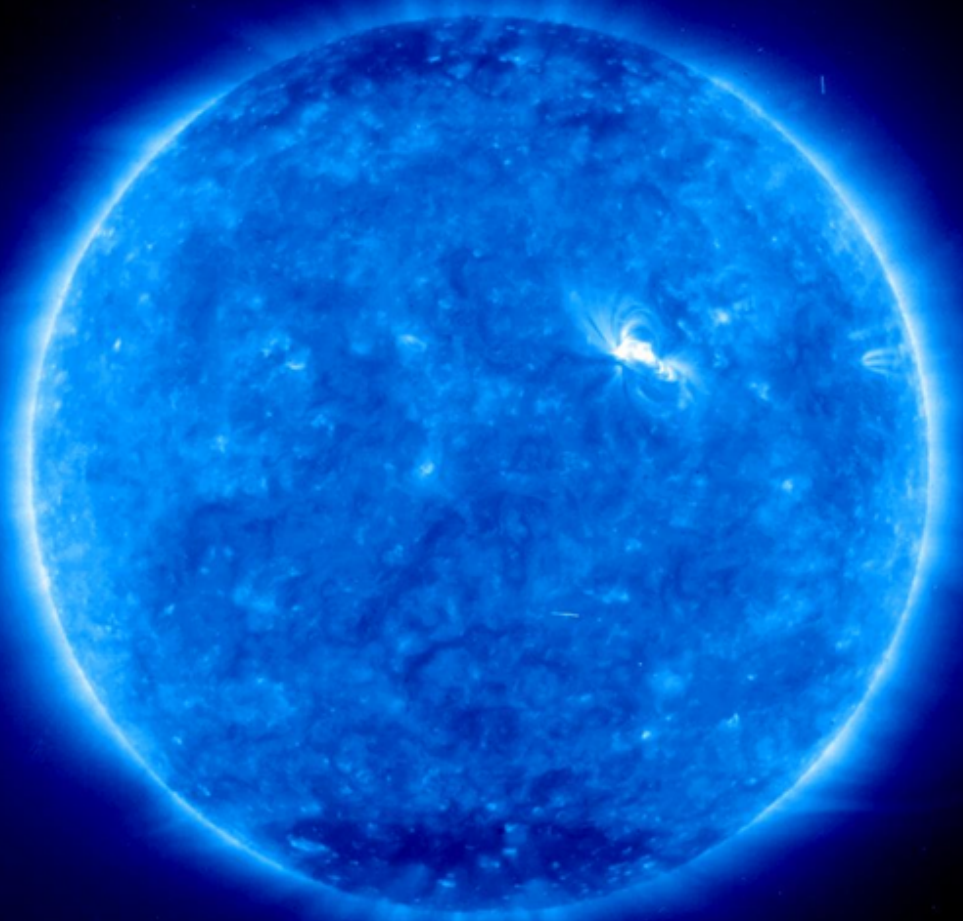
Solid Ion Source for Laboratory Nuclear Astrophysics Research



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Solid Ion Source for Laboratory Nuclear Astrophysics Research

by

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FUSION of small nuclei creates most of the energy found in stars. Laboratory Nuclear Astrophysics is the study of such reactions in the laboratory. Numerous beam and foil experiments have been undertaken in an effort to explore fusion enhanced by condensed matter. These experiments have produced substantial evidence for the catalyzing effects of metals as well as variations in the effectiveness of different types of metal. Current focus is on the construction of a low energy accelerator to study the laboratory nuclear astrophysics reactions ^{6}Li(d,α)α and ^{7}Li(d,α)n. This experiment is unique in that it reverses the usual technique by bombarding deuterated metallic targets with heavier ions rather than with deuterons. We have constructed a solid ion source for an accelerator and have done some testing. We were able to measure sporadic ion currents peaking at about 1500nA. Some improvements are suggested.

Acknowledgements

I would like to thank Steven E. Jones for his valuable insights and Dominik Alder for machine training and rescuing me from malformed parts.

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NOTE TO THE READER: As you peruse the pages of this manuscript pay attention to the colored boxes in the margins. Tan boxes highlight important points. Blue boxes contain anecdotal quotes by famous or aspiring scientists.

Chapter 1: Introduction

1.1 Overview

NUCLEOSYNTHESIS of the elements and energy production in stars comes from nuclear fusion. Studying fusion reactions using reactant energies typical of stars is categorized as Laboratory Nuclear Astrophysics. In terrestrial settings we lack the high-density high-mass conditions found in stars; therefore, we must find other ways of overcoming the Coulomb barrier that separates nuclei. The Laboratory Nuclear Astrophysics Research Group at Brigham Young University is currently constructing a particle accelerator to study nucleosynthetic reactions catalyzed by metals at low energies. Aided by specialized detection systems, our research group endeavors to measure low energy fusion reactions in a unique way by bombarding deuterated metal targets with heavier ions. We hope first to study the reactions ^{6}Li(d,α)α and ^{7}Li(d,α)α,n and obtain data that leads to a theory explaining the catalyzing effects of metals.

"If we knew what it was we were doing, it would not be called research, would it?"
-Albert Einstein

1.2 Background

NUCLEAR fusion is a reaction that joins two nuclei to create new distinct nuclei. Depending on the masses of the nuclei involved, fusion can release an enormous amount of energy. Fusion of elements smaller than iron expels energy; conversely, it requires energy to fuse elements larger than iron. When fusion reactions are exothermic, the mass of the resulting nucleus is smaller than the sum of the particles' previous masses. The discrepancy in mass is the origin of the energy released in the reaction. That energy can be calculated with Einstein's famous equation: $E = mc^2$.

