# Optimization of Spin-Polarization of Helium-3 Target Cell by Thermal Convection Processes


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## Abstract

Spin-polarized Helium-3 ($^3$He) cells have been used in many experiments at Jefferson Lab as effective neutron targets to get access to the neutron properties. In order to achieve the performance required for future 12 GeV experiments, the cell design has recently been modified to allow convection. The spins of the three nucleons cause the nucleus of $^3$He to resemble a single neutron, due to the pairing spins of the two protons. The $^3$He is polarized via alkali-Hybrid Spin Exchange Optical Pumping (HSEOP), with the use of additional rubidium and potassium atoms in the pumping chamber of the target cell. The new cell design differs from previous cells by using convection processes, rather than diffusion, to more rapidly transfer polarized $^3$He gas to the target chamber. The focus of this project was to study the effects of the new convection system, at various gas velocities, on adiabatic fast passage (AFP) polarization loss that results from measuring the polarization of $^3$He with Nuclear Magnetic Resonance (NMR). Convection was induced in the target cell by use of a Kapton Flexible Heater on one transfer tube. When the gas was maximally polarized, Pulse NMR was used on the opposite transfer tube to depolarize a slug of gas, which was detected by two separate NMR coils along the target chamber. The gas velocity was then extracted from the data by identifying troughs in the NMR signal. Further tests were performed to calculate the AFP loss at various gas velocities. It was found that an appropriate gas velocity of 6.05 cm/min occurred with a heater power of 13.5 W and achieved an absolute AFP loss of 0.82% in the target chamber and 0.83% in the pumping chamber. It was found that the AFP loss in the target chamber was much smaller than in the pumping chamber without convection, and both losses were significantly less. Contrary to original predictions, results indicate that while the AFP losses in the pumping and target chambers were approximately equal with the use of convection, losses increased as opposed to being averaged between. These results are necessary for making predictions and plans for experiments that will use this type of target cell to increase flexibility of space. High polarization in a high current beam will be achieved by continuously replenishing gas in the target chamber with newly polarized $^3$He.


