An Intense Cold Atom Source

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Introduction

We are developing an intense source of cold atoms based on continuous post-nozzle injection of lithium atoms into a supersonic helium jet. The design combines aspects of seeded supersonic jet methods[1,2,3], helium buffer gas techniques[4], and magnetic atom optics.[5,6] We expect the brightness of the extracted lithium beam to be substantially larger than what can be achieved by laser-cooling. A possible application of this source is a pump for an atom laser.

We present here the details of the design and theoretical performance predictions. The design includes a novel helium jet source and sorption pump, a thermally shielded lithium source, and a magnetic lens. We also report our progress in testing these components.

Experimental Overview

A synopsis of the experimental sequence follows. A rough schematic of the process can also be seen to the right.

1. Helium gas cooled to 5 Kelvin escapes into vacuum through a nozzle and expands supersonically. In the expansion the helium cools rapidly to several milliKelvin in the moving frame.
2. Hot lithium gas is injected into the jet.
3. The lithium thermalizes with the helium and becomes entrained.
4. Cold lithium and helium gas pass through a skimmer.
5. Lithium is extracted from the helium flow by magnetic focusing.

Potentially following this step we can further enhance the brightness of the extracted lithium beam via laser-cooling.

Predictions

We performed numerical simulations to find optimal parameters for the experiment. Representative results from these simulations are depicted in figures 1 and 2. These calculations show that high capture efficiency and extraction are possible. They also allow us to make reasonable predictions about the expected performance of the source.

Projected Source Operating Parameters

Helium flux*	1×10^{20} s^{-1}
Lithium flux**	1×10^{17} s^{-1}
Lithium transverse temperature	10 to 100 mK
Lithium forward energy	18 Kelvin
Capture half-angle of focusing magnet	0.073 radians
Focused lithium flux	3×10^{14} s^{-1}

*: Limited by pumping capacity and heat load due to condensation.

**: Limited by cooling capacity of helium jet.

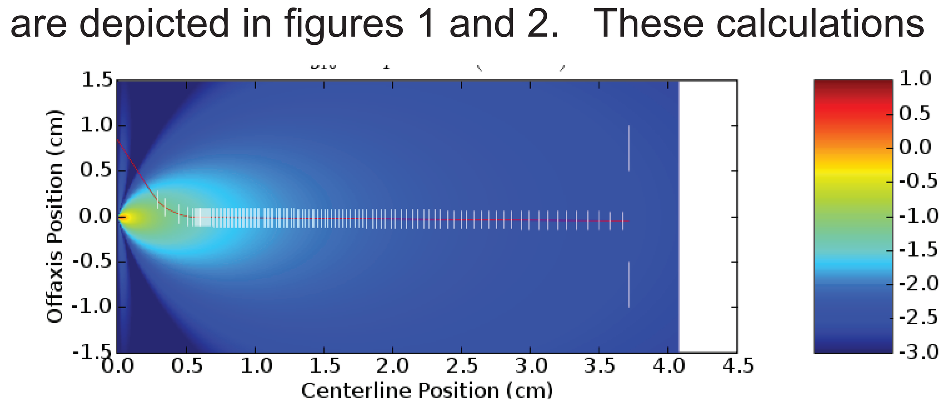


Figure 1. Shown above is the simulated average path of a lithium atom entering the jet having a given a particular initial velocity. White hash marks represent collisions with helium atoms. The background color represents the local temperature of the jet in Kelvin on a $\log_{10}$ scale. The trajectory is calculated using a viscous damping model.

