Metastability Exchange Optical Pumping of 3He at 1.5T for a in-situ polariser

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Introduction :

When in 1994 hyperpolarised noble gas was used in Magnetic Resonance Imaging (MRI) for the first time, new possibilities for imaging of the body airspace opened up. Since the sensitivity of this method, when applied to lungs imaging, is many orders of magnitude higher as compared to standard proton MRI, it has already become an important research tool for the diagnosis of human lung diseases. This new application renewed interest in ^{3}He optical polarisation techniques, improvement of their efficiency, and implementation in polarisers that can be routinely used in the clinical environment. In standard Metastability Exchange Optical Pumping (MEOP) conditions, which means low magnetic field (~ mT), the achieved nuclear polarisation can exceed 80% but only at low pressures (~ 1mbar). Thus, for using ^{3}He for lungs imaging, the gas needs to undergo a delicate process of compression to atmospheric pressure. This low pressure of a few mbar at which routine in-situ low field polarisers work is the main drawback as it is responsible for a quite low throughput of only few standard cubic centimeter per minute (scc/min). This production rate is fair enough for MRI of rat lung (figure 1) where only a few mL are required. But the amount of gas needed for a good quality human lung experiment is around 300 mL which means a few hours of polarization.

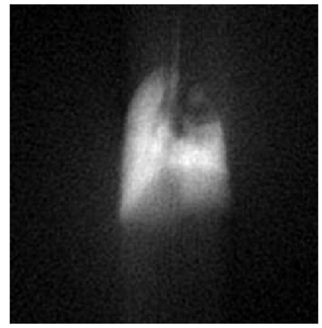

figure 1: Radial picture taken on our 0.1T permanent magnet (manufactured by AMAG), SMIS console, FOV 80 mm, SW= 10kHz, 128 samples per 200 views

Lately, the increase of optical pumping efficiency in higher pressures was obtained by carrying out optical pumping in higher magnetic field[1]. These first studies were performed at different field strengths from 0.45T to 2T and a considerable increase of nuclear polarisation for pressure 32 mbar (52%) and 64 mbar (44%) was observed in comparison to the standard conditions. When the operating magnetic field is increased to 0.1 T, the nuclear relaxation rate in the discharge plasma is reduced and MEOP remains efficient up to higher gas pressures. This dramatic increase in polarisation was the first motivation to study the feasibility of building a high field polariser in-situ inside the most commonly used 1.5T scanner. The first results of this study are presented here and show that it is possible to optically pump ^{3}He at 1.5T and at pressure of the order of a few 100 mbar.

Materials and methods:

The scheme of the experimental setup is displayed on figure 2. A radio frequency discharge generated by some electrodes tightened around the ^{3}He cell is creating a plasma. This plasma populates the metastable excited energy level 2^3S_1 of ^{3}He from which it is possible to optically polarise the gas using a pump laser whose frequency is tuned to 1083nm. There are a few transition lines available for the pump power. We used the line $f2^m$ as labelled as in ref. 2 as it was found to be the most efficient for MEOP in high field[1]. The optical detection of nuclear polarisation is based on the absorption measurements of two closed single transitions using a weak probe beam[1]. All the experiments were performed inside a superconducting magnet of 1.5T (*Magnex Scientific).*The first part of this study was the investigation of the best experimental conditions for performing MEOP at 1.5T. A systematic study using closed bone shaped cells of 11 cm length, Ø 15 mm containing different pressures (32, 67, 96, 128, 267 mbar) was performed over different parameters: pump beam power (0.5, 1, 2, 5 W), discharge intensity and laser beam shape. In a second time, we checked if these results could be reproduced inside some home made opened cells (Ø 15 mm and Ø 30 mm). This last part required the building of a new gas handling system, copied from our low field polarizer[3], to control the purity of the cells and the pressure of ^{3}He.

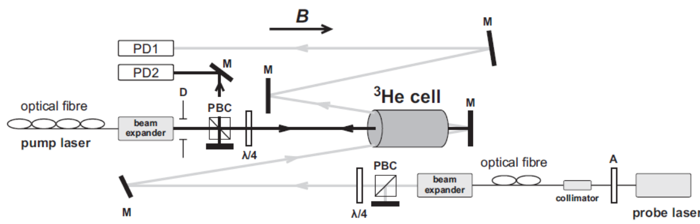

figure 2: scheme of the experimental setup.

Results:

A comparison between two set of data acquired with closed cells are displayed on figure 4. Two physical quantities of major interest for the design of a high field polariser are represented in functions of ^{3}He pressure. The first one is the maximum polarisation obtained at this pressure and the second one is the production rate defined as follow: R=(cell volume [mL]*pressure [Atm])/(3*t_b), where 3*t_b is the time to reach 95% of the final polarisation. R is expresses in standard cubic centimetre per minute (scc/min). A comparison is made between the results obtained three years ago[1] with a Gaussian shape of the pump beam and the new set of data acquired recently by modifying the beam profile using new optics (pairs of axicons). In high field and high pressure the metastable atoms are present only closed to the electrodes generating the plasma, which means close to the walls of the cell. This new optics reverse the Gaussian beam profile into a circular shape beam where the excited atoms of ^{3}He are present to make the pumping more efficient. The results is a 25% increase in polarisation and a maximum polarisation of 31% obtained in 267 mbar (67% at 32 mbar). These are the best polarisation values never published for MEOP at these pressures. If one looks at the production rate, these volume efficiency ratio for such polarisations are also the highest never produced. The tests with opened cells are still under process but the first results (54% at 32 mbar with production rate of 0.38 scc/min) confirms the same tendency although they show a slight decrease of flow and polarisation. We then hope to build in the next few months a prototype of the first high field in-situ polariser never produced, working inside 1.5T scanner in hospital and capable of producing the necessary dose of hyperpolarised ^{3}He for human lung imaging in less than 20 min.

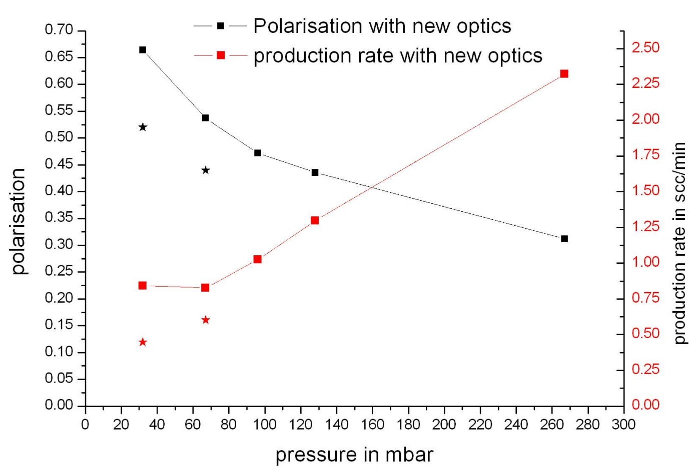

figure 4: Polarisation (black) and production rate (red) obtained in sealed cells of ^{3}He for different pressure. A comparison is made between old data[1] (stars) obtained 3 years ago and new data (square) with use of new optics.

References:

1 A. Nikiel et al. European Physical Journal, vol. 144: 255-263, 2007.
2 E. Courtade et al. European Physical Journal D, vol 21: 25-55, 2002.
3 K. Suchanek et al. Optica Applicata, vol 35: 263-276, 2005