High magnetic field research using nuclear magnetic resonance: options and instrumental challenges

Steffen Krämer
EMFL-LNCMI, CNRS, Univ. Grenoble Alpes, INSA-T and UPS, Grenoble, France

Strong magnetic fields are an extremely powerful tool for investigating, modifying and controlling different states of matter on microscopic and macroscopic length scales. Whereas commercial superconducting magnets reach magnetic fields up to 28.3 T, with 30.6 T in perspective, stronger fields are only available at specialized large-scale facilities. Due to very high acquisition and operating costs, such facilities currently only exist in a few places in the world (Europe, USA, China and Japan).

The four sites of the EMFL at Dresden (Germany), Grenoble (France), Nijmegen (The Netherlands) and Toulouse (France) offer the scientific and industrial community continuous fields in variable geometry, from 10 T at 376 mm diameter to 38 T at 32 mm, as well as pulsed fields up to almost 100 T during 20 milliseconds and up to 200 T during a few microseconds. Moreover, the magnetic fields can be combined with very low temperatures, high pressure as well as with neutrons, X-rays and free-electron lasers. In this presentation, the available macroscopic and microscopic experimental techniques will briefly be overviewed including the instrumental challenges due to the particular constraints of the high magnetic field environment.

The main part focuses on very high magnetic field nuclear magnetic resonance (NMR) at EMFL-LNCMI Grenoble. There, NMR is extensively used in solid-state physics to study high-temperature superconductors, heavy fermion systems, quantum magnetism and other correlated electron systems. Using selected research projects, we will demonstrate the potential of NMR in such compounds including the necessary instruments and methods for broadband NMR on oriented single crystals up to 42 T and low temperatures down to 50 mK.

Recently, the application field of NMR at Grenoble has been enlarged towards resolution-enhanced NMR. Using examples from past and ongoing research activities, we show the potential of this technique in resistive high-field magnets for the study of low sensitivity quadrupolar nuclei in material science as well as nuclear magnetic relaxation dispersion (NMRD) studies of protons in water with dissolved paramagnetic ions up to 1.4 GHz/33 T. In addition to basic research issues, the latter activity serves the development of future contrast agents for magnetic resonance imaging in high magnetic fields.

However, due to their limitations in field homogeneity and stability, resolution enhanced NMR studies in such magnets require tailored methods in order to overcome these drawbacks that will be discussed. These include broadband tunable NMR probes, ferro-shims and microliter sample volumes to overcome the field inhomogeneity, NMR spin-locks and multi-pulse NMR sequences to eliminate impacts of magnetic field drift and fluctuations as well as reference deconvolution to improve of the signal-to-noise ratio.

Finally, we briefly show how NMR can be used for magnetic-field metrology, i.e., for the calibration and characterization high-field magnets.