Because of the favorable energy yields of such nuclear processes, one might expect fusion to occur readily, but such is not the case. Dr. Steven E. Jones, a physicist at Brigham Young University,

"I don't like it [quantum mechanics], and I'm sorry I ever had anything to do with it."
-Erwin Schrodinger

Nuclei must overcome the Coulomb barrier in order to fuse.

explains why not, "In relatively cold terrestrial conditions, the nuclei are surrounded by electrons and can approach one another no more closely than is allowed by the molecular Coulomb barrier. The rate of nuclear fusion in molecular hydrogen is then governed by quantum mechanical tunneling through that barrier, or equivalently, the probability of finding the two nuclei at zero separation."[2]

Unfortunately, a complete explanation of Dr. Jones' statement would require a detour through quantum-mechanical theory that we cannot afford to take here. The important thing to know is that on earth atoms lack the energy required to overcome the repulsive force between nuclei of different atoms. This repulsive force creates a minimum separation distance for any two nuclei and is called the Coulomb barrier. The Coulomb barrier prevents two nuclei from drawing near enough to fuse. Thus, fusion only occurs as often as nuclei can tunnel through the Coulomb barrier.

1.2.1 Stellar Nucleosynthesis

FUSION occurring in stars is termed stellar nucleosynthesis; stellar because of where it occurs and nucleosynthesis because new nuclei are created. The high-temperature and high-density interior of stars facilitates tunneling of nuclei. Even so, stellar reaction rates are quite slow; in stars, the fusion rate is only one atom in every 10^{23} per second.[3] Stars' shear mass allows for enough nucleosynthetic reactions to fuel themselves; the slow reaction rate explains how stars burn for billions of years without exhausting their fuel.

The two fusion processes that account for the vast majority of the nuclear energy produced by stars are the proton-proton chain and the CNO cycle (see figure 1). The proton-proton chain is a complex series of reactions that consumes mostly protons and creates a diverse population of new elements. The CNO cycle is similar to the proton-proton chain in that it consumes protons but it follows a more specific

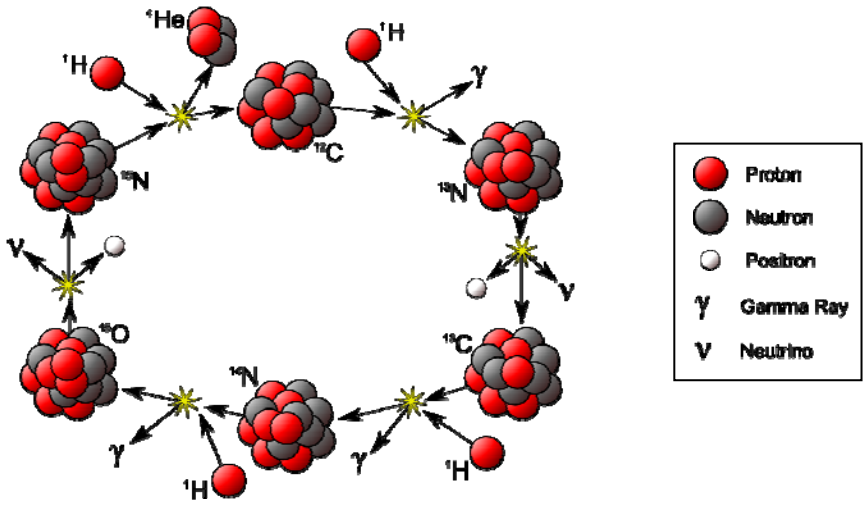


Figure 1: The CNO Cycle[4]
In the CNO cycle, four protons are converted into an alpha particle, two positrons, three gamma rays and two neutrinos by a series of nucleosynthetic reactions involving isotopes of carbon, nitrogen and oxygen.

Only one atom in every 10^{23} fuses each second in the interior of a star.[3]

cycle involving Carbon, Nitrogen, and Oxygen. Small stars like our Sun rely more heavily on the proton-proton process, whereas larger stars get the majority of their energy from the CNO cycle[3]. Below is a simplified formula for the CNO cycle and the energy it produces:

$$4p \rightarrow \alpha + 2e^{+} + 3\gamma + 2\nu \qquad 25.03\text{MeV} \qquad (1)$$

"My goal is simple. It is complete understanding of the universe, why it is as it is and why it exists at all." Stephen Hawking

1.2.2 Laboratory Nucleosynthesis

LABORATORY nucleosynthesis is an attempt to duplicate the nucleosynthetic reactions that occur naturally in stars. Since Earth lacks the high density conditions of stars, creating fusion in a laboratory can be tricky.

In 1947, a muon-catalyzed nuclear fusion theory was suggested by F. C. Frank and Andrei D. Sakharov to explain reactions observed in the emulsion of radiographic film.[5] Muons (μ^{-}) are elementary particles with the same charge as an electron but with 207 times the mass and an average lifetime of only 2.2μs.[6] Because muons are so massive, they orbit much closer to the nucleus and thus allow nuclei to get closer together. Luis W. Alvarez *et. al.* later observed muons catalyzing fusion reactions in hydrogen gas bubble chambers at the

The fusion of hydrogen nuclei is the principle means of energy production in stars.[2]

University of California Berkeley in 1956.[7] They witnessed the nucleosynthesis of helium in a hydrogen bubble chamber (see figure 2). Below is the muon catalyzed reaction they observed:

$$p + d + \mu^- \rightarrow {}^3He + \mu^- \quad (2)$$

(The d in equation 2 stands for deuterium, which is an isotope of hydrogen having one added neutron. Tritium (t) is a radioactive isotope of hydrogen containing two neutrons. Deuterium and tritium can also be written as ^2H and ^3H respectively.)

"The electron is not as simple as it looks."
-(William) Lawrence Bragg

Observation showed that multiple fusion events could be catalyzed by one muon during its short life. In light of this, efforts were made at Los Alamos Meson Physics facility (LAMP) to step up muon catalyzed fusion using tritium in the following reaction:[8]

$$t + d + \mu^- \rightarrow {}^3He + \mu^- \quad (3)$$

Luis Alvarez *et. al.* achieved two fusions per muon.