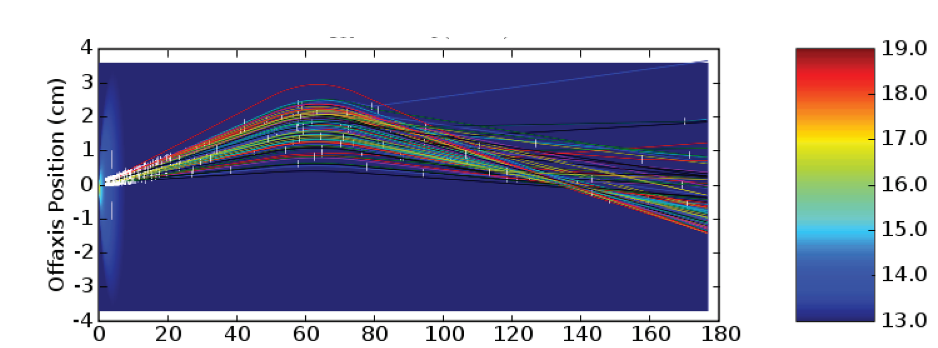
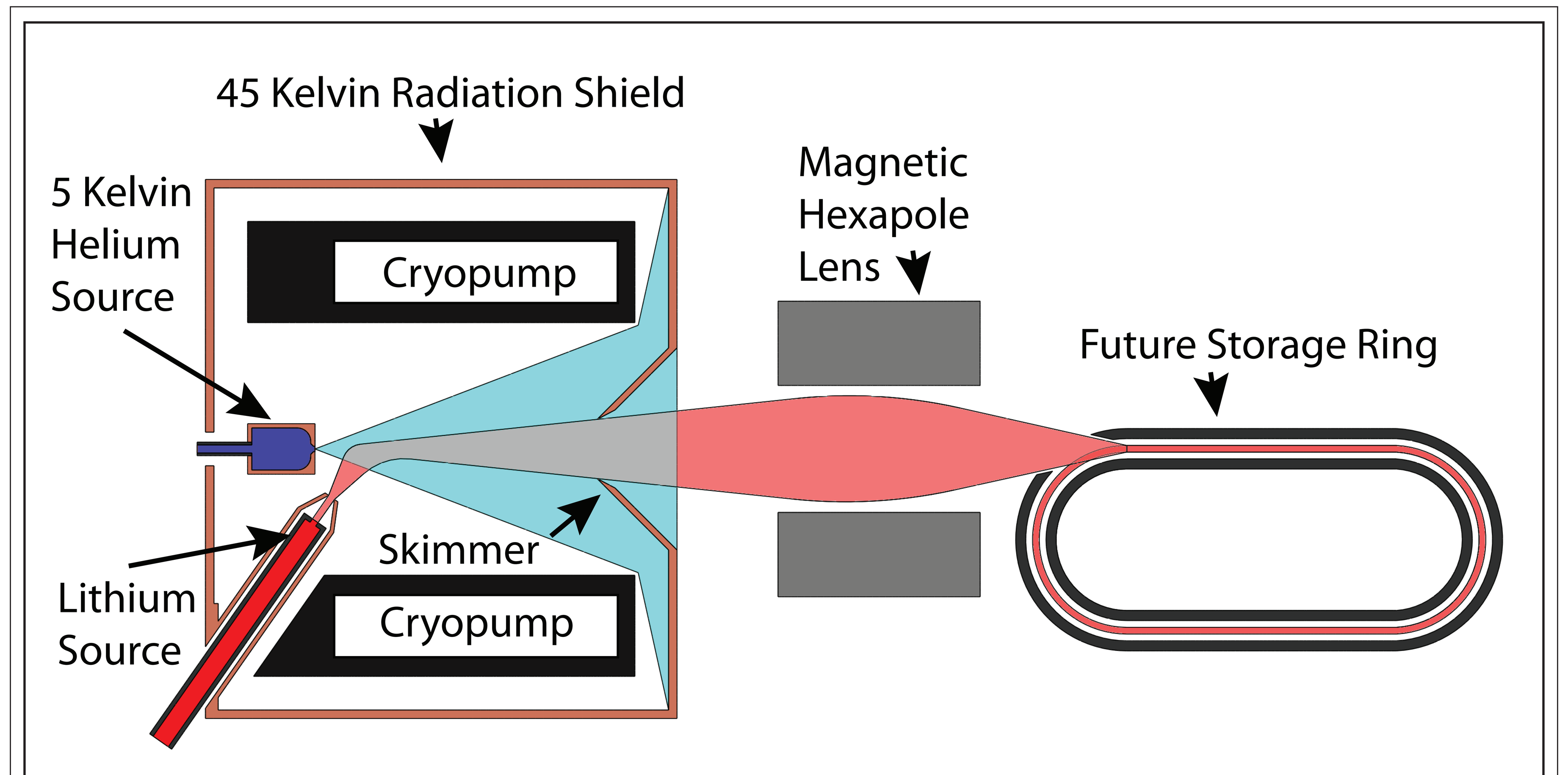


Figure 2. This plot shows trajectories of individual lithium atoms beyond the skimmer as they pass through the field of the hexapole lens. White hash marks indicate collision events with helium atoms. Each particle's flight is modelled using conventional Monte Carlo methods.



Experiment Schematic

Materials and Methods

1. Helium Jet Source

Helium is delivered to the nozzle from a room temperature cylinder. In order to precool it to the required 5 Kelvin, it is passed through a long copper tube that is thermally anchored to the cold stages. To ensure the helium gas reaches the required temperature, the thermally anchored portions of the tube are helically wound to areas having a good conductive path. The 5 Kelvin thermal anchor of the helium source can be seen in figure 3 to the right. After passing through the tubing, the helium enters a small reservoir and is allowed to escape through the nozzle.

