Liquid Hyperpolarized Xenon Production by Phase Exchange

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Introduction: Hyperpolarized (HP) ^{129}Xe is being used in an increasing number of magnetic resonance experiments in biology and medicine [1]. Most current schemes for producing large amounts of highly polarized ^{129}Xe rely on accumulation in the solid state and subsequent volatilization [2-4]. Here we present a new method for producing HP ^{129}Xe that combines spin exchange optical pumping (SEOP) with phase exchange between the gas and liquid phases. By condensing to liquid a large fraction of the sample, this scheme permits the polarization of many more ^{129}Xe atoms in a given sealed-cell volume than would otherwise be possible [5]. The key innovation is a cell in which gas-phase spins are polarized at one end and then driven convectively to a liquid reservoir.

Materials and Methods: The convection cell and oven are shown in Fig. 1. The cell is permanently sealed and has one contiguous volume of about 11 cm^3. The convection loop is formed by the spherical front chamber and a sideways u-tube extending to the rear of the cell, where a small reservoir of liquid sits (blocked by capacitors in the photo). The front (100°C) and rear (-110°C) temperatures in the two-chambered oven were kept constant using forced air and gas from nitrogen boil-off, respectively. The oven was placed inside a horizontal-bore 0.94 T magnet, and NMR signals were acquired with an Apollo spectrometer (Tecmag, Houston, TX) and separate probes mounted around the liquid reservoir, along the upper arm of the convection loop, and around a side arm connected to the spherical chamber. The xenon was polarized in the spherical chamber by SEOP with a 13-W frequency-narrowed diode laser array and then traveled *via* convection to the liquid reservoir, polarizing the liquid by phase exchange. The Xe partial pressure inside the cells corresponds to the vapor pressure at -110°C, or 900 mbar. Thermal-equilibrium signals were initially acquired on the liquid so that the hyperpolarization could later be measured. With the cell in phase equilibrium, signal transients for both phases were measured starting both with zero polarization (spin-up) and with finite polarization and the laser blocked (spin-down).

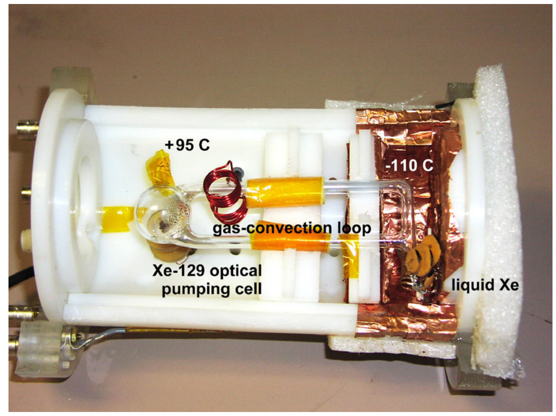

Figure 1: Convection cell inside the two-chambered oven. Laser light enters from the left through the glass window. ^{129}Xe is polarized by SEOP in the spherical front chamber and carried by convection to the rear of the cell where phase exchange polarizes the liquid through the left, and the polarized gas exchanges with the liquid xenon at the back of the cell, which is kept near the triple point.

Results: Table 1 shows final (saturation) polarizations after spin-up for two cells with different Xe partial pressures. Typical spin-up times for the liquid are ≈ 15 min and somewhat faster for the gas. Figure 2 shows an example liquid spin-down from the 7000 mbar cell. The flatter curve at times up to 10 min is real; the polarization decay is not mono-exponential.

Xenon Pressure	Liquid Polarization	Gas Polarization	Liquid Volume
7000 mbar	5.0 ± 0.5 %	6.3 ± 0.8%	.18 ± .09 mL
4000 mbar	5.7 ± 0.6%	7.6 ± 0.9%	.14 ± .01 mL

Table 1: Final (saturation) liquid and gas polarizations for two different convection cells. The maximum polarization observed for the 4000 mbar cell was 8%, but no gas polarization was measured at that time.

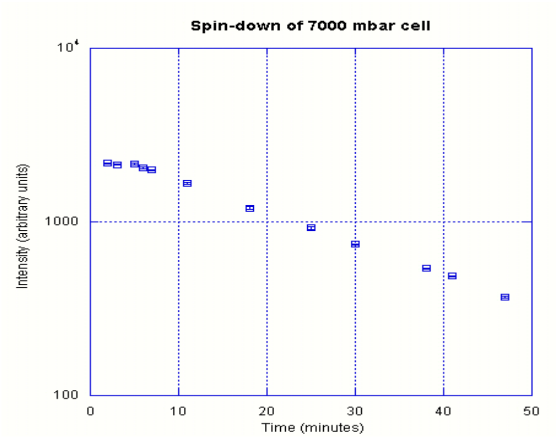

Figure 2: Decay of the liquid signal for the 7000 mbar cell after the laser is blocked. The initial decay ($t \leq 10$ min) is slow because the liquid exchanges with more highly polarized gas.

Discussion: The convective flow in these cells arises naturally from the large temperature gradient. The flow direction is always clockwise with respect to Fig. 1. We have developed a mathematical model for the spin-up and spin-down behavior. Phase exchange couples the two linear differential equations for the gas and liquid polarizations and yields a bi-exponential solution. The model relies on the assumption of uniform polarization in both the gas and the liquid at all times. Using time-of-flight MRI techniques and the coil on the upper arm, the gas flow rate was measured to be 10-20 cm/s, much faster than the spin-exchange rate. We have acquired MR images of the liquid column at various time points and the signal intensity appears homogeneous throughout. The cell design and other parameters have yet to be optimized, but we conclude that this new scheme has potential (1) for producing large quantities of HP ^{129}Xe without going through the solid phase (where polarization losses in the freeze-thaw cycles are a common problem) and (2) for providing a novel platform for polarization transfer experiments, whereby the liquid spin reservoir can be maintained at a constant value indefinitely.

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