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Physica B 356 (2005) 103–108
PHYSICA B
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First results from Tyrex, the new polarized-^{3}He filling station at ILL

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Abstract

A new filling station for nuclear polarisation of ^{3}He gas has been constructed at the ILL, Grenoble. The "Tyrex" machine uses metastability-exchange optical pumping for polarising the ^{3}He gas at about 1 mbar pressure. The gas is then compressed up to several bars via a hydraulic titanium-alloy piston compressor. The machine can provide about 1.5 bar-l/h of polarised gas—an order-of-magnitude increase over the first filling station installed at the ILL in 1996. The compressed, polarised gas is used for polarising neutron beams for condensed-matter and fundamental physics experiments. First results are presented and examples of implementations on existing neutron instruments at ILL are described.

PACS: 61.12.Ex; 61.12.Ld; 29.30.Hs

Keywords: Metastability-exchange optical pumping; Neutron spin filter; Polarised neutron scattering

1. Introduction

The Institut Laue-Langevin traditionally has a strong record in the use of polarised neutron techniques for condensed-matter investigations [1–4]. With the advent of polarised-^{3}He as a viable technique for neutron-beam polarisation, a filling station for polarised-^{3}He gas was installed at ILL in 1996 in collaboration with Mainz University [5]. This was based on an LNA laser coupled to a double-stage twin piston compressor, developed at Mainz. The facility provides 55% nuclear-spin polarisation in cells of up to 5 bars pressure at a production rate of about 0.3 bar-l/h. In order to improve on this performance, a new device was proposed, which was funded jointly by the British partner of the ILL (EPSRC), an RTD contract within EC-FP5 (ENPI) coordinated by ILL, and the CEA-Grenoble. The new filling station has been nicknamed Tyrex.

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0921-4526/$ - see front matter
doi:10.1016/j.physb.2004.10.057

Tyrex uses metastability-exchange optical pumping (MEOP) to obtain high polarisation at low pressure (about 1 mbar) of pure ^{3}He gas. A weak electron discharge is established using radio-frequency electrodes. The population of the first excited (metastable) state is optically pumped using infrared resonant light of the appropriate circular polarisation. The low-density polarised gas is then compressed to the several bars of pressure required for neutron spin-filter applications, using a hydraulic titanium-alloy piston compressor.

The paper is organised as follows. Section 2 deals with the technical description of the Tyrex filling station: gas circuit, laser optics, and compression. The production of spin-filter cells with long relaxation times is described in Section 3. Section 4 deals with recent progress in magnetostatic cavities and Section 5 describes the first experiment performed on the PF1B fundamental-physics beamline.

2. Technical description of Tyrex

The layout of Tyrex is schematically shown in Fig. 1. Five optical pumping cells (OPCs) are filled with high-purity low-pressure ^{3}He gas via a getter purifier and a liquid-N_2 trap. The incoming gas flow is regulated by controlling the pressure gradient between the getters and the OPCs, which are separated from the incoming tube by a glass capillary. With this system, we can control the pressure in the OPCs from 0.5 to 1.5 mbar. The OPCs are 2.3 m long and provide a total gas volume of 37 l.

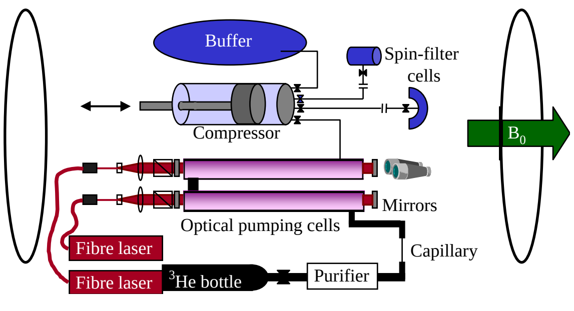

Fig. 1. Tyrex layout.