## Polarized $^3$He Convection Cell

### Alkali-Hybrid Spin Exchange Optical Pumping (HSEOP)

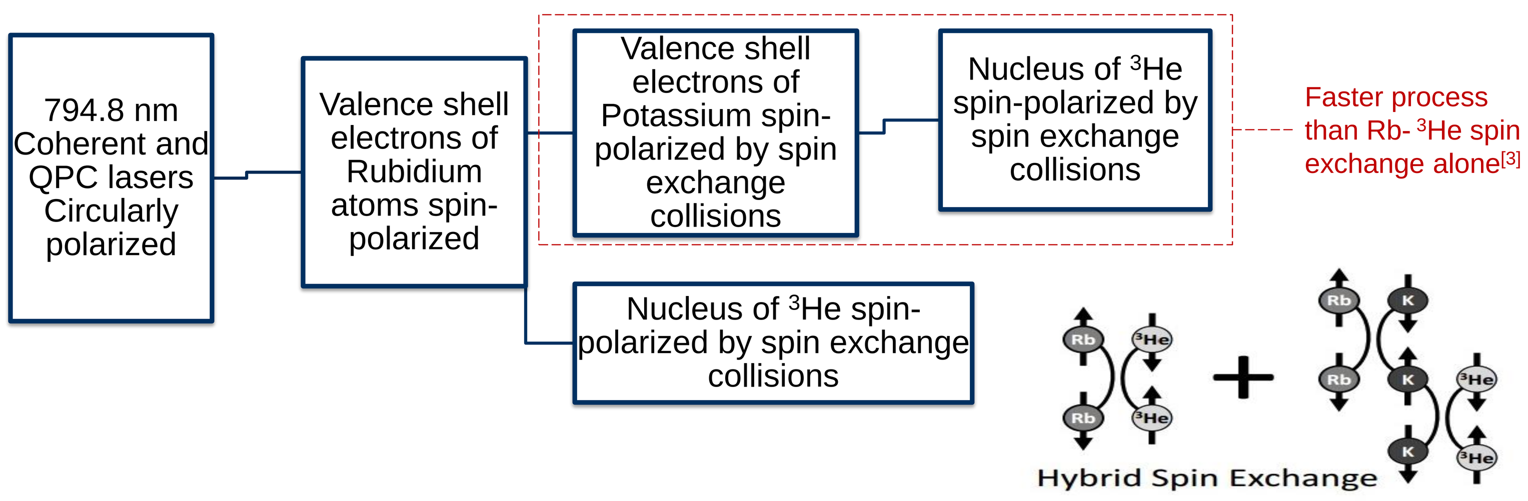


*Figure 1: HSEOP graphical representation as created by Dolph[1]*

### Diffusion Cell Vs. New Convection Cell

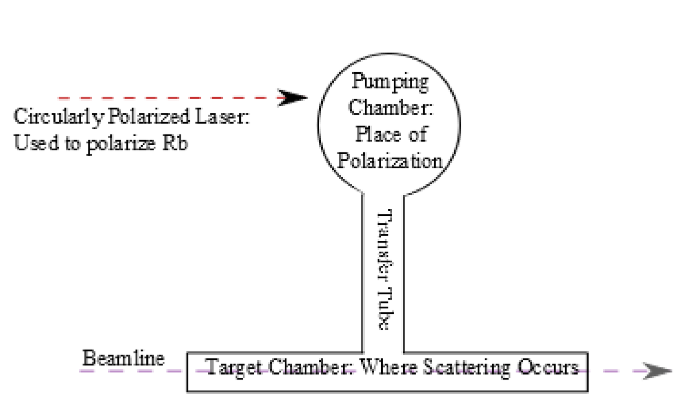


*Figure 2: Previous cell would polarize gas in the pumping chamber and allow the gas to diffuse to the target chamber. This process was slow, but was capable as a target in the previous era.*

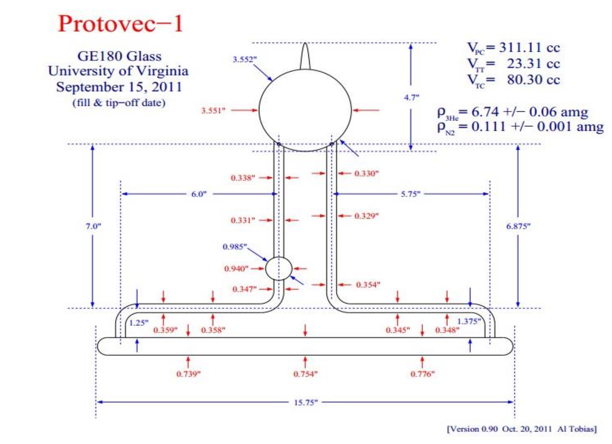


*Figure 3: New convection cell polarizes gas in pumping chamber and uses thermal convection induced by a 10 cm flexible heater to transfer the gas in a counter-clockwise direct to the target chamber by $F_{buoyancy} = \Delta\rho V_t g$*

Advantages of New Convection Cell:

- **Fast transport** of gas between pumping and target chambers
- Low polarization gradient
- Allows for **flexibility of cell design** including the possibility of shielding, multiple pumping chambers, and placement of pumping chamber

## Optimizing Convection Speed

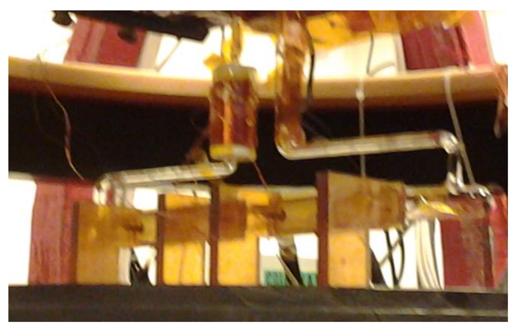

*Figure 4: Photograph depicting transfer tubes and target chamber of cell with heater and pulse NMR coil.*

