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NUCLEAR PHYSICS A
Nuclear Physics A 758 (2005) 775c–778c

Study of ^{7}Be+d reactions for Standard Big Bang Nucleosynthesis

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The recent WMAP results tightly constrain the baryon density in the universe, which in turn constrains the light element abundance predicted in Standard Big Bang Nucleosynthesis (SBBN). There is a discrepance in the ^{7}Li abundance which cannot be explained by uncertainties in the main reactions included in the SBBN. Up to now, the influence of the reaction ^{7}Be(d,p)2α has been neglected. We have investigated this reaction at SBBN energies using a radioactive ^{7}Be beam and a $(CD_2)_n$ self-supporting target at the CYCLONE RIB facility at Louvain-la-Neuve. The experimental method is briefly described. Preliminary results and consequences for primordial nucleosynthesis are discussed.

1. INTRODUCTION

The precise value of the baryonic content of the Universe, $\Omega_b h^2 = 0.0224 \pm 0.0009$[1], recently obtained by WMAP [1] has triggered a renewed interest in reconciling observational and calculated ligh-element (^{4}He, D, ^{3}He and ^{7}Li) abundances. In a recent paper [2], we have compared the observed and calculated light-element abundances (Figure 1 in [2]) using (i) the baryonic density from WMAP and (ii) the SBBN rates from a new compilation based on an R-matrix analysis of the main SBBN cross sections [3]. We have

[1]Ω_b is the ratio of the baryonic density to the critical density, h is the Hubble constant in units of 100 km$\cdot$s$^{-1}\cdot$Mpc^{-1}

0375-9474/$ – see front matter
doi:10.1016/j.nuclphysa.2005.05.192

found a very good agreement for deuterium, reinforcing confidence in the deduced $\Omega_b h^2$ value. The agreement for ^{4}He is not as good but remains acceptable while ^{3}He was not considered because of its uncertain galactic rate of production and destruction. The ^{7}Li abundances measured in halo stars of the Galaxy were considered up to now as representative of the primordial abundance. However, the ^{7}Li abundance of [2] that agrees with the WMAP value is a factor of more than 3 larger than its most recent observational determination [4]. Figure 1 shows the ^{7}Li abundance by number relative to H as a function of the baryon-to-photon ratio η or $\Omega_b h^2$ (solid curve). The horizontal hatched region represents primordial ^{7}Li abundances (95% c.l.) deduced from halo star observations taking into account all known sources of uncertainties [4]. The vertical shaded region represents the (1 σ) $\Omega_b h^2$ limits provided by WMAP [1]. If large observational bias or nuclear uncertainties can be excluded, new physics has to be invoked to resolve this discrepancy.

However, before suggesting that new physics may be needed, effects related to uncertainties in the SBBN reaction rates have to be excluded. For high baryon density, the ^{7}Li abundance from SBBN models arises principally from ^{7}Be that further decays to ^{7}Li. Hence reconciliation of SBBN, WMAP and ^{7}Li observations by nuclear physics effects can only come from ^{7}Be production and destruction rates. In SBBN, the main reactions are ^{3}He$(\alpha,\gamma)^7$Be and ^{7}Be(n,p)^{7}Li which are sufficiently well known [3] to exclude this option. However, other reactions which have been neglected up to now have to be considered. This is the case for the ^{7}Be(d,p)2α reaction.

The present rate of ^{7}Be(d,p)2α ($Q = 16.490$ MeV) comes from an estimate by Parker [5] based on experimental data above the c.m. energy of 0.6 MeV from an early work of Kavanagh [6]. In Ref. [6], protons corresponding to the 0^+ ground state and the first excited state (3.06 MeV, 2^+) in ^{8}Be were detected at 90° using a NaI(Tl) detector. The estimate of the ^{7}Be(d,p)2α cross sections at the SSBN Gamow window ($T = 0.1 - 1$ GK, $E = 0.11 - 0.56$ MeV) implies an extrapolation of about two orders of magnitude. If the actual ^{7}Be(d,p)2α rate were a factor of about 100 larger at these low energies, where no data exist at present, the ^{7}Li disagreement would vanish. The measurement of the ^{7}Be+d cross section at SBBN energies is thus of the greatest importance. We have performed such a measurement at the CYCLONE RIB facility at Louvain-la-Neuve. The experimental set-up and preliminary results are presented in the next section. Consequences for primordial nucleosynthesis are briefly discussed.

2. MEASUREMENT OF THE ^{7}Be(d,p)2α CROSS SECTION

We have used a post-accelerated ^{7}Be^{1+} radioactive beam at a nominal energy of 5.8 MeV provided by the CYCLONE110 cyclotron. A detailed description of the production of the ^{7}Be radioactive beam can be found in Ref. [7]. In order to minimise the contamination from the ^{7}Li isobaric beam, the ^{7}Be beam was completely stripped to ^{7}Be^{4+} by transmission through a thin ^{12}C foil, before passing through a dipole magnet. The beam passed two collimators before impinging on the target which consisted of a 200 μg/cm^2 $(CD_2)_n$ self-supporting foil with a very thin Au coating evaporated on its upstream surface. The Au layer, together with the C content in the target, were used for normalization by measuring the elastic scattering of ^{7}Be. Prior to the ^{7}Be(d,p)2α study, the beam energy was determined by means of a calibrated Si detector situated at 0°. We obtained

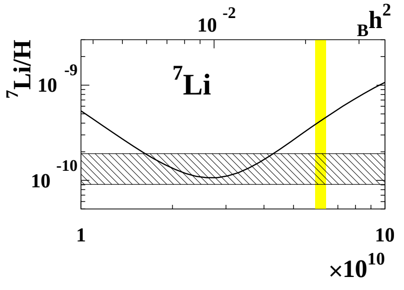

Figure 1. ^{7}Li abundance (relative to H) as a function of the baryon-to-photon ratio η or $\Omega_b h^2$ (see text).

