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The Study of $^{12}C(\alpha,\gamma)^{16}O$ in Massive Stars at Explosive Conditions

Kalpana Duorah and Aditi Bezbarua

Department of Physics, Gauhati University, Pin-781 014, India

Abstract. Massive stars ($M \geq 10M_{\odot}$) and supernova are found to be the possible sites for explosive thermonuclear burning. When a massive star collapses, shock waves moving through various convective zones produces explosive situations. The gravitational collapse of a helium exhausted core leads to violent instabilities. The reaction $^{12}C(\alpha,\gamma)^{16}O$ is being studied under this condition. Recently it has been found that the coefficients in the semi-empirical mass formula are temperature dependent. Assuming the volume and surface binding to be effective, the nuclear masses, Q values, and reaction rates are calculated. Carbon alpha reaction is found to attain explosive proportion at the high temperature range considered here.

1. Introduction

In stars the production of ^{16}O is supposed to take place in the red giant stage. The reaction $^{12}C(\alpha,\gamma)^{16}O$ competes with the triple alpha process in the consumption of helium. This forms the later burning stages in massive stars $M \geq 10M_{\odot}$ and in supernova nucleosynthesis (Weaver and Woosley 1993). The Supernova 1987A in the LMC is providing us with an excellent opportunity to test the theory of massive star evolution and high temperature nucleosynthesis.

Radical change of composition takes place during the last few minutes of supernova explosion. The solar abundance pattern can be explained more clearly through explosive burning nucleosynthesis. In the case of 1987A Supernova, it is observed that all materials of $Z \geq 24$ are made in the explosion and elements $Z \leq 24$ in the presupernova star before the explosion (Pinto 1989). Shock waves propagating through the convective layers of the star towards the the core, leave behind a temperature $T \geq 5 \times 10^{9}K$. At these temperatures, materials burn to nuclear statistical equilibrium in about the hydrodynamic time from 0.1 to 1 sec. For temperatures in excess of $T_9 \geq 5$,(temperature expressed in $10^{9}K$ unit) relevant to the presupernova condition, this reaction may proceed through many higher resonance states.

2. Temperature Dependent Mass Formula

In this work we are presenting some results pertaining to $^{12}C(\alpha,\gamma)^{16}O$ reaction in high temperature situations. It is realised that nuclear masses vary with temperature. While calculating the reaction rate and other parameters, we incorporate the temperature dependent volume and surface energy terms only in the mass formula. The semi empirical mass formula provides a simple

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parametrization of binding energy for all known nuclei. Davison et al. (1994) put forward the idea that the coefficients of mass formula are determined by fitting the experimentally determined ground state energies of nuclei throughout the periodic table to a function of the mass number A and the nuclear charge Z. We use the temperature dependent coefficient $\alpha(T)$ and $\beta(T)$ for the calculation of the masses of the nuclei. We have considered only these two temperature dependent constants. The new masses of nuclei $^{12}C, ^{16}O$, ^{20}Ne are being calculated by using $\alpha(T{=}1)$ and $\beta(T{=}1)$ for the range of temperature $T \geq 1.0 \times 10^9 K$. These masses are then used to calculate the Q values. We finally calculate $N_A < \sigma V >$ for $3\alpha \rightarrow ^{12} C$, $^{12}C(\alpha, \gamma)^{16}O$ and $^{16}(\alpha, \gamma)^{20}Ne$ reactions with new temperature dependent mass values.

3. Conclusion

Though $^{12}C(\alpha, \gamma)^{16}O$ is a non-resonant reaction, at higher temperatures the variation of masses means that the contribution from higher excited levels makes the reaction rate increase explosively at temperatures $T_9 \geq 4$. Thus, it is expected that new results on the abundance ratios of these nuclei can be obtained for comparison with data available from some high energy events in astrophysics.

References

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