Determination of ^{8}Li(n,γ) cross section via Coulomb dissociation of ^{9}Li (INTC-P-543)

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Motivation:

Considerable attention has been paid to the possibility that the early universe might have been rather inhomogeneous.

Some of the reactions, which can occur at the onset of neutron-rich nucleosynthesis, are shown in Fig.1. The main product sequence, according to Malaney and Fowler, is

$^{1}H(n,\gamma)^{2}H(n,\gamma)^{3}H(d,n)^{4}He(t,\gamma)^{7}Li(n,\gamma)^{8}Li(\alpha,n)^{11}B(n,\gamma)^{12}B(\beta)^{12}C(n,\gamma)^{13}C(n,\gamma)^{14}C(\beta)^{14}N$

Astrophys. J. **345**, L5 (1989)

From Fig.1, it is clear that the reaction path becomes quite complicated between ^{6}Li and ^{9}Be.

The heavy elements may be produced primarily as a consequence of the two reactions $^{7}Li(\alpha,\gamma)^{11}B$ and $^{8}Li(\alpha,n)^{11}B$.

This latter reaction must compete with the $^{8}Li(n,\gamma)^{9}Li$ and $^{8}Li(d,n)^{9}Be$ reactions which reduce the heavy element production by turning the reaction flow back toward ^{6}Li.

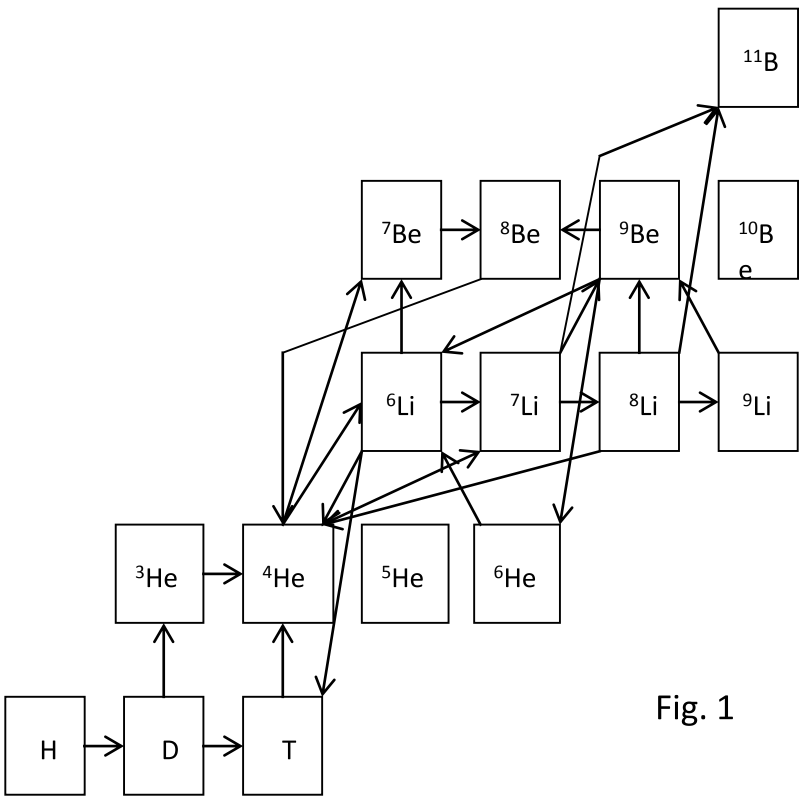


Fig. 1

^{8}Li(n,γ)^{9}Li reaction

It is difficult to evaluate the merits of inhomogeneous nucleosynthesis, because the rates of several important reactions, some of which are mentioned in the above paragraph, are either not measured or not well established. For example, only few reactions involving ^{8}Li have been measured.

Clearly in the inhomogeneous nucleosynthesis scenario ^{8}Li(n,γ)^{9}Li reaction plays an important role as it affects the primordial abundance of A>12 matter. The main production sequence for A>12 goes through the chain ^{7}Li(n,γ)^{8}Li(α,n)^{11}B. However, the neutron capture on ^{8}Li to ^{9}Li may reduce the amount of ^{11}B by 40-50% by turning back the reaction flow to ^{4}He.

Previous attempts to study this reaction were mostly through (d,p) reaction. ^{8}Li's half-life of less than 1 second makes it very difficult to prepare a ^{8}Li target and bombard it with neutron. Consequently, a direct measurement of the capture cross section is nearly impossible. Only a couple of experiments were attempted where (n,γ) [2, 3] was studied through Coulomb dissociation and using the principle of detailed balance the required cross section was determined. Therefore, all previous attempts to measure this reaction were through the reverse reaction.

