaction competes with the $^{22}Ne(\alpha,n)^{25}Mg$ reaction to significantly suppress the neutron production. Our current understanding of those reaction rates at $E_\alpha = 400 - 1000$ keV (at ^{26}Mg excitation energy $E_x = 10.9 - 11.5$ MeV) which corresponds to the Gamow window is one of the most important sources of uncertainty in the nucleosynthesis of heavy elements and urgently needs to be improved [2].

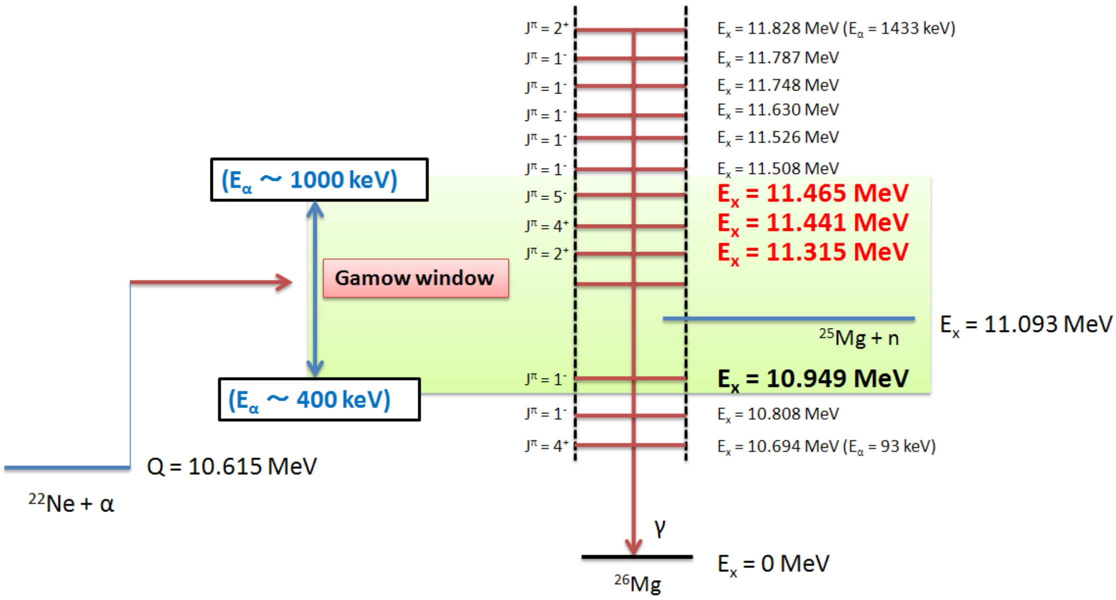


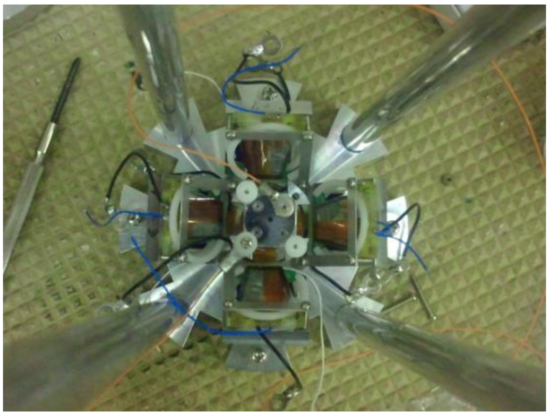
Figure 1: Level scheme of ^{26}Mg showing its high density, the $^{22}Ne + \alpha$ entrance channel and the two competing exit channels ^{25}Mg + n and $^{26}Mg + \gamma$. E_x and J^π values were taken from [3, 4].

The two competing reactions have been investigated by direct measurements and several resonances have been reported in the energy range of $E_\alpha = 0.8 - 2.25$ MeV [5, 6, 7, 8]. However, due to the Coulomb barrier, the cross section and details of the resonances remain uncertain for lower energies. Previous transfer reaction studies using the $^{22}Ne(^6Li, d)^{26}Mg$ reaction [4, 9], neutron radiative capture $^{25}Mg(n, \gamma)^{26}Mg$ [10, 11, 12, 13], a photoneutron measurement [14], and $^{26}Mg(\gamma, \gamma')^{26}Mg$ measurements [15, 16, 17] indicate a high level density of ^{26}Mg and more resonance states with information on spin (J), parity (π), and partial waves (Γ_n, Γ_γ, Γ_α). Some of their results are summarized in Fig. 1.