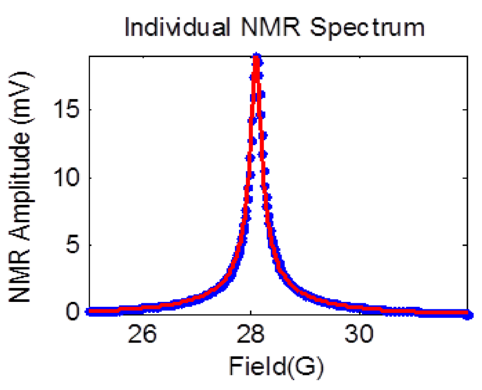


*Figure 5: Individual NMR Signal with fit*

The NMR measurement was controlled and recorded using a LabView program created by Jie Liu. The NMR signal is directly proportional to the polarization of the gas as follows[2]:

$$S_{NMR} \propto \langle P \rangle \frac{H}{\sqrt{(H_0 - \frac{\omega}{\gamma})^2 + H^2}}$$

Thus, the NMR signal is used to identify the location of the depolarized slug at a specific time as in Figure 7. The gas velocity is therefore:

$$Velocity = \frac{Distance\ between\ pickup\ coils}{Time\ between\ NMR\ signal\ minimums}$$

$^3$He has a tendency to relax into an unpolarized state during the process of the NMR measurement during spin-flip while the field is near resonance. This percent of polarization loss is called Adiabatic Fast Passage loss (AFP loss).[3]

