Popular project summary

Modern nuclear magnetic resonance (NMR) scanners and spectrometers use magnetic fields hundreds of thousands of times stronger than the Earth's magnetic field. The mere use of a strong magnetic field, however, is not enough to noninvasively image interior of a human body or perform analytical measurements of complex chemical systems – the field additionally needs to be extremely homogeneous. Only a combination of these two factors enables application of NMR in a vast range of applications ranging from basic research (physics, chemistry, biology, geology, etc.), through applied research (medicine, pharmacology, etc.) to strictly utilitarian measurements (search for mineral deposits, magnetic resonance imaging, food industry, etc.).

Providing very strong, but uniform magnetic field is a major technical challenge in NMR. For that purpose today's NMR devices use superconducting magnets (cooled to a temperature of several Kelvin) that are "homogenized" to part-per-million (or even part-per-billion) level with a set of a complex magnetic-field coils. This makes NMR devices complicated, motionless, and very expensive. Using a strong field also limits the applicability of the technology to nonmagnetic objects only (e.g., the technique cannot be used for during biopsies). These problems were the ones that drive interest in NMR at ultra-low/truly-zero magnetic fields. The ability to conduct such measurements, however, requires addressing the problem of low signal-to-noise ratio of NMR signals at weak fields.

In our study, we propose a **completely new approach to NMR**. We will carry out the NMR **measurements in a very weak/truly-zero magnetic fields**. For such measurements, we plan to compensate for the deterioration of sensitivity by the application of remote polarization of NMR samples (application of independent preparation and measurement regions) and the use of the most sensitive known magnetometers (optically-pumped magnetometers). The combination of these two approaches will allow the measurement of NMR signals even in the absence of any external fields. In case such measurements, the NMR signals arise from the interaction between molecule’s nuclei which is mediated by an electron. This will provide **zero-field NMR with capabilities to determine molecular structure, strength and orientation of the chemical bonds**. Moreover, since the measurements will be performed in very weak field, one of the major problems of conventional NMR associated with magnetic-field inhomogeneity will be alleviated. Consequently, **the observed NMR resonances will be extremely narrow**, so that the technique becomes **ultra-precise sensor for changes of molecular structure induced by internal and external factors** (e.g., changes in the environment).

Since the NMR signal from each molecule is unique, we plan to **create a database of zero-field NMR spectra**. Eventually, this should enable **chemical fingerprinting** of unknown chemical samples. In particular, we want to conduct research that will allow detection of liquid explosives, i.e., the materials conventional NMR is blind to.

We also wanted to use a method in basic research. For example, we want to use it for **searches of the so-called exotic spin coupling**, i.e., spin interactions predicted theoretically but never detected experimentally. Our estimates show that the use of zero-field NMR will allows exploration of the possibility of existence of such interaction at the level unattainable for other techniques.

The proposed research will for solid grounds for further development of the technique. Several further application in medicine and industry are already foreseen with further ones to come. We believe, that the technique burdens the potential to become a complementary method for traditional NMR.