On-site production of hyperpolarised ^{3}He for lung MRI

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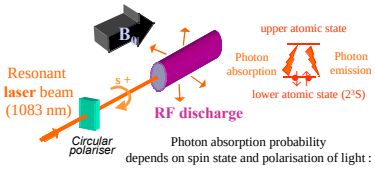
Proton (^{1}H) MRI of tissues is routinely used for diagnosis, but this technique cannot be used for lung examinations. Laser **Optical Pumping** (OP) can almost fully polarises ('hyperpolarises') the nuclei in a **helium-3 gas.** MRI of this gas mixed as a tracer in the air breathed by subjects or patients provides accurate maps of its distribution in lungs and of various other quantities of potential physiological interest.

Prospects for the use of hyperpolarised gas MRI depend on the outcome of clinical evaluation of the specific potential for diagnosis of this new modality. They also depend on the **development of efficient techniques to produce and manage hyperpolarised gas.** We explore the potential of **simple compact devices** based on use of fibre lasers and peristaltic compressors for flexible on-site gas production.

Principle of operation

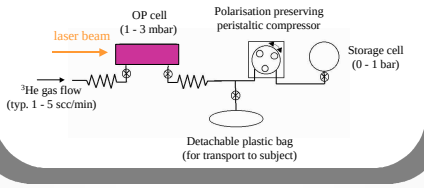
Principle of Optical pumping (OP): (A. Kastler, Nobel prize 1967)
selective optical transitions induce population transfer between atomic states

OP of helium-3: plasma discharge in low-pressure gas to populate 2^3S state
+ collisions to overpopulation of selected state to ground state nuclei
High efficiency: max. polarisation >80% - 1 polarised nucleus / absorbed photon



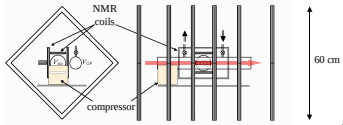
Photon absorption probability depends on spin state and polarisation of light :
net transfer from ↓ to ↑

Principle of gas polarisation for MRI:
- ultra-pure ^{3}He gas is flown through OP cell (acquires nuclear polarisation M_{OP})
- polarised gas is extracted from OP cell and accumulated at increasing pressure P_{acc} ~ t
  ideally (i.e. with no relaxation losses) : $M_{acc}=M_{OP}$
- when required ^{3}He ***dose*** is obtained, it is:
  1- mixed with neutral gas if desired (e.g. 0.5 litre N_2)
  2- extracted into the bag (reversing compressor rotation)
  3- delivered to be inhaled from the bag



Managing polarisation losses
Hyperpolarised gas tends to lose nuclear magnetisation : **decay** (relaxation) **time** T_1
Origin : fluctuating magnetic interactions
(usually from movement of gas atoms in non-uniform magnetic field **B**)
Reduction : homogeneous **B** over volumes with low-pressure (fast moving) gas
high pressure (slow) gas in regions with poor **B** homogeneity
use selected non-magnetic materials in contact with the gas

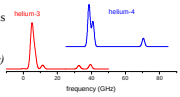
Solutions used : gas in contact with glass, selected plastics and ultra-pure fused silica
specially designed 6-coil magnet (also for NMR measurement)



Current performance and prospects (summer 02)

Compact fibre lasers tailored for OP of helium

- 1083 nm wavelength tunable on He transitions
  (over 80 GHz i.e. 0.3 nm)
- broadband emission (multimode operation)
  (~ 2 GHz to match atomic Doppler profile)
- several Watts for fast and efficient OP



(→ laser diode + Yb doped fibre amplifier
IPG: up to 40W http://www.ire-polusgroup.com/)

→ **all Yb doped fibre laser + amplifier**
Keopsys : 2W or 5W
http://www.keopsys.com/

Portable devices, easy to operate anywhere (e.g. hospital)

Gas production results

Initial measurements with 20 cm OP cell:
M_{OP} ~ 30 to 35% M_{acc} ~ 25 to 30%

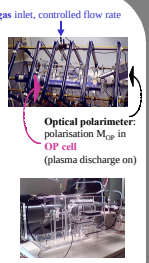
final dose ~ 50 to 100 standard cm^3 of gas (30 min)
~ 15 to 25 eq. cm^3 of fully polarised gas

Current measurements with 50 cm OP cell (2W laser):
M_{OP} (no flow) ~ 60% at 1.3 mbar
M_{OP} (2scc/min flow) ~ 45% at 3 mbar → $\mathbf{M_{acc} \sim 40\%}$

T_1 ~ 10 h (fused silica storage cell) → constant M_{acc} for ~ 1 h
Reliability : >1 year operation of 2 devices
~ 2 h compressor servicing every ~ 50 h of operation

Prospects:
with 5W laser + higher compressor pumping speed
M_{acc} > 50% at 3scc/min? - M_{acc} ~ 40% at 5scc/min?

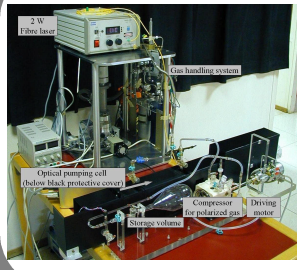
Cost of components:
~ 50k€ without ^{3}He, including 2W laser



NMR measurement of M_{acc} in **0.5 litre storage cell**
(FID after 5° tipping, 28 kHz)

Examples of applications

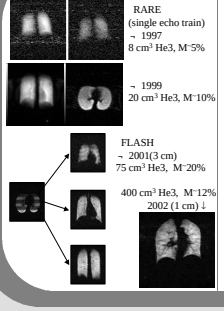
Initial bare-bone system in Kremlin-Bicêtre hospital



- No applied field
  (5G from scanner at 10 m)
- No measurement of M

Gas delivery to subject :
1 litre plastic bag (Tedlar®)

Lung imaging (0.1T, U2R2M)



RARE
(single echo train)
¬ 1997
8 cm^3 He3, M~5%

¬ 1999
20 cm^3 He3, M~10%

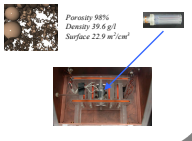
FLASH
¬ 2001(3 cm)
75 cm^3 He3, M~20%

400 cm^3 He3, M~12%
2002 (1 cm) ↓

Other applications

- Polarised neutron spin filters :
a simple system may produce large M in He3-He4 mixtures
Peristaltic compression OK up to
2 bar (1 stage) or >5 bar (2 stages)
…remains to be tested with polarised gas

- Diffusion in porous materials
(other than lungs!)
e.g. silica aerogels, model systems to study phase transitions in mildly confined / disordered media



New system in LKB

Fully equipped to monitor M.
Used for tests, for developments, and to produce gas for
ultra-low field NMR and MRI

New 5 mT vertical system for in-vivo HP-He3 lung NMR

LKB

PHIL Polarised Helium to Image the Lung
Project funded in the 5th Framework Program (FP5)