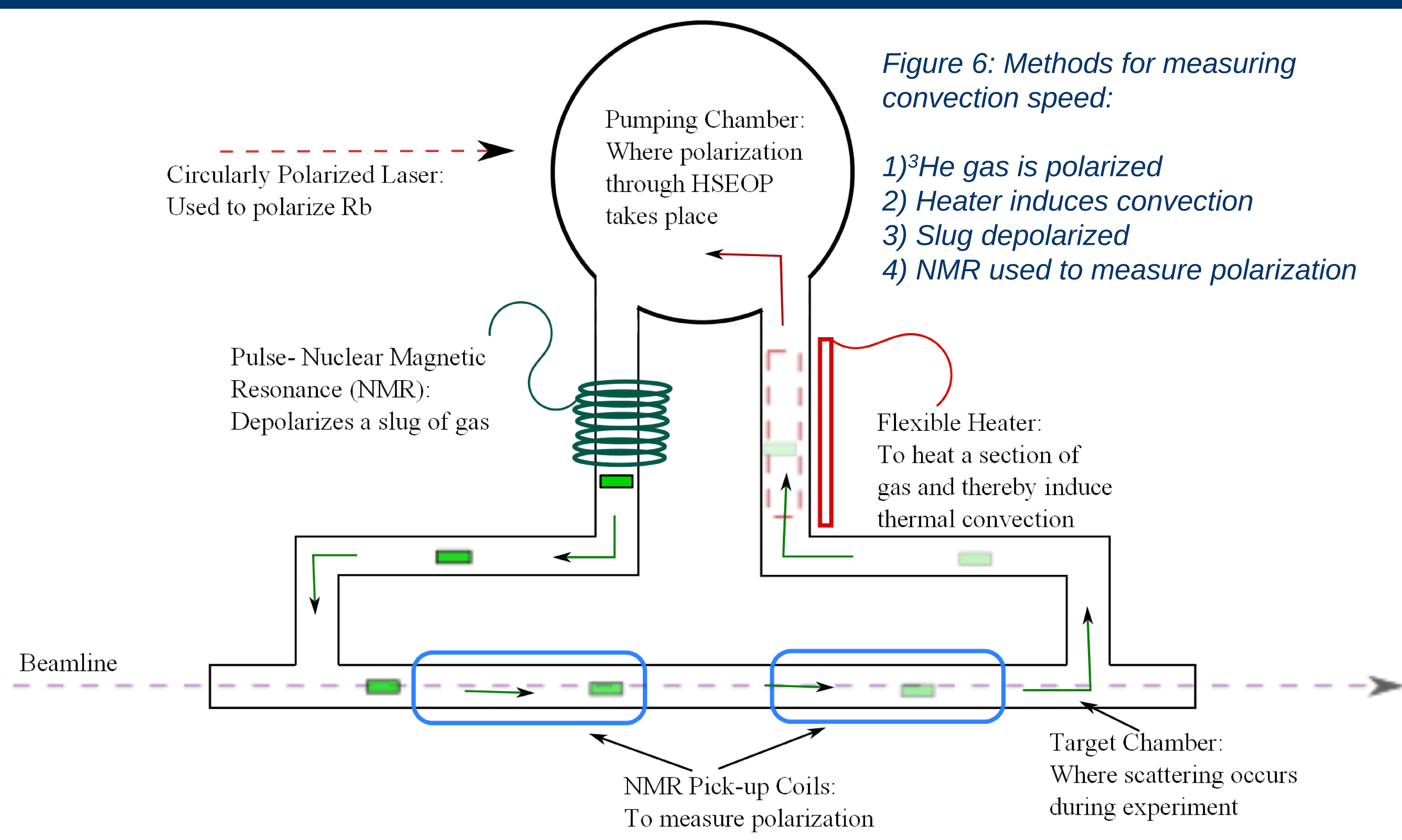


*Figure 6: Methods for measuring convection speed:*

*1)$^3$He gas is polarized*
*2) Heater induces convection*
*3) Slug depolarized*
*4) NMR used to measure polarization*

## Results and Discussion

| Heater Power (W) | Temperature Difference of Transfer Tubes (°C) | Convection Speed (cm/min) |
|---|---|---|
| 14 | 16.4 | 6.55 |
| 13.5 | 14.7 | 6.05 |
| 13 | 13.8 | 4.86 |

*Table 1 (above): Results of three tests of convection speed*

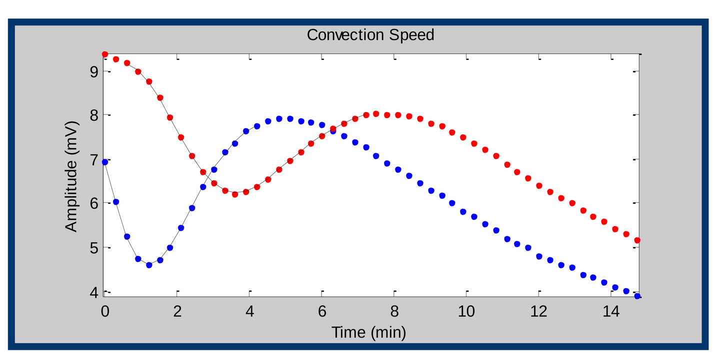


*Figure 7 (left): Plot of the amplitudes of 60 NMR signals over a period of 15 minutes. Heater power of 13.5 W indicates a convection speed of 6.05 cm/min*

A **gas velocity** of approximately 6 cm/min was easily achievable with 13.5 W heater power. Study of other heater powers allows for knowledge of faster velocities, if higher beam current is used. While achieving this velocity, **AFP losses remain low** and equalize for target and pumping chamber.

*Table 2 (right):Results of two AFP loss tests. Tests with convection were with heater power of 13.5 W*

| Convection? | Chamber | AFP loss |
|---|---|---|
| no | Target | 0.23% |
| no | Pumping | 0.70% |
| yes | Target | 0.81% |
| yes | Pumping | 0.83% |

## Conclusion and Future Steps

This study of the new thermal convection $^3$He target cell indicates that this cell will be a significant improvement to the previous diffusion cell with the convenience of a simple design with no moving parts. The following have been achieved with this cell:

- Rapid polarization
- Reasonable gas velocities with a simple heater to avoid difficulties in design
- Minimal polarization losses due to NMR measurement

This cell design will be used in experiments after the 12 GeV upgrade as an effective polarized neutron target with the convenience of flexibility easily conformable with experimental design.

Studies of polarization gradients, theoretical gas velocities, and possibly radiation shielding effects are in the future for this cell.

## References


[1] Dolph, P. A. M. 2010. High-Performance Nuclear-Polarized $^3$He Targets for Electron Scattering Based on Spin-Exchange Optical Pumping. Ph. D. Thesis, University of Virginia.

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[3] Singh, J. 2010. Alkali-Hybrid Spin-Exchange Optically-Pumped Polarized $^3$He Target Used for Studying Neutron Structure. Ph. D. Thesis, University of Virginia.



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