A Metastability Exchange Optical Pumping (MEOP) high field polarizer for helium-3 working in a clinical scanner

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Introduction :

Polarized ^{3}He is used as a contrast agent for lungs magnetic resonance imaging that has recently reached the pre-clinical applications since the sensitivity of this method is many orders of magnitude higher than standard proton MRI. Metastability Exchange Optical Pumping (MEOP) is one of the main methods to obtain hyperpolarized ^{3}He. In MEOP standard conditions, which means low magnetic field of few mT, the development of dedicated lasers at 1083 nm allows polarization values up to 75 % to be obtained in semi commercial systems[1]. Nevertheless, such values are obtained only at low pressure (~ 1mbar) and that is why a delicate process of compression to atmospheric pressure is required. Moreover, the production rates R (R=Polarisation*pressure [mbar]/t_B[s], t_B being the build-up time of the polarization) is only about 0.15 mbar/s in the best conditions and that is why high production systems need a huge volume of pumping cells, which is not practical for clinical environment. During the last 5 years, the efficiency of MEOP was improved by our group by performing it at higher pressures and at higher magnetic field.

Systematic studies at high magnetic field:

Some systematic studies were carried out at different magnetic field (from 0.45 T to 4.7 T) with five 20 mL sealed cells filled with pure helium-3 at 32, 67, 94, 128, 267 mbar. The results showed that, at fixed pressure, the polarization values obtained were increasing with the magnetic field. A second study on the influence of the laser beam shape[2] showed that higher polarization values and production rates could be obtained at higher pressures with an annular shape of the pump beam that matches exactly the distribution inside the cell of metastable state atoms from which optical pumping is performed. The last results obtained at 1.5 T showed that high polarization values could be obtained at more than 100 mbar (67 % at 32 mbar and still 31 % at 267 mbar) and although the build-up time process is longer, the production rates obtained were increased by at least one order of magnitude (R=1.5mbar/sec) compare to low field.

Design of the polarizer:

Following the promising results obtained during the systematic studies at 1.5 T, a prototype of polarizer working directly inside a clinical scanner was built to produce quickly required doses of polarized helium-3 for human lungs imaging. A schematic of the high field polarizer is displayed on figure 1. A gas handling system connected to the main optical pumping (OP) plate with a flexible pipe is supplying with ^{3}He at a pressure of about 30 mbar the 3 OP cells (length: 80 cm, diameter: 2.4 cm) connected in series. A 10 W annular laser beam at 1083 nm is divided into three beams and aligned with each cell with a set of polarizing beam splitters and mirrors. Each beam is circularly polarized with a quarter-wave plate and the transmission is monitored with photodiodes. ^{3}He is passing through each cell before being compressed by a peristaltic compressor (driven by a non-magnetic pneumatic engine) into a 500 mL storage cell. When the required amount of polarized gas has been accumulated, the plate containing the storage cell, engine and compressor is disconnected from the polarizer. This latter can be taken out from the scanner and replaced by a patient. The gas is then extracted into a Tedlar bag and inhaled into the lungs before the imaging sequence starts.

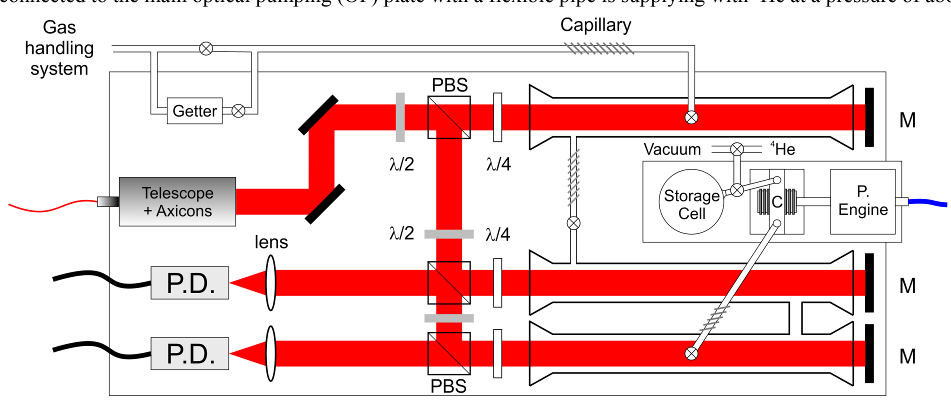

figure 1: scheme of the high field polarizer (see text). PBS: Polarizing Beam Splitter, M: Mirror, P.D.:PhotoDiode, P. Engine: Pneumatic engine, C: peristaltic Compressor, λ/2 and λ/4: half-wave and quarter-wave plates.

Results:

We report the construction of a compact high field ^{3}He polarizer working in clinical scanner. The gas handling system (80*80 cm) and the OP plate (150*35 cm) fits on the clinical bed of the scanner and inside the ^{3}He birdcage coils (figure 2). After 9 accumulations performed in hospital, the system has typical throughput of 15 scc/min (standard cubic centimetre per minute), which is 5 times higher than our previous low field compact polarizer[3], for an average nuclear polarization of 35 %. The system needs to run for approximately 40 min to obtain 600 mL of ^{3}He, which is enough to perform two good quality ventilation images of the human lungs. A second advantage is the possibility to reduce the loss after compression due to gas transportation or during storage in non-homogeneous area of the magnetic field. The gas is produced directly inside the scanner, stored at the same location and can be used briefly after. The system was finally validated by acquiring set of human lung images (figure 3).

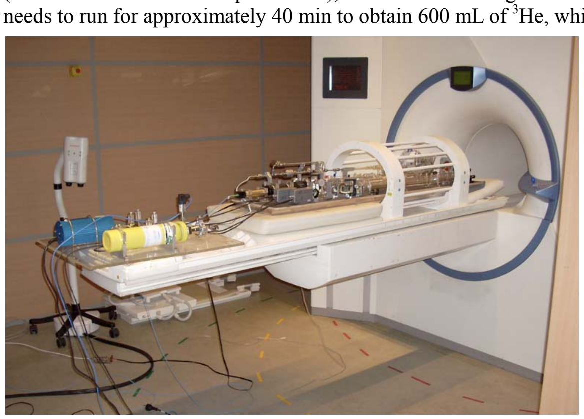

figure 2: Picture of the high field polarizer outside the MRI scanner

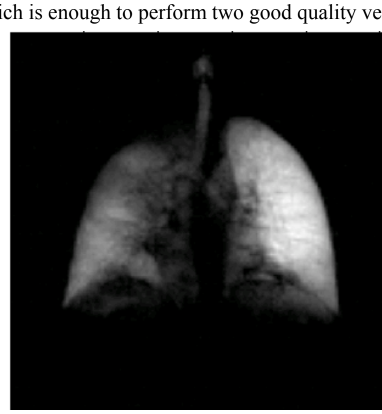

*figure 3: ^{3}He coronal image of the lungs of a healthy volunteer using a FLASH sequence (20 cm slice thickness, 38 cm FOV, 128*128 matrix 8.6° flip angle, 7.9 ms repetition time, SNR: 56)*

References:

1 M. Batz et al. Journal of Research of NIST, vol 110: 293-298, 2005.
2 T. Dohnalik et al. European Physical Journal AP, vol 54: 20802, 2011.
3 G. Collier et al. Optica Applicata, vol 42, 2012