The main constraint in the previous Coulomb dissociation experiments using beam energies between 30-40 MeV/A was low beam intensity of ^{9}Li and the inability to separate the contribution of the coulomb dissociation from that of nuclear dissociation and only upper limits of the cross section was established.

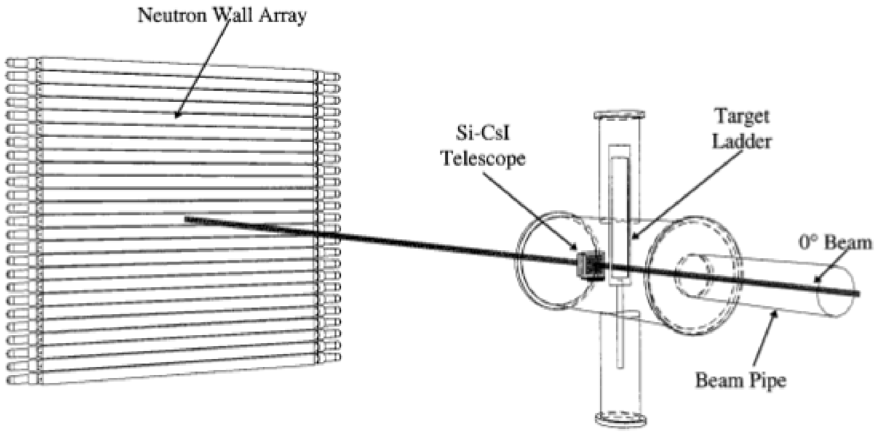
Coulomb dissociation of ^{9}Li

Previous Works

Experiments:

In an earlier work on ^{8}Li(n,γ)^{9}Li by P.D. Zecher et al. at Michigan State University with beam energy 28.5 MeV/nucleon placed both the fragment and neutron detectors at zero degrees with respect to the beam to accommodate the forward focusing, **P.D. Zecher et al, Phys. Rev. C 57 (1998) 959.**

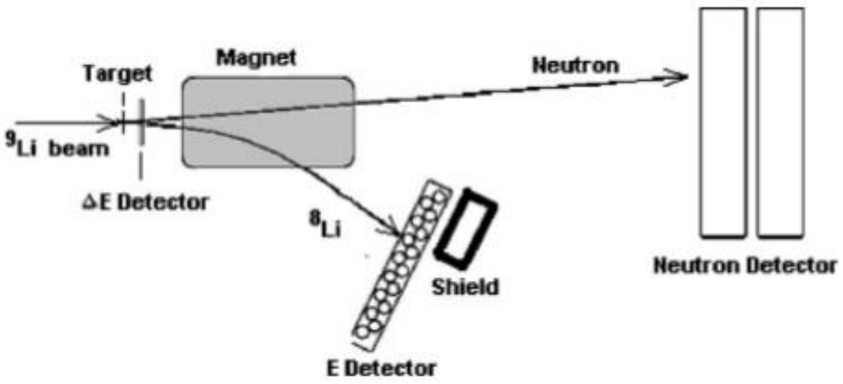
Only the upper limit of the cross-section of the Coulomb dissociation was reported because of determination of the nuclear dissociation could not be done which required to be subtracted from the total. Beam intensity of ^{9}Li was about 5000/sec.



Previous Works

H. Kobayashi et al, Phys. Rev. C 67, 015806 (2003)

^{9}Li beam on Pb target at NSCL, with beam intensity 10^4/sec and the beam energy 39.7 MeV/nucleon. They measured upper limit for the reaction rate only.



Comparison of reaction rates for the direct capture of the ^{8}Li(n,γ)^{9}Li reaction at T_9=1.

	Year of Publication	Reaction Rate (in $cm^3 mole^{-1} s^{-1}$)
Theoretical	1988	43000
	1991	21000
	2016	5900
	1993	5300
	1994	4500
	2005	4000
	2008	2900
	1999	2200
Experimental	1998 (P.D Zecher et al)	<7200
	2003 (H. Kobayashi et al)	<790

This table is taken from "Sergey Dubovichenko, Albert Dzhazairov-Kakhramanov, Int. Jour. Mod. Phys. E 26, 1630009 (2017)"

The Table on left shows the wide differences of the theoretical calculations as well as between the two previous experimental works.

Merits of our proposed experiment

The theoretical calculation has shown that the differential cross section in the forward angles are mainly due to Coulomb part [5]

While, nuclear effects remain almost constant over a large range of beam energies [7] Coulomb dissociation cross section (above the Coulomb barrier) decreases with increase in the beam energy [5,7,8] and consequently, the nuclear contributions would only increase if we increase the beam energy. The Coulomb dissociation cross-section also increases with the mass of the target [6].