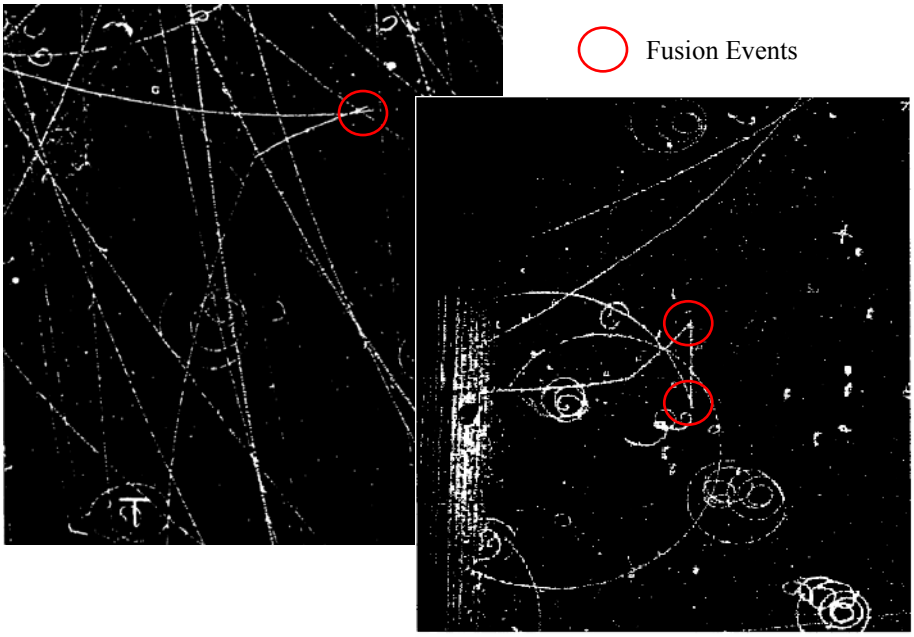


Figure 2: Muon catalyzed fusion in a hydrogen bubble chamber[9]
Luis W. Alvarez *et. al.* witnessed the nucleosynthesis of helium in a hydrogen bubble chamber. The paths of electrically charged particles show up in white against the background. Particles with less momentum have more curved paths and may spiral inward. LEFT: A muon can be seen entering from the left. The gap in the path is where the muo-atom complex is formed and fusion occurs. Subsequently the muon is ejected and the sharp change in the direction of its exit path indicates where it decays to an electron. RIGHT: One muon catalyzes two fusion events before decaying.

In 1986, after four years of hard work, physicists at LAMP were able to get single muons to catalyze an average of 150 reactions before decaying to an electron.[10] They demonstrated that fusion is possible at less than stellar conditions in bound systems. This realization has driven a succession of experiments done at BYU and other institutions.

Physicists at LAMP hold the world record for 150 fusions per muon[10].

1.3 Recent Experimentation

EXPERIMENTATION that is more contemporary has moved from muons to other means of catalyzing fusion reactions. Dr. Jones and other physicists at BYU hypothesized that metals could catalyze fusion and that some metals enhance fusion more than others.[2] This hypothesis has been the premise for research around the globe. Interestingly, recent findings are confirming the BYU hypothesis (see figure 3). The German physicist F. Raiola and his colleagues have determined that several metals such as palladium, platinum and titanium significantly

A hypothesis for laboratory nucleosynthesis is proposed.

Material	U_e (eV)		Material	U_e (eV)
D_2 gas*	25±5		Co	640±70
Pd	800±90		Ti	550±90
Sb	720±500		Al	520±50
Pt	670±500		Sn	130±20
Pd-Li	1500±310		Au-Li	60±150

Figure 3: Empirical d-d Fusion Enhancement Factors[14]
This table shows the d-d fusion enhancement of several metals over d-d fusion in D_2 gas. Some metals like palladium (Pd) enhance fusion more than others. In addition, some metal alloys enhance fusion greatly (Pd-Li), while others show little enhancement (Au-Li).
*D_2 gas data was obtained by U. Griefe, *et. al.*[13] whereas all other data was obtained by F. Raiola, *et. al.*[14]

"A theory can be proved by experiment; but no path leads from experiment to the birth of a theory."
-Albert Einstein

enhance deuteron-deuteron (d-d) fusion rates. Also alloys of certain metals evoke a synergistic effect additionally enhancing fusion.[14] Furthermore, they show that the temperature of the metal may play an important role in its catalyzing effects.[15]

BYU's metal catalyzed fusion hypothesis is corroborated.

Physicists determine the extent to which metals catalyze fusion by calculating the astronomical S-factor of deuterium in each respective metal or metal alloy. The astronomical S-factor is a measure of a particle's effective cross sectional area and energy. The effective cross section of a particle is usually measured in units of barn(b). Comically, the name barn comes from the colloquial expression to "hit the broad side of a barn" which makes it easier to remember. Accordingly, deuterons with larger cross sections and higher energies have a larger S-factor are more likely to enter into nucleosynthetic reactions.

Since a particle's S-factor is proportional to its respective energy the S-factor decreases as the particle's energy decreases. Until recently, no one was able to measure fusion reactions at very low energies; consequently, the values for the S-factor are generally extrapolated down for those energies. Recent improvements in detection methods, however, have shown that the cross sectional area for deuterium actually increases for deuterium bound in metals at very low energies (see figure 4).[13]

"I render infinite thanks to God for being so kind as to make me alone the first observer of marvels kept hidden in obscurity for all previous centuries."[1]
-Galileo Galilei

Presently, we cannot explain why the S-factor increases so dramatically for deuterium in some metals at very low energies. Several research groups around the world have been trying to characterize the ability of various metals to catalyze fusion. We hope to search for a catalyst to enhance deuteron-lithium fusion at low energies.

