2 - 9 Progress of the Nuclear Astrophysical Research at IMP

Tang Xiaodong[1,2]

([1]Institute of Modern Physics, Chinese Academy of Science, Lanzhou, 730000, China;
[2]Joint department for nuclear astrophysics, Lanzhou University and Institute of Modern Physics, Lanzhou 730000, China)

The nuclear astrophysical research program at IMP focuses on the nuclear process happening in stellar environments. Our research has been taken place using the facilities such as HIRFL at Lanzhou, 3 MV Tandem accelerator lab in Bucharest, China JinPing deep underground Lab in Sichuan. Research highlights and major achievement in experimental techniques are given below:

1) One of the longstanding problems of the big bang theory is that the theory overpredicted the ^{7}Li abundance. It was found that the observed primordial abundances of deuterium, helium, and lithium could be explained simultaneously using a slightly modified version of the classical distribution (non-extensive statistics).

2) The ^{12}C+^{13}C fusion reaction is studied down to 2.323 MeV, the lowest energy ever reached for this reaction. This cross section measured at such a low energy rules out the prediction of hindrance model while it confirms the predicted trend of S-factor by other models, such as CC-M3Y+Rep, DC-TDHF, KNS, SPP and ESW.

3) A X-ray burst calculation using the new experimental mass data of ^{82}Zr and ^{84}Nb eliminates the existence of the previously proposed Zr-Nb cycles.

4) Time Projection Chamber (TPC) is a key instrument for the reaction study with radioactive ion beams. A 240-channel TPC has been built to realize the study the fusion reaction with neutron rich beams.

5) The alpha background in the ^{3}He counter is an important parameter for the experimental study of the ^{13}C(α,n)^{16}O reaction at the China JinPing deep underground Lab. The lower background was found to be 0.6 cnt/day/counter for a GE commercial counter. A coincidence technique between the ^{3}He counter and the surrounding scintillator is being developed to realize the desired background by suppressing this background by a factor 10.

Our research in 2018 will continuously focus on the ^{12}C+^{12}C fusion reaction at stellar energies, studying the fusion reaction using active target technique. We also will strengthen the collaboration with astronomical and astrophysical communities. Finally, we would like acknowledge the financial supports from MOST, NSFC and CAS.

2 - 10 An R-Matrix Reanalysis Based on the ^{15}O(α, α)^{15}O Data*

Hu Jun and Ru Longhui

Novae emit gamma rays during the first several hours after the explosion at energies of 511 keV and below[1]. ^{18}F is the most important gamma-ray source because of its relatively large abundance and long half-life ($t_{1/2}$ = 109.8 m). The ^{18}F(p, α)^{15}O is the main destruction reaction of ^{18}F, which may constrain the amount of ^{18}F severely. However, the reaction rate of ^{18}F(p, α)^{15}O is still very uncertain.

The reaction rate of ^{18}F(p, α)^{15}O is determined by the properties of relevant levels in the ^{19}Ne compound nucleus. It was previously thought that the primary uncertainty arose from the unknown interference sign between the $3/2^+$ states[2]. However, a recent theoretical study[3] predicted that a broad $1/2^+$ level near E$_x$ = 7.9 MeV (Γ_α = 139 keV) would interfere with a subthreshold $1/2^+$ resonance (E_x = 6.0 MeV, Γ_α = 231 keV) to reduce the influence of $3/2^+$ resonance contributions.

A measurement of ^{15}O(α, α)^{15}O was performed by Torresi, *et al.*[4] at LNL in Italy recently. The excitation function at $\theta_{\mathrm{c.m.}}$ = 180° has been analysed using an R-Matrix code AZURE2[5]. They discovered 7 new levels and extracted the Γ_α of observed levels for the first time. It should be noted that the spin and parity assignments could be uncertain because of the absence of excitation functions at other angles. To check the reliability of their data and search for the predicted $1/2^+$ states, we reanalysed the excitation function using the same R-Matrix code AZURE2. It was strange we could not repeat Torresi's fit based on their fit parameters, see Fig. 1(a). In a conference article[6] written by the same authors, the shown data of excitation function was extended to $E_{\mathrm{c.m.}}$ = 6 MeV. However, there was no explanation for these discarding data in the regular paper Ref. [4]. For clarity and integrity, we adopted the data from Ref. [6] to make the R-Matrix analysis, the fit is shown in Fig. 1(b). The fit results are summarized in Table 1, and the Torresi's fit parameters are also listed for comparison.

