2 - 19 Study of Astrophysical $^4He(np,\gamma)^6Li$ Reaction Rate in a Novel Quasi-deuteron Capture Mechanism

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The consistency of the measured abundances of deuterium and ^{4}He relative to hydrogen with the predictions of the standard Big-Bang Nucleosynthesis (BBN) model is a major triumph of modern cosmology. However, there remain significant discrepancies between observations and predictions for the absolute abundances in ^{7}Li and ^{6}Li nuclide. Similar to the ^{7}Li case, the ^{6}Li abundance observed in metal-poor halo stars exhibits a plateau as a function of metallicity, suggesting a big bang origin. While inferred primordial abundance of ^{6}Li is larger than BBN prediction by 3 orders of magnitude. Also, the inferred ^{7}Li abundance is 3 times smaller than the BBN prediction. In the past 20 years, those discrepancies between the prediction and the observation were not solved. In the standard BBN model, possible solutions of the "lithium problems" from nuclear physics aspect might rely on still are that a larger reaction network. An exhausted BBN network, involving those reactions induced by the short-lived nuclei, was implemented for solving the ^{6}Li problem by Boyd et al.[1], and it was found that these additions only had little effect on the final BBN abundances. All reactions involved in the past BBN calculation are two-body reactions. In this work we introduce a three-body $^4He(np,\gamma)^6Li$ reaction into our network calculation and try to address the ^{6}Li problem in an attentive way.

In the past, two mechanisms for three-body reaction $^4He(2n,\gamma)^6He$ were devised[2]. One is a sequential neutron-capture mechanism which the unbound ^{5}He is formed as an intermediate state; another is the formation of an intermediate state of in a form of dineutron. Although both mechanisms form an intermediate particle-unbound component, in equilibrium between formation and decay, their time sequence is totally different. It shows that the $^4He(2n,\gamma)^6He$ rate can be enhanced by several orders of magnitude by dineutron-capture mechanism relative to sequential two neutron-capture mechanism. Enlightened by this dineutron-capture mechanism, the $^4He(np,\gamma)^6Li$ reaction rate is studied via the quasi-deuteron one-step capture mechanism.

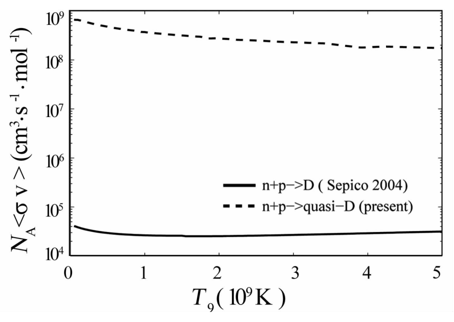

Fig. 1 Reaction rate for quasi-deuteron forming via n-p scattering. The recent rate[4] for $p(n,\gamma)^2H$ is shown for comparison.

In previous study[3], the quasi-deuteron formation of ^{6}Li which pictures ^{6}Li as an alpha core with an orbiting deuteron was investigated experimentally, however, the expected results had not been achieved. But still no strong evidence does show that this type of mechanism don't exist in nature. Here we propose the n-p correlated nucleus (quasi-deuteron) exists in a quasi-deuteron form, which is very loosely bounded. With the experimental n-p scattering cross-section data, we calculated the reaction rate of quasi-deuteron as shown in Fig. 1. The rate of $^1H(n,\gamma)^2H$ is also shown for comparison. It is found that the rate of forming quasi-deuteron is larger than that of $^1H(n,\gamma)^2H$ by 4 orders of magnitude. However, this might not enhance the abundance of ^{6}Li dramatically as the binding energy of quasi-deuteron is so small that it will be dissociated by the photons quickly. It practical impact should be checked by the later BBN calculation.

