Study of the astrophysical α + ^{22}Ne reaction using ^{6}Li(^{22}Ne,^{26}Mg)*d* alpha transfer with TIARA and the MDM spectrometer

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In the He-burning phase of massive stars, the ^{22}Ne(α,n)^{25}Mg reaction is considered to be a main neutron source driving the synthesis of nuclides in the A=60-90 mass range during the *s* process [1]. A variety of attempts to experimentally determine the rate for this reaction in the Gamow window corresponding to *s* process temperatures (T = 0.2-0.3 GK) have been made either through direct ^{22}Ne(α,n)^{25}Mg measurements [2] or indirect measurements such as ^{22}Ne(^{6}Li,*d*)^{26}Mg [3-5]. However, direct measurements have been hindered by the small cross section due to the Coulomb barrier and the resonances at $E_α$ < 830 keV ($E_α$: energy of α particle in the laboratory system) have not been identified with this method. The indirect measurements have identified many low-energy resonances, but unambiguous determination of the resonance parameters such as spin-parity ($J^π$), partial wave widths of respective decay channels (Γ_γ, Γ_n and Γ_α) in ^{26}Mg produced by α + ^{22}Ne has remained a longstanding problem, especially for resonances near the Gamow peak ($E_α$ = 400 – 1000 keV). Of these uncertainties, the ratio of Γ_n and Γ_γ to determine the branching ratio of *n* and γ emission channels plays an important role in obtaining the neutron yield for the *s* process. The ^{22}Ne(α,γ)^{26}Mg reaction (Q=10.615 MeV), which competes with the ^{22}Ne(α,n)^{25}Mg reaction (open above the excitation energy of ^{26}Mg, E_x=11.093 MeV), may be of considerable strength and could significantly suppress neutron production during He burning (E_x=10.9-11.5 MeV). To address this problem, we performed an experiment using the ^{6}Li(^{22}Ne,^{26}Mg)d α-transfer reaction in this work. Because both the α and ^{22}Ne have ground states with $J^π=0^+$, the α-transfer reaction preferentially populates natural parity states in ^{26}Mg. This helps to enable studies of the resonance parameters of astrophysically relevant natural parity states in ^{26}Mg. Furthermore, the inverse kinematics approach enables us to determine Γ_n / Γ_γ by direct measurements of the ratio of produced ^{25}Mg and ^{26}Mg ions.

We performed the experiment at Cave 3 using a 7 MeV/u ^{22}Ne beam from the K150 cyclotron. ^{6}Li-enriched (99%) lithium flouride (LiF) targets with a thickness of 30 μg/cm^2 on a graphite backing foil (10 μg/cm^2) were prepared so that the energy loss of the ^{22}Ne beam and deuterons in those materials will be negligibly small. The beam bombarded the target at an intensity of about 3 nA for about 10 days. Recoil Mg ions were transported to the Oxford ionization chamber at the back of the MDM spectrometer [6]. 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 [7]). Since the Mg ions are stopped inside the chamber and the first and the second MicroMegas detectors provide ΔE and E_{res} (residual energy), respectively. The Mg ions are clearly identified from other elements using a conventional E-ΔE technique as shown in Fig. 1. Furthermore, it was found ^{26,25}Mg isotopes were clearly identified from each other based on the focal plane positions (Fig. 2). A large Si detector array, TIARA [8] surrounded by four HPGe clover detectors, was used for particle identification and measuring the angular distribution of light particles (deuterons). The energies of deuterons were measured to determine excitation energies of ^{26}Mg and the background events such as compound nucleus reaction were minimized to be negligibly small in the data by requiring the coincidence detection of Mg ions and deuterons.

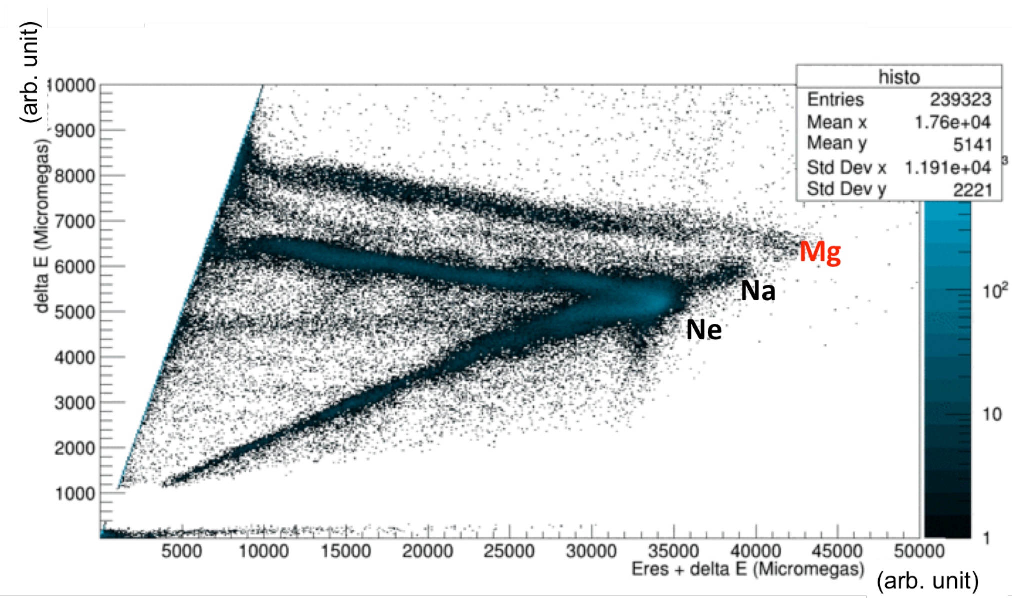

FIG. 1. Particle identification of Mg ions using a conventional E-ΔE method. Mg ions are stopped inside the Oxford chamber and ΔE and E_{res} signals are obtained from the deposited energies in two MicroMegas detectors, respectively.

