# Spin polarization of xenon films at low temperature induced by $^3$He

N. Biškup [a,b], N. Kalechofsky [b], D. Candela [a,1]

[a] *Physics Department, University of Massachusetts, Amherst, MA 01003, USA*
[b] *Oxford Instruments America, Concord, MA 01742, USA*

**Abstract**

We have measured the $^{129}$Xe spin-lattice relaxation time $T_1$ for xenon films adsorbed on silica gel in an 8 T magnetic field at dilution refrigerator temperatures, both with and without $^3$He filling the sample cell. Without $^3$He, $T_1$ increases rapidly as the temperature is lowered. With $^3$He, $T_1$ has a temperature-independent value of about 1000 s. Using this technique, it is possible to brute-force polarize large quantities of xenon in high $B/T$ conditions.

*Key words:* helium-3; NMR; films and interfaces; hyperpolarized

## 1. Introduction

Recently, important applications have arisen for matter prepared with hyperpolarized nuclear spins such as $^3$He and $^{129}$Xe [1]. Usually hyperpolarization has been produced by optical pumping at room temperature, but brute force polarization at high magnetic fields and dilution-refrigerator temperatures is another possibility. For example, the equilibrium polarization of $^{129}$Xe in a 16 T field at $T = 15$ mK is 29%.

A major obstacle to brute-force polarization of $^{129}$Xe is the long spin-lattice relaxation time $T_1$, which prevents bulk solid xenon from reaching equilibrium polarization in a reasonable period of time. It has been known since the 1980's that the surface nuclear spins in substances immersed in liquid $^3$He are rapidly relaxed by the $^3$He [2]. The mechanism is quantum tunneling of $^3$He atoms in the localized (solid-like) layer that forms near solid surfaces, a process that persists to arbitrarily low temperatures [3,4].

The difficulty with applying this method to hyperpolarizing $^{129}$Xe is achieving sufficiently large surface area to polarize large quantities of xenon. In this paper we describe preliminary experiments that use a new method to overcome this difficulty: the xenon is plated onto a substrate with very high specific surface area (silica gel is used here), which is then immersed in liquid $^3$He in high $B/T$ conditions.

The relaxation time for *surface* $^{129}$Xe spins $T_{1s}$ depends upon the distance between the $^{129}$Xe and $^3$He nuclei, as well as the spectral density of tunneling in the localized $^3$He layer at the $^{129}$Xe Larmor frequency [3,4]. Unfortunately neither quantity is accurately known for $^3$He-$^{129}$Xe interfaces, which to our knowledge have not been explored before this work. Nevertheless, by extrapolating the measured $T_{1s}$ for other substances in contact with $^3$He [4] we make the following rough estimate: $T_{1s} \approx (4100\text{ s})(B/16\text{ T})$ where $B$ is the applied field. Furthermore, we estimate that for $^{129}$Xe films thinner than 100 atomic layers spin diffusion between surface and interior $^{129}$Xe spins does not present a significant bottleneck for the overall $T_1$ value.

## 2. Experimental methods and results

We have constructed a cell containing powdered silica gel substrate [5] along with a sintered-silver heat exchanger, which was cooled by a dilution refrigerator in an 8 T NMR magnet. The silica gel was contained in an epoxy lower portion of the cell, which extended into a small birdcage NMR resonator [6] tuned to 92 MHz,

[1] Corresponding author. E-mail: candela@physics.umass.edu

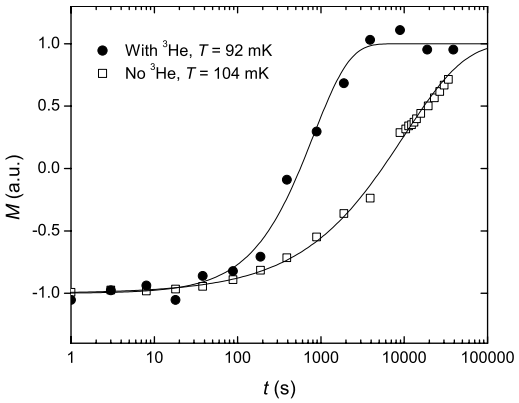


Fig. 1. Recovery of $^{129}$Xe nuclear magnetization following an inverting pulse or saturating comb. The magnetization data have been rescaled to an arbitrary range of $(-1, 1)$. The curves show fits to the data as follows. With $^3$He: simple exponential recovery with $T_1 = 814$ s. No $^3$He: stretched exponential recovery with $T_1 = 1.0 \times 10^4$ s and stretching exponent $\alpha = 0.6$.

