Direct Optical Hyperpolarization of Liquids

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Introduction: Conventional magnetic resonance technology for imaging (MRI) and spectroscopy (NMR) uses powerful magnetic fields to polarize the spin vector of protons inside the nuclei of various molecules of interest. This approach only enables a tiny fraction of the available protons to contribute to the net polarization; a 1.5 Tesla field, at body temperature, creates a net polarization of only 5 protons out of million. Optical pumping techniques, (using circularly polarized light, the principles of hyperfine nuclear interactions and molecular angular momentum conservation), achieve molecular orbital spin saturation and nuclear polarization levels of up to 40% [1].These methods, however, are only suitable for hyperpolarizing gasses (species with a low probability of hyperpolarization detuning due to thermal molecular interactions) like Xe and He and have an inherently low throughput. We present here a novel hyperpolarization approach that uses light endowed with orbital angular momentum (OAM) to directly hyperpolarize liquids. This method has the potential to dramatically increase the sensitivity, resolution, and signal-to-noise of MRI/NMR, and will enable new MRI contrast mechanisms to be explored.

Theory: This method takes advantage of the angular momentum conservation law applied to photons carrying spin and OAM interacting with molecular orbitals. It has been previously demonstrated theoretically and experimentally that when photons interact with molecular orbitals, electron states reach a saturated spin state [1] and molecular angular momentum (rotation around molecule center of mass) aligns (via Larmor precession) along the propagation axis of incident light [2]. In this work, we have shown that an additional consequence of this interaction will be that all magnetons precessions associated with the molecules (including electrons and nucleons) are oriented along the propagation axis of incident light. This effect is proportional to the value of the OAM carried by the light beam.

Materials and Methods: The feasibility of this NMR hyperpolarization method was verified experimentally. A light source (532nm, 0.5W, solid-state diode pumped laser) with OAM was generated using a phase hologram mode converter [3]. The light with OAM was focused onto a liquid sample (index matching oil, refraction index of 1.516, Cargille Laboratories, Cedar Grove, NJ) using a Zeiss objective lens with an f/# of 0.65, resulting in a beam with a radius of approximately 2.9μm. Approximately 30 μL of the sample was contained within a receiver coil with an inner-diameter of 2mm and a length of 10mm. A static magnetic field (B = 0.18T) was applied perpendicular to the light beam. A mechanical shutter was used to expose the sample to alternating periods (each lasting 70ms) of OAM light and dark. Measurements were synchronized to the onset of the dark period, such that a free induction decay (FID) would be observed if a polarization was induced during the “light on” period. The signal collection coil was electrically connected to a 50Ω input low noise amplifier with 40dB gain. The amplified output was recorded with a Tektronix TDK700 series scope, on a 5mV input scale range, using 25MHz sampling frequency, 20MHz input low-pass filter,16bits resolution, and 200K samples. The acquired data was then passed to an FFT algorithm (average factor of 20). Measurements were performed using light with OAM values between ***l***=1 and ***l***=19; controls were performed with ***l*** = 0 and with no light. The results obtained with this experimental setup were then compared to an MR spectroscopy measurement performed on a standard Philips 1.0T Panorama scanner (PRESS sequence, FOV=1cm^3, FA=90^o, TE/TR=50/2500ms, NSA=24, BW=8000Hz, NP=16384).

Results: According to the gyromagnetic ratio, the hydrogen proton NMR signal at B=0.18T is expected to appear at 7.78 MHz. Under the control conditions (i.e. no light and light with ***l***=0), no NMR signal was observed at or near 7.786MHz. When light with ***l***=17and ***l***=19 were used, an NMR signal with an SNR of approximately 5 was observed at 7.786MHz (**Figure 1**). The features within the NMR spectra obtained using optical OAM hyperpolarization corresponded quite well with the NMR spectrum obtained using the 1.0T conventional scanner (**Figure 2**).

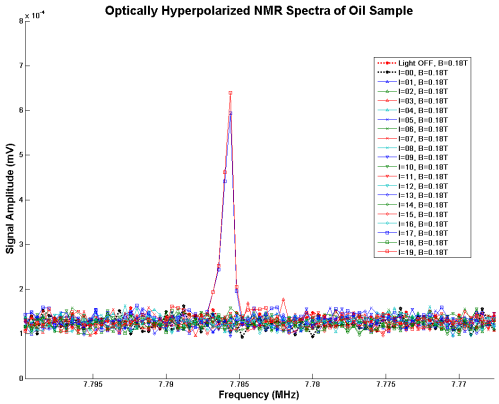

Figure 1: Experimental Spectra

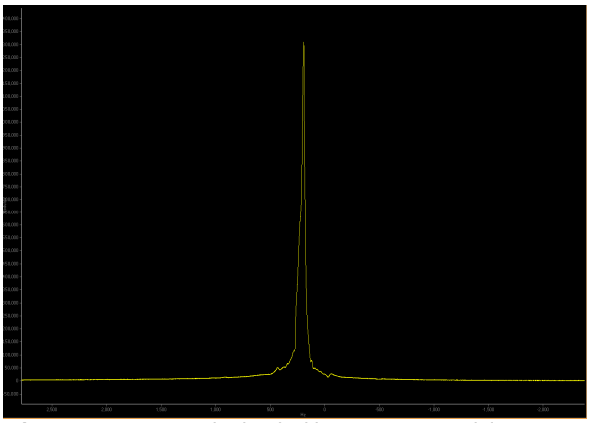

Figure 2: Spectrum obtained with 1.0T Commercial Scanner

Conclusions: This novel method enables direct hyperpolarization of liquids using light with orbital angular momentum. This study has demonstrated the proof of concept of using this method to obtain NMR measurements from extremely small samples (the volume of sample in the active region of the focused OAM light is less than 1pl) and relatively quickly (the polarization developed in less than 70ms).

References:

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