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# TEST OF $^3$HE IMPLANTED TARGET

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## Abstract

The proton-proton chains (p-p chains), a series of nuclear reactions were proposed several decades ago as a way in which hydrogen burning can occur in smaller main sequence stars. The 3He + 4He? 7Be reaction determines the path that the p-p chains follow. At present the cross section for this reaction has not been precisely determined. To measure this cross section a 3He target and 4He beam are to be used. 3He exists as a gas so a method to manufacture a solid 3He target was needed. A 3He beam was used to implant 3He into Aluminum to make a solid 3He target. This paper reports measurements of the composition of targets made by 3He implantation into Aluminum.

## Introduction

In 1913 an experiment was carried out by Geiger and Marsden, graduate students of Ernest Rutherford, in which 4He was fired at thin gold foils. Detectors were placed at all angles with respect to the target to detect scattered 4He. At the time Rutherford accepted J.J. Thompson's theory of the atom which did not include a nucleus and then calculated that the probability of particles scattering backwards was ~ 10-400 according to Thompson's model. The experiment was run and significant back scattering was detected. From this experiment Rutherford was able to form two conclusions: "The major part of an atom...is concentrated in a nucleus with a positive electric charge" and "the interaction between incident alpha-particles of energies between about 2 MeV and 6 MeV and nuclei ranging from Al to Au can be adequately explained by the electrostatic force alone..."[Bu88]

Astrophysicists suspected that the energy contained in the nucleus could be a source of energy in stars. Hans Bethe, studying nuclear reactions, proposed a set of reactions for which this was plausible called the Carbon-Nitrogen cycle (CNO cycle) which uses 12C as a catalyst for 1H burning. It was then calculated that only hotter, more massive stars could be powered by this reaction. Another series of nuclear reactions for smaller, fainter stars, like the sun, are the proton-proton chains (1H-1H-chain). [Bu88]

The net effect of hydrogen burning is to convert 41H into 4He. i.e.:

41H --> 4He + 2e++ Óe

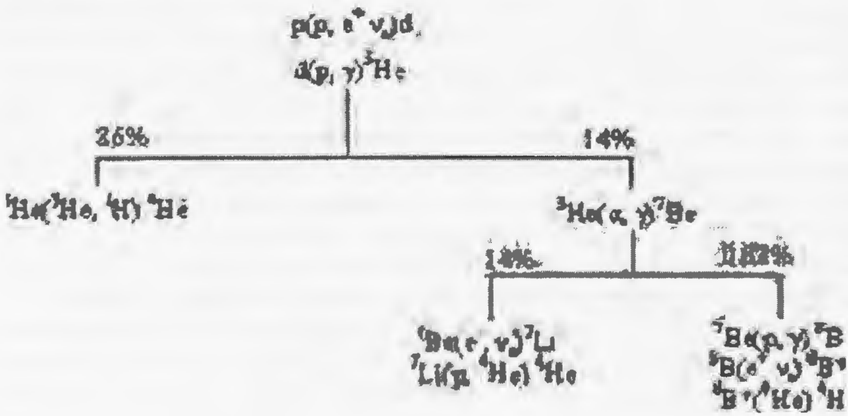
Converting 4 1H into 4He results in a product of smaller mass. The lost mass is converted into energy by E=mc2. This accounts for the large amount of energy emitted by the sun and stars.

The probability of four 1H all coming together simultaneously is essentially zero so a series of two body interactions were established obtaining the same end result. Following is a chart of the nuclear reactions in the p-p chain and their approximate branching ratios.

Chain I Chain II Chain III

The first reaction, p(p,e+ Óe)d is limited by the weak force and is the reason why smaller stars use nuclear fuel slowly and still burn today. The weak interaction gives a cross section about 20 orders of magnitude smaller than the cross sections coming from strong nuclear interactions.[Ro88] The purpose of this experiment is to measure the cross-section of 3H + 4He? 7B + Á, which determines the branching ratio for p-p chain II,
with more precision.

***Fig 1:proton-proton chains***



**Procedure**

3He is a gas under normal conditions. A gas target cannot easily be used under a vacuum so 3He was implanted into aluminum foil targets to make a solid target. The implantation was done at Triangle University Nuclear Laboratory at Duke University using an 80 keV 3He beam from the polarized ion source. The target was biased to 50 kV, slowing the 3He ions to 30 keV at time of implantation. To achieve homogenous implantation the beam was rastered, exposing the target uniformly. The procedure can be found in Ref. [Pr04].