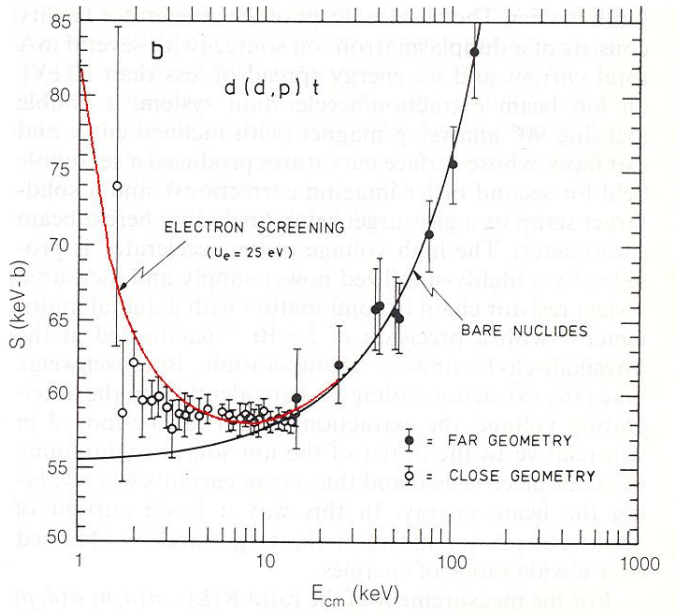


Figure 4: Energy Dependence of the Astronomical S-Factor[13]
The black line indicates the previously accepted extrapolation of the S-factor calculated from d-d fusion measurements of a deuteron beam through deuteron gas. The red line indicates a new plot for the S-factor given recent data by U. Griefe *et al*. in bound metallic systems.

Advancements in particle detection make it possible to accurately measure low energy fusion in metals.

"Probability has turned modern science into a truth casino."
-Bart Kosko

Chapter 2: Current Experimentation

2.1 Experimental Design

"There is not the slightest indication that energy will ever be obtainable from the atom."
–Albert Einstein[12]

CURRENTLY the Laboratory Nuclear Astrophysics research group is working to build a low energy charged particle accelerator. An accelerator will allow us to direct a beam of energetic ions at different targets. We plan to use metallic targets such as palladium, titanium and copper that have been infused with deuterium atoms. When the incident ions collide with the deuterons, fusion may occur. Observing the products of the reaction will allow us to determine whether fusion reactions are taking place. Eventually we hope to understand the mechanisms by which these reactions proceed and how certain metals catalyze it.

Typical accelerators at BYU create beams of particles with energies ranging between 400KeV and 2MeV. The accelerator currently under construction will operate at energies below 50KeV from a solid ion source. Currently the department only has gas ion sources so we have constructed a solid ion source. A low energy accelerator will allow us to conduct fusion experiments at low energies much faster than our past experimental designs allowed.

BYU does not currently have a solid ion source accelerator.

The experimental design of the proposed accelerator less complicated than that of more common Van de Graff generators. Van de Graff accelerators send radio waves through a gas sample to ionize it.[16] Rather than using a radio frequency source for a continuous stream of ions, our accelerator will use a low voltage electrical arc to create a burst of ions from a solid sample. The arc mechanism used will be similar to that found in arc welders. Once the ions are created they are accelerated across a variable electric field to a target metal foil loaded with deuterium (see figures 5). With the proposed experimental setup, the incident ions should have average energies below 50KeV according to the equation below:

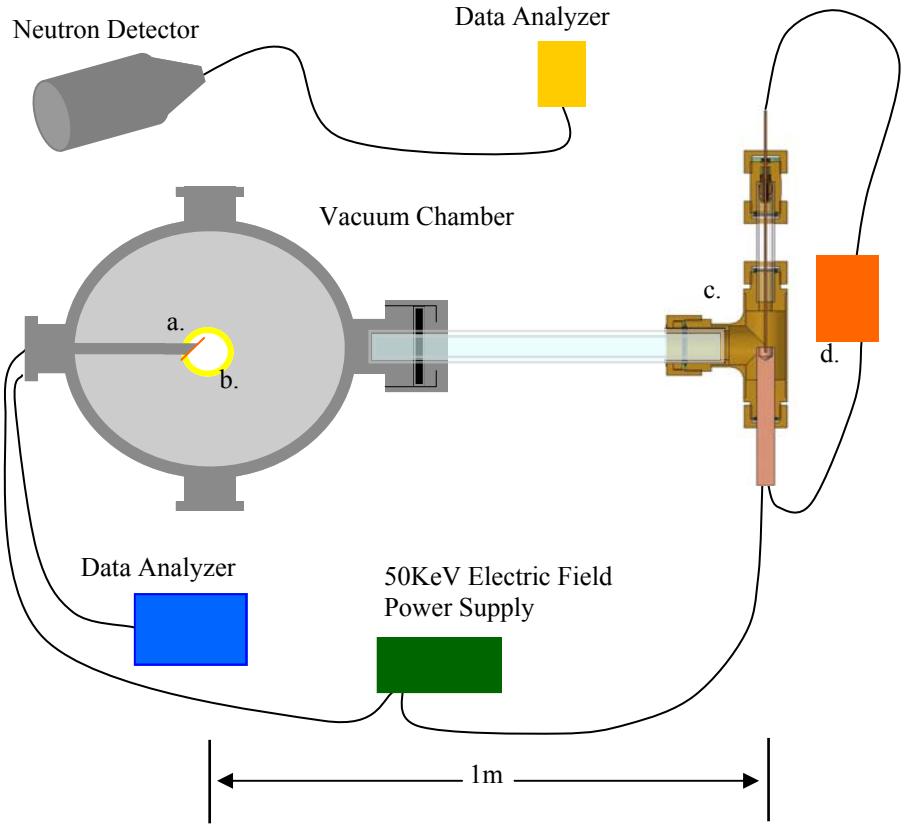


Figure 5: Low Energy Charged Particle Accelerator

a. Target Foil
b. Charged Particle Detector
c. Ion Source
d. Arc Power Supply

The material to be ionized is placed in the ion source and a low voltage arc is applied to vaporize the material. The resulting ions are accelerated down the glass tube by a 0-50KeV electric field. As the accelerated ions strike the target foil, fusion events may occur. Nucleosynthesis is detected by charged particle and neutron detectors.