Presently, ambiguities of some resonance states in the Gamow window (E_x = 10.9 - 11.3 MeV; E_α = 400 - 1000 keV) which expectedly play significant roles in the neutron production in the s-process have shown considerable differences between some experiments. For instance, the energy level corresponding to the E_α ~ 830 keV (E_x ~ 11.3 MeV) resonance reported by [5, 7, 8, 9] has not been clearly identified in $^{25}Mg(n, \gamma)^{26}Mg$ measurements [12]. In this work, we studied the feasibliity of $^{6}Li(^{22}Ne, ^{26}Mg)d$ α-transfer reaction to investigate these resonance levels identifying possible $^{22}Ne + \alpha$ resonances. This reaction selectively populates natural-parity states in ^{26}Mg and the observed α-unbound states should, therefore, correspond to resonances for α-capture on ^{22}Ne. This technique will also lead to a future experiment to directly measure the branching ratio between the γ-ray and neutron emission channels by separating the outgoing ^{26}Mg and ^{25}Mg.

2. Development of detector systems and experimental setup

The $^{6}Li(^{22}Ne, ^{26}Mg)d$ α-transfer experiment was performed using a 110 MeV ^{22}Ne beam from the JAEA (Japan Atomic Energy Agency) -Tokai tandem accelerator. The energies of recoil deuterons were measured to determine the excitation energy of ^{26}Mg. Although previous $^{22}Ne(^{6}Li, d)^{26}Mg$ studies obtained important information about resonances of ^{26}Mg at E_x = 9.3 – 12.1 MeV, insufficient energy-resolution and deuteron background from indirect reaction prevented them from resolving some peaks clearly [4, 9]. To improve the resonance spectra, we attempted to remove the deuteron background by coincidence detection of ^{26}Mg and deuteron in inverse kinematics (i.e, $^{6}Li(^{22}Ne, ^{26}Mg)d$).



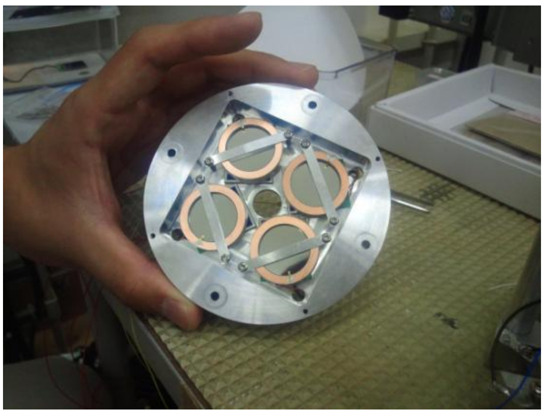


Figure 2: Photographs of the Si ΔE-E detector systems for detecting deuteron (left, ΔE with 70 μm thickness) and Mg (right, ΔE with 20 μm thickness), respectively. In both systems, the same E detectors with 300 μm thickness were used and placed immediately behind the ΔE detector (not seen in the photos, see also the setup in Figure 3).

A $^{6}Li_2CO_3$ (95% enriched) target (20 μg/cm^2) on a carbon foil (20 μg/cm^2) was exposed to 10 particle nA ^{22}Ne beam with the size of ϕ = 1 mm. Focusing the beam size to ϕ = 1 mm was essential to optimize the energy resolution by limiting the angular acceptance of the reaction products. This was achieved by using double Ta slits placed before the target.

Two sets of four Si ΔE-E detectors with sensitive areas of ~ 4 cm^2 were placed at θ_{cm} = 25° (in center of mass frame), corresponding to θ = 3° and -130° with respect to beam direction in laboratory frame for the detection of Mg and deuteron, respectively. The detectors for Mg were covered by aluminium plates with apertures of ϕ = 1.1 mm to limit the angular acceptance and to suppress elastic scattering components. The detection systems for Mg and deuterons are shown in Fig. 2.

In Fig. 3, a schematic view of our experimental set up is described.