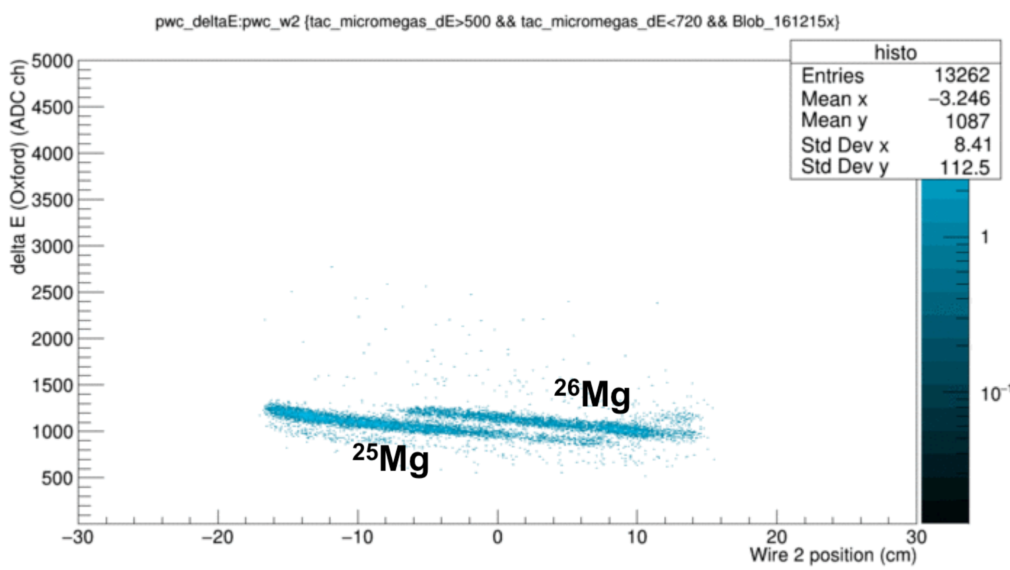

FIG. 2. Isotope separation of ^{25,26}Mg ions based on positions detected in the second proportional wire of Oxford chamber.

Currently, further data analysis combined with all the data from TIARA, Ge detectors, and Oxford chamber is ongoing. Fig.3 shows the preliminary ^{26}Mg excitation energy spectra gated on ^{26}Mg and ^{25}Mg (produced by neutron emission of ^{26}Mg above the neutron separation energy (S_n)), respectively. While some resonance peaks are clearly confirmed, the expected four resonance states in the Gamow window are not resolved yet. After some corrections for, e.g., beam position and energy losses in Si dead-layers and targets are made, however, further improvement of energy resolution will be achieved. We expect various resonance parameters of ^{26}Mg in the Gamow peak such as J^{π}, E_x, Γ_n, Γ_γ will be elaborated shortly to study the s-process neutron source.

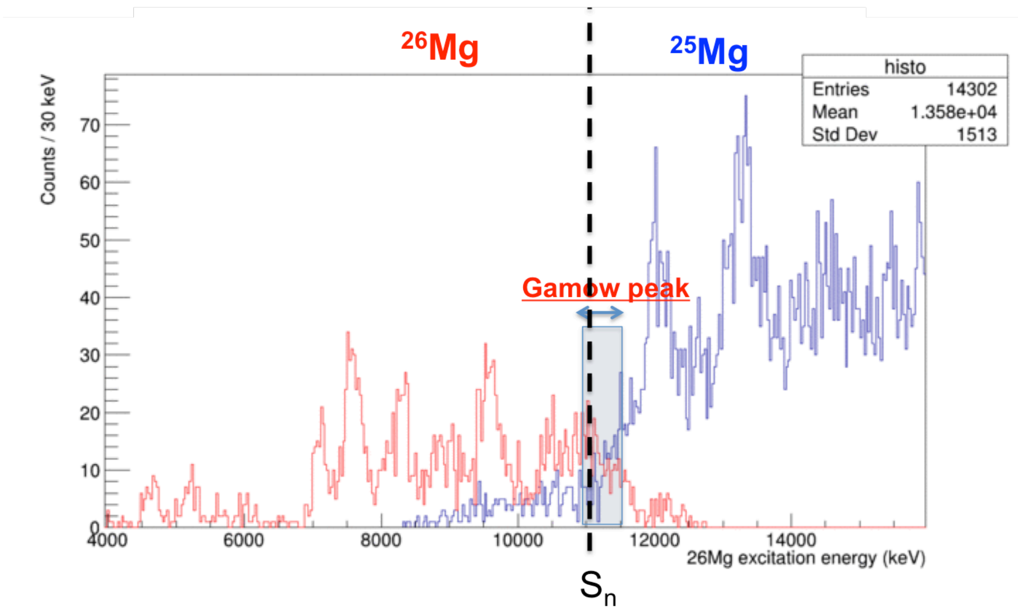

FIG. 3. ^{26}Mg excitation energy spectrum from the preliminary online data analysis. Four resonance peaks are expected in the Gamow peak window.

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