Key Reactions in Nuclear Astrophysics: ^{12}C$(\alpha,\gamma)^{16}$O and ^{12}C+^{12}C Fusion*

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The capture reaction ^{12}C$(\alpha,\gamma)^{16}$O takes place in the helium burning of Red Giants and is generally accepted to be a key process of nuclear astrophysics. The reaction rate at the relevant Gamow energy ($E \approx 300$ keV at $T \approx 2 \times 10^8$ K) determines - together with the convection mechanism at the edge of the stellar core - the ^{12}C/^{16}O ratio at the end of helium burning. This, in turn, influences not only the nucleosynthesis of elements up to the iron region but also the subsequent evolution of massive stars, the dynamics of a supernova, and the kind of remnant after a supernova explosion. For these reasons, the cross section should be known with a precision of at least 10%. However, the radiative capture cross section at the astrophysical energies is too small to be measured directly and in spite of tremendous experimental efforts in measuring the cross section over nearly 40 years, one is still far from the needed precision since higher energy data have to be extrapolated down to 300 keV. Contributions from E1 and E2 ground state transitions have to be taken into account, as well as cascade transitions. The presence of subthreshold levels further complicates the extrapolation. Our current knowledge of the extrapolated cross section is mostly based on R-matrix analyses of γ-ray capture and elastic scattering data. The β-delayed α-decay of ^{16}N provides information on the properties of the subthreshold 1^- level. A general overview is given on the current experimental data basis for ^{12}C$(\alpha,\gamma)^{16}$O with a focus on the direct measurements of the last years.

The fusion reactions ^{12}C(^{12}C,α)^{20}Ne ($Q = 4.62$ MeV) and ^{12}C(^{12}C,p)^{23}Na ($Q = 2.24$ MeV) are referred to as carbon burning in stars. In massive stars the ashes produced during helium burning become the fuel for further nuclear-burning processes, leading to the synthesis of most elements with mass numbers larger than 20. As helium burning progress, a core develops composed primarily of carbon and oxygen. Since the Coulomb barrier is lowest for the carbon nuclei, these will be the first to interact, resulting in the formation of neon, sodium and magnesium. Consequently, these ^{12}C+^{12}C fusion reactions represent key processes since they influence not only the nucleosynthesis but also the subsequent evolution of a star. However, at the astrophysical relevant energies the reaction rate of these fusion reactions is not very well known and provided only by extrapolations of high energy data. These fusion reactions have now been studied from E = 1.9 to 4.75 MeV by γ-ray and particle spectroscopy using thick carbon targets with ultra-low hydrogen contamination. The data reveal new information down to the range of the Gamow peak for carbon burning in massive stars, which takes place at temperatures $T \approx (5 - 10) \times 10^8$ K. The possible impacts of the results on various astrophysical sites, e.g. supernovae progenitor stars, will be discussed.

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