Low-energy ^{12}C states in three-α model

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To consider bound and excited states of the ^{12}C nucleus as a three-α (3-α) system is one of typical examples in few-body problems. Since low energy continuum states of the ^{12}C nucleus play an important role in the triple-alpha (3α) process, by which three α particles are fused into a ^{12}C nucleus in stars, these states have been attracting the interest of researchers in view of astrophysics as well as nuclear physics.

In a recent paper [1], the 3α reaction rate is calculated by considering the inverse reaction of the fusion, namely the E2-photodisintegration of ^{12}C(2_1^+) state:

$$^{12}\mathrm{C}(2_1^+) + \gamma \to \alpha + \alpha + \alpha, \tag{1}$$

where the total angular momentum of the finnal 3-α state is 0. In Ref. [1], a wave function for the process (1) is defined and solved by applying the Faddeev three-body formalism in coordinate space. Calculations were performed for the energy of 3-α states from 10 keV, where a sequential process via two-α resonant state ^{8}Be(0_1^+) ($E_{2\alpha} = 92$ keV) may not be dominant, to 600 keV, which is well above the energy of the so called Hoyle resonant state, ^{12}C(0_2^+) ($E_r = 380$ keV). From the cross sections of this process, the 3α reaction rate was calculated for stellar temperatures of $T_7 = 1 - 100$, where $T_7 = T/(10^7\mathrm{K})$.

In the present work, the calculations are extended by increasing energies of 3-α states up to several MeV, where some additional 0^+ resonant states emerge. From the calculated cross section, a sequential contribution, in which the 3-α disintegration proceeds via the ^{8}Be(0_1^+) state, is extracted. The difference between the full and the sequential cross sections is therefore the contribution from the direct 3-α process. Fig. 1 shows (preliminary) results.

In Fig. 1, besides the sharp peak of the Hoyle state, we observe two peaks having rather large widths, which may correspond to 0^+ resonant states of ^{12}C recently discussed in Refs. [2,3]. It is noted that while the second (small) peak is dominated by the sequential process, the third peak is not, which makes the shape of the total cross section obscure.

The 3α reaction rate calculated from the cross sections is shown in Fig. 2 comparing with a standard rate of the Nuclear Astrophysics Compilation of Reaction Rates (NACRE) [4]. The difference at $T_7 > 100$ may be due to a contribution from the 2^+ resonant state of ^{12}C, which is included in the NACRE rate but not in the present calculation.

Studies about the nature of two 0^+ resonant states and calculations of the integration process having 2^+ final 3-α states are currently in progress.

[1] S. Ishikawa, arXiv:1305.0927 (to be published Phys. Rev. C).

[2] C. Kurokawa and K. Kato, Phys. Rev. C **71**, 021301 (2005).

[3] M. Itoh, *et al.*, J. of Phys.: Conf. Ser. **436**, 012006 (2013).

[4] C. Angulo, *et al.*, Nucl. Phys. A **656**, 3 (1999).

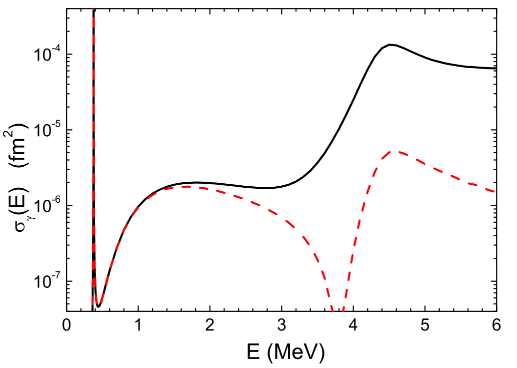

Figure 1: E2 photodisintegration cross section as a function of the 3-α energy E. The solid curve is the full cross section. The dashed curve denotes the sequential contribution.

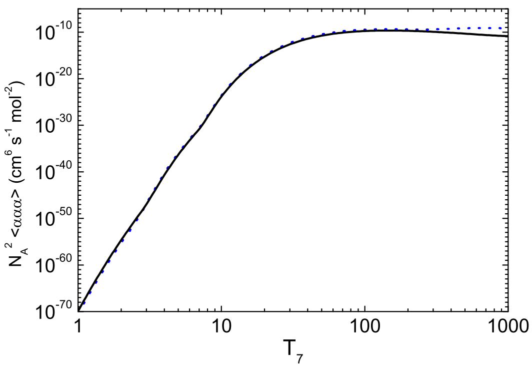

Figure 2: The 3α reaction rate calculated from the calculated E2 photodisintegration cross section (solid curve) compared with the NACRE rate (dotted curve).

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