The proposed particle accelerator will accelerate ions at energies below 50KeV.

"Through random chance, I decided one day that I would build a proton accelerator… but the actual construction is a bit of a mystery… This problem is also escalated by the fact that I'm in 7th grade…"
–Demodocus[17]

$$U = q(V_{inital} - V_{final}) \quad (4)$$

Much experimental data has been collected with deuteron beams at higher energies. Reactions at lower energies have been largely neglected because detectors capable of distinguishing the products of such reactions did not exist. Physicists at BYU have developed some of the most advanced neutron detectors in the world. These detectors are able to discriminate between background noise and neutrons that come from fusion even at low energies. We have also acquired charged particle detectors that can reliably differentiate alpha

particles from protons, deuterons, and tritons (see appendix II). With these new tools we plan to measure reactions with heavier ions at lower energies in order to see just how well metals catalyze fusion.

Although several different fusion reactions could be used to study the catalyzing effects of metals, one of the most promising reactions is d-d fusion. Below are the products and branching ratios for this reaction:[6]

$$d + d \rightarrow p + t \qquad 1{:}2 \qquad (5)$$

$$\rightarrow n + {}^{3}He \qquad 1{:}2 \qquad (6)$$

$$\rightarrow {}^{4}He + \gamma \qquad 1{:}10^{6} \qquad (7)$$

There are several reasons why d-d fusion is attractive for experimentation: deuterium is not radioactive like tritium and it fuses more readily than does ^{1}H. Additionally, deuterium can be extracted from water where it exists naturally.

The reactions we wish to study, however, are fusing lithium and deuterium nuclei. Two such reactions are as follows:

$$^{6}Li + d \rightarrow \alpha + \alpha \qquad 22.4MeV \qquad (8)$$

$$^{7}Li + d \rightarrow \alpha + \alpha + n \qquad 15.0MeV \qquad (9)$$

"It should be possible to explain the laws of physics to a barmaid."
-Albert Einstein

2.2 Machining and Assembly of Parts for the Ion Source

THE FIRST step in building the accelerator is to create the solid ion source. This has been constructed mainly from brass and copper. Pieces such as the ultratorr-style fittings were machined from brass because of its ease and availability. Other pieces such as the anode were made from copper for efficient electrical conduction.

The ion source has a copper rod that rises vertically into a copper T-tube. The copper rod, which acts as an electrode for the electrical arc, has a small hole bored in one end that contains the solid sample to be ionized. A tungsten cathode from an arc welder is held firmly by a collet seated in one of the male fittings. The tungsten and collet fitting apparatus is electrically isolated from the copper T-tube and sample reservoir by a glass tube (see figure 6).

2.2.1 Vacuum Fittings

SEVEN ultratorr-style fittings were machined for the ion source: three male fittings and four female fittings. These fittings are useful for creating high vacuum seals around cylindrical objects such as glass tubes or metal electrodes. They create vacuum tight seals by

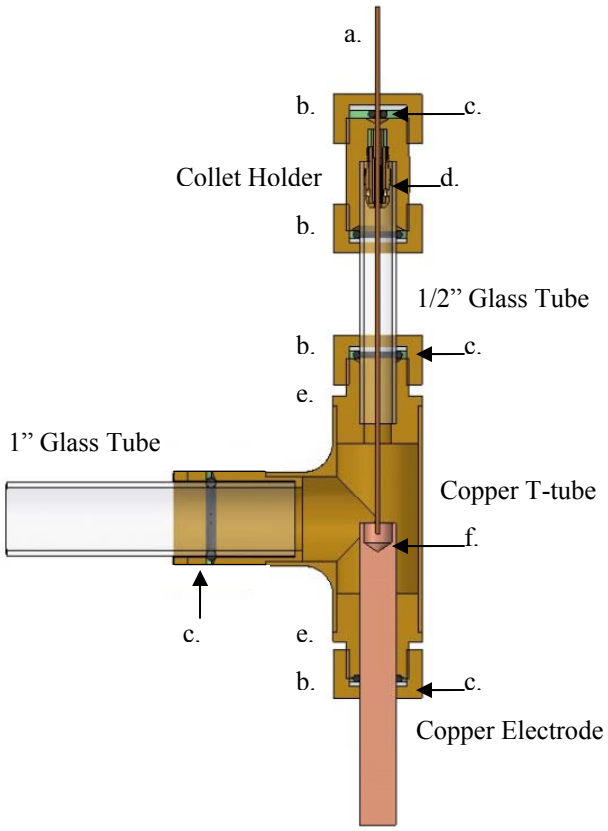


Figure 6: Ion Source Cutaway Diagram

a. Tungsten Electrode
b. Female Vacuum Fittings
c. O-Rings
d. Collet
e. Male T-Tube Fittings
f. Solid Sample Reservoir

compressing a rubber O-ring between the male fitting and a washer. The male fitting has a slanted surface that forces the O-ring tightly around the cylindrical surface passing through the fitting.

We custom machined all of the fittings on the lathe in the underground lab. Two of the male fittings, the T-tube fittings, were made to slide into opposite ends of a 1 1/8" copper T-tube and secure a glass tube and copper rod respectively. These fittings each have a threaded end that is received by corresponding female fittings and a smooth end that fits into the copper T-tube (see figure 7).

We used a 7/8-14 threading to connect the male and female fittings. In order to satisfactorily thread the female fittings, we custom made a tool from steel to cut out the threading as we turned the piece on the lathe.

