Hyperpolarization of flowing water by dynamic nuclear polarization

K. Yamada,[*1, *2] K. Tateishi,[*1] and T. Uesaka[*1]

Magnetic resonance angiography (MRA) is a technique for imaging blood vessels based on magnetic resonance imaging (MRI) for the evaluation of aneurysms, stenosis, occlusions, and so on. To obtain clear images, imaging time need to be done for a long for signal averaging, and this makes the resolution, in particular of heart, worse due to the beating. To overcome this problem, the injection of polarized water into a blood vessel was demonstrated[1)]. Both the imaging time and the resolution were improved through the use of this method. In this experiment, the polarized ^{1}H spins in water were generated by dynamic nuclear polarization (DNP) method. The method can be used to polarize > 30% of ^{1}H spins using cryogenics and sub-terahertz devices, however, about 90% of the polarization was relaxed before injection, due to the short spin-lattice relaxation time of ^{1}H spins.[2)] In this work, we adopted the flow-DNP method to polarize ^{1}H spins in flowing water for simplicity.

The DNP method is used to transfer electron spin polarization to nuclei with microwave irradiation. We applied it to flowing water (flow-DNP).[3)] This is a very compact, cheap, and versatile method for polarizing liquid-state samples. We would like to apply this method not only to MRA but also for various studies such as on proteins using high-resolution NMR system.[4)]

Experimental setup of flow-DNP is shown in Fig. 1. A microwave cavity with a frequency of 9 GHz is placed in the electromagnet. The external magnetic field is set at 0.3 T. Water is flowed into the cavity by a pump. The tube in the cavity is filled with gels functionalized with radicals to slow down the flow rate only inside the cavity. The microwave irradiates the radicals with an incident power of 3 W. Although the polarized water is looped back to the pump in current setup, it will be sent to the MRI system in the future. The coil in the NMR is placed in the downstream direction of the cavity to check the polarization. The enhancement factor ϵ of the polarization is given as

$$\epsilon = 1 - \rho f s \frac{|\gamma_e|}{\gamma_n},$$

where ρ is the coupling factor, f is the leakage factor, s is the saturation factor, and γ_e and γ_n are the gyromagnetic ratios of the electron and ^{1}H, respectively. With the above setup, ρ, f, and s are estimated to be 0.07, 0.90, and 1, respectively,[3)] and the expected polarization is 0.0041 %.

[*1] RIKEN Nishina Center
[*2] Department of Physics, Toho University

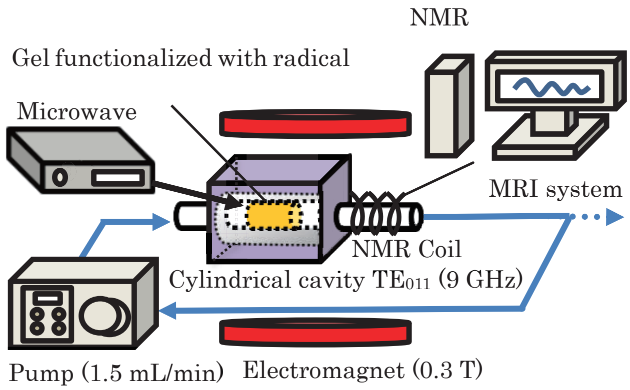

Fig. 1. Experimental set up for flow-DNP.

We constructed the system except for the gel this time, and detected the NMR signal of ^{1}H spins in the flowing water with a flow rate of 1.5 mL/min for demonstration. The result is shown in Fig. 2. Although the line width is a little broad compared to the one obtained from a conventional solution NMR, it is narrow enough for flow-DNP. Next year, we will synthesize the gel and carry out the flow-DNP experiment.

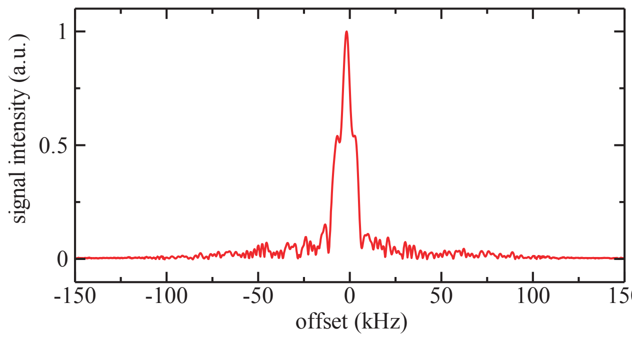

Fig. 2. NMR signals of the ^{1}H spins in flowing water in thermal equilibrium. Offset means the difference between the resonance frequency of ^{1}H and the frequency of electromagnetic waves.

References
1) J. Ardenkjaer-Larsen et al., Magn. Reson. Med. **71**, 50 (2014).
2) Q. Chappuis et al., J. Phys. Chem. Lett. **6**, 1674 (2015).
3) M. D. Lingwood et al., J. Magn. Reson. **205**, 247 (2010).
4) M. Reese et al., J. Am. Chem. Soc. **131**, 15086 (2009).