Experimental study of astrophysically important $^{22}Ne(\alpha,n)^{25}Mg$ reaction via $^{22}Ne(^{6}Li,d)^{26}Mg$ at sub-Coulomb energies

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The $^{22}Ne(\alpha.n)^{25}Mg$ reaction is one of the two main neutron source reactions for the slow neutron capture process (s-process) in Asymptotic Giant Branch (AGB) stars. The s-process is responsible for the formation of about half of the elements heavier than Iron [1]. The $^{22}Ne(\alpha.n)^{25}Mg$ reaction is dominant for the weak component of the s-process during the helium burning and carbon-shell burning phases of an AGB star [2]. The present one-two orders of magnitude uncertainty in the $^{22}Ne(\alpha.n)^{25}Mg$ reaction rate at 0.1-0.3 GK has significant implication on the final abundances of the s-process isotopes.

The direct measurement for this reaction is difficult to carry out due to its small cross section at energies relevant for nuclear astrophysics. The goal of this project is to constrain the $^{22}Ne(\alpha.n)^{25}Mg$ reaction rate using α-transfer reaction $^{22}Ne(^{6}Li,d)^{26}Mg$ and $^{22}Ne(^{7}Li,t)^{26}Mg$ by measuring the partial α widths of the near α-threshold excited states in ^{26}Mg, that play a key role for the $^{22}Ne(\alpha.n)^{25}Mg$ reaction. Performing the α-transfer reaction at sub-Coulomb energies for both the entrance and exit channels significantly reduces the model dependence of the extracted partial α widths

The experiment was carried out using 1.0 MeV/u ^{22}Ne beam produced by the K150 cyclotron and the Multipole-Dipole-Multipole (MDM) Spectrometer. We used a LiF target of thickness 30 ug/cm^2 on a ^{12}C backing of thickness 10 ug/cm^2. The MDM Spectrometer was placed at 5^0 from the beam axis and the magnetic field was set to measure the deuterons populating the 10.6 -11.5 MeV excitation energy range of ^{26}Mg corresponding to the Gamow energy window. These deuterons were observed using the focal plane detector (Oxford). This experiment had an energy resolution of around 100 keV.

Silicon detectors placed in the target chamber were used for monitoring the beam and for absolute normalization through the $^{6,7}Li+^{22}Ne$ elastic scattering. The focal plane Oxford detector was modified to measure the low energy deuterons by installing an array of 7 CsI (Tl) detectors (5x5 cm^2 each) and removing the exit window. These modification (combined with energy losses and tracking in proportional wires of Oxford detector) allowed reliable identification of the α-transfer reaction events.

Fig. 1 shows the excitation energy spectrum for the state in ^{26}Mg populated in $^{22}Ne(^{6}Li,d)^{26}Mg$ reaction. The state at 11.3 MeV plays an important role for the $^{22}Ne(\alpha.n)^{25}Mg$ reaction at astrophysical energies [3] and is the lowest excitation energy state that has been observed in direct $^{22}Ne(\alpha.n)^{25}Mg$ measurements [3].

In order to verify that direct α transfer is the dominant reaction mechanism, two alpha-transfer reactions were carried out, the $^{22}Ne(^{6}Li,d)^{26}Mg$ and $^{22}Ne(^{7}Li,t)^{26}Mg$. It was observed that the two reactions populate the same states and produce similar resonance strength for the populated states. The absolute normalization was performed using elastic scattering of $^{6}Li/^{7}Li$ by ^{22}Ne and augmented by direct measurements of the beam integral by the Faraday cup placed on the beam axis.

