Towards zero- and ultra- low-field nuclear magnetic resonance with atomic magnetometers

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Devices using nuclear magnetic resonance (NMR) are routinely used for non-invasive medical imaging as well as chemical analysis [1]. Conventional NMR requires high (>1 T) magnetic field for samples' polarization and magnetization detection. The need for ultra-strong homogenous field is possibly the largest drawback of standard NMR, leading to high cost and low mobility of NMR scanners and spectrometers. This also limits the technique applicability (e.g., inapplicability to people with pacemakers).
In recent years, efforts has been made to perform NMR experiments at ultra-low magnetic fields or even entirely without the field [2]. Aside from solving the problems arising from the high magnetic field, rich chemical information can be extracted under these conditions [3]. Additionally, at zero- and ultra-low fields spin relaxation processes are suppressed, leading to ultra-narrow NMR lines leading to high spectroscopic sensitivity of the technique [4] and high spatial resolution of imaging [5].
In zero- and ultra- low-field (ZULF) NMR experiments, where inductive coils are not applicable, direct detection of samples magnetization takes place through application of the most sensitive magnetic-field sensors: superconducting quantum interference devices (SQUIDs) or atomic magnetometers [6]. Former solution seems especially promising, as atomic magnetometers can operate near room temperature, can be miniaturized and still routinely reach the near-DC field sensitivity better than 10 fT $\mathrm{Hz}^{-1/2}$. This last feature guarantees high SNR of measured NMR signals, while the first two open avenue for construction of portable NMR devices.
In our presentation, we describe experimental setup used to perform preliminary NMR experiments at zero and ultra-low magnetic field using high sensitivity atomic magnetometers. An atomic magnetometer, used for the purpose, exploits nonlinear Faraday rotation. Our device can be used in nearly identical experimental configuration to measure quasi-static magnetic field or oscillating magnetic fields tuned to particular frequency. With this respect, the devices can be used for spectroscopy, as well as, imaging. To eliminate environmental noise, which is predominant in the setup, a gradiometer scheme, employing differential signal from two sensors is used. This enables measurement of magnetization of a sample, shuttled pneumatically from a high field region produced by constructed pseudo-Halbach magnet, where samples are polarized, to a volume inside an ultra-low magnetic field, where detection is performed. Thanks to the broad, tunable range of the magnetometer and a remote prepolarization scheme, this experimental arrangement is suitable for simultaneous detection of NMR signals from different nuclei species at low magnetic fields, as well as spatial imaging with information encoded by magnetic field gradients.

References

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