Study of astrophysically important low-energy resonances in α + ^{22}Ne reaction using ^{6}Li(^{22}Ne,^{26}Mg)*d* alpha transfer with TIARA and MDM spectrometer

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In core He burning and C-shell burning of massive stars (> 8 solar mass), the ^{22}Ne(α,n)^{25}Mg reaction is considered to be a dominant neutron source for the weak s-process during which nuclides in the A=60-90 mass range are produced [1]. The reaction also largely contributes to the neutron production for the main s-process in He-low and intermediate mass asymptotic giant branch (AGB) stars during which nuclides in the A~90-209 are produced [1]. Some attempts to experimentally determine the rate for this reaction at the Gamow window corresponding to the *s* process temperatures (T = 0.2-0.3 GK, equivalent to E_α = 400 – 900 keV, where E_α is energy of α particle in the laboratory system, and E_x=10.9-11.5 MeV, where E_x is excitation energy of ^{26}Mg) have been made through direct (^{22}Ne+^{4}He or α+^{22}Ne) measurements [e.g., 2]. However, they have been hindered by the small cross section due to the Coulomb barrier and the resonance at E_α ~ 830 keV (E_x ~ 11.32 MeV in ^{26}Mg excitation energy) is the lowest resonance identified with this method. Although indirect methods such as ^{26}Mg(α,α')^{26}Mg, ^{22}Ne(^{6}Li,*d*)^{26}Mg, ^{25}Mg(n,γ), ^{26}Mg(γ,γ') reactions [e.g., 3-6] have been used to identify lower-energy resonances, there remain many uncertainties in spin-parity (J^π), partial wave widths of respective decay channels (Γ_γ, Γ_n and Γ_α) of these resonances. Since past studies identified particularly two resonances, E_x=11.32 and 11.17 MeV above neutron separation energy (S_n=11.093 MeV), have the largest contribution to the neutron production during the s-process, unambiguously determining J^π, Γ_γ, Γ_n and Γ_α for these resonances is important.

To determine these resonance parameters, we performed an experiment using the ^{6}Li(^{22}Ne,^{26}Mg)d α-transfer reaction. Because both the α and ^{22}Ne have ground states with $J^\pi=0^+$, the α-transfer reaction preferentially populates natural parity states in ^{26}Mg. This helps us to enable studies of the resonance parameters of astrophysically relevant natural parity states in ^{26}Mg, and J^π of these resonance states can be determined by measuring the angular distribution of deuterons. Furthermore, the inverse kinematics approach enables us to determine Γ_n / Γ_γ by direct measurements of the ratio of produced ^{25}Mg (^{26}Mg*$\rightarrow$^{25}Mg$_{g.s.}$ + n) and ^{26}Mg (^{26}Mg*$\rightarrow$^{26}Mg$_{g.s.}$ + γ) ions at the resonance states. Determining Γ_n / Γ_γ is important to understand the neutron yield of these resonances. The ^{22}Ne(α,γ)^{26}Mg reaction can be of considerable strength to compete with the ^{22}Ne(α,n)^{25}Mg reaction at E_x=11.32 and 11.17 MeV resonances and therefore could significantly suppress neutron production for the s-process.

The experiment was performed at Cave 3 using a 7 MeV/u ^{22}Ne beam from the K150 cyclotron. ^{6}Li-enriched (99%) lithium flourite (LiF) targets with the thickness of 30 μg/cm^2 on a graphite backing foil (10 μg/cm^2) were prepared so that the effect of the energy loss of the ^{22}Ne beam and deuterons in those materials on the final energy resolution will be negligibly small. The beam bombarded the target at an intensity of about 3 nA for about 10 days. A large Si detector array, TIARA [8] was used for measuring the energies and angular distribution of light particles (deuterons). The deuteron energies and angles were used to determine excitation energies of ^{26}Mg. TIARA consists of two types of Si detectors, Hyball and Barrel, which cover 145 – 170° and 40-145° in laboratory frame, respectively (see [8]). TIARA was surrounded by four HPGe clover γ-ray detectors, which were used to confirm the populated states of ^{26}Mg. Recoil Mg ions were delivered to the Oxford ionization chamber placed at the back of the MDM spectrometer at 0°with ±2°acceptance [9]. The Oxford chamber consists of four proportional wire counters to determine the trajectories of particles and two MicroMegas detectors to measure the deposited energies in the gas (see details in [10]). The chamber was filled with isobutene gas at 35 torr to stop the Mg ions with the energies of our interests in the region of the second MicroMegas detector. The first and the second MicroMegas detectors thus provide ΔE and E_{res} (residual energy), respectively, and the Mg ions are clearly identified from other elements as shown in [11]. Moreover, ^{26,25}Mg isotopes were identified from each other based on the hit positions on the second wire which is located near the focal plane.

