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Recent THM investigations of the ^{7}Be(n,α)^{4}He reaction in the BBN scenario

L. LAMIA(1)(2), R. G. PIZZONE(2), C. SPITALERI(2), C. BERTULANI(3), S. HAYAKAWA(4), S. Q. HOU(3)(5), M. LA COGNATA(2), M. MAZZOCCO(6)(7), G. G. RAPISARDA(2), S. ROMANO(1)(2), M. L. SERGI(2) and A. TUMINO(8)(2)

(1) *Dipartimento di Fisica e Astronomia "Ettore Majorana", Università di Catania - Catania, Italy*
(2) *Laboratori Nazionali del Sud, INFN-LNS - Catania, Italy*
(3) *Department of Physics and Astronomy, Texas A&M University-Commerce, Commerce, TX, USA*
(4) *Center for Nuclear Studies, The University of Tokyo - Tokyo, Japan*
(5) *Institute of Modern Physics, Chinese Academy of Sciences - Lanzhou, China*
(6) *Dipartimento di Fisica, Università di Padova - Padova, Italy*
(7) *INFN, Sezione di Padova - Padova, Italy*
(8) *Facoltà di Ingegneria e Architettura, Università degli Studi di Enna "Kore" - Enna, Italy*

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Summary. — ^{7}Be-n induced reactions play a key role in the final lithium abundances as produced during the Big Bang Nucleosynthesis (BBN). This has triggered a lot of works in the last years in which various experimental approaches have been followed. Here the recent investigation performed via the Trojan Horse Method (THM) will be discussed and its impact evaluated.

1. – Introduction

Although the primordial Big Bang Nucleosynthesis (BBN) has been proved to be valid for deuterium and helium isotopes, several issues are still present for the primordial lithium (Li) for which the *predicted* abundances remain higher by a factor ∼2.5-3 when compared with the *observed* ones in halo stars [1-3]. In view of this, nuclear physics solutions have been strongly investigated since they could play an important role for shedding-light on such a discrepancy by studying the reaction network intervening in the BBN nucleosynthesis. Starting from such consideration, an intense experimental program has been carried out by several groups thus allowing for a comprehensive study of the nuclear processes involving the unstable ^{7}Be isotope by means of different experimental approaches [4-8]. Although laser-driven plasma experiments [9] could open new frontiers in the evaluation of half-life time variation in plasma conditions, this solution doesn't seem to be of some usefulness for BBN as pointed out in [3]. Thus, nuclear physics solutions have been deeply studied. In particular, the two ^{7}Be(n,p)^{7}Li and the ^{7}Be(n,α)^{4}He reaction channels have been investigated since their net effect of destroying the unstable ^{7}Be thus affecting the final amount of lithium. Besides the role of the (n,p) channel recently studied in [10], the ^{7}Be(n,α)^{4}He was surely the most poorly known since not experimental cross section data were available up to the last 5 years at the BBN energies, i.e. lower than $\sim$500 keV. Additionally, [11] suggested that a factor 2 of reduction in the final ^{7}Be abundance could have been achieved by increasing the oldest ^{7}Be(n,α)^{4}He reaction rate of Wagoner [12] by a factor 60 at BBN energies. Although this possibility had been already considered unlikely, experimental investigations started to be necessary. In the following, the main results obtained by the recent Trojan Horse Method (THM) investigation will be discussed.

2. – The THM investigation

The Trojan Horse Method is an indirect technique whose first theoretical description has be given in [13]. In the following years, THM has been improved both regarding the experimental applications as well as also to the theoretical description [14-17]. THM allows one to measure the cross section for a two-body reaction A(x,c)C by properly selecting the quasi-free contribution of the A(a,cC)s reaction, in which nucleus a is chosen because of its dominant x$\oplus$s cluster configuration. The $A + a$ process is induced at laboratory energies well above the Coulomb barrier, thus allowing the transfer of the *participant* particle x in the A nuclear field. Additionally, the $x - s$ binding energy in a compensates the energy of the incoming projectile in order to induce the $A - x$ reaction at low, i.e. astrophysically relevant, energies [14, 15]. Although THM has been historically used to measure charged-particle induced reaction cross sections for devoted astrophysical scenario (see [18-24] and ref. ther.), recently it has been found to be useful for investigating neutron induced reactions [25]. This opens new frontiers to probe such processes for which direct determinations are often difficult to be performed, as in the case of n-induced reactions on short-lived radioactive isotopes.

