Quantum control protocols for nuclear spin hyperpolarisation

Institut für Theoretische Physik
Prüfer: Prof. Martin B. Plenio

Aufgabenstellung

A key challenge in the quantum manipulation and detection of small nuclear spin ensembles is their minute level of polarisation at thermal equilibrium which is of the order of 0.001% for a magnetic field of 2 Tesla at room temperature. Overcoming this challenge holds the key for the realisation of quantum applications ranging from quantum simulators to nanoscale NMR devices. These will be turned from lab demonstrations to realistic applications by polarisation schemes that enable their efficient initialisation and read-out. An important breakthrough in this respect has been the realisation that the electron spin of the nitrogen vacancy (NV) centres in diamond can be optically initialised nearly perfectly even at room temperature and ambient conditions allowing for rapid electron spin polarisation to be generated optically or chemically far above thermal equilibrium and subsequently transferred to surrounding nuclei. These systems present a unique opportunity for polarising and initialising spin baths and unlocking the potential of nanoscale applications including the initialisation of quantum simulators based on nuclear spin arrays in diamonds, magnetic resonance imaging (MRI) tracers via diamond nanoparticles and the enhancement of nanoscale nuclear magnetic resonance (NMR) using NV spin ensembles.

In Science Advances 4, eaat8978 (2018) http://advances.sciencemag.org/content/advances/4/8/eaat8978.full.pdf our group has presented a new approach for performing dynamic nuclear polarisation, termed PulsePol, which combines fast polarisation transfer with remarkable robustness against a broad range of experimental imperfections including power and detuning fluctuations. In sharp contrast to all earlier schemes we design sequences of short pulses (much shorter than the nuclear Larmor period), with extended waiting periods between the pulses, that control the electron-nuclear interaction such that polarisation transfer is achieved through the accumulated dynamics between pulses. We demonstrated this principle both theoretically and experimentally.

In this project you will improve on the basic control sequences that we have developed both by analytical construction and by numerical optimisation. There is the potential for significant improvements in polarisation performance. The best sequences that you will develop will find applications in experimental work on hyperpolarisation both in the academic environment of Ulm University and in the recent high technology start-up NVision Imaging Technologies.