FRINGE FIELD EFFECTS ON HYPERPOLARIZED ^{129}XE FOR A CONTINUOUS FLOW SEOP SETUP

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Introduction: Hyperpolarized noble gases produced by spin exchange optical pumping (SEOP) provide high NMR sensitivity at low spin densities. Usually, the gas is accumulated and then brought into the fringe field of an NMR magnet, to maintain sufficient Zeeman splitting, while being slowly released into the object of interest. The unavoidable passage through the field gradient into the magnet center induces relaxation effects. Investigating this process for ^{3}He gas phase MRI [1], it was surmised that such effects are not a problem for ^{129}Xe gas MRI. However, conditions can be different, especially among experiments designed to establish xenon biosensors as functionalized contrast agents in solution [2,3]. Phantom experiments on xenon-saturated solutions require an adequate repetitive gas delivery method. Constant, reproducible xenon delivery (especially important for CEST-based detection techniques) can be achieved by a SEOP polarizer operated in continuous flow mode in direct proximity to an NMR magnet [4]. In such a setup, the hyperpolarized gas being bubbled into the phantom has to pass directly from the pumping cell through the fringe fields of both the pumping cell and the NMR spectrometer. Several SEOP setups work with a cell design where the hyperpolarized gas is leaving the pumping field radially [5,6]. This becomes a problem when a relative long cell is used for fast polarization pick-up in combination with a coil setup of small diameter (to keep the setup compact) but more than two coil elements. Here, we studied the influence of the pumping field configuration and the resulting net fringe field next to an actively shielded 9.4 T NMR spectrometer on the achievable ^{129}Xe signal under continuous gas flow.

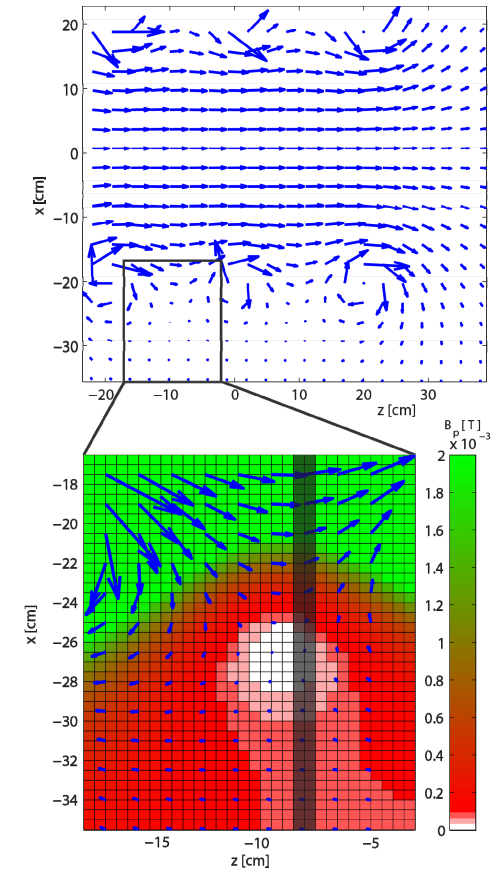

Fig 2: *Magnetic vector field simulation of three current loops at z = [-20,0,20] cm illustrates the pumping field $\boldsymbol{B}_p$. A closer look of the pumping cell outlet is shown as an overlay of the vector field with the absolute field strength. The pumping cell outlet is depicted as a transparent black bar.*

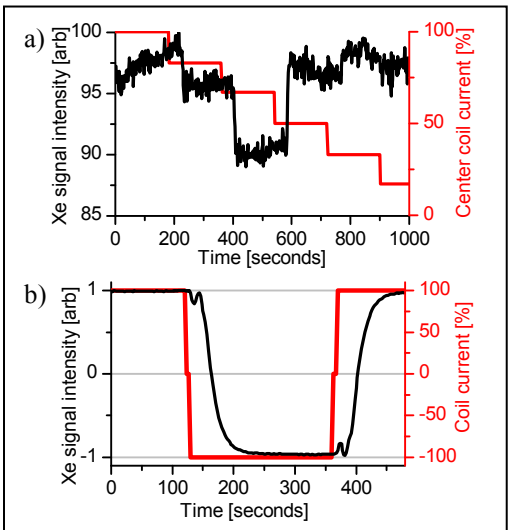

Fig 1*: Integrated Xe signal intensity while a) systematically varying the current through the center coil and b) inverting the direction of $\boldsymbol{B}_p$.*

Methods: The configuration of the pumping field $\boldsymbol{B}_p$ was modified in a three-coil setup with a variable current I_c for the center coil. This varies the field produced by the center coil at it's center from 0 to 19 G. The net field was calculated using Biot-Savart's law to yield corresponding vector field maps for $\boldsymbol{B}_p$ [7]. Changes in $\boldsymbol{B}_p$ also vary the net field that the gas experiences when flowing into the NMR magnet, thus causing different relaxation of the hyperpolarization prior to arrival in the high detection field. Teflon tubing guides the gas flow (0.35 SLM of a mixture containing 2% Xe, 10% N_2, 88% He) from the polarizer outlet into a 10 mm NMR tube with an inlet connector and an outlet vent connected to a mass flow controller. The ^{129}Xe NMR signal was recorded in gas phase immediately upon arrival at the spectrometer sweet spot to directly reveal correlations between signal changes and modification of $\boldsymbol{B}_p$. Single shot spectra were taken every 2 seconds while $\boldsymbol{B}_p(I_c)$ was changed ca. every 3 min.

Results and discussion: Fig. 1 a) illustrates the changes in Xe polarization as a function of I_c. While it is not apparent for this integrated data, there is an immediate change in the location and width of the Xe peak. An immediate response must originate from gas that experiences field changes just before it enters or inside the NMR detection coil. Hence, it is assigned to modified shim conditions inside the spectrometer and reveals minor penetration of $\boldsymbol{B}_p$ although the NMR magnet is actively shielded ($\boldsymbol{B}_p$ can shift the ^{1}H water signal up to 4 Hz and cause ca. 40 Hz additional line broadening). A signal decrease on a time scale of tens of seconds after changing I_c must be due to increased relaxation on the way from the polarizer into the magnet. The lowest signal intensity is observed for ca. I_c = 2.72 A (68%). Fig. 2 illustrates that for this value there exists a spot near the gas outlet tubing where the net field $\boldsymbol{B}_p$ is expected to vanish. However, the gas flow velocity seems to be high enough to limit signal loss due to temporarily insufficient Zeeman splitting to less than ~10 % when compared to maximum signal at I_c = 4 A (100%). Additional effects are seen when inverting the orientation of $\boldsymbol{B}_p$, Fig. 1 b). Approximately 10 seconds after inverting the field there is a brief loss in signal intensity followed by a recovery. This is attributed to the changing magnetic field inducing relaxation of the Xe on it's way to the NMR detection coil. Though the change in polarization of the rubidium is almost instantaneous, the Xe takes approximately 80 seconds to completely repolarize. Our study reveals that the Xe NMR signal indeed depends to a measurable extent on the net fringe field when operating a continuous flow SEOP setup in direct proximity to an NMR magnet. It can therefore be optimized when paying attention to the fringe field conditions.

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