Laser-polarised He-3: a model system, a tool for applications

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http://www.lkb.science/polarisedhelium/

Polarised $^3$He: methods and applications

Hyperpolarisation by optical pumping (OP) in a He plasma

- RF discharge: $^3$He $\rightarrow$ $^3$He* metastable excited state
- OP cycles between hyperfine sublevels $\rightarrow$ nuclear spin orientation of $^3$He*
- Collisional de-excitation (fast $\tau$ process) $\rightarrow$ transfer to $^3$H (no loss of nuclear polarisation)

Standard Metastability Exchange OP
Room T: 300K, $p = 1$ mbar, $B = 0.5 - 5$ mT
M $\approx 80$% $\Rightarrow$ $M = \mu B/kT$ ($10^{-9} - 10^{-5}$ for $B = 1$ mT $- 1$ T)
Fast pumping: a few tens of seconds $\rightarrow$ suited for massive gas production

Applications of hyperpolarised (HP) $^3$He gas

- Neutron spin filters (polarisers, analysers)
- High precision Zeeman magnetometers
- Nuclear targets...
- MRI of the lung air spaces (HP gas replaces Boltzmann-polarised H)

At LKB: methodological developments, in vitro / in vivo validation
On-site production of HP gas + MRI at B= 1 to 6 mT $+~collab.$ for high-B tests

Exotic travel on the Bloch sphere in NMR

Conventional NMR: Rotating wave approximation (RWA)
$\Rightarrow$ Evolution driven by the resonant circular component, $B_1^\ast$.

$\text{RWA is not valid at low } B_2 \text{ for strong } B_1 \text{ (short RF pulses)}!$

Collison-induced transfer between $2^3P$ sublevels
A strong enhancement of nuclear angular momentum loss rate occurs during OP

Low temperature experiments with hyperpolarised $^3$He$-^3$He solutions

- Stochastic maser onset with interplay of RD and DDF
- Dynamic precession instabilities

Internship project: hands-on NMR or MRI experiments, measurements on polarised gas or water samples, advanced data analysis based on lattice simulations.

PhD topics: Artefacts and limitations in gradient-free imaging
- Bloch Siegert effects - RF gradients
- Impact of restricted diffusion on image quality
- Computer lattice simulations, in vivo experiments

 Radial diffusion (false)$\rightarrow$ + Primordial nulls

Nonlinear NMR with “magic” pulses

Nonlinear NMR in strongly magnetised liquids

$\Rightarrow$ Nonlinear terms in the Bloch equations
- Nuclear precession affected by radiation damping ($\cdot$) and nuclear polarisation ($\cdot$)
- Current dipolar field ($\cdot$)
  - High density and nuclear polarisation
  - Population monitoring in the $2^3P$ Zeeman sublevels.

Internship project: laser resonance spectroscopy, absorption and line shape measurements, optical polarimetry in weak rf gas discharges, use of visible and infrared solid state lasers.

PhD topics:

- Develop an improved MEOPE model for numerical computations.
- Extend high-$B$ MEOPE to cryogenic temperatures
  - A challenging first step towards high resolution magnetometry at elevated $B$ & low $T$
  - Very large bore 7 T magnet under implementation at CEA Saclay – WideNMR project (2016-2019).

Low temperature experiments with hyperpolarised $^3$He$-^3$He solutions

- Stochastic maser onset with interplay of RD and DDF
- Dynamic precession instabilities

Internship project: make a comprehensive analysis of available data, perform new series of numerical simulations to optimally exploit this material.

PhD topics: will crucially depend on internship findings.
$\Rightarrow$ New generation of experiments?