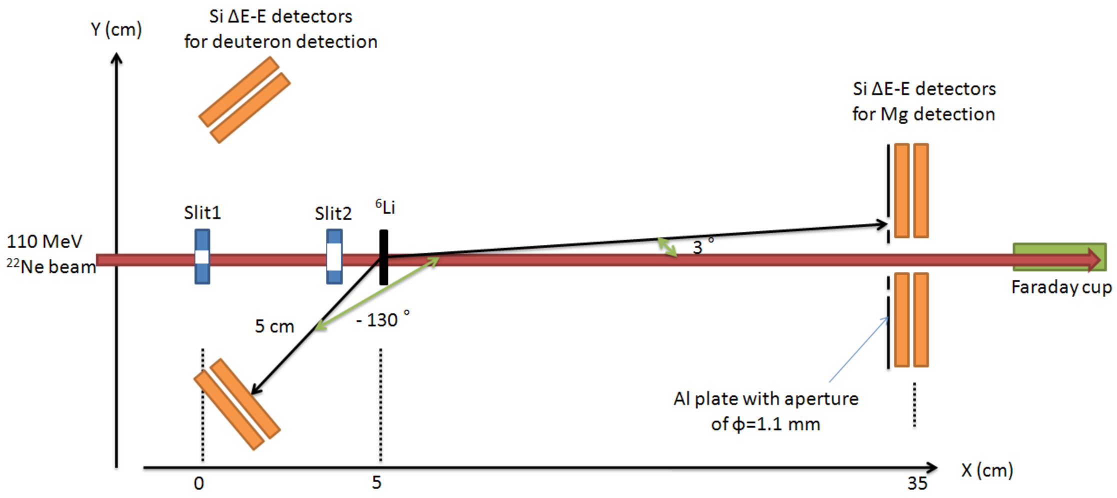


Figure 3: Schematic view of the experimental set up.

3. Results

Figure 4 show the E-ΔE plots of particles observed in the deuteron and Mg detectors, respectively. They enable us to easily identify deuterons and Mg from other particles. The energy resolution of the deuteron detectors was 65 keV (ΔE+E total) measured immediately following the beam irradiation using a ^{241}Am α source. While charge identification of the detected particles in the Mg detector can be possible, mass separation of Mg isotopes is unfortunately not enough.

The E-ΔE plot of coincidence events in Mg detector with deuteron detector is shown in Fig. 5. Therein, the coincidence events with deuteron are marked in red. It is obvious that we succeeded in detecting the expected Mg-d coincidence events. We also ascertained that the obtained yield of Mg-d coincidence gave roughly good agreement with the expected values using the ^{22}Ne(^{6}Li, d)^{26}Mg cross section data [9]. Thus we concluded that the ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer experiment can be a good tool to search for resonance levels of ^{22}Ne + α reactions in the Gamow window at stellar He burning in massive stars. However, poor statistics made a clear resonance assignment of ^{26}Mg difficult from the deuteron energy spectrum in this work. In a future experiment, we are therefore planning to obtain the more precise resonance information of ^{26}Mg within the Gamow window with improved statistics.

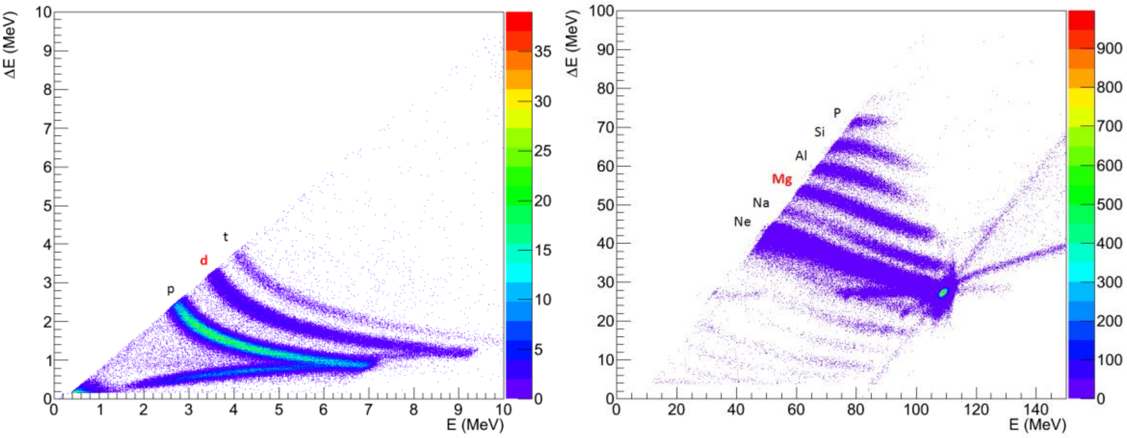


Figure 4: (Left) E-ΔE plot of light particles observed in the detectors at θ = -130°. (Right) E-ΔE plot of heavy particles observed in the detectors at θ = 3°.

