The HELPING project

High field Enhancement of nucLear Polarisation In Noble Gases

Renforcement de la polarisation nucléaire des gaz rares à haut champ

Nuclear Magnetic Resonance (NMR) is a sophisticated and powerful analytical method with numerous applications in research, health care, and industry. However, its use is limited by the low intrinsic sensitivity of inductive detection (owing to a low energy difference between nuclear spin states, even above 1 Tesla) and by the low polarisation that is established at thermodynamic equilibrium (i.e., the relative difference in populations for states with opposite spin orientations). **Hyperpolarisation** is relevant when a strong boost in sensitivity is needed. Polarisation enhancement factors can reach several orders of magnitude. This has paved the way to advances in science and applications.

Laser-polarised noble gases have found applications in functional lung imaging and biomedicine, as well as in basic research. Optical pumping techniques have been extensively studied at low magnetic field (1–10 mT). But detection of the NMR signal at high field is usually needed, for increased sensitivity (thanks to operation at high frequency) and spectral resolution (large chemical shifts). It allows a more detailed analysis of the system, at the expense of polarisation losses due to gas handling and transfer into the NMR apparatus.

Hyperpolarisation of noble gases at high magnetic field lies at the heart of the HELPING project. Scarcely explored up to now, **it is of fundamental interest** (it can shed light on polarisation build-up and decay processes) and **it can help reduce, or even eliminate, the dead time for gas transportation in practice**. **New features are expected**, owing to field-dependent atomic level structures, collisional interactions, and nuclear relaxation processes. **Overall optimisation of polarised gas delivery also requires meeting inherent technical constraints** (bore size, magnetic susceptibility of materials).

The HELPING project mainly deals with **hyperpolarisation of spin-1/2 atoms**, **129Xe** et **3He**, and includes tests with quadrupolar isotopes, **21Ne** (spin 3/2) et **83Kr** (spin 9/2). Xenon strongly interacts with its surrounding and 129Xe exhibits a wide range of frequency chemical shifts that are particularly relevant for NMR spectroscopy. Helium, smaller in size, interacts weakly with nearby atoms hence 3He has low nuclear relaxation rates; it is also an excellent gas probe for systems with nanoscale void spaces. 21Ne et 83Kr can both provide additional information in NMR studies in various materials or media, through data that are more easily interpreted (21Ne) or more sensitive to surface properties (83Kr).

The HELPING project relies on **in-depth studies, with combined optical and NMR measurements**, that are made possible by the **recent implementation, at CEA Saclay, of a purchased 7 T NMR spectrometer/imager**. It capitalises on the almost unique features of the instrument (a super-wide bore magnet, ratings for high quality MRS and 3-axes MRI, multi-channel detection). Work will focus, first, on **hardware developments** for noble gas hyperpolarisation in, or very close to, the measurement area. It will, then, consist in experimental investigations aiming at:

- **In-depth study of spin exchange optical pumping (SEOP)** of 129Xe in alkali vapours and SEOP tests with 83Kr,
- **Assessment of the limits of metastability exchange optical pumping (MEOP)** in pure 3He, **extension to 3He-4He gas mixtures**, and MEOP **tests at cryogenic temperatures**,
- **In-depth study of a new (non-optical) hyperpolarisation scheme**, recently discovered in 3He gas discharges, called **PAMP** (**Polarisation of Atoms in a Magnetised Plasma**).

Computational models and simulations will be jointly developed to rationalise experimental results and propose novel sets of experimental parameters that may allow gas delivery with optimal nuclear polarisation or magnetisation (the product of polarisation and atom number density) for the selected isotopes. Finally, work will be applied to **NMR characterisation of porous materials and magnetometry.**