Decay properties of ^{22}Ne + α resonances 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 plays a secondary role in 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]. While various attempts to experimentally determine the rate for this reaction at the *s* process temperatures (T = 0.2-0.3 GK, equivalent to $E_{\alpha,\mathrm{lab}}$ = 400 – 900 keV, namely, E_x=10.9-11.5 MeV in the excitation energy of ^{26}Mg) have been made by direct (^{22}Ne+^{4}He or α+^{22}Ne) measurements [e.g., 2], they have been hindered by the small cross sections due to the Coulomb barrier. Thus the resonance at $E_{\alpha,\mathrm{lab}}$ ~ 830 keV (E_x ~ 11.32 MeV) 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., 3-7] have been used to identify lower-energy resonances, there remain many uncertainties in spin-parity (J^π), partial 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 impact on the neutron production during the s-process [e.g., 7], 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 with a large Si detector array, TIARA [8], and HPGe detector array, and the MDM spectrometer [9,10]. 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 selectively study 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*→^{25}Mg + n) and ^{26}Mg (^{26}Mg*→^{26}Mg + 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 competes with the ^{22}Ne(α,n)^{25}Mg reaction at E_x=11.32 and 11.17 MeV resonances and therefore may 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 (95%) lithium fluoride (LiF) targets with the thickness of 30 μg/cm^2 on a graphite backing foil (10 μg/cm^2) were prepared and bombarded with the beam at an intensity of about 3 nA. Details of the experiment can be found in [11].

The ^{26}Mg excitation spectrum measured in the present experiment is shown in Fig. 1 [12]. It is evident that the resonance of our interest (E_x=11.32 MeV) is clearly observed and we concluded the branching ratio of Γ_n / Γ_γ = 1.14±0.26 from the ratio of ^{25}Mg/^{26}Mg ions observed by the MDM at the resonance energy after the efficiency correction. This result indicates Γ_n / Γ_γ is largely overestimated in past direct measurements as discussed below, which performed the (α,n) and (α,γ) measurements independently. Since the (α,γ) resonance of the resonance is relatively well constrained as 37±4 μeV [13,14], whereas (α,n) strength has large discrepancies among the past measurements, (α,n) strength was determined by multiplying the (α,γ) strength with the Γ_n / Γ_γ obtained in the present work. The obtained (α,n) strength is thus 42±11 μeV, which is much smaller than the past measurements (inflated weighted average of 140±30 eV [7]). The (α,γ) and (α,n) strengths of the E_x=11.17 MeV resonance are estimated from the Γ_α determined by [15] with the branching ratio (Γ_n / Γ_γ=0.2-0.6) and the J^π (2^+) from [6]. Fig. 2 shows the final stellar reaction rates (as a ratio to ones by Longland *et al.* [7]) as a function of stellar temperature. It is clearly seen that the obtained new reaction rates are about 3 times lower than the values conventionally used in the past nuclear astrophysics studies in the s-process temperature range.

