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Description of three-body radiative capture reactions using an analytical transformed harmonic oscillator basis

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Nucleosynthesis of light nuclei is an important problem in nuclear astrophysics. The radiative three-body capture processes, such as the triple alpha process, have been described traditionally as two-step sequential reactions. However, it has been shown in the recent years that the direct three-body recombination may play an important role in describing the reaction rates for the entire temperature range relevant in astrophysics. At the helium burning stage of stars, the triple alpha reaction for the formation of 12C is the main nucleosynthesis process overcoming the instability gaps at mass numbers A=5 and A=8. At low temperatures, where sequential models fail, the reaction rate of such process is still an open problem in nuclear astrophysics. This problem also applies to neutron rich environments, where the formation of 6He (alpha + n + n) and 9Be (alpha + alpha + n) has been linked to the nucleosynthesis by rapid neutron capture (r-process) in type II supernovae.

Other important processes may occur in different astrophysical scenarios. In a binary system that consists of two stars, a normal star (main sequence or red giant) and a compact object such as a neutron star, the transfer of H-rich material from the normal star to the neutron star provides an ideal medium for nucleosynteshis through rapid proton capture (rp-process). Among the rp-process appears the formation of 17Ne (15O + p + p). The interest of this reaction arises from the fact that 15O is a waiting point in the CNO cycle, and this rp-process can bridge towards the production of heavier elements.

The description of three-body capture reactions requires a complete three-body formulation of the system. The complete computation of this reactions in the whole energy range requires a narrow grid of continuum or scattering states right above the breakup threshold, which is a difficult task. The asymtotic behavior of continuum states for system with several charged particles is not known in general, and very involved procedures are needed to deal with this problem. We show a pseudo-state method, called the analytical transformed harmonic oscillator (THO) method, as a continuum discretization approach to describe the above mentioned three-body capture reactions. The THO basis is generated with an analytical local scale transformation of the harmonic oscillator functions, and the parameters of the transformation govern the density of PS at a given energy, allowing the construction of an optimal basis for each observable of interest. Our method describes both bound and continuum (resonant and non-resonant) states of the system in a full three-body quantum formalism without requiring the previous knowledge of the continuum asymptotic behavior. We have successfully applied the formalism to the nucleus 6He [PRC 88 (2013) 014327]. Calculation on 9Be, 12C and 17Ne are in progress.

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