Nowadays, the three-body reaction rate following the method used in the dineutron capture in Ref. [5] is being calculated. The reaction rate of the three-body reaction can be described by a double integral,

$$N_A^2 < 1pn > = N_A^2 \int_{E_1} \frac{d < (p,n) > (E_1)}{dE_1} \frac{2\hbar}{\Gamma_2(E_1)} \times \left[\int_{E_2} \frac{d < (d,\gamma) > (E_1,E_2)}{dE_2} dE_2 \right] dE_1 \quad (1)$$

Here, $\Gamma_2(E_1)$ is the energy-dependent width of quasi-deuteron, and E_1 and E_2 denotes the collision energy in the center-of-mass system. The differential represent the integrands of the $<\sigma\upsilon>$ integration for the single-step reaction rate and is described by

$$\frac{d < \sigma\upsilon >}{dE} = \sqrt{\frac{8}{\pi\mu}} \frac{1}{(kT)^{3/2}} \sigma(E) E \exp(-\frac{E}{kT}) \quad (2)$$

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The cross section of the formation of quasi-deuteron was calculated as discussed above, and the analytic expression is obtained by fitting the n-p scattering data. The width of quasi-deuteron virtual state of a 0^+ resonance was about $\Gamma_2(E_1) = 9\times10^{-8}$ MeV derived from the n-p scattering curve. The loosely bounded quasi-deuteron might have a bigger radius than a real deuteron, and this possibly results in a larger (α, γ) cross section as well. The detail effect is now under evaluation. For simplicity, here we can take the cross section of ^{2}H(α,γ) ^{6}Li as that of quasi-deuteron capture on ^{4}He, which gives the lower limit of ^{4}He (np,γ) ^{6}Li rate. The calculation of the ^{4}He(np,γ)^{6}Li rate is still in progress.

References

[1] R. N. Boyd, et al., Phys. Rev., D82(2004)105005.
[2] Amy Bartlett, et al., Phys. Rev. C74(2006)015802.
[3] D. G. Proctor, W. H. Voelker, Phys. Rev., 118(1960)217.
[4] P. D. Serpico, et al., JCAP, 12(2004)010.
[5] K. Nomoto, et al., Astron. Astrophys., 149(1985)239,

2 - 20 Investigation for Resonant Scattering of ^{17}F+p

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X-ray bursts[1] are probably an important source for the production of proton-rich nuclei via the high temperature rp-process[2], and the ^{14}O (α, p) ^{17}F reaction is thought to be one of the crucial stellar reactions during the ignition phase. By far, its reaction rate is still uncertain. Therefore, the studies of this waiting-point reaction are of great nuclear astrophysical importance to understand the energy generation and nucleosynthesis in the explosive stellar environments.

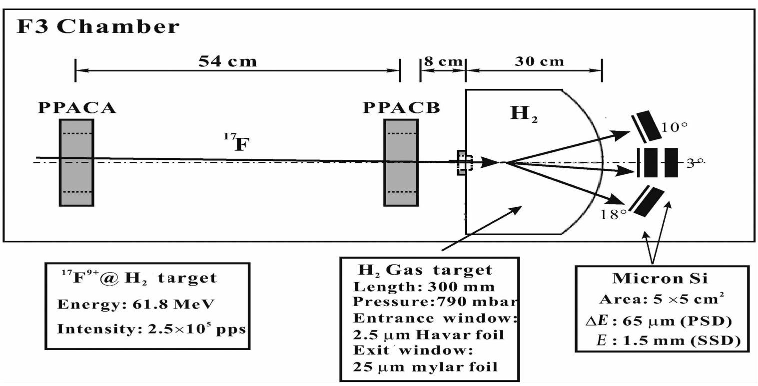

Fig. 1 Schematic diagram of experimental setup at F3 chamber.

The reaction ^{14}O(α, p) ^{17}F is mainly resonant[3, 4], and its reaction rate depends on the resonant properties of those excited states above the α threshold in the compound nucleus ^{18}Ne. In this work, the proton resonant properties in ^{18}Ne have been studied by the resonant elastic and inelastic scattering of ^{17}F+p with a ^{17}F beam bombarding a thick H_2 gas target. The experimental goal was to determine the spin-parities and

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