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Proposal to the ISOLDE and Neutron Time-of-Flight Committee

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

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Abstract:
In the inhomogeneous big-bang nucleosynthesis scenario, the two important reactions for the heavy element production are ^{7}Li(α, γ)^{11}B and ^{8}Li(α, n)^{11}B. This latter reaction must compete with the ^{8}Li(n, γ)^{9}Li and ^{8}Li(d, n)^{9}Be reactions. The neutron capture on ^{8}Li to ^{9}Li may reduce the amount of ^{11}B significantly by turning back the reaction flow. Previous attempts to study ^{8}Li(n, γ)^{9}Li were mostly through (d,p) reaction with only a couple of experiments where direct (n, γ) was studied through Coulomb dissociation. The main constraint in the previous measurements was low beam intensity and the difficulty to separate the contribution of the Coulomb dissociation from that of nuclear dissociation. In the proposed experiment we plan to separate these two contributions using low beam energy of 7 MeV/A and take advantage of higher ^{9}Li beam intensity offered by HIE-ISOLDE. We plan to use the scattering chamber and SAND array at the third beamline of HIE-ISOLDE.

Requested shifts: 18 shifts
Installation: [3rd beamline, Scattering Chamber + SAND Array]

1 Introduction:

Considerable attention has been paid to the possibility that the early universe might have been rather inhomogeneous, consisting of high-density proton rich regions along with low-density regions, which were comparatively neutron-rich. This was the natural consequence of neutron's longer mean free path, for which it could diffuse out of the high-density zones. Although D, ^{3}He and ^{4}He are produced in the observed relative abundances, there may also be non-negligible production of A >12 isotopes. Some of the reactions, which can occur at the onset of neutron-rich nucleosynthesis, are displayed in Fig. 1. The main products sequence of heavy elements has been identified

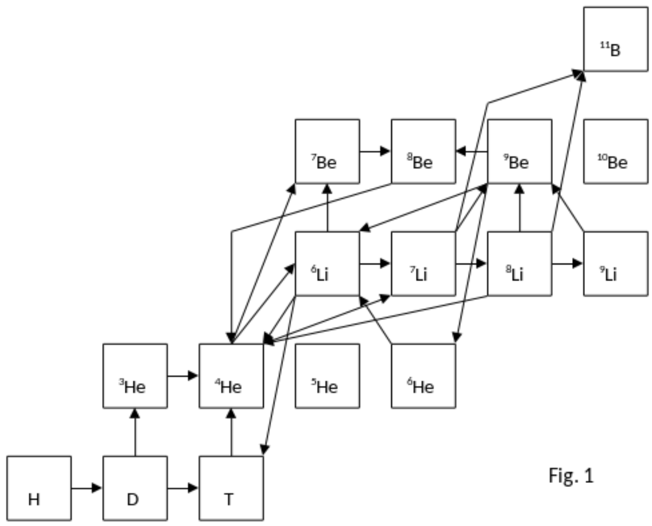

Figure 1: Production sequence of elements

by Malaney and Fowler [1] and the recommended reactions rates have also been given. The main product sequence, according to them, is ^{1}H(n,γ)^{2}H(n,γ)^{3}H(d,n)^{4}He(t,γ)^{7}Li(n,γ)^{8}Li(α,n)^{11}B(n,γ)^{12}B(β)^{12}C(n,γ)^{13}C(n,γ)^{14}C(β)^{14}N. However, from Fig.1, it is clear that the reaction path becomes quite complicated between ^{6}Li and ^{9}Be. The two reactions that can become important for the heavy element production are ^{7}Li(α,γ)^{11}B and ^{8}Li(α,n)^{11}B. This latter reaction must compete with the ^{8}Li(n,γ)^{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.

It is difficult to evaluate the merits of inhomogeneous nucleosynthesis versus standard big-bang 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 and thus any conclusions regarding A>6 nucleosynthesis must be regarded as tentative.

2 Proposed Experiment:

Clearly in the inhomogeneous nucleosynthesis scenario ^{8}Li(n,γ)^{9}Li reaction plays an important role in determining the produced amount of matter at A>12. 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 with only a couple of experiments where direct (n,γ) [2, 3] was studied through Coulomb dissociation and using the principle of detailed balance to determine the required cross section. The half-life of ^{8}Li 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. Therefore, all previous attempts to measure this reaction were through the reverse reaction. In modern particle accelerators it is possible to produce a beam of ^{9}Li nuclei, perform a measurement of the inverse reaction ^{9}Li(γ,n)^{8}Li, and use the principle of detailed balance to deduce the cross section for the neutron capture 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 difficulty to separate the contribution of the coulomb dissociation from that of nuclear dissociation. It would also be interesting to study Coulomb-nuclear interference in the context of the reverse reaction ^{9}Li(γ,n)^{8}Li.