It can be seen from Table. 1, the locations of two $1/2^+$ states in **bold** are close to the predicted region. However, the 6.277 MeV state is with a significant narrow α width compared to the theoretical prediction. Recently, a 6.286

MeV, $1/2^+$ state was observed by Bardayan, *et al.*[7]. The Γ_α cannot be obtained owing to the limitation of their experimental technique. The present work may give the experimental Γ_α of this $1/2^+$ state for the first time. The properties of 7.951 MeV state is consistent with the theoretical value. This may imply that one of the predicted $1/2^+$ states has been observed using the ^{15}O(α, α)^{15}O measurement. In order to confirm the present results, we plan to perform a new ^{15}O(α, α)^{15}O measurement at RIBLL1. Three silicon telescopes at different angles will be installed. The information from other angles may constrain the level properties obtained here.

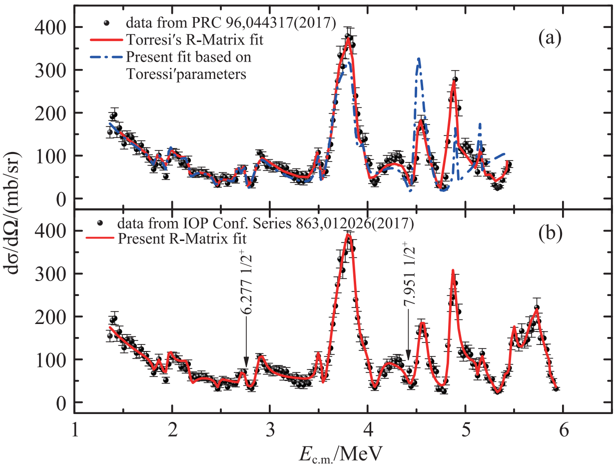

Fig. 1 (color online) Comparison of the R-Matrix fits between the present and Torresi's work.

Table 1 Tabulation of the resonance parameters extracted from the R-Matrix fit. Also presented is the results from Torresi, *et al.*

^{19}Ne present work			^{19}Ne Torresi's work		
E_x/MeV	J^π	Γ_α/keV	E_x/MeV	J^π	Γ_α/keV
5.365	$1/2^+$	8	5.359(6)	$1/2^+$	10(3)
5.479	$3/2^+$	9	5.487(4)	$3/2^+$	9(2)
5.714	$5/2^-$	55	5.704(8)	$5/2^-$	29(6)
6.0	$3/2^-$	6	5.983(9)	$3/2^-$	21(8)
			6.197(8)	$1/2^{(-+)}$	16(5)
6.258	$5/2^+$	2	6.279(2)	$5/2^+$	6(2)
6.277	$\mathbf{1/2^+}$	**4**			
6.415	$1/2^-$	83	6.395(5)	$1/2^-$	181(58)
7.05	$7/2^+$	21	7.03(4)	$7/2^+$	12(3)
7.153	$3/2^+$	220	7.153(9)	$3/2^+$	233(44)
			7.378(7)	$7/2^+$	121(9)
7.39	$5/2^+$	152	7.469(7)	$5/2^+$	83(17)
7.617	$3/2^+$	150	7.568(27)	$(3/2, 1/2)^+$	774(144)
7.755	$7/2^+$	665			
7.951	$\mathbf{1/2^+}$	**141**			
8.092	$9/2^+$	100	8.022(4)	$9/2^+$	64(10)
8.106	$5/2^+$	107	8.223(7)	$5/2^+$	377(34)
8.390	$13/2^-$	58	8.428(2)	$(13/2^-, 11/2^+)$	4(1)
8.62	$1/2^-$	574			
8.654	$9/2^-$	2	8.68(1)	$(9/2，7/2)^-$	3(1)
8.701	$1/2^+$	37			
8.915	$1/2^-$	116			
8.931	$3/2^-$	14			
8.955	$1/2^+$	25			
8.998	$11/2^-$	47	(8.79)8.92(9)	$11/2^{(-,+)}$	4(1)
9.257	$3/2^+$	190			
9.587	$5/2^-$	316			