The gas in the OPCs is excited by an RF discharge and the resultant metastable atoms are optically pumped using an array of fibre lasers. Tyrex disposes of five fibre lasers, one per OPC, each delivering 4 W, and manufactured by Keopsys (Lannion, France). The configuration is that of a tunable all-fibre MOPFA (Master Oscillator Power Fibre Amplifier) with a knob on the front face being coupled to a Piezo-element acting on Bragg gratings in the oscillator. The wavelength is centred at 1083 nm, tunable over 60 GHz. These units have been customised for ^{3}He-MEOP in collaboration with the Laboratoire Kastler-Brossel (Paris). They provide a bandwidth of 2 GHz optimised for the Doppler width of the gas and the light emission is multimode with a time structure well-matched to the metastable state of the ^{3}He atom [6].

A telescope is used to enlarge the 6 mm beam up to the diameter of the OPCs (60–80 mm). After refinement of the linear polarisation with a beam splitter cube, a $\lambda/4$ plate is used to transform linear polarisation into circular. The reflected beam serves to align the laser polarisation, and is not used for optical pumping.

A dichroic mirror is used at the end of each OPC. It reflects the 1083 nm IR light very efficiently while maintaining its circular polarisation. This end-mirror is transparent to visible light making it possible to observe the fluorescence line at 667.8 nm. This is an intense red line (3^1D_2-2^1P_1), the circular polarisation of which is used to monitor the polarisation of the ^{3}He gas via an optical polarimeter [7]. The polarimeter uses a binocular system, which gives reproducible results, but is very sensitive to alignment errors, making it difficult to translate the polarimeter from one OPC to the next.

The polarised gas passes through a liquid-nitrogen cold trap before arriving at the compressor. The Tyrex compressor [8] is made of non-magnetic titanium alloy and is driven by a hydraulic system carefully designed to avoid contamination of the compression chamber by hydraulic oil and air. Two differential pumping chambers ensure a vacuum $<10^{-6}$ mbar behind the piston. The compression chamber has a volume of 5.2 l and a dead-volume of only

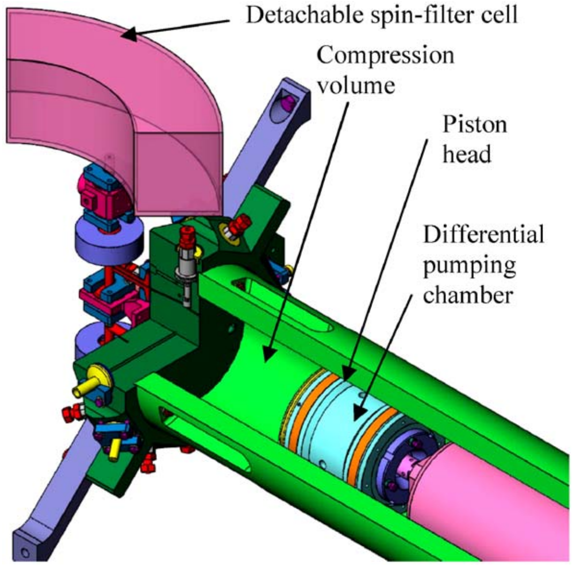

Fig. 2. Cut-away view of the Tyrex compressor head. The head of the piston is exposed to show the differential pumping chamber which ensures that the gas in the compression volume is not contaminated.

$0.14\,cm^3$, which is pumped out between compression cycles. A cut-away view of the compressor head is shown in Fig. 2, showing the differential pumping chamber which ensures that the gas in the compression chamber is not contaminated.

The piston works in two compression stages during the filling of a spin filter cell, one from the optical pumping cells to the buffer cell and one from the buffer cell to the target (spin-filter) cell, by virtue of bypass valves in the head. The present buffer cell is made of GE224 "quartz" glass and will be replaced at the end of this year, by a new buffer cell made of GE180 glass. The ^{3}He gas flow is typically between 1 and 2 bar-l/h depending on the pressure in the OPCs. A standard ILL spin-filter cell can be filled to a pressure of 4 bars in about half an hour.

The compressor can fill two cells simultaneously or fill one cell while the other is being evacuated, by two independent outlet ports.

The measured relaxation times for some critical components of Tyrex are given in Table 1.