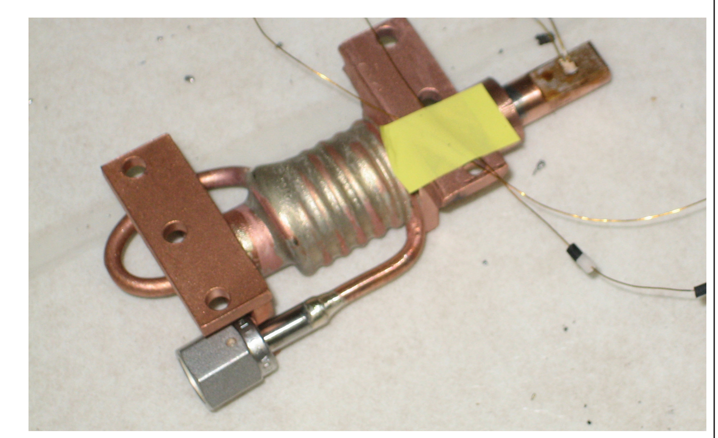


Figure 3. A picture of the 5 Kelvin anchored section of the helium source. The helium is cooled from 45 Kelvin to 5 Kelvin as it passes through the helical coil. A thermal sensor can be seen just atop the nozzle itself.

2. Charcoal Cryosorption Pump

In order to run the experiment in a continuous mode we need a large pumping speed. To that end, we have developed a novel pump for use in jet experiments. The expansion region of the jet is completely surrounded by cryosorption panels slotted into a barrel. These panels can be seen in figure 4. The barrel consists of 60 4"x16" sheets of copper, which are coated with activated coconut charcoal. The entire barrel is cooled to 5 Kelvin. A total of about 2 pounds of charcoal were used, which amounts to an estimated capacity for helium gas of over 100,000 torr-liters. At our intended flux, this provides about 10 hours of run time. Regeneration of the array is possible by heating to 90 Kelvin.

We've made some preliminary measurements of the pump's performance. Utilizing a sniffer tube method, we find that the charcoal pump maintains a helium pressure below 10^{-5} torr with a nozzle flux of 5×10^{19} atoms/s for total gas loads up to 50,000 torr-liters. Further studies of this pump are in progress.

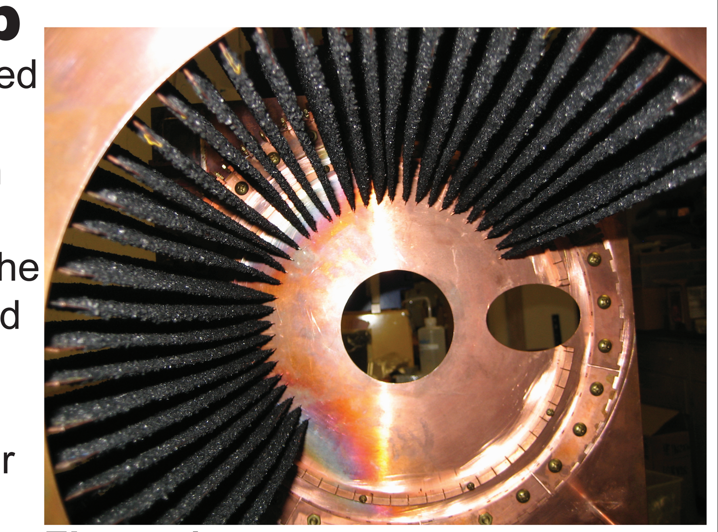


Figure 4. The cryosorption pump as seen from the helium nozzle. The inner and outer diameters of the barrel are 8" and 16", respectively. In this image, a number of the panels have been temporarily removed.

2. Lithium Beam Source

Our source of lithium atoms is based on the design of a conventional atomic beam oven. A schematic can be seen in figure 5. The source consists of a heated, thin-walled, stainless steel tube filled with lithium. The lithium reservoir extends outside the vacuum, and is heated externally by heater wires to 1000 Kelvin. The portion of the tube that extends into vacuum is heated by driving a current through the tube to reach the operating temperature of 800 Kelvin. Extensive heat shielding is required. Baffling of black body radiation reaching cryogenic surfaces is extremely important due to limited cooling power.

Presently, we have achieved the desired temperatures in the tube and are ready to measure the flux and temperature of the beam.