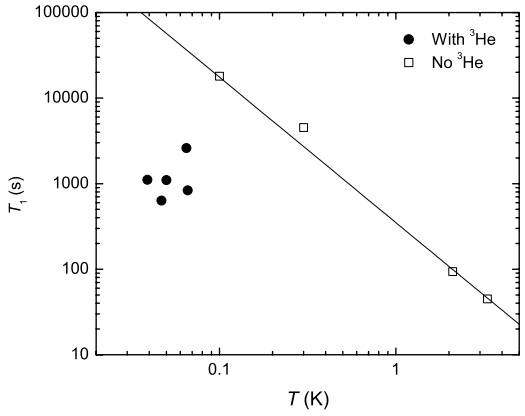


Fig. 2. Spin lattice relaxation time $T_1$ measured for $^{129}$Xe as a function of temperature and $^3$He coverage. With $^3$He present in the cell, $T_1$ is temperature independent with a value of approximately 1000 s. With no $^3$He present, $T_1$ is longer and strongly temperature-dependent. The line shows a power-law fit, $T_1 \propto T^{-1.7}$.

the $^{129}$Xe Larmor frequency at 8 T. The magnetic field could also be lowered, to measure the $^3$He NMR signal at the same frequency. A vibrating-wire viscometer at the top of the cell permitted the $^3$He liquid level to be monitored. A heated fill line was used to admit xenon to the cell. The cell was maintained at approximately 90 K during the xenon condensation process. The volume of xenon condensed was typically 20% of the available pore space, corresponding to approximately three atomic layers on the substrate.

The spin-lattice relaxation of $^{129}$Xe was measured by small-angle tipping pulses after either a magnetization-inverting $\pi$ pulse or a magnetization-destroying comb of large-angle pulses. The magnetization was sampled over a very large range of times (0.1 - 40,000 s) to ensure that very rapidly or slowly relaxing spin populations were not missed.

As shown in Fig. 1, addition of $^3$He to the cell significantly shortens $T_1$, and also changes the recovery curve from a stretched exponential $(M(t) - M(\infty) \propto \exp[-(t/T_1)^\alpha])$ to a simple exponential. The stretched-exponential form is typically due to a wide distribution of $T_1$ values for individual $^{129}$Xe spins.

Figure 2 shows the temperature dependence of $T_1$ measured with and without $^3$He in the cell. In the absence of $^3$He, $T_1$ is strongly temperature dependent. The mechanism of relaxation without $^3$He is not known, although it presumably reflects interactions with the silica surface and/or adsorbed impurities such as $H_2O$ and $O_2$. This relaxation rate is well fit by a power law (Fig. 2). When $^3$He is added to the cell, the relaxation time reduces to a temperature-independent value $T_1 \approx 1000$ s. This compares favorably to the estimate above.

## 3. Conclusions

We have demonstrated that macroscopic quantities of solid xenon can be brute-force polarized at dilution refrigerator temperatures, using the $^3$He-porous substrate method. A number of obstacles remain to developing this method into a practical method for producing hyperpolarized $^{129}$Xe gas. In particular, it may be necessary to switch off the relaxation process before attempting to remove the xenon sample to low $B/T$ conditions. Addition of $^4$He to the cell could provide such a switch, as $^4$He preferentially occupies sites adjacent to solid surfaces. Significantly, spreading of $^4$He over the xenon surface will occur by superfluid film flow. Like the tunneling process that is used to induce relaxation, this is a quantum process that can proceed at arbitrarily low temperatures.

## References

[1] T. Pietrass, Magn. Reson. Rev. **17** (2000) 263.

[2] P. C. Hammel, et al., Phys. Rev. Lett. **51** (1983), 2124.

[3] S. Maegawa, A. Schuhl, M. W. Meisel, M. Chapellier, Europhys. Lett. **1** (1986), 83.

[4] O. Gonen, P. L. Kuhns, C. Zuo, J. S. Waugh, J. Magn. Reson. **81** (1989), 491.

[5] Alfa Aesar #42725, nominal surface area 500 $m^2$/g.

[6] H. Akimoto, D. Candela, J. Low Temp. Phys. **121** (2000), 791.