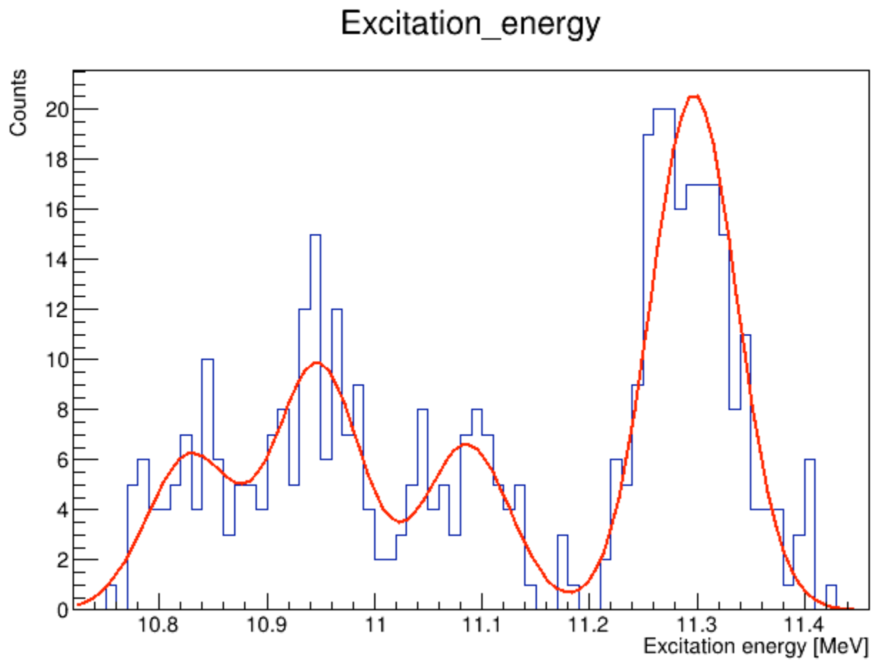

FIG. 1. Spectrum of ^{26}Mg excited states populated in $^{22}Ne(^{6}Li,d)^{26}Mg$ reaction.

All of the states populated in $^{22}Ne(^{6}Li,d)^{26}Mg$ reaction have been observed before [3,4,5]. However, there is no definitive spin-parity assignments for any of them. We assumed spin-parities of 0^+, 1^- and 2^+ in order to evaluate an impact on the astrophysical reaction rate. It was observed that the upper and lower bounds for the reaction rate was obtained when a 0^+ and 2^+ assignment was given for all the resonances respectively. Even the upper limit that follows from our measurements is substantially below the $^{22}Ne(\alpha.n)^{25}Mg$ reaction rate suggested in [4]. This is mostly because we do not see the strong resonance at 11.17 MeV observed in [4], indicating that this is most likely the high spin state that is readily populated at high energy [4], but cannot be populated at sub-Coulomb energy. The high spin state cannot have any significant impact on the reaction rate due to small penetrability factors. Fig. 2 demonstrates an impact of the lower $^{22}Ne(\alpha.n)^{25}Mg$ reaction rate on the production of the isotopes formed by the s-process. The calculations were made using code NEWTON (Nucleosynthesis of Elements With Transfer Of Neutrons) for a stellar model of 1.5 solar mass and solar metallicity (low temperature and low neutron density). While these results are still preliminary, we believe that the presently accepted $^{22}Ne(\alpha.n)^{25}Mg$ reaction rate is too high and reduction of this rated based on the results of the measurements described in this report has significant consequences on the final outcome of the s-process abundancies.

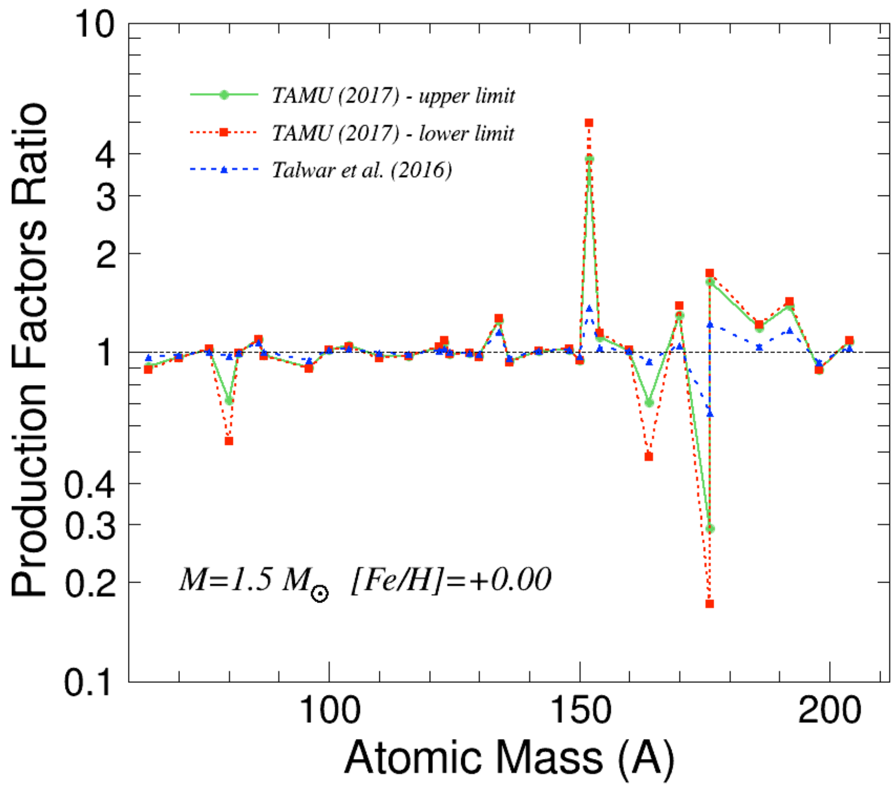

FIG. 2. The production factor for s-process only isotopes for the rates from the present work and of Talwar et. al [4] as a ratio to the production factors calculated using reaction rates of [2] for a stellar model of 1.5 solar mass and solar metallicity.

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