A low field MRI system for hyperpolarized $^3$He imaging

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Introduction

A low magnetic field Magnetic Resonance Imaging (MRI) system for small animal lung imaging using hyperpolarized $^3$He gas is presented. The hyperpolarized $^3$He gas at 1 barb pressure and 30% polarization is obtained by the metastability exchange optical pumping technique. The MRI unit is based on a permanent magnet of open geometry, built from a new generation Nd-B-Fe magnetic material. It produces the magnetic field of 88 mT with homogeneity better than 50 ppm in the 10 cm diameter sphere, after application of passive shimming. The magnetic field gradients of 30 mT/m are generated by a set of biplanar, actively shielded gradient coils. The first $^3$He images of various biological objects, as well as $^3$He images of the rat lung in vivo obtained in the described system are shown.

In terms of sensitivity and resolution, the technique is superior to conventional ¹H MRI, and offers great possibilities in early diagnosis of lung diseases.

Principle of optical pumping

The polarized $^3$He is obtained in the metastability exchange optical pumping process. In the first phase, the helium atoms in the $1^1S_0$ ground state are transferred to the $2^3 S_1$ metastable state by the application of weak rf discharge. Then the optical pumping between the hyperfine sublevels of $2^3 S$ and $2^3 P$ states proceeds using the transition at $\lambda=1083$ nm wavelength. As a result the total angular momentum of the metastable atom becomes oriented. The nuclear polarization of the ground state $^3$He atom builds up during so-called metastability exchange collisions. During the collisions the nuclear orientation remains unaffected while the electronic states of the atoms are exchanged.

Gas production system

Based on the above principle, a dedicated, table-top $^3$He optical polarizer was built to produce hyperpolarized $^3$He gas for MRI applications. A homogeneous magnetic field $B_0$ is produced by a set of six coaxial coils which produces a homogeneous field of the order of 25 G in a sufficiently large volume to accommodate a cell where the optical pumping takes place (OP cell), as well as a storage cell. The optical cell is first evacuated by a system with the turbomolecular pump, and then filled with few mbars of $^3$He gas, using the gas handling system. A DBR laser diode delivering up to 50 mW of power is used for optical pumping.

After the optical pumping process has been completed, the gas is extracted from OP cell using a non-magnetic peristaltic compressor and accumulated in the storage cell. When the required amount of $^3$He is obtained, it is mixed with neutral gas ($N_2$ or $^3$He), extracted into the syringe and delivered to the MRI scanner.

MRI system

A low field MRI system for imaging small animal lungs using hyperpolarized $^3$He consists of the permanent magnet producing the static field $B_0$, a set of biplanar, actively shielded gradient coils, and the rf coil. All experiments are controlled by a commercial MR Research Systems console supplemented by a home-built frequency converter, which makes it possible to perform the experiments on either $^3$He or $^1$H frequencies.

References