Large Volume Production and Delivery of Hyperpolarized ^{129}Xe

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Introduction

Hyperpolarized gases are recognized in the MRI community as a new high performance diagnostic tool[1]. Although ^{3}He polarizing methods are well understood and implemented[2], technology for polarizing ^{129}Xe to high levels and in large quantities has slowed progress. We present a design for a low-pressure high-flow optical pumping polarizer based on the large spin-exchange rates between Rb and Xe via long-lived van der Waals molecules. Optimization of the running parameters and novel high-performance polarizer components are reported. High polarization xenon was accumulated and transferred to an off-site MRI center for collaborative research. The scientific advantages of xenon, including its low diffusion constant and solubility in tissues, as well as its practical advantages of cost and unlimited availability can now be exploited.

Methods

A general schematic of the polarizer is presented in Fig.1. A mixture of Xe, He, and N_2 controlled by individual mass flow controllers enters the polarizing column through the Rb saturator. Designed as a long helix with pools of Rb sitting on bottom bumps, the purpose of the saturator is to heat up the input gas mixture such that Rb vapors will be carried away with the gas mixture into the main column. The mixture moves further into the straight vertical column where the optical pumping process happens. A novel optical setup produces and collimates a circularly polarized laser beam which preserves a round shape throughout long polarizing cells. This arrangement delivers ~90W of circular polarized laser power with a FWHM ~2nm. The laser is directed downward from the top of the column towards the gas mixture. A spectrometer monitors continuously the laser spectrum and the Rb absorption line. As the gas mixture moves upwards, the laser is absorbed by the Rb, and the Rb-Xe spin exchange occurs. Xenon accumulates polarization as it moves through the column. The top half of the column serves for cooling down the mixture and trapping Rb vapor on the walls. A 5" water cooling jacket improves the process. Gas mixture containing highly polarized Xe is transferred through the down-tube to the xenon accumulation setup, a cryogenic dewar working at liquid nitrogen temperature. A spiral shaped freeze-out was shown to minimize the losses of polarization during freeze-thaw cycles. We built a NdFeB permanent magnet box with a field of 0.31 T to be used in xenon accumulation. Polarization recovery ratios as function of quantity of accumulated xenon were measured using this setup. Relaxation times in gas and frozen state could be measured by thawing the gas back into the down-tube.

An NMR coil system, designed in a cosine-theta configuration and placed around the 2" dia. down-tube region, works at 33.7 kHz to measure the polarization. The NMR signals are generated and acquired with a SMIS MRI machine and processed in Matlab. Xenon polarization is calibrated against the proton signal in water, after flip angle calibrations were done.

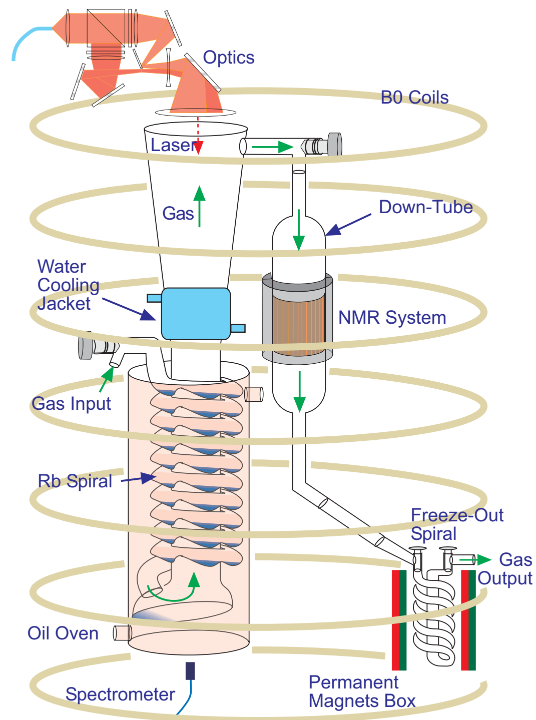

Fig.1: Polarizer schematic with major components (not to scale).

Results and Conclusions

The dependence of the production rate and output polarization on flow velocity, temperature, and nitrogen partial pressure were studied. Optimum running parameters for the system were found to be 160^{0} C temperature, 125 torr saturation for nitrogen partial pressure, and about 1.4 liters/minute total flow rate. We ran the polarizer at 500 torr total pressure. The polarization of xenon as a function of its flow rate for the optimum conditions is shown in Fig.2 with a maximum at 62% polarization for 0.3 liters/hour, and 19% for 6 liters/hour xenon flow rate. A new freeze-out design for trapping the polarized xenon was demonstrated to allow full 100% recovery of the xenon polarization after freeze-thaw cycles for quantities up to 0.5 liters. Relaxation times for polarized xenon were measured in the gas and in the frozen states showing T_1 values greater than 2.5 h. Delivery methods for polarized xenon were developed for both frozen and gas state, and MRI images were achieved at a site remote from the polarizer after two hours delivery time. Further work of polarized xenon application in lung imaging is underway.

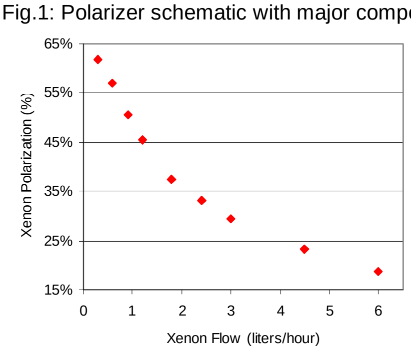

Fig.2: Xenon polarization numbers at optimum found running parameters and 500 torr total pressure.

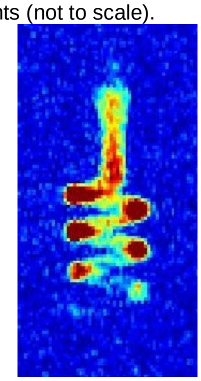

Fig.3: Image acquired after frozen xenon was delivered to BWH.

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