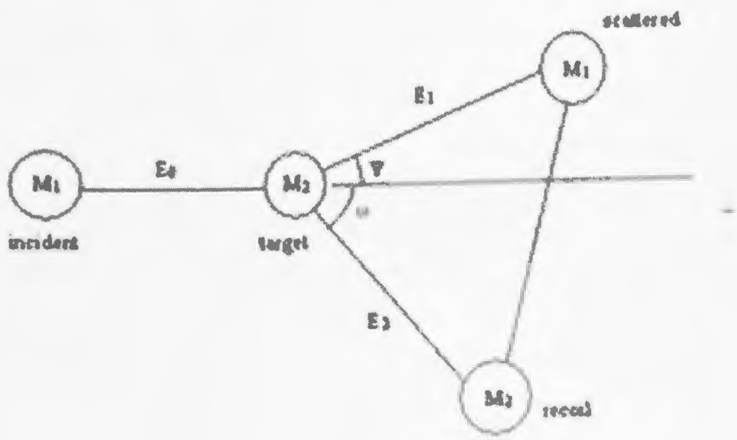
To test the target a 2.5 MeV beam of 1H from a tandem van de Graff accelerator was scattered from the implanted target. Spectra of back-scattered 1H was measured at an angle of 173° from the target (see Fig. 3 and 4).

## Results and Discussion

Kineq, from the Oak Ridge National Laboratories, Milner nuclear data analysis software package was used to model the elastic scattering. Kineq calculates kinematic parameters of two-body collisions modeling these as perfectly elastic. These calculations are based on the principles of conservation of energy and momentum. For the purpose of this experiment the calculations were carried out from the lab frame of reference. The energy of the scattered particle is calculated as follows.

E1/ E0= [M12/( M2+ M1)2 ]{cosæ + [(M1/ M2)2 – sin2æ]1/2}2 [Ma 68]

***Fig 2: Schematic of the particle collision defining the variables in the above equation.***



From figure 2 the scattered particle energy is E1 and our beam energy is ¬Eo. It is obvious that the scattered energy is a function of M2 and Eo. The larger the target mass, the larger the recoil energy. (Eo is held constant at 2.5 MeV during the experiment.)

Chart 1 follows with column one being the possible scatterers.

***Chart 1: Species including 3He, 27Al, and possible contaminants, predicted values calculated by Kineq, and the experimental energies detected by the left detector at 173°***

| species | 1H (MeV) predicted | 1H (MeV) experimental |
|---|---|---|
| 3He | .63 | .64 |
| 6Li | 1.273 | 1.2 |
| 7Li | 1.404 | 1.4 |
| 12C | 1.787 | 1.7 |
| 14N | 1.875 | None detected |
| 16O | 1.940 | 1.9 |
| 27Al | 2.154 | 2.1 |
| 56Fe | 2.327 | 2.3 |

The experimental energy in chart 1 is calibrated to be ((9.6*10-4)*(channel)+0.10)MeV. The calculations in chart 1 are done assuming the target is infinitely thin.

