Radiative capture ^{17}O$(\alpha,\gamma)^{21}$Ne nuclear reaction of astrophysical interest

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Introduction

Final heavy element abundances strongly depend on the slow neutron capture process in massive stars. In metal poor massive stars, elements with mass numbers between 60 and 90 are produced by iron seed nuclei during the core helium and shell carbon burning phases. The temperature for core helium burning is around $0.2 - 0.3$ GK, corresponding to a centre of mass (E_{cm}) energy range of interest (Gamow window) between about 0.3 and 0.65 MeV[1]. At the begining of carbon shell burning, temperatures are higher at around 0.8 and 1.3 GK, with a corresponding Gamow window between $E_{cm} = 0.7$ to 1.8 MeV. Production of elements in the weak s-process depends on the neutron density and main source of neutron density is the reaction ^{22}Ne$(\alpha,n)^{25}$Mg [2]. As the rate of neutron capture is comparatively slow with respect to the decay rate of unstable or metastable reaction products, the production of elements follow the valley of stability.

In metal poor stars, due to the lower abundance of heavier neutron poison ^{25}Mg, the isotope ^{16}O is the main neutron poison in the environment via the reaction ^{16}O$(n,\gamma)^{17}$O. The captured neutrons may then again be released by the reaction ^{17}O$(\alpha,n)^{20}$Ne while the the competing reaction channel ^{17}O$(\alpha,\gamma)^{21}$Ne permanently removes them[3]. Best *et al.* [4] calculated the reaction rate of the (α,γ) channel and showed that it is strong enough to compete with the (α,n) channel. This somewhat lessens the effect of neutron recycling in the process of burning stages.

There are a few calculations for the ^{17}O$(\alpha,\gamma)^{21}$Ne nuclear reaction. CF88 [5], assumes the branching ratio between two competitive channels (α,γ) and (α,n) to be 0.1 at low energies and at about 1 MeV it drops to 5×10^{-4}. These values were obtained by extrapolation from the experimental data at higher enegy from the ^{18}O$(\alpha,\gamma)^{22}$Ne and Hauser-Feshbach calculation at lower energy part. Descouvemont [6] also calculated the reaction rate using the Generator Coordinate Method (GCM). The branching ratio turned out to be of the order of 10^{-4} at all energies in his calculation. This huge disagreement strongly affects the s-process abundances. In a bid to resolve this disagreement, we have used the R-matrix code AZURE2[7], to calculate the reaction rate of the (α,γ) channel of astrophysical interest using the experimental data availble lately by Taggart *et al.* [1] in the present work.

Calculation

The contributions of the narrow resonances to the reaction rate are calculated by taking the sum of the single level narrow approximation. Following Taggart *et al* [1], all four resonances corresponding to energies $E_{cm} = 0.633, 0.721, 0.810$ and 1.122 MeV have been used in our calculation. We find that, among all these states, the two at 0.633 and 0.81 MeV contribute the lion's share to the reaction rate. Resonance widths are also taken from Taggart *et al.*[1]. We have included a few higher compound nucleus energy levels, as there should be a resonance at an energy where a level in the compound system exists, but the strength of that resonance can often be rather uncertain being based on indirect determinations of partial widths.

The Q-value of the ^{17}O$(\alpha,\gamma)^{21}$Ne reaction

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is high 7.348 Mev [8] and the reaction products have higher excitation energies so that many nuclear states are populated [1]. It is therefore very difficult to extract the significant data from the background of such states particularly in the astrophysical energy range of interest.The channel radius should be set, typically $a = 1.4(A_1^{1/3} + A_2^{1/3})$ in fm. In principle the final fits is of course independent of the channel radius chosen. We have restricted the maximum orbital momentum to 7, maximum gamma multiplicity to 4, and maximum gamma multipolarity per decay to 2.

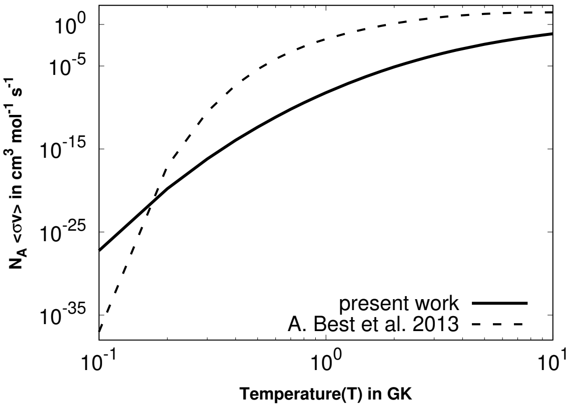

FIG. 1: Calculated $^{17}O(\alpha,\gamma)^{21}Ne$ reaction rate in comparison with existing resulta[4].

Results

Using observed resonances, Best *et al.*[3] confirmed the CF88 [5] estimation at par with their findings. At T = 1GK, $N_A\langle\sigma v\rangle|_{Best2011} = 1.8 \times 10^{-2} cm^3 mol^{-1} s^{-1}$ and $N_A\langle\sigma v\rangle|_{CF88} = 4.6 \times 10^{-2} cm^3 mol^{-1} s^{-1}$. However, Taggart *et al.*[1] obtained a reaction rate at about 100-1000 times lower than that of the CF88 estimation.

The present calculation predicts the reaction rate to be lower by a factor of about 1000-10000 than the CF88 estimation. Calculated reaction rates at different temperatures have been plotted in Fig. 1 and compared with values from literature[4]. It is noteworthy that level density within Gamow window typically comes around 1.5 per 100 keV [1], which is far below than that used in Hauser Feshbach treatment in CF88[5]. This is the reason behind overestimation of reaction rate by CF88[5].

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