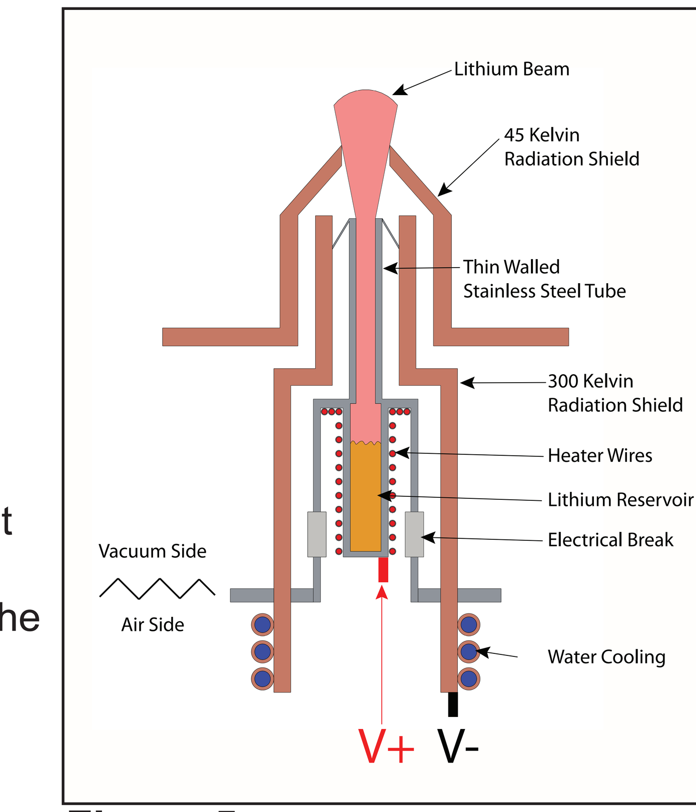


Figure 5. A schematic drawing of the lithium beam oven.

3. Magnetic Hexapole Lens

After the lithium thermalizes with the helium, we need to extract it from the jet. To that end we have designed and constructed a magnetic lens to focus the atoms. The lens is constructed in 10 layers, each 1" thick and 11" in diameter. Each layer contains 24 individual NdFeB magnets. These magnets are arranged to form the hexapolar Halbach array,[7] as seen in figure 7. Their magnetizations are aligned in such a way as to form a nearly perfect radial harmonic potential. The lithium atoms, due to their magnetic dipole moment, will feel a linear force directed towards the axis of the lens. The unaffected helium will continue uninhibited and eventually be pumped away.

The lens itself has just been completed and its field characteristics are being measured. A preliminary measurement of the field depth can be seen in figure 6.

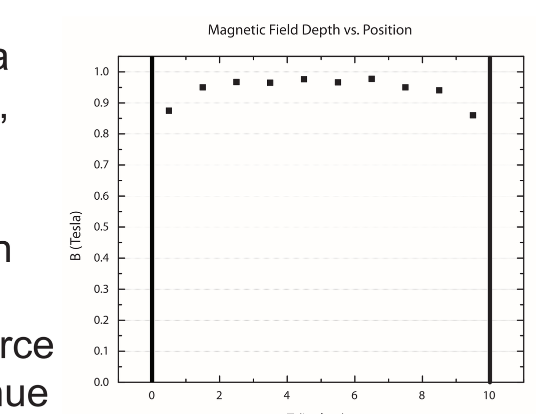


Figure 6. Preliminary measurements of field depth at various positions along the lens. The physical extent of the lens is indicated by the vertical lines at 0 and 10 inches.

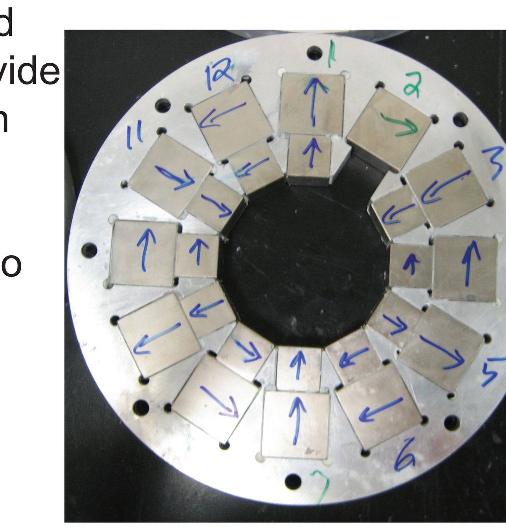


Figure 7. Shown above is a single layer of the lens. Magnetization directions of individual magnets are drawn on.

Conclusions

We have what we believe is a very promising, intense source of cold atoms. It is particularly interesting in that it should simultaneously provide large rates of atoms, high phase space densities, and cw operation. In addition, it can potentially be adapted to other species.

We are currently finishing up with individually characterizing the experiment's components and should be ready in the coming months to begin injecting the helium jet with lithium.

References

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