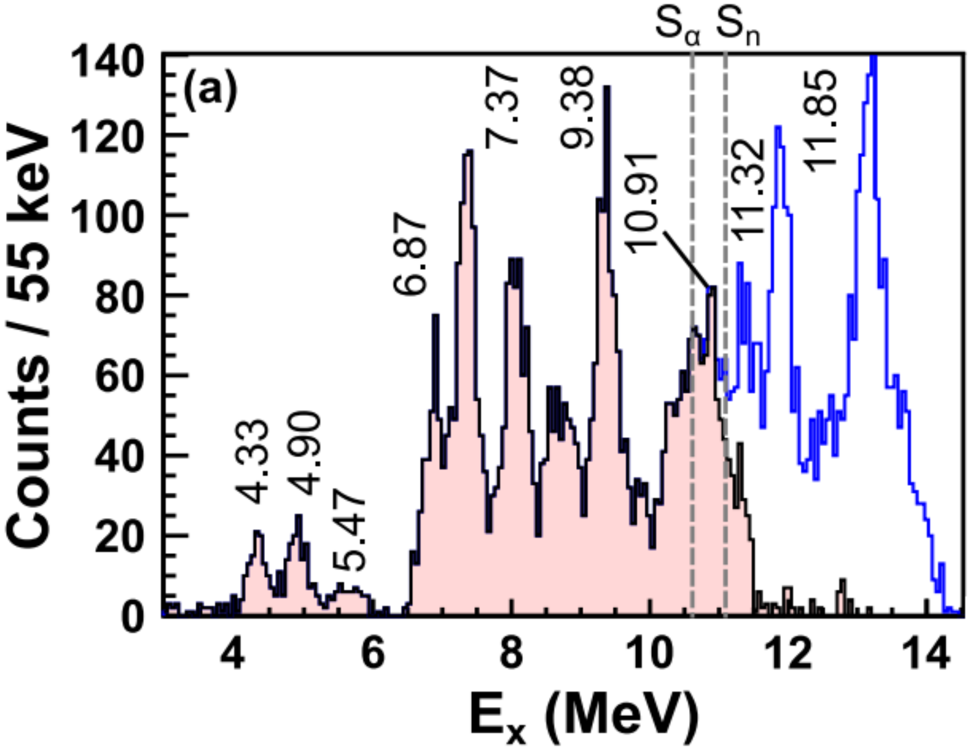

Fig. 1. ^{26}Mg excitation energy spectrum (red shadow: contribution from ^{22}Ne(^{6}Li,d)^{26}Mg, blue: sum of contributions from ^{22}Ne(^{6}Li,d)^{26}Mg and ^{22}Ne(^{6}Li,d+n)^{25}Mg). E_x=11.32 MeV resonance peak is distinct in both spectra.

Currently we are evaluating effects of our new results on s-process chemical abundances, and the results will be published soon.

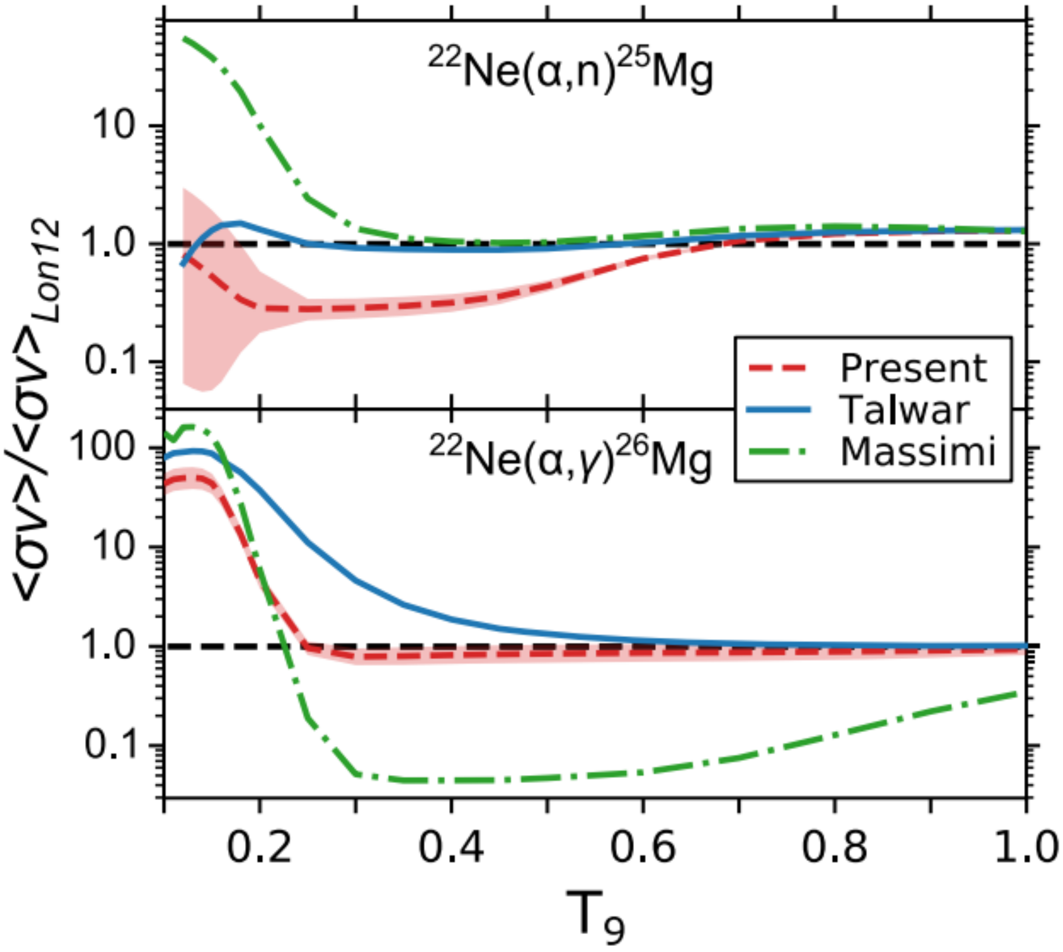

Fig. 2. Ratios of stellar reaction rates to Longland *et al.* [7] for ^{22}Ne(a,n)^{25}Mg (top) and ^{22}Ne(a,g)^{26}Mg (bottom) reactions as a function of temperature (in unit of GK).

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