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2 - 11 Reevaluation of the Astrophysical ^{7}Be(n,α)^{4}He Reaction Rate Relevant to BBN

Hou Suqing

Regarded as one of most challenging questions in cosmology and astrophysics, cosmological lithium problem refers to Big Bang model predict about three times ^{7}Li as much as we can observe. Over the past two decades, it has motivated many scientists to explore the solution of eliminating this discrepancy between calculations and observations.

It was pointed out that the ^{7}Li abundance will be greatly reduced in the BBN calculation if the destruction rate of ^{7}Be is enhanced[1]. One of the candidate channels to destruct ^{7}Be is the reaction ^{7}Be(n,α)^{4}He, which was regarded as the secondary important reaction in affecting the ^{7}Li abundance by destructing the ^{7}Be nucleus in BBN and has not been well studied so far. The ^{7}Be(n,α)^{4}He reaction rate was first estimated by Wagoner in 1969[2], which has been primarily adopted in the current BBN simulations. This simple estimate involved only a direct reaction contribution without the contributions from resonance. In our previous work[3], we revised this rate based on the indirect cross-section data available for the ^{4}He(α,n)^{7}Be and ^{4}He(α,p)^{7}Li reactions by applying the charge symmetry and the principle of detailed balance. Our result shows that the previous Wagoner rate is overestimated by one order of magnitude.

Later, several experiments were carried out subsequently by different groups to ascertain its reaction rate. The ^{7}Be(n,α)^{4}He cross-section direct measurement has been measured by Barbagallo, *etal.* for the first time from10 meV to 10 keV neutron energy at the n-TOF facility[4]. Their result confirms previous measurement performed in the 1960s at a nuclear reactor and also pointing out the overestimation of one order of magnitude in Wagoner rate. Based again on application of the detailed-balance principle, Kawabata, et al. performed cross-section measurement of time-reverse reaction ^{4}He(α,n)^{7}Be to derive ^{7}Be(n,α)^{4}He reaction rate in vicinity of effective energy range of producing ^{7}Be[5].

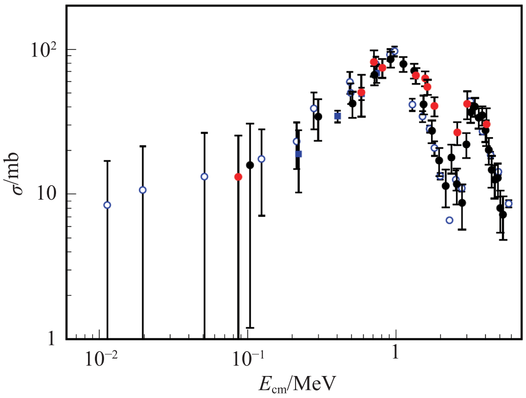

Fig. 1 (color online) ^{7}Be(n,α)^{4}He cross section as derived in Ref. [6] by using ^{2}H breakup data (full red circles) and ^{3}He breakup data (full black circles). They are compared with the data of Hou et al.[3] (2015; empty blue circles) and those of Kawabata et al.[5] (2017; full blue squares). The original figure is from Ref. [6].

Most recently, new ^{7}Be(n,α)^{4}He reaction cross section is derived by applying identical method in Hou, *etal.*[3] to the already available ^{7}Li(p,α)^{4}He experimental data measured via the Trojan Horse Method (THM)[6]. The advantage of adopting THM data is that it can reduce the source of uncertainty because several sets of data from