The photons for the inverse reaction are obtained by passing the ^{9}Li through the virtual photon field near a high Z nucleus such as Pb or U. However, there is a drawback in the process. It is important to separate experimentally the purely electromagnetic response through Coulomb excitation of ^{9}Li predominantly by soft dipole E1 excitation from the effects of nuclear interaction. Earlier measurements were done at 28.53 MeV/nucleon and 39.7 MeV/nucleon with beam intensities of about 0.5-1.0 x 10^{4}. Because of the low beam intensities it was not possible to separate the contribution of the Coulomb dissociation from that of nuclear dissociation and only upper limits of the cross section was established. In our experiment we plan to separate these two components using lower beam energies of about 7 MeV/A over a large range of angles and take advantage of higher ^{9}Li beam intensity offered by ISOLDE.

3 Implementation:

The scattering chamber and SAND array at the third beamline of HIE-ISOLDE would be suitable for the detection of charged particles and neutrons from the reaction ^{9}Li(n,γ). The MAGISOL Si-detector set-up at SEC gives a very large angular coverage for the detection of products ^{8}Li and unreacted ^{9}Li and we also expect particles from other channels of the reaction for other higher excitation states of ^{9}Li. The highly efficient plastic-scintillator array, SAND can be used to detect the neutrons emitted from the breakup. We plan to use a Pb target of thickness 10 mg/cm^2 and a 7 MeV/u ^{9}Li beam of about 10^5 particles/second and observe the breakup of ^{9}Li into ^{8}Li + n in the virtual photon field of Pb. With a total estimated cross section of 10 mb, beam intensity of 10^5 pps, we can expect a reasonable count rate in the detector.

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

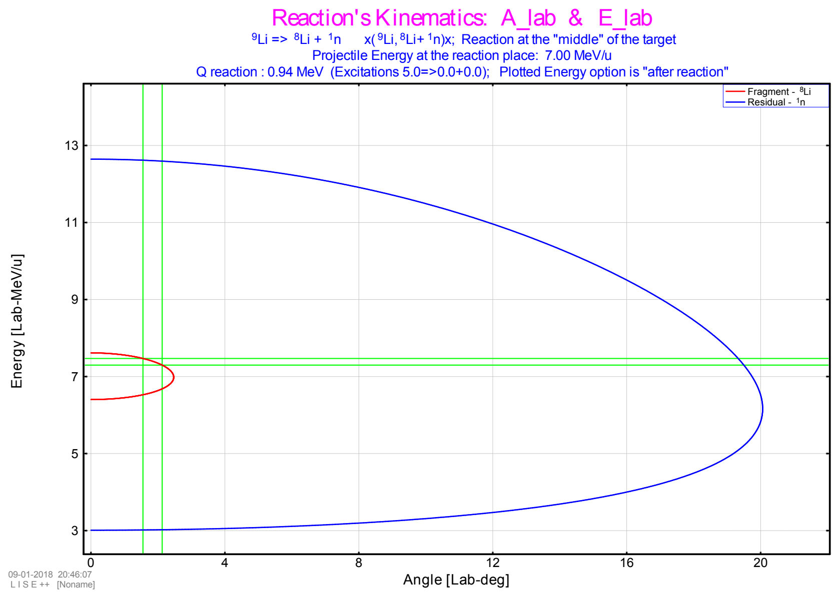

Figure 2: ^{8}Li and neutron kinematic curve

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. These neutrons can be detected with the existing SAND array. For that it would be better to move the array closer to the scattering chamber. Since the γ-energy is not known for individual event, we need to measure ^{8}Li also.

The ^{8}Li is confined to forward angles of about 2.5 degree assuming ^{9}Li excitation of 5 MeV. For 10 MeV excitation, ^{8}Li opens up to about 6.5^o. We will need a Si detector to be placed along the beam in order to detect ^{8}Li. That should not be a problem as the beam intensity is about 10^5 counts/sec. Energy of ^{8}Li varies between 6-8 MeV/u. With the available ΔE-E detector of thickness 60μm and 1500μm respectively, the energy straggling is about 250 keV for both ^{8}Li and ^{9}Li in ΔE. Since the separation between ^{8}Li and ^{9}Li in ΔE would be about 600 keV, we should be able to detect energies of both ^{8}Li and ^{9}Li with clear discrimination between the two.

Summary of requested shifts: 15 Shifts of beam on target, 3 shifts for preparation.

References

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises:

Part of the		
Si detector array	☒ Existing	☒ To be used without any modification
SAND Array	☒ Existing	☐ To be used without any modification ☒ To be modified (to be brought closer to reaction chamber)
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT

Hazards named in the document relevant for the Scattering Chamber + SAND array installation in the 3rd beamline of HIE-ISOLDE.

Additional hazards: none