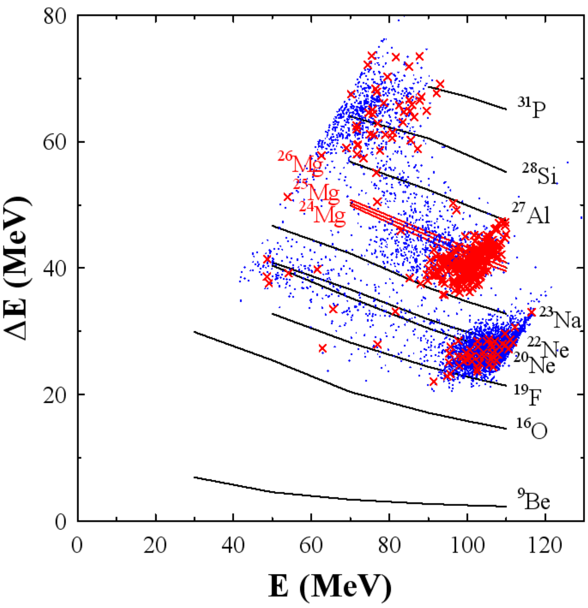


Figure 5: E-ΔE plot of the Mg detector in coincidence with events in the deuteron detector (blue). The coincidence events with deuteron are plotted in red.

4. Summary

We investigated the ^{6}Li(^{22}Ne, ^{26}Mg)d α-transfer reaction to search for resonance levels of ^{22}Ne + α reactions in the Gamow window for stellar He burning in massive stars. Coincidence detection of Mg and deuterons was achieved leading to an improvement of the resonance spectra of ^{26}Mg measured by previous ^{22}Ne(^{6}Li, d)^{26}Mg experiments by reducing the deuteron background from indirect reactions. However, poor statistics made a clear resonance assignment difficult in this work. In a next experiment, we plan to obtain a more precise resonance spectra of ^{26}Mg with improved statistics. Furthermore, this technique will also lead to a future experiment to directly measure the branching ratio between γ- and neutron-emission channels by separating the outgoing ^{26}Mg and ^{25}Mg particles.

Acknowledgments

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References

[1] F. Kappeler et al., Rev. Mod. Phys, 83 (2011) 157.

[2] A. I. Karakas et al., Astrophys. J. 643 (2006) 471.

[3] R. Longland et al., Phys. Rev. 85 (2012) 065809.

[4] C. Ugalde et al., Phys. Rev., C 76 (2007) 025802.

[5] K. Wolke et al., Z. Phys. A 334 (1989) 491.

[6] V. Harms et al., K. –L. Kratz, and M. Wiescher, Phys. Rev. C 43 (1991) 2849.

[7] Drotleff et al., Astrophys. J. 414 (1993) 735.

[8] M. Jaeger et al., Phys. Rev. Lett. 87 (2001) 202501.

[9] U. Giesen et al., Nuc. Phys., A, 561 (1993) 95.

[10] T. A. Walkiewicz et al., Phys. Rev. C 45 (1992) 1597.

[11] H. Weigmann, R. L. Macklin, and J. A. Harvey, Phys. Rev. C 14 (1976) 1328.

[12] P. E. Koehler et al, Phys. Rev. C 66 (2002) 055805.

[13] C. Massimi et al., Phys. Rev. C 85 (2012) 044615.

[14] B. L. Berman, R. L. Van Hemert and C. D. Bowman, Phys. Rev. Lett. 23 (1969) 386.

[15] R. Schwengner et al., Phys. Rev. C 79 (2009) 037303.

[16] R. Longland et al., Phys. Rev. C 80 (2009) 055803.

[17] R. J. deBoer et al., Phys. Rev. 82 (2010) 025802.