Chapter 9
The Cosmologically Relevant ^{7}Be(n,α)^{4}He Reaction in View of the Recent THM Investigations

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Abstract The cosmologically relevant ^{7}Be(n,α)^{4}He has been matter of recent studies aimed at contributing to the long-standing Li-problem. Here a brief description of the twin THM investigations will be shown and the main results discussed.

9.1 Introduction

Lithium puzzle is one the most intriguing unsolved problem at our days. Its predicted abundance by CMB evaluations is generally accepted to be a factor $\sim$3 higher than the one deduced by halo stars observations (see [1] for a general review). However, recent observations and stellar models for Pop.II stars seem to alleviate such a discrepancy. These models tend to predict a higher value of primordial lithium [2], starting from which possible stellar depletion mechanism could have left the lithium value at the currently observed value. In this charming scenario, nuclear physics solutions have been largely investigated in the past [3, 4] and reaction rate determination for both the producing and the destruction channels involving lithium are really necessary in order to reduce the corresponding uncertainties. In particular, the role of the unstable ^{7}Be ($t_{1/2}$ = 53.22 $\pm$ 0.06 d) during BBN era is currently matter reflecting in a boost of devoted experimental investigations [5–7]. Recently, the Trojan Horse Method (THM) [8–16] have been applied for measuring the cross section of the (n,α) reaction channel on ^{7}Be by means of charge-symmetry hypothesis applied to the previous ^{7}Li(p,α)^{4}He THM data corrected for Coulomb effects. The deduced ^{7}Be(n,α)^{4}He data overlap with the Big Bang nucleosynthesis energies and the deduced reaction rate allows us to evaluate the corresponding cosmological implications [17]. In addition, the BELICOS (BEryllium and LIthium in the COSmos) experiment has been also performed at INFN-LNL via THM application to the ^{7}Be+^{2}H quasi-free reaction reaction ignited at a beam energy of 20 MeV. A parallel experiment has been also discussed in [18].

9.2 The THM Experiments

Recently, the ^{7}Be(n,α)^{4}He cross section has been derived by applying the charge-symmetry hypothesis to previous ^{7}Li(p,α)^{4}He THM data, as discussed in [17]. Charge-symmetry hypothesis (CSH) is still a largely debated topic in nuclear physics particularly for low-energy induced reactions. However, the agreement between the cross section values derived in [6] by means of the detailed balance principle and the ones derived in [19] represents a test for the goodness of CSH for this system.

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For the purpose of our 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 [11, 20]. 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 ^{7}Li(p,α)^{4}He THM data covering a center-of-mass energy $E_{Li-p}>1.644$ MeV have been taken into account. These data have been then correct for Coulomb effects and threshold energies, as discussed in [17]. The result of such investigation show a marked agreement with the trend of the cross section data of [6, 19], 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 [19]. From the deduced reaction rate, we found a very small decrease within 10% of the corresponding reaction rate. Although this results improve the production of lithium, its impact is far to solve completely the lithium-problem thus suggesting, once again, other solutions rather than the nuclear ones [4, 17].

Besides the previous investigation, the ^{7}Be(n,α)^{4}He reaction (Q = 18.99 MeV) has been studied by means of the THM applied to the quasi-free reaction ^{2}H(^{7}Be, α^4He)p (Q = 16.765 MeV), by using a 20.4 MeV ^{7}Be beam impinging on a 400 μg/cm^2 thick CD_2 target. By using deuteron as TH-nucleus, the two emerging alpha particles have been detected while the kinematical quantities of the undetected proton have been reconstructed by means of momentum-energy conservation laws. The experiment has been performed at the EXOTIC facility [21]. A ^{7}Be beam has been produced by means of a 33 MeV ^{7}Li beam interacting with a 1 bar H_2 cryogenic gas target. At the end of the beam line, an intensity of 5–8 $\times 10^5$ pps and a purity of about 99% were measured. The adopted experimental setup for the present ^{7}Be+^{2}H has been described in [22]. It is part of the EXPADES array described in [23]. The detectors have been located around the so-called QF angular pairs, i.e. the angular pairs at which alpha particles are emitted in correspondence of low-momenta of the undetected proton, thus completely covering the kinematic region at which the contribution of the QF reaction mechanism is expected to be dominant. A symmetrical configuration of the detection system has been chosen to double statistics. The alpha particles emitted in the angular range 27° ± 8° have been detected by means of a ΔE-E telescope made up of an ionization chamber (IC), (ΔE stage), and two 300 μm silicon detectors acting as E stage. The IC's have had an active depth of 61.5 mm and have been filled with 100 mbar isobutane gas. Entrance and exit windows were made up by 1.5 μm thick mylar foils with an effective area of 60 × 60 mm^2 to match the E silicon-stage. The further stage of the analysis foresees the selection of the events corresponding to the three-body reaction channel ^{2}H(^{7}Be, α^4He)p. By using the standard ΔE-E technique to select the Z = 2 loci in the telescopes, the alpha-alpha events of interest have been reconstructed once the energy loss in the CD_2 target as well as in the IC has been properly evaluated. To assess the proper selection of the exit channel the experimental Q-value spectrum has been deduced for the selected events, leading to an experimental value of about 16.76 MeV, in agreement with the theoretical one of 16.765 MeV. A Gaussian fit of such a peak leads to a FWHM of about 2 MeV, reflecting the experimental FWHM of the ^{7}Be beam (FWHM≈1 MeV), energy loss effects in the CD_2 target (≈0.7 MeV) and angular resolution (±0.4°) effects. In order to select the QF-reaction mechanism, on which the full THM data analysis is based, the trend of the momentum distribution for the p-n intercluster motion inside deuteron has been studied, showing a good agreement with the theoretical Hulthen wave function in momentum space. This agreement marks unambiguously the QF-reaction mechanism thus allowing us to further proceed in the extraction of the ^{7}Be(n,α)^{4}He cross section. Thus, the two body reaction cross section needs to be properly evaluated taking into account HOES (half-off energy shell effects) as well as normalization to the available direct data of [5, 6, 19].

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