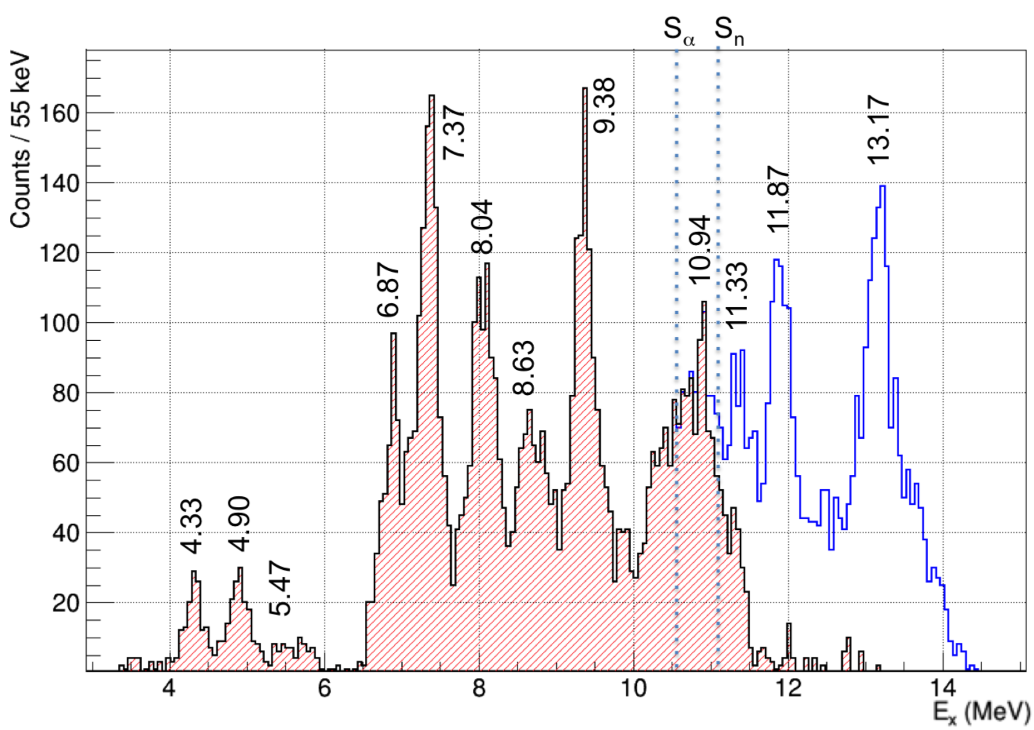

FIG. 1. ^{26}Mg excitation energy spectrum (red shadow: contribution from ^{22}Ne(^{6}Li,d)^{26}Mg, blue: sum of contributions from ^{22}Ne(^{6}Li,d)^{26}Mg and ^{22}Ne(^{6}Li,d+n)^{25}Mg). E_x=11.32 MeV resonance peak is distinct in both spectra.

^{26}Mg excitation spectrum measured with the Hyball is shown in Fig. 1. It is evident that we observe the resonance of our interest (E_x=11.32 MeV) and we concluded the branching ratio of Γ_n / Γ_γ = 1.25±0.28. This result indicates Γ_n / Γ_γ is overestimated in past direct measurements (Γ_n / Γ_γ = 3.8±0.9), which performed the (α,n) and (α,γ) measurements independently. Fig. 2 shows angular distribution of E_x=11.32 MeV resonance and some low-lying excitation states, together with DWBA calculations assuming various J^π for comparison. We can confirm the calculations assuming the known J^π agrees with our date well. Although it is not possible to assign definite J^π to the E_x=11.32 MeV resonance among possible J^π =0+, 1-, 2+, we concluded that $J^\pi = 2^+$ is the most probable by comparing spectroscopic factors and resonance strength extracted assuming these J^π with results by past measurements, (see [12] for details).

Currently we are making an effort to evaluate effects of our new results on s-process chemical abundances.

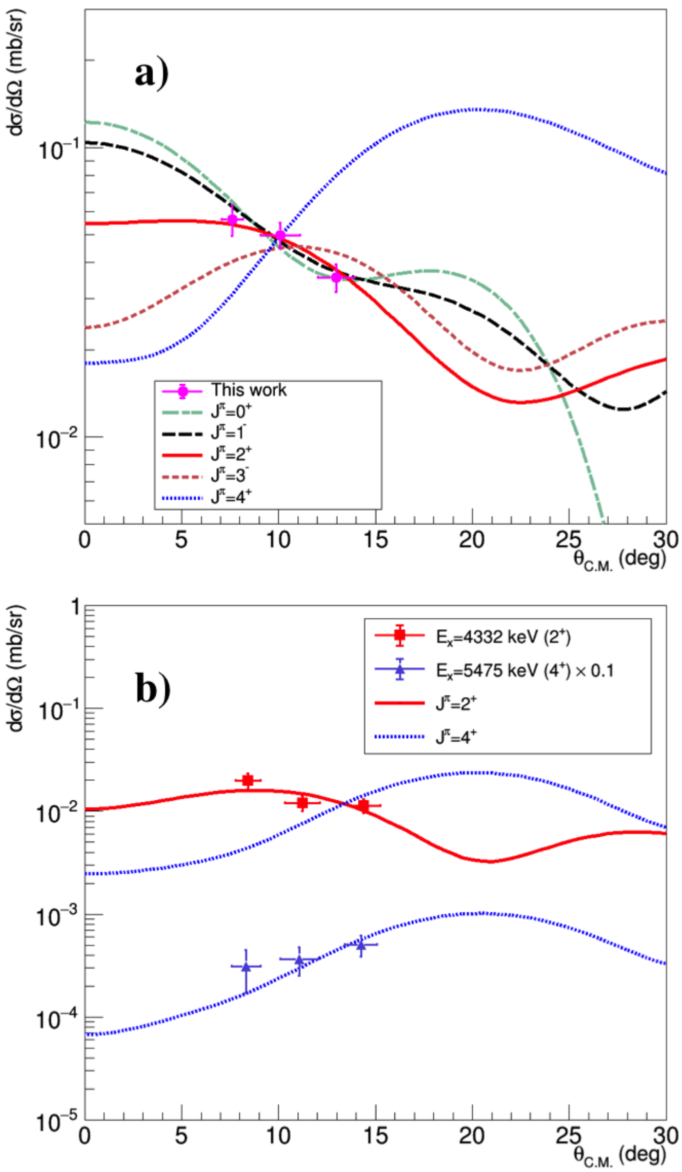

FIG. 2. Angular differential cross sections of a) Ex=11.32 MeV, b) low-lying states where J^π are well established from past measurements, together with DWBA calculations.

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