In the case of the cosmologically relevant ^{7}Be(n,α)^{4}He reaction, the corresponding cross section has been recently derived in [26]. It has been made by applying the charge-symmetry hypothesis to already existing ^{7}Li(p,α)^{4}He THM data, as discussed in [26], while two further THM data analysis are still ongoing [27, 28].

Charge-symmetry hypothesis (CSH) is still a largely debated topic in nuclear physics particularly for low-energy induced reactions [26]. However, the most recent ^{7}Be(n,α)^{4}He direct measurements performed by [8] nicely agree with the ones derived by [6], being these last ones based on CSH. This could be assumed as an evidence of CSH validity for this system. For the purpose of our THM work, two data sets have been considered for applying CSH to the already existing THM ^{7}Li(p,α)^{4}He data. In particular, we adopted the data discussed in [29, 30]. These data allowed for the extraction of the ^{7}Li(p,α)^{4}He via a deuteron and ^{3}He breakup THM experiments, separately. In addition, because we are interested in using the experimental data useful for the ^{7}Be(n,α)^{4}He investigation, only part of available data have been considered. In particular, because of the difference in mass of the two entrance channels ^{7}Li+p and ^{7}Be+n, a difference of 1.644 MeV is present between the center-of-mass energies covered in the two cases. For such a reason, only the ^{7}Li(p,α)^{4}He THM cross section data, $\sigma_{p\alpha}$, covering a center-of-mass energy E_{Li-p}>1.644 MeV have been taken into account. These data have been then converted

Table I. – *Comparison between BBN predictions and observations. (a) The mass fraction for ^{4}He is taken from* [32]. *(b) Deuterium abundance is the mean average from* [33]. *(c) The ^{3}He abundances are adopted from Ref.* [34] *as a lower limit to the primordial abundance. (d) Observations from stars belonging to the "lithium plateau"* [2]. *D/H is in units of 10^{-5}, ^{3}He/H in 10^{-6} and Li/H in 10^{-10}.*

Yields	[31, 26]	Observed
^{4}He/H	$0.2485^{+0.001}_{-0.002}$	$0.256 \pm 0.006^{(a)}$
D/H	$2.692^{+0.177}_{-0.070}$	$2.82 \pm 0.26^{(b)}$
^{3}He/H	$9.441^{+0.511}_{-0.466}$	$\geq 11. \pm 2.^{(c)}$
^{7}Li/H	$4.441^{+0.317}_{-0.276}$	$1.58 \pm 0.31^{(d)}$

to the $\sigma_{n\alpha}$ ones of the ^{7}Be(n,α)^{4}He channel via the formula:

$$\sigma_{n\alpha} = \sigma_{p\alpha} \cdot \frac{E_{\mathrm{Li-p}}}{E_{\mathrm{Li-p}} - 1.644} \cdot \frac{P^n_{l=1}(E_{\mathrm{Li-p}} - 1.644)}{P^p_{l=1}(E_{\mathrm{Li-p}})} \tag{1}$$

where $\mathrm{P}^{n,p}_{l=1}$ represent the penetrability for the neutron and proton channel, respectively [26].

The result of such investigation show a marked agreement with the trend of the cross section data of [6] and [8], with the advantage of producing a cross section measurement right in the energy region of BBN. The good agreement once again showed the goodness of our assumption as previously done in [6]. The THM reaction rate has been then used for running the evolutionary code described in [31] and the calculated primordial abundances fare given in Table I. These values have been then compared with the observed ones for helium-4, deuterium, helium-3 and lithium-7 as reported in [32-34, 2], respectively. Besides the already mentioned agreement for deuteron and helium isotopes, a marked disagreement appears for lithium, thus leaving still open the *li-problem* in cosmology. A possible way to reconcile BBN predictions with halo stars observation could have been the increase of a factor ∼4 of the ^{7}Be(n,p)^{7}Li reaction rate of Smith el al. 1993 [35] [26]. Such a solution was already at that time unlikely to occur as later confirmed by the devoted cross section measurement of [10]. Thus, although the improvements in the reaction cross section measurements, lithium problem remain still an open issue for cosmology.

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