Production of large volumes of Hyperpolarised ^{3}He by Metastable Optical Pumping (MEOP)

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Introduction

The metastability exchange method for polarizing ^{3}He nuclei [1] has demonstrated to be capable of very high ^{3}He polarisation and production rates [2] making it an ideal candidate for clinical lung MRI and for neutron spin filters. Optical pumping is performed at low pressure ~ 1 mbar, thus for effective delivery to a patient the polarised gas must be compressed by a factor of ~ 10^4 without substantial loss of polarisation. Various groups have demonstrated non-magnetic piston, diaphragm and peristaltic pumps to achieve this compression [2-6]. The team at Mainz [2] has demonstrated ^{3}He hyperpolarisation greater than 70% after compression with production rates higher than 5 bar litre/hour. This system is extremely costly (> £1M), complex and large with a total optical cell length in excess of 25 metres coupled to a custom built piston compressor and high power fibre laser. Since 1996 the Nottingham team has has a simpler single optical cell MEOP facility for its low-field lung MRI programme. Though more modest than the Mainz "state of the art" facility, it is fully automated, features a novel peristaltic compressor and was the first MEOP system to use a Yb Fibre laser for optical pumping [10]. Figure 1 shows a photo of the Nottingham MEOP facility. Figure 2 shows production rates for the current "state of the art" facility at Mainz

A High Performance Compact MEOP Facility

By 2000 collaboration between teams at Nottingham, ISIS and NIST focused on the design and construction of an optimised compact MEOP facility small enough to fit into an "on-beam" neutron experiment at ISIS and NIST as well as being capable of producing bar/litre quantities of highly polarised ^{3}He for lung MRI. New technologies and developments to be incorporated within this design were:

- Two optical cells with inter-cell diffusion limiter - optimised parameters for each cell
- Fibre laser to pump each cell - simpler optics leading to purer circular polarisation
- Optmised version of the peristaltic compressor used on the Nottingham MEOP kit
- Use of GE180 glass for storage of the hyperpolarised 3He with T1 > 100 hours
- Incorporation of multi-line C8 and C9 optical pumping to improve polarisation

Figure 3 shows a schematic of this facility [6] while Figure 4 shows preliminary results of improved polarisation and pump-up times using multi-line optical pumping [7]. Development of the above facility now forms part of a major new initiative between ISIS and ILL, Grenoble.

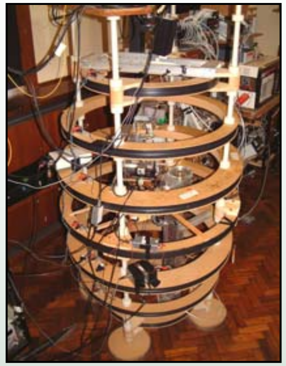

Figure 1 The Nottingham ^{3}He MEOP Facility

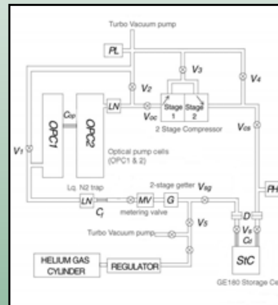

Figure 3 Optimised two-cell ^{3}He MEOP Polariser Schematic

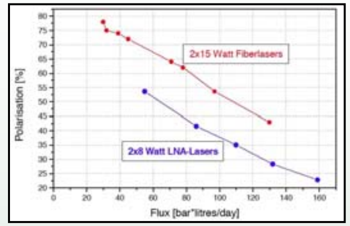

Figure 2 Production rates for the Mainz ^{3}He MEOP Facility

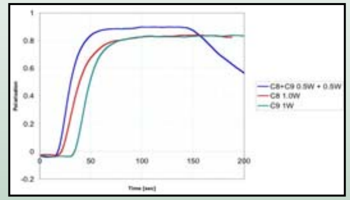

Figure 4 Multi-line pumping of C_8 and C_9 transitions of ^{3}He showing improved ^{3}He polarisation

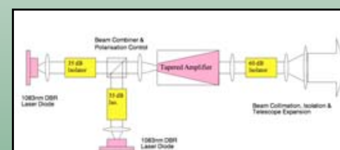

Figure 5 Schematic of twin seeded Tapered laser

New Technologies and Physics

By the start of the BT Programme in 2003 two new major advances in ^{3}He MEOP had been reported - the first was a new simple and low-cost laser technology for optical pumping at 1083nm - monolithic tapered laser diodes reported by the author [7,8] and the discovery of a new high pressure MEOP regime at moderate magnetic fields [9]. These two advances promise improved production and simplification of the compressor requirements compared to conventional low-pressure MEOP. The new tapered laser allows for easy implementation of multi-line pumping via multi-seeding of the tapered laser (see figure 5) whereas high pressure MEOP allows effective polarisation of the ^{3}He at more than 80 times the pressure of low-pressure MEOP (~ 1 mbar). The moderate B-Field required (B > 1000 Gauss) raises the exciting possibility for in-situ production within the Nottingham low-field MRI facility.

High Pressure ^{3}He MEOP Programme

A collaborative programme between Nottingham and ISIS has now started with a range of high pressure ^{3}He MEOP cells being made at ISIS and a new field-cycling facility being built at Nottingham. This facility has options of Yb Fibre and multi-seeded tapered lasers for optical pumping and probing of the ^{3}He hyperpolarised gas. The experiment uses a compact 4 coil set field cycled via a 30 Amp PSU to achieve B-fields up to ~ 1000 Gauss. A separate 2 coil Helmholtz coil set is used to take NMR data using a Magritek NMR spectrometer (see Polarimetry Poster at this meeting - Gemma McGough et al). The current facility is show in Figure 6. The initial aim of the experiment will be to see if there is an optimum B-field and ^{3}He pressure. Experiments planned for 2006 are to extend to ^{3}He/^{4}He isotropic mixtures and triple line pumping of these isotropic mixes [7].

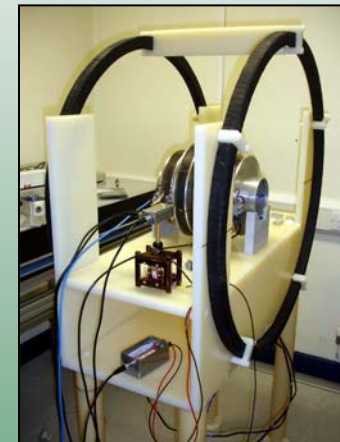

Figure 6 Photo of the new Field Cycling High Pressure MEOP Kit

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