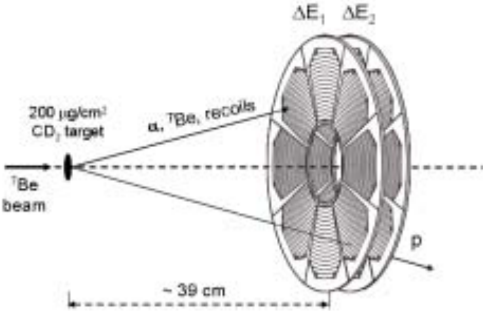

Figure 2. Schematic lay-out of the experimental set-up (see text).

a laboratory energy of 5.545 MeV (FWHM $\sim$ 4%). This energy was degraded down to 1.710 MeV (FWHM $\sim$ 12%) using a 6 μm Mylar foil situated at about 50 cm from the target. No ^{7}Li contamination was observed, as we expected from a completely stripped ^{7}Be beam. With such a set-up, we were able to investigate the center-of-mass energy range between 1.2 and 0.96 MeV (for a beam energy of 5.545 MeV) and between 0.38 and 0.15 MeV (for 1.710 MeV).

The reaction products were detected using a stack of two LEDA [8] detectors covering an angular range of $\theta_{\rm lab} = 7^\circ - 17^\circ$ (Figure 2). ΔE_1 consisted of eight strip detectors of 0.3 mm thickness, ΔE_2 consisted of four sectors of 0.3 mm thickness and four sectors of 0.5 mm thickness. High energy protons corresponding to the ground state and the first excited state in ^{8}Be were not completely stopped in the $\Delta E_1 - \Delta E_2$ telescope, while protons corresponding to other higher excited states in ^{8}Be were stopped. α particles, recoil and scattered particles were completely stopped in ΔE_1.

Figures 3 and 4 show two typical spectra obtained at beam energies of 5.545 and 1.710 MeV, respectively. The proton signals are well separated from the uncorrelated background ($\Delta E_2 < 500$ keV). The difference in the deposited energy observed in the spectra is due to the different Si wafer thicknesses (0.3 and 0.5 mm, respectively) used in ΔE_2. The regions indicated correspond to the signature of the ground state and first excited state in ^{8}Be. The protons corresponding to other higher excited states in ^{8}Be, not observed in [6], represent about 30% of the total number of events.

Data is still under analysis. Preliminary estimates indicate that the cross sections obtained from this measurement will not dramatically change the conclusions with respect to the ^{7}Li abundance. Final results will be published soon [9].

3. CONCLUSIONS

The ^{7}Be(d,p)2α reaction is related to the ^{7}Be production and destruction rates in SBBN models and influences the ^{7}Li primordial abundance. If the ^{7}Be(d,p)2α cross section

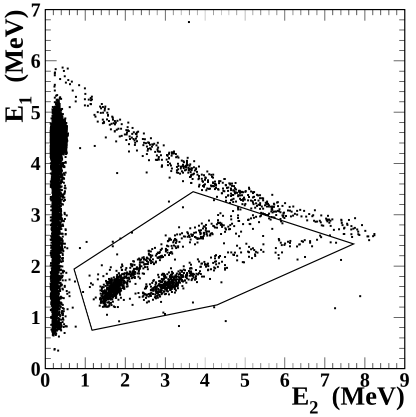

Figure 3. ΔE_1-ΔE_2 typical proton spectrum obtained at a beam energy of 5.545 MeV on a 200 μm $(CD_2)_n$ target. The regions indicated corresponds to the signature of the ground state and the first excited state in ^{8}Be (see text).

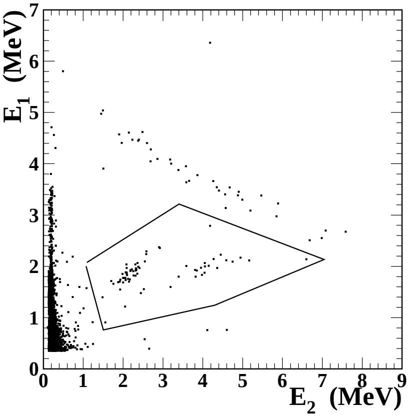

Figure 4. Same as Fig. 3 for a beam energy of 1.710 MeV, corresponding to a c.m. energy range of 0.38 to 0.15 MeV. This spectrum was obtained during about 26 hours of running time with an averaged ^{7}Be beam current of 2×10^6 pps.

were a factor of about 100 larger at the energies of SBBN (below 600 keV), it would account for the discrepancy between the observed and the calculated ^{7}Li abundance. To investigate this, we have measured the ^{7}Be(d,p)2α cross section using an isobarically pure ^{7}Be radioactive beam at the CYCLONE RIB facility at Louvain-la-Neuve. Data are under analysis. However, preliminary estimates tend to indicate that no significant change in the cross section should be expected. Consequently, the ^{7}Li anomaly would still be an open issue.

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