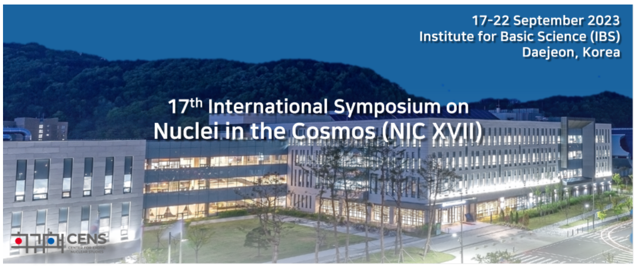

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Analytic expression of triple-α reaction rates by a non-adiabatic three-body model

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Triple-α reaction plays a significant role in nucleosynthesis heavier than ^{12}C and concomitant stellar evolution [1]. The reaction rates of this reaction at the helium-burning temperatures, $T_9 > 0.1$, are dominated by the sequential process via two narrow resonances: $\alpha + \alpha \rightarrow ^8$Be($0_1^+$), ^{8}Be+$\alpha$ $\rightarrow ^{12}$C(0_2^+: $E = 0.379$ MeV) [2,3], and they have been thought to decide a fate of massive stars up to their supernova explosion. T_9 is temperature in the unit of 10^9 K; E is the center-of-mass energy to the 3α threshold in ^{12}C.

In NACRE [2], ^{8}Be is assumed to be bound as a particle, and the reaction rates have been estimated by an improved model with the sequential process based on [4,5]. To determine the rates more accurately, the precise experimental decay studies of the 0_2^+ resonance have been performed recently (e.g. [6]). The theoretical models have also been being developed during decades. To take account of 3α continuum states distorted by the long-range Coulomb interaction, the methods with hyper-spherical coordinates are used in [7-10], and the Coulomb modified Faddeev method is also adopted in [11]. Whereas ^{8}Be continuum states are treated adiabatically in Refs. [9-11], the direct process from ternary continuum states, $\alpha + \alpha + \alpha \rightarrow ^{12}$C, is calculated non-adiabatically in Refs. [7,8]. Although the theoretical models are consistent with each other at the helium-burning temperatures, they make the large difference in the rates below $T_9 = 0.07$. From the comparison between the calculations, Ref. [7] has found that the current reaction rates at $T_9 = 0.05$ can be reduced by about 10^{-4}, because of the assumed ^{8}Be.

In this presentation, I review the non-adiabatic approach to the triple-α reaction, and provide the derived rates. I use the Faddeev hyper-spherical harmonics and R-matrix (HHR*) expansion method [7,12,13], and I confirm that the photo-disintegration of ^{12}C(2_1^+($E = -2.835$ MeV) $\rightarrow 0^+$) for $0.15 < E < 0.35$ MeV is 10^{-15} – 10^{-3} pb order of cross sections. The resultant rates are shown to have the strong temperature dependence below $T_9 = 0.1$, as well as NACRE, and their numerical values are expressed in a simple analytic form [2,14].

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