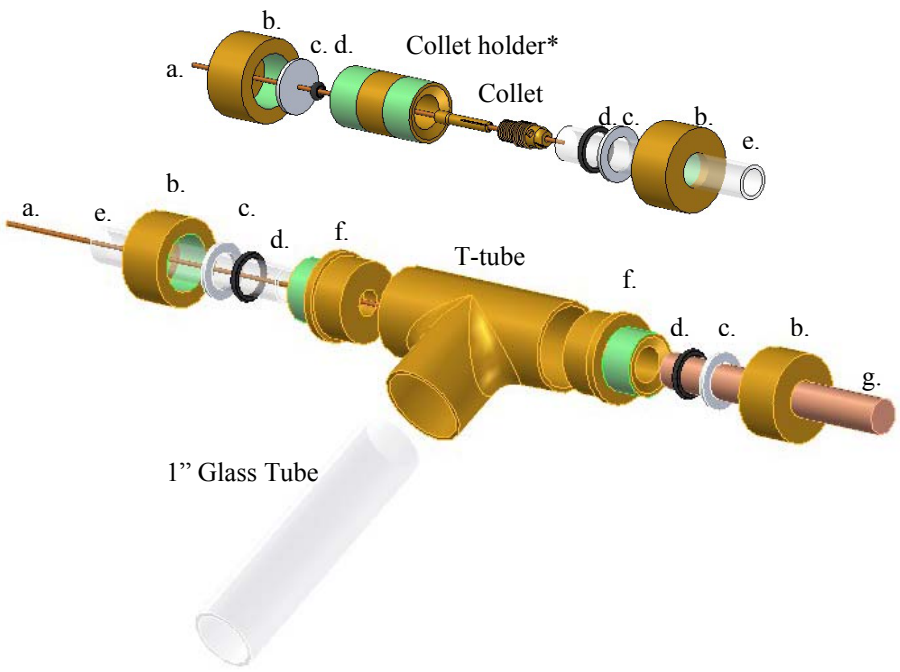


Figure 7: Ion Source, Exploded View

a. Tungsten Electrode
b. Female Vacuum Fittings*
c. Washers
d. O-Rings
e. 1/2" Glass Tube
f. T-Tube Fittings*
g. Copper Electrode

*The green color on the fittings indicate areas to be machined with 7/8" – 14 threading

The other male piece, the collet holder, houses the collet and tungsten rod and is attached to the ion source via the glass tube coming from the upper end of the copper T-tube. This piece was the most complicated to make as it required threading both ends of the outside for coupling with two female fittings as well as threading on the inside for receiving the collet.

2.2.2 Assembly of the Ion Source

ASSEMBLY for the ion source consisted chiefly of soldering and cementing with epoxy. The T-tube fittings were soldered into the copper T-tube. After we had finished, we checked to see if the fittings would hold a high vacuum. Initially we found that one of the soldered seals was not vacuum tight so we had to solder it again.

Once the soldered seals proved they were worthy of holding a high vacuum, we installed a 1" diameter glass tube with a wall thickness of 1/4" in the open end of the T-tube. We chose a tube with a thick wall to securely support the ion source. In order to cement the glass tube into position, a rubber O-ring was placed around the glass 1 1/2" from the end. Then we spread epoxy on the outside of the glass tube up to the O-ring. The O-ring served to dam up the epoxy while it set. Finally we carefully inserted the glass tube into the T-tube and positioned it so that it was straight while the epoxy hardened.

"If I have seen farther than other men, it is because I stood on the shoulders of giants."
-Sir Isaac Newton

The last step in the assembly was to silver solder tabs for connecting wires to the copper electrode and the collet holder. After soldering, all parts were cleaned by sonication in acetic acid. The assembled ion source was then attached to a vacuum chamber and appropriately wired as shown in figure 8.

2.3 Testing for Ion Creation

BEFORE we could use the ion source in the accelerator, we had to verify that ionization actually occurred. We prepared and loaded a

lithium sample into the ion source from within a glove bag in an argon environment. Then we attached the ion source to a vacuum chamber and connected the electrodes to a transformer (for procedure on lithium loading see appendix I).

"One thing they don't tell you about doing experimental physics is that sometimes you must work under adverse conditions... like a state of sheer terror."
–W.K. Hartmann

To ionize the lithium we used a 15V step down transformer capable of delivering a 100A current to create the arc. Then we applied a 200V potential from the ion source to a faraday cup (figure 8) where we measured the current from the ions with a nanoamp sensitive ammeter (see figure 9).

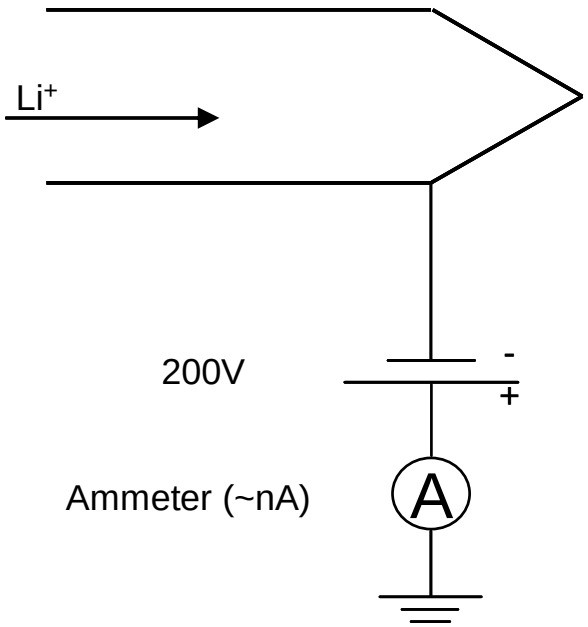
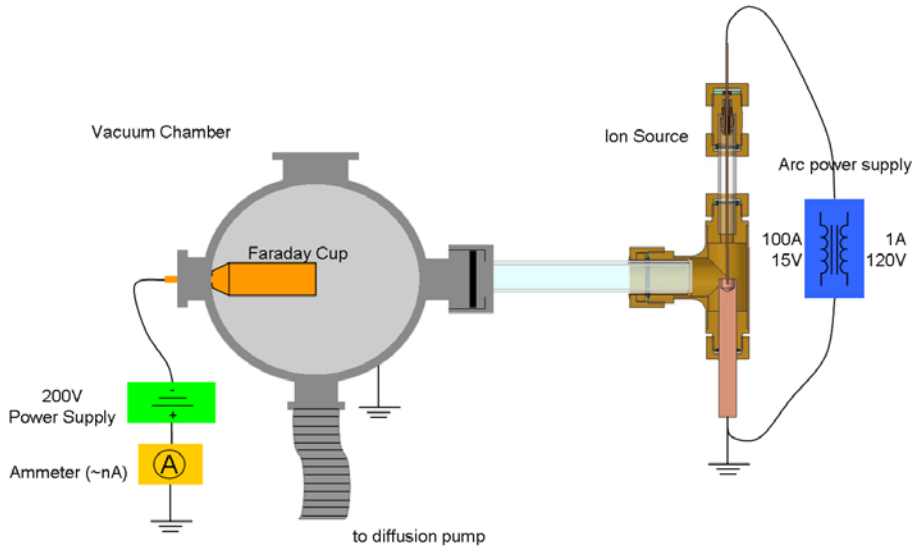


