Rapid Production of Hyperpolarized 3He Gas for MRI

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Introduction

Spin-exchange optical pumping (SEOP) [1] is widely employed to generate samples of hyperpolarized ^{3}He for magnetic resonance studies, most notably MRI studies of the lung [2]. One drawback to SEOP is the time to polarize the gas; existing polarizers typically require 10 h or more to achieve 40-50% polarization in quantities of gas ~1 bar·L. Two recent advances in the physics of SEOP have led to dramatic enhancements in polarization efficiency: the use of spectrally narrowed diode-laser arrays [3] and "hybrid" SEOP, which employs both potassium and rubidium as alkali-metal intermediaries [4]. We have combined these techniques in constructing two polarizers, a prototype system at Utah and a more fully engineered system at PNNL. We report up to 50% ^{3}He polarization in 0.5 bar·L of gas in valved and refillable glass cells, achieved in 4 h.

Methods

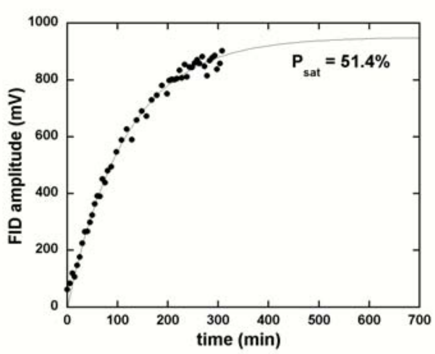
The Utah and PNNL polarizers are essentially identical except for the diode-laser array: The Utah system uses an array rated for 50 W (Quintessence Photonics) with a final output power from the external cavity of 31 W. The PNNL system uses an array rated for 60 W (Nuvonyx, Inc.) with an output power of 34 W. The external cavity [3] narrows the laser spectrum from 2.0-2.5 nm to 0.2-0.3 nm (FWHM), providing a correspondingly larger light intensity per unit frequency in the central portion of the Rb absorption spectrum.

The glass vessels used are 5 cm dia. spherical bulbs connected to a glass valve *via* a 10-cm length of 0.5-1.0 mm capillary [5]. The cells typically have volumes of 60 cm^3 and are filled to a pressure of 6-8 atm ^{3}He. Rb and K metal are distilled separately into each cell. The target ratio K:Rb in the condensed phase is roughly 30:1, based on a desired vapor-pressure ratio K:Rb ≈ 10:1 [4]. The laser light is absorbed by Rb atoms, but spin-exchange takes place primarily with K atoms (polarized by rapid electron spin-exchange with the polarized Rb atoms). The increased efficiency of K-^{3}He spin-exchange is realized by increasing the temperature of the optical pumping oven to the point (typically to 225-240 °C) where 70-75% of the laser light is absorbed (a typical light-absorption value for our Rb-only cells). The alkali-metal—^{3}He spin-exchange rate increases compared to Rb-only cells due to the additional polarized K atoms in the vapor.

In experiments done on the PNNL polarizer, the absolute ^{3}He polarization was determined by comparing the NMR signal from a HP gas vessel to the signal from a ^{3}He phantom at thermal polarization in a 2-T magnet. At Utah, polarimetry was done by comparison with a water sample in an electromagnet at two fields corresponding to the same NMR frequency (32.5 MHz) for both nuclei

Results

The figure shows a polarization transient for a hybrid cell (designated 122KRb) tested at Utah. A saturation ^{3}He polarization of 51% is indicated by a fit to the appropriate exponential function, with a characteristic polarization time τ = 116 min. The table shows a summary of results for several cells, including τ, room-temperature relaxation times, optimal pumping temperature (determined empirically) and final polarization achieved. Results are also shown for a single Rb-only cell (26Rb) for comparison.



Cell	τ (min)	Pol (%)	T_1 (min)	Temp C
114KRb (Utah)	51	28	95	220
116KRb (Utah)	154	50	2560	175
122KRb (Utah)	116	51	1110	225
107KRb (Utah)	83	38	570	240
26Rb (PNNL)	338	50	3120	165

Discussion

Based on the room-temperature relaxation times T_1 for most of our hybrid cells, we would expect much higher saturation ^{3}He polarizations than reported here. We conclude that inefficient coupling of laser light into these spherical cells combined with relatively high K:Rb ratios significantly reduces the alkali-metal polarization, thus also reducing the final ^{3}He polarization. (A method for better control of K:Rb is under study.) However, the achievement of 50% polarization in 4 h with SEOP still represents a dramatic improvement for large quantities of hyperpolarized ^{3}He compared to what is typically achieved by various groups for imaging studies.

References

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