

Continuous Proton Hyperpolarization via SABRE and Hollow Fiber Membranes

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Purpose

Hyperpolarized contrast agents allow for an observation of short processes, where only few molecules contribute to the MR-signal. The drawback of weak signals due to small spin density is compensated by the hyperpolarization that allows for high signal enhancements. While this offers many interesting applications, most methods rely on a generation of the hyperpolarization via a batch mode. When only limited volumes can be hyperpolarized, the experiment is also limited in duration.

In this contribution a proton hyperpolarization is maintained continuously over 12 hours in one single experiment. This is achieved by combining the SABRE² hyperpolarization method with the use of hollow fiber membranes³ (figure 1).

Methods

Pyridine (0.1 ml), a catalyst (40 mg) and D₂O (120 ml) are filled in a circular flow setup containing a hollow fiber membrane module, a detection chamber - located inside a 4.7 Tesla MRI machine and a pump (50ml/min). Parahydrogen is supplied to the module from a commercial parahydrogen source at a rate of 200 ml/min (Para-Gen, Bruker, Germany), and hydrogen is removed from the module into a fume hood (figure 2).

Results

A continuous hyperpolarization can be maintained with this setup (see figure 3). As soon as parahydrogen is supplied, a hyperpolarization - causing negative enhancements - is instantaneously available. If the parahydrogen supply is closed the enhancement falls towards the thermally level (=1) as soon as all parahydrogen is converted.

The long lasting hyperpolarization can be investigated extensively; here the imaging experiments are presented showing clearly the geometry of the detection chamber and the dependency on the echo time due to the 180° phase shift between signals from thermally polarized water and hyperpolarized substrate (figure 4).

Discussion

The hyperpolarization can be maintained over 12 hours and stable enhancements are realized. This has been exploited for example to acquire MR-images. Because of the continuous character high flip angles (90°) can be used since the hyperpolarization is renewed after each line. This results in very efficient usage of the hyperpolarization. The continuous supply of a hyperpolarized substrate in combination with the use of high flip angles allow for very efficient usage of a hyperpolarization. Combined with the small technical requirements for this setup this method offers a new method to investigate processes in cases where short processes have to be monitored or where averaging techniques have to be used for the hyperpolarized media.

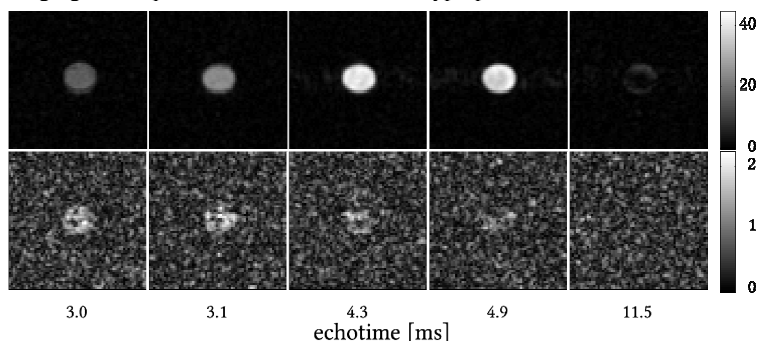


Figure 4: MR images of hyperpolarized pyridine (top) and thermally polarized reference (bottom) in SNR units. Due to the 180° phase shift between the two polarizations and the chemical shift the optimal echo time can be found at 4.3 ms¹ (gradient echo sequence, FA: 90°, TR: 1 s, bandwidth: 1040 Hz/pixel, matrix size: 64 × 64, resolution: 0.67 mm/pixel).

References

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3. Roth, M., et al., Continuous 1H and 13C Signal Enhancement in NMR Spectroscopy and MRI Using Parahydrogen and Hollow-Fiber Membranes. *Angew. Chem.* **2010**, 122 (45), 8536-8540.

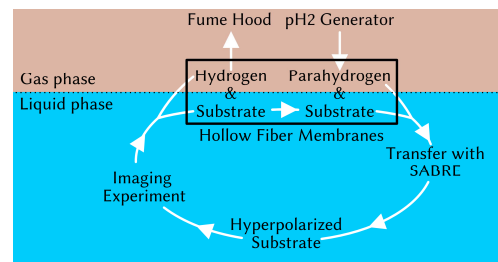


Figure 1: The SABRE process transfers the spin order of parahydrogen (supplied from the top) onto a substrate by contact at a metallic catalyst (right). Then MRI experiments are performed on the resulting hyperpolarized substrate. The thermally polarized substrate and hydrogen are present afterwards (top left). Hydrogen is exchanged by diffusion through the hollow fiber membranes.

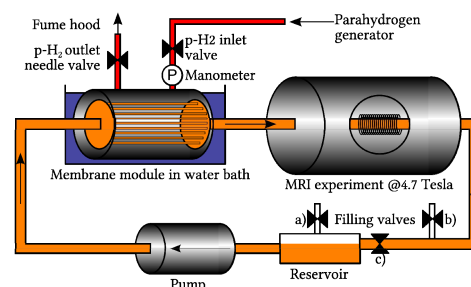


Figure 2: Schematic drawing of the circular flow setup containing the hollow membrane fiber module, where the hyperpolarization and hydrogen exchange occurs, the 4.7 Tesla MRI machine with the detection chamber inside and the pump.

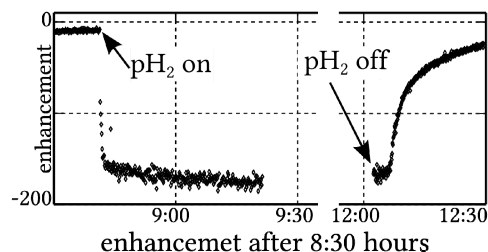


Figure 3: Hyperpolarized pyridine is available as soon as parahydrogen is supplied to the system. High enhancement factors of up to -200 can be reached, depending on the magnetic field at the place of the hollow fiber membrane module. The level of hyperpolarization is constant over several hours.