All valves have been designed to optimise gas transfer and to reduce polarisation losses. This is done by minimising the area of the metallic surfaces seen by the polarised gas. Wherever possible, the polarised gas can only access the inner surfaces of the glass tubing. Where depolarisation is inevitable, such as in small volumes close to metallic valves, the partially depolarised gas is not delivered to the buffer cell, but pumped out into the recuperation system between each cycle. Polarisation losses through the compressor are measured to be less than 1%. This was done by running the compressor in a closed cycle: polarised gas is taken from the OPCs and compressed into the buffer cell. It is then expanded back into the OPCs via the compressor and the cycle is repeated a number of times to increase sensitivity to depolarisation. After ten such cycles, the measured depolarisation is consistent with just the wall-relaxation of the buffer cell.

Table 1
Typical relaxation times in critical components of Tyrex

	Pressure	T_1
OPCs—no discharge	0.9 mbar	30′
OPCs—standard discharge	0.9 mbar	10′
Compression chamber	10 mbar	5 h
Present buffer cell (GE224)	200 mbar	45 h
New buffer cell (GE180)	200 mbar	100 h

A reproducible 75% of nuclear polarisation in the OPCs is obtained in static mode (no flow). In standard operating mode, we obtain 70% polarisation in the OPCs, which due to the loss-less nature of the compression is transferred unchanged to the spin-filter cell.

The hydraulic power system, the piston compressor head and all the ^{3}He gas circuitry is monitored by a LabView program with a friendly graphical user interface. A real-time closed loop controls the movement of the piston to a precision of 3 μm, which is measured using an optical sensor. All the electronic control values, sensors and gauges are accessible via a high speed digital interface.

The accurate control of the compressor and the flexibility of the control software are key features of Tyrex. They allow, for example, to transfer small amounts of polarised gas, from the buffer or the target cell, to the OPCs to measure its nuclear polarisation via the polarimeter, by controlling precisely the volume of the compression chamber. Another possibility is to maintain the polarisation in the buffer cell by polarisation-preserving cycles. This consists in regularly removing small amounts of gas from the buffer, boosting its polarisation in the OPCs and then putting it back in the buffer cell.

3. Detachable cells

Spin-filter cells, mounted on the Tyrex compressor head are filled with compressed, polarised gas and then detached for use on neutron beams. At present, three types of spin-filter cells are produced for use at the ILL: GE224 ‘‘quartz’’ cells, GE180 reblown glass cells and Pyrex cells with single-crystal Si windows. The ILL has several years of experience in producing Cs-coated quartz cells. GE224 ‘‘quartz’’ glass can be purchased as flat plates and as cylinders of almost any diameter. This allows great flexibility in the shape of the cells that can be produced in this way, such as the ‘‘banana’’ cell used to demonstrate wide-angle polarisation analysis on D1B [9]. The ILL regularly produces Cs-coated cells of this type with relaxation times of the order of 150 h, though there are still improvements to be made in terms of reproducibility.

Recent results reported from the group of T. Gentile at NIST have encouraged us to explore the properties of GE180 glass. Sealed cells made of this material and coated with Rb have shown relaxation times of many hundreds of hours [10]. Unfortunately, GE180 glass is only available in a single tube size and needs to be reblown to make neutron spin-filter cells. So far, we have produced 10 cylindrical spin-filter cells of GE180, with the help of a local glass-blower. So far, none of these cells has been Cs-coated, but the performance of the bare, unwashed glass is already very promising with relaxation times all in the 40–80 h range.

The third type of spin-filter cell consists of flat single-crystal Si windows mounted on a cylindrical Pyrex body. This type of cell is particularly useful on reflectometry and small-angle scattering instruments where it is essential that the spin-filter cell does not contaminate the transmitted beam with small-angle scattering. Fig. 3 shows three generations of Si-window cells—the cell on the left is the latest. It has an external diameter of 14 cm and a total volume of 1.3 l.