Figure 8: Faraday Cup Schematic
Lithium ions from the ion source were accelerated towards the Faraday cup by a 200V potential. The ions bounced around against the inside walls of the cup depositing their charge. We detect ion presence with an ammeter measuring the current resultant from the charge deposited by the ions.



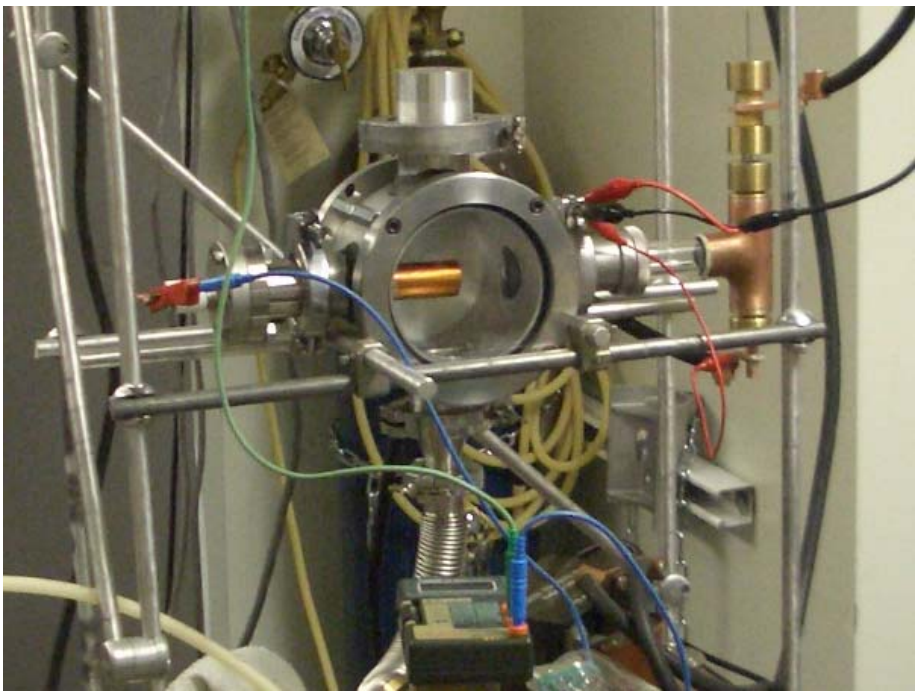


Figure 9: Experimental Setup for Ion Source Testing
The vacuum chamber is in the center containing a Faraday cup. The ion source is attached to the right. A 15V, 100A step down transformer is wired to the ion source and a 200V potential is applied from the ion source to the Faraday cup. Towards the bottom of the picture is shown the ammeter connected in series with the Faraday cup.

"Theory is when you know how it works but it still doesn't. Practice is when it works but you don't know why. In this Department [Physics], theory and practice are joined together: nothing works and no one knows why!" João Batista[17]

Chapter 3: Concluding Remarks

"A perfection of means, and confusion of aims, seems to be our main problem."
-Albert Einstein

3.1 Results

WHEN WE applied an electrical arc from the tungsten to the lithium sample, we were able to see red flashes of light indicating that lithium was at least burning if not ionizing. Moreover during arcing we were able to detect a small fluctuating current that peaked at about 1500nA. Unfortunately we were not able to sustain a stable arc. It was, however, encouraging to verify that at least some ions were created.

3.2 Conclusions and Future Research

IN ORDER TO use the ion source we created to conduct fusion experiments with the proposed low energy accelerator, several improvements must be made to the system. Primarily, an arc stabilizer must be connected to the ion source to insure more steady ionization of the solid lithium sample. Additionally we found that two structural changes could be made to the ion source assembly that would improve its usability.

First we found that we need a way of adjusting the tungsten electrode to lithium sample distance. When the ion source was attached to the vacuum chamber, the collet holder was held vertically in place by the 1/2" glass tube. Because of the weight of the collet holder, it slid down on the glass tube until the tungsten rod came in contact with the copper electrode. In our trial run we used a nonconductive spacer to support the collet holder to allow for proper separation of the electrodes. Retrofitting the 1/2" glass tube with a vernier screw to set the electrode separation would secure the collet holder and tungsten in place.

The above problem highlighted another improvement that could be made to the ion source; a window to view the electrode separation. Initially we planned to look down the 1" glass tube in

order to lower the tungsten rod to the appropriate distance for electrode separation. When we had the ion source in the glove bag and were loading the ion source with the lithium sample, we found it difficult to see through the bag and down the tube. If a copper cross were used rather than a T-tube, a window could be added to the new opening that would facilitate positioning the electrodes.

The above recommendations should improve the ion source sufficiently that it could be used as intended on a low energy accelerator. The solid ion source would then allow the Laboratory Nuclear Astrophysics Research Group to study the fusion of lithium and deuterium in bound metallic systems.

Appendix I: Lithium Handling Procedure

PURE lithium is a soft pliable metal that is less dense than water. Lithium reacts with air at room temperature oxidizing quickly. Lithium also reacts violently with water and is flammable. When ignited it burns with a crimson color. Because of these properties, care must be taken when handling elemental lithium.