***Fig 3: Proton back-scattering spectra from the control target detected by the left detector at an angle of 173°***

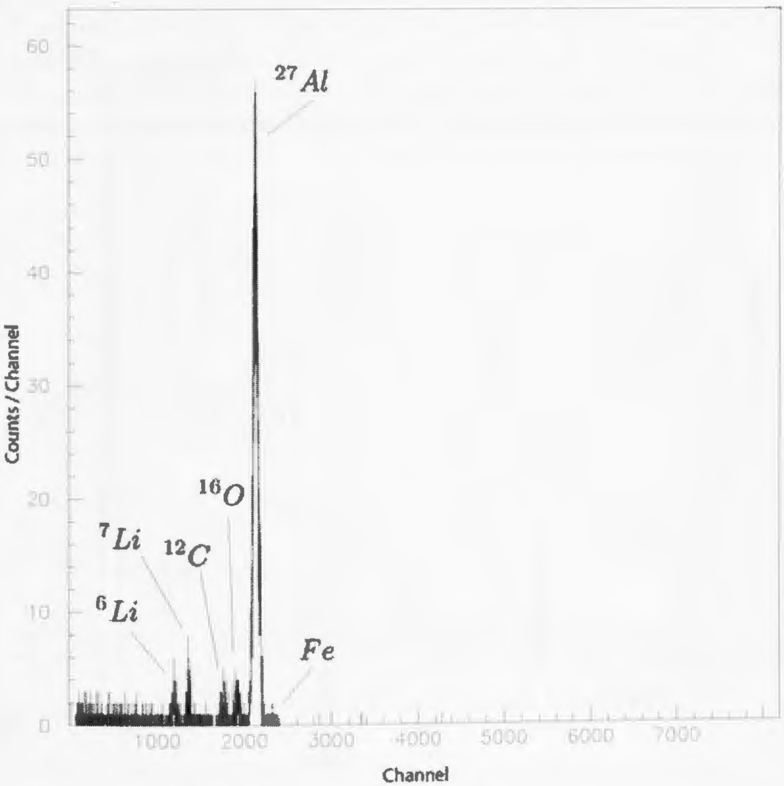


***Fig 4: Proton back-scattering spectra from the 3He, Al and contaminants from the 3He implanted target detected by the left detector at an angle of 173°***

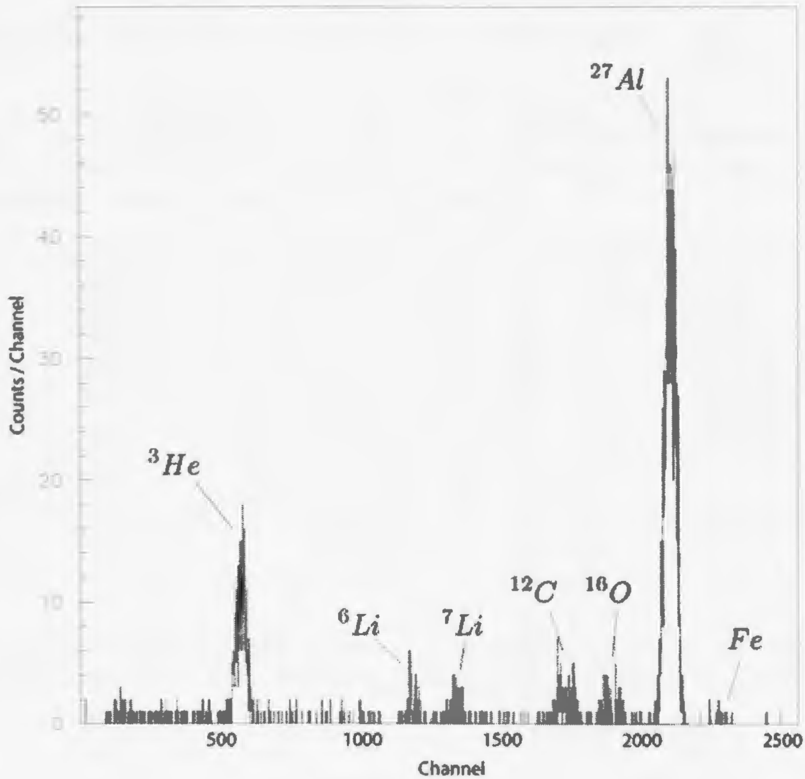



Fig. 3 and 4 show spectra of back-scattered 1H with Fig. 3 being an Aluminum target with no implanted 3He and Fig. 4 being the target with implanted 3He. 12C, deposited by the beam has a double peak in the figures because detection is occurring from nucleus-1H collisions in the front of the target and also nucleus-1H collisions in the back of the target which also occurs with the 16O seen from the oxidation of the Aluminum.

## Conclusion

While confirming the presence of implanted 3He in the aluminum target, other contaminant species were detected though not all were expected. The origin of 6Li and 7Li contamination is unknown at present. 12C contamination is a result of pump oil and gasket grease in the vacuum system. 16O contamination is a result of the exposure of the Aluminum to air which allowed oxidation before installing the targets into the vacuum. 14N could be expected from the air but none was detected. The Aluminum targets acquired were not pure so there was a small amount of 56Fe and similar heavy atoms detected. The desired species 3He was detected in significant amounts in the target that had undergone implantation, but not in the control, as expected.

## References

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