HIE-ISOLDE is best suited to do this experiment because:

1) It is possible to do the experiment at much lower energy and
2) It offers order of magnitude higher beam intensity than the previous experiments.

The choice of our beam energy of 7 MeV/A , not much above the coulomb barrier, and the angle of observation of reaction products for the channel (γ,n) will give predominantly the Coulomb component. However, for better idea of Coulomb-nuclear interference, we must also experiment with different targets of varying Z from low-Z to high-Z targets.

Implementation:

We would like to use a Pb target of thickness 10 mg/cm^2 and a 7 MeV/u beam of ^{9}Li beam of about 10^5 pps to observe the breakup of ^{9}Li into ^{8}Li+n.

With a total estimated cross section of 10 mb, beam intensity of 10^5 pps, we expect good number of coincidence events.

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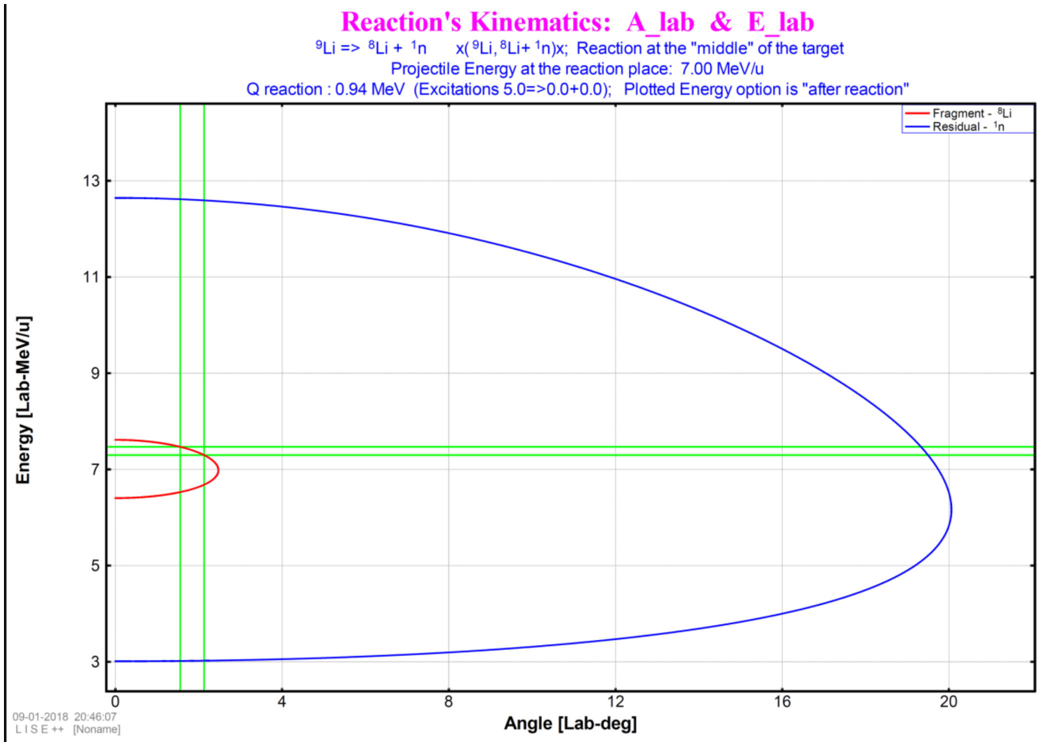

The angular and energy distribution of ^{9}Li, ^{8}Li and neutron is obtained using LISE, for the beam energy 7 MeV/u.

Implementation:

The scattering chamber in the third beamline of HIE-ISOLDE would be suitable for the detection of particles from the reaction ^{9}Li(n,γ) as it comprises the charged particle detectors as well as the neutron detector array (SAND).

For the breakup of ^{9}Li, it must have an excitation energy of at least 4.06 MeV. Assuming an excitation of about 5 MeV, the neutron would be emitted in the angular range 0^{o} - 20^{o} with an energy between 3-13 MeV.

^{8}Li is confined to forward angles of about 2.5^{o} assuming ^{9}Li excitation of 5 MeV. For 10 MeV excitation of ^{8}Li opens up to about 6.5^{o}. We will need a Si detector to be placed along the ^{9}Li beamline in order to detect ^{8}Li. Energy of ^{8}Li varies between 6-8 MeV/u. With the available ΔE-E detector of thicknesses 60 μm and 1500 μm respectively we should be able to detect energies of both ^{8}Li and ^{9}Li with clear discrimination between the two.

Requested shifts:

15 Shifts of beam on target, 3 shifts for beam preparation, installation of detectors and calibration.

References

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Thank you