In order to insure that an oxide layer does not form on the outside of our lithium sample, we loaded the sample into the ion source in an argon environment. The following outlines the procedure we follow for loading the lithium into the ion source and vacuum chamber.

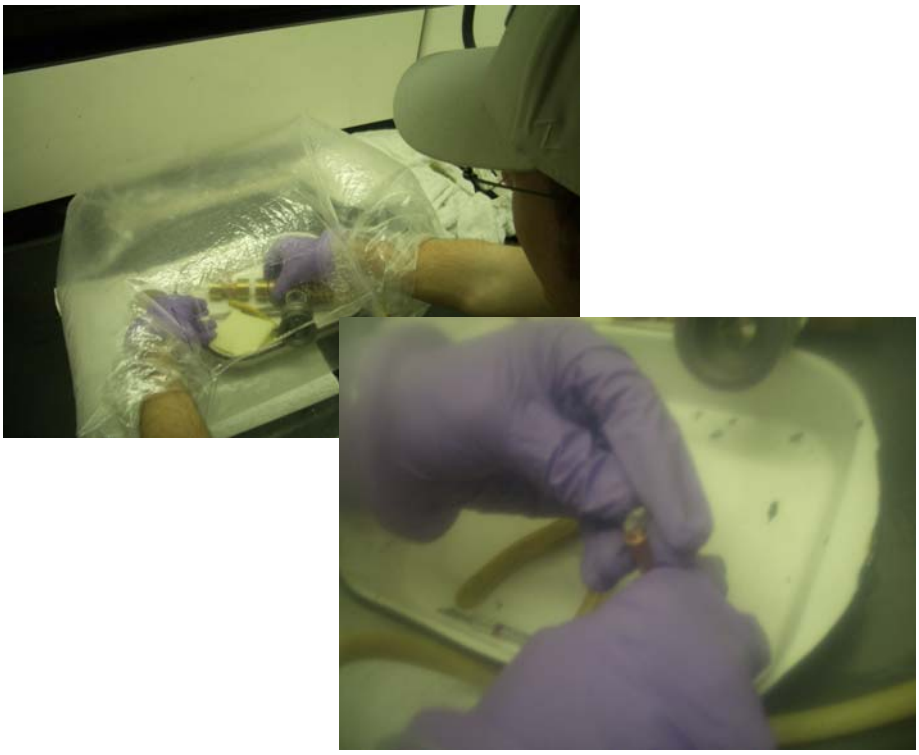


Figure 10: Handling Lithium in a Glove Bag
Because lithium reacts oxidizes quickly it is necessary to work with pure lithium in an inert environment. We used a plastic glove bag filled with argon gas to load the lithium sample into the ion source.

Lithium Loading Procedure

1. Gather all necessary instruments in a 9x11" pan, and place the pan in the fume hood.
    a. Place a dry washcloth on the bottom of the pan.
    b. Put a scalpel, wire cutters and a 3x5" paper card in the pan.
    c. Put the bottle containing the lithium metal sample in the pan.
2. Carefully remove the ion source from the vacuum chamber and place it in the pan, on top of the washcloth.
    a. Unscrew the vacuum fitting around the copper rod.
    b. Gently remove the copper rod and place the rod with the ion source and vacuum fitting in the 9x11" pan.
3. Ready the plastic glove bag for working in an inert argon environment.
    a. Replace the nitrile gloves at the ends of the sleeves of the plastic glove bag by folding the end of the sleeve over the inner plastic hoop, stretching the open end of the glove over the hoop and securing both the sleeve and glove with the outer hoop.
    b. Remove the PVC clamp on the argon bag and gently force out all air by rolling the bag towards the opening. (Be careful not to tear the glove bag when removing or replacing the PVC clamp.)
    c. Release enough argon to replace the air in the surgical rubber tube with argon.
    d. In the fume hood, hold the open end of the argon bag closed with one hand and insert the surgical rubber tube into the small hole near where the arm sleeves are located.
    e. Fill the bag with the argon gas and leave the gas flowing until you have finished loading the lithium sample.
4. Put the 9" by 11" pan with the instruments, ion source and lithium sample into the argon environment.

a. Hold the glove bag over the 9x11" pan and move the pan into the bag through the large opening.

b. Seal the glove bag by rolling the open end over the wooden dowel and then sliding the PVC clamp over it taking care not to tear the bag.

c. Insert your arms through the sleeves in the plastic bag and place your hands into the gloves.

5. Loading the lithium sample into the ions source.

a. Unscrew the two plastic bottles holding the lithium stick and remove the lithium. (Remember that argon is heavier than air so keep the lithium as low as possible.)

b. Use the scalpel to scrape off the oxide layer on one end of the lithium stick.

c. Use the wire cutters to cut off a chunk of the lithium just large enough to fill the reservoir in the copper anode.

d. Smash the small chunk of lithium into the reservoir to maximize the lithium surface touching the copper and prevent the sample from falling out. (It may be helpful to use the side of the wire cutters to press the soft lithium into the reservoir.)

e. Place the copper rod into the ion source and replace the ultratorr-style fitting. (Look down the glass tube of the ion source to make sure that the copper anode is placed a proper distance from the tungsten cathode.)

6. Place the lithium stick back into the two plastic bottles and tighten each respective lid.

7. Remove the ion source from the argon environment and reinstall it onto the vacuum chamber.

a. Cover the open glass tube of the ion source with the 3x5" card. (Take care to keep the card flush against the opening to

limit air access to the lithium while transporting the ion source.)

b. Remove the PVC clamp from the argon filled glove bag and carefully remove the ion source.

c. Flush out the air in the vacuum chamber by replacing it with argon.

d. Hold the glass tube of the ion source up to the receiving port of the vacuum chamber with the 3x5" card between the two.

e. Quickly remove the card and tighten the vacuum fitting.

8. Evacuate the vacuum chamber below 10^{-6}torr.

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"Very strange people, physicists - in my experience the ones who aren't dead are in some way very ill"
-Mr. Standish[18]