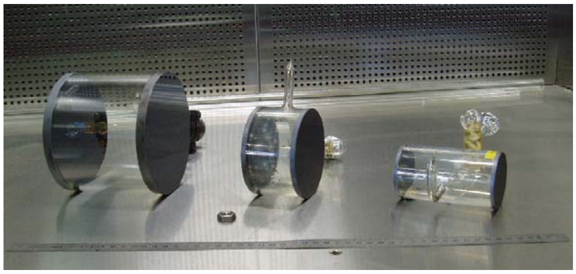

Fig. 3. Si-window cells for reflectometry and SANS.

The disadvantage of this type of cell is that the overpressure in the cell cannot exceed 600 mbars. The window is fixed to the Pyrex body using molecular bonding, which relies on the surfaces being very smooth and clean, and is not very strong. Relaxation times of this type of cell after Cs-coating are typically of the order of 150 h.

4. Magnetostatic cavities

Maintaining good polarisation of the spin-filter cell requires a very homogeneous magnetic field both during transport from Tyrex and on the neutron instrument itself. The ILL now provides a wide range of high-homogeneity magnetostatic cavities, specialised in providing different degrees of transportability, cell volume and shielding from external fields. The most recent effort focuses on the ‘‘magic-box’’ design—so-called because when first made, their performance was better than predicted by finite-element calculations. The basic idea is to use μ-metal to act simultaneously as the poles of the magnet and screens against external fields [11]. Versions using copper coils and permanent magnets (Fig. 4) have been constructed, providing relaxation times up to 400 h and allowing operation at a distance of less than 1 m from a 2 T cryomagnet. The magic-box setup can shield the spin-filter cell from external fields of the order of 50 G.

Fig. 4. The permanent-magnet "magic-box" transporter.

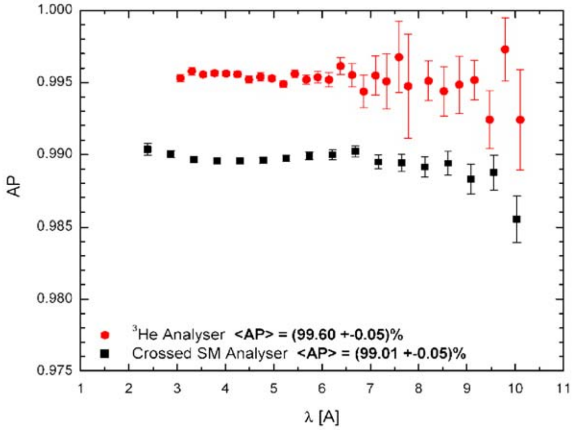

Fig. 5. Comparison of double SM analyser in crossed geometry (XSM) with the ^{3}He spin filter [12].

5. First experiment

The first experiment performed with polarised ^{3}He from Tyrex was aimed at characterising the degree of polarisation of the incident beam on PF1B, a beamline for fundamental physics measurements.

Many experiments in particle physics with cold neutrons require both, a high degree of neutron polarisation and its precise measurement. The neutron polarisation enters linearly in the measurements of beta and antineutrino asymmetry in neutron beta decay. Improvements of these experiments are particularly important to test the unitarity of the CKM matrix and to search for right handed currents. Their next generation aims to push the precision below 0.1%. This requires a corresponding precision of the polarisation measurements.

In this experiment super mirror (SM) polarisers were used to polarise a white neutron beam. The polarisation resulting from spin dependent reflection on magnetised SM depends sensitively on both wavelength and angle [12]. These variations can be considerably suppressed by the use of a crossed geometry of the supermirror polarisers/analysers (XSM). Opaque ^{3}He spin-filters [13] have been used to qualify this technique completely, as they provide 100% analysing power, which does not depend on the angular and spatial distribution of the beam.

The beam was polarized by double XSM bender. The polarization obtained was measured with opaque polarized ^{3}He spin-filter and with double XSM analyzer. The results are presented in Fig. 5. Here we plot the product (AP) of the polarising and analysing power of the full setup. Values obtained are compared. The values 99.01(5)% (XSM) and 99.60(5)% (^{3}He) differ significantly, which can be accounted for by beam depolarisation (~0.4% per collision) in the SM benders [12].

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