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Further limit on 3α decay of Hoyle state

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The Hoyle state, second 0^+ resonant excited state of ^{12}C at excitation energy of 7.654 MeV, plays an important role to understand a variety of problems of nuclear astrophysics as well as the stellar nucleosynthesis process as a whole [1,2]. Recent triple alpha reaction rate calculation assumes that the formation mechanism of ^{12}C is through sequential two step process, i.e. through the intermediate ground state of ^{8}Be nucleus. However, the structure of this state has unusual nature as from the cluster model, it has a linear chain like structure of three alpha particles [3] and at the same time from inelastic scattering it was found that this state has a abnormally larger radius compare to the ground state of ^{12}C [4] and possesses a gas like structure i.e., loosely bound 3α [5, 6]. All these unusual properties of this state may change the decay mode of ^{12}C, from which reaction rates for carbon as well as other heavy elements have been calculated. First experimental effort to estimate the branches of sequential and direct decay mode of Hoyle state have been performed in 1994 by M. Freer, using Dalitz plot for three body decay and its projection in terms of ^{8}Be like pairs, and obtained an upper limit of 4% on direct 3α decay branches bypassing the ground state of ^{8}Be [7]. In a recent work by Raduta et al. [8], two direct decay branches have been identified, direct decays into equal energy (DDE) and direct decay in linear chain (DDL), with a combined direct decay branching of 17(5) %. So, this total direct decay branches not only implies a corresponding percentage of reduction in the reaction rate calculation in triple α process but also for modification of recent theoretical prediction for reaction rate calculation. In Manfredi et. al [9], 2012, they have been estimated the decay branches using ^{8}Be like pairs and root mean square energy deviation methods and obtained for the direct decay in phase space (DDΦ) 3.9 % and DDE is 0.45 % with a upper confidence limit of 99.75 %. More recently, O. S. Kirsebom et. al.[10], estimated using the symmetric Dalitz plot and its radial projection, in a complete kinematical experiments (total detected events of 5000) and have got an upper limit for DDE 0.09%, DDL 0.09% and DDΦ 0.5% at 95% confidence limit. Therefore, it is important to verify the recent result with higher statistics to resolve the ambiguity. Here, we will discuss in details about a new measurement of inelastic scattering of α on ^{12}C at 60 MeV to study the decay channels of Hoyle state in a complete kinematical experiment with a larger statistics than ever use before. We have used here all these three methods (^{8}Be like pairs, root mean square energy deviation and the radial projection of symmetric Dalitz plot, as have been used in references [7-10]) with three body decay Monte Carlo simulation, taking into accounts the experimental effect, to estimate the decay channels of Hoyle state and have been estimated and restricted with an upper limit of DDE 0.6 %, DDΦ 0.9 % and DDL 0.3 % with a 99.75 % upper confidence limit. The experimental measurement and data analysis details will be discussed here.

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