Study of the contribution of the ^{7}Be(d, p) reaction to the ^{7}Li problem in the Big-Bang Nucleosynthesis

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Abstract. Our research goal is to measure the ^{7}Be(d, p) reaction to shed light on the ^{7}Li problem in the Big-Bang Nucleosynthesis. We are developing an unstable ^{7}Be target for a high-resolution measurement of the ^{7}Be(d, p)^{8}Be reaction. We plan to compare two methods to produce the ^{7}Be target: (1) *Activation method*, and (2) *Implantation method*. We performed an activation method experiment at the Van de Graaff at Osaka University, and obtained the cross-section data. A second experiment to obtain more accurate data will take place at the Tandem Electrostatic Accelerator, Kobe University. We have also made a ^{7}Be target with implantation method at CRIB, Center for Nuclear Study, University of Tokyo. An experiment to measure the (d, p) reaction with the implanted target is scheduled for 2018 at Japan Atomic Energy Agency, tandem facility.

1 Introduction

The overestimation of primordial ^{7}Li abundance in the standard Big-Bang Nucleosynthesis (BBN) model is one of the known and unresolved problem. A recent theoretical BBN model predicts a primordial ^{7}Li abundance that is about 3 times larger than the recent precise observation [**?**]. The difference is quite large while the abundance of the other light nuclei are reproduced well. This is one of the biggest problems in the BBN models and it illustrates the incomplete knowledge of the processes of the primordial formation of our universe.

Light nuclei were produced up to ^{7}Be by nuclear reactions in several hundred seconds following the Big Bang (Figure **??**). ^{7}Li nuclei were predominantly produced by the β decay of ^{7}Be in the standard BBN model. The β decay half life of ^{7}Be, 53.22 days = 5 million seconds, is much longer

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than the timescale of the production of light nuclei after the Big Bang. Thus, one possible scenario to solve the ^{7}Li problem is that ^{7}Be was destructed in the timescale of the nuclear reactions.

There are several possibilities to destroy ^{7}Be, for example the ^{7}Be(d, p)^{8}Be, the ^{7}Be(n, α) or ^{7}Be(n, p) reactions are considered [**?**]. We focus on the ^{7}Be(d, p)^{8}Be reaction since the contribution from ^{7}Be(d, p)^{8}Be is suggested to be larger than ^{7}Be(n, α)^{4}He [**? ?**].

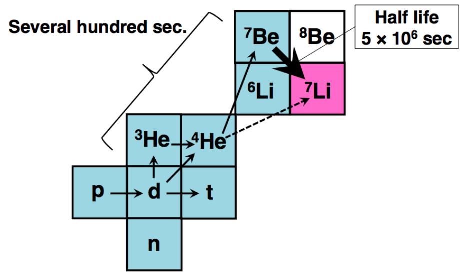

Figure 1. Light nuclei were produced in several hundred seconds following the Big Bang. ^{7}Li was produced by the β decay of ^{7}Be. The β decay half life of ^{7}Be is 5 million seconds, which is much longer than the timescale of the nuclear reactions.

2 Experimental Method and development

The goal of the experiment is to measure the cross section of the ^{7}Be(d, p)^{8}Be reaction in the BBN energy region of 100 - 400 keV. We plan to measure the ^{7}Be(d, p)^{8}Be reaction in direct kinematics with a ^{7}Be target since the available data are insufficient in the accuracy or in the energy range [**? ?**]. We are developing an unstable ^{7}Be target for a high-resolution measurement of the ^{7}Be(d, p)^{8}Be reaction. The development of the unstable target is a big technical challenge. We apply two different methods to make the ^{7}Be target, the *Activation method*, and the *Implantation method*.

2.1 Activation method

The activation method is a simple but effective way to make the ^{7}Be target. The first experiment was performed at the Van de Graaff, Osaka University, in December 2015. We used a natural Li target as a host target to produce the ^{7}Be target. A proton beam at 2.6 MeV was injected to activate ^{7}Li in the natural Li target to ^{7}Be. We immediately changed the beam to deuteron after the target production and measured proton from the (d, p) reaction by three layer Si detectors. Cu absorbers were placed in front of Si detectors to prevent low charged particles from damaging the detectors. The incident deuteron energy was 2 MeV. The analysis was done by the "thick target method". This method can be applied when the target is thick and the energy loss of incident beam is obvious in the target. The reacted incident deuteron energy was obtained by the detected proton energy. The number of the ^{7}Be target was calculated depending of the thickness of the Li host target. We obtained the cross section using the activation target. Figure **??** shows the measured cross sections of the ^{7}Be(d, p) reaction as a function of on the incident deuteron energy.

This cross section at 0.4 MeV (BBN energy region) has a contamination from the second 2^+ excited state of ^{8}Be. We could not separate the reaction which made the second 2^+ excited state of ^{8}Be with the high energy of deuteron (≈2 MeV), since the incident energy was determined by the detected proton energy. However, this problem will be solved with using a lower incident deuteron

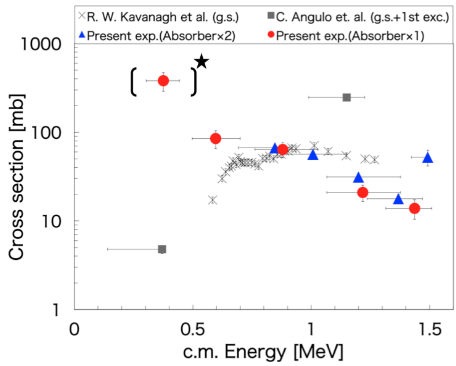

Figure 2. The cross section of the ^{7}Be(d, p) reaction as a function of the incident deuteron energy with the reference data [**? ?**]. This data was obtained using the activated ^{7}Be target. ★ This plot is preliminary.

energy that inhibits the higher excited state of ^{8}Be. An additional experiment is already planned at the Tandem Electrostatic Accelerator, Kobe University for March 2018. We plan to apply the method to produce ^{7}Be and measure the ^{7}Be(d, p)^{8}Be reaction.

2.2 Implantation method

The development of the implantation method is also ongoing. In the implantation method, ^{7}Be particles are implanted into a host target. We performed an experiment to produce a ^{7}Be implanted target at CRIB, Center for Nuclear Study (CNS), University of Tokyo, in June 2016. The primary beam was ^{7}Li^{2+} at 5.6 MeV/nucleon. The secondary beam was produced by the ^{1}H(^{7}Li, ^{7}Be) reaction. The secondary beam energy was 4.0 MeV/nucleon. A 10 μm thick gold foil as a host target was irradiated with the ^{7}Be beam after an energy degrader made of gold with a thickness of 15 μm and 2 mm diameter collimator. We evaluated the amount of the implanted ^{7}Be by detecting 477 keV γ rays with a $LaBr_3$ detector after the implantation. The γ ray is emitted in the electron capture decay of ^{7}Be with a branching ratio of 10.4%. We obtained 1.3×10^{11} ^{7}Be particles after 19 hours of irradiation.

We also performed a development experiment at CRIB to obtain an intense beam of ^{7}Be in 2017. We obtained 1.2×10^{12} ^{7}Be particles after the optimization of the magnets setup and settings of beamline optics. As the next step, we plan to measure the ^{7}Be(d, p) reaction at Japan Atomic Energy Agency, tandem facility. The ^{7}Be target will be produced at CRIB before the (d, p) reaction measurement. The experiment is planned for 2018.

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