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SQUID measurements of remanent magnetisation in refillable ^{3}He Spin Filter Cells (SFC)

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Abstract

A strong influence of external magnetic fields on the relaxation time constant T_1 of glass cells serving as reservoirs for polarised ^{3}He, observed for various alkali metal coated cells made of different glass types, was initially associated with the presence of a large number of ferromagnetic clusters on the glass surface. Later experiments showed the presence of the so-called "T1 hysteresis" phenomenon with a similar distinctiveness also in uncoated cells made of pure synthetic quartz glass. It suggests that the origin of such a relaxation is a macroscopic magnetisation in the bulk of the cell. We present the results of a multi SQUID system investigation on magnetised and non-magnetised quartz glass cells, Cs-coated as well as bare-wall, to be used as neutron spin filters at HMI Berlin. The presence of a macroscopic remanent magnetic moment in the cells after their exposition to external magnetic fields has been experimentally shown. More than 80% of the remanent magnetic moment of the magnetised cells was found to be concentrated in the region of the glass valves. SQUID measurements reveal the existence of some remanent magnetisation in all valve parts and also in the vacuum grease, but most magnetic are the plastic parts and the O-ring. Different valve and sealing types have been compared in order to find the less magnetisable one.
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1.Introduction

Jacob at al. [1] who for the first time showed the so-called "T_1 hysteresis" in sealed ^{3}He storage cells made of Pyrex or aluminosilicate glass tried also to demonstrate the magnetisation of those cells by other methods like SQUID or ESR. Anyhow, these studies showed no significant results and the authors attributed the observed strong ^{3}He relaxation in the magnetised cells to the presence of a large number of ferromagnetic relaxation centres, assumed to be created by a reaction of Rb with iron-containing impurities on the glass surface. These results stimulated us to start with investigations on the magnetic field influence on the relaxation behaviour in refillable (valved) cells made of quartz glass. The concentration of Fe impurities in quartz glass is much lower than in borosilicate or aluminosilicate glasses, (0.2 ppm in quartz glass compared to 210 ppm in GE 180). Thus one could not expect to see the effect as distinct as in Pyrex. Nevertheless a strong influence of external magnetic fields on the relaxation time constant T_1 has been found also in quartz glass cells [2]. Moreover the phenomenon has been observed both in Cs-coated and in bare-wall cells. According to Ref.[3], the relaxation mechanism induced by an exposition of a quartz glass cell to an external magnetic field which exceeds only a few hundred Gauss is much stronger than the initial surface relaxation. It can only be removed by degaussing the

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cell, whereas so far no surface treatment is known to do so. This may suggest that magnetisation - at least partly - takes place in the bulk of the wall material and creates a macroscopic field near the surface. Such remanent field should be detectable by very sensitive methods like multi-SQUID array measurements in a well screened magnetic chamber.

2.Experimental setup

The measurements have been done in a mu-metal magnetic-shielded room at the Benjamin Franklin Hospital in Berlin using a multi-channel SQUID system developed and constructed at the Physikalisch–Technische Bundesanstalt (PTB) in Berlin. The system is routinely used to record injury related biomagnetic fields from patients. A schematic view of the used setup is presented in Fig. 1. The measured cell is fixed on the non-magnetic table under the 83-channel SQUID array situated in the liquid He Dewar. The distance between the table and the Dewar bottom can be adjusted and was chosen for 80 mm during all our measurements. The distance between the bottom of the Dewar and the magnetic sensors was 25 mm. Thus the distance in vertical direction (z) from the cell to the sensors was 1 to 2 times larger than the dimensions of the cell (50 mm in diam.). The total distance between cell and detector has been varied periodically with 0.4 Hz by means of a mechanical modulation device moving the table along the x-axis with a deflection of 15 cm. The oscillating field values $B_k(t_i)$ from the k-channel sensor were converted to correlation field amplitudes A_k which were integrated into a single map covering an area of about 210 mm in diameter in the xy-plane, describing the z-component of the magnetic field. The 83–SQUID system consists of seven 11-SQUID modules and 6 single channel modules. 49 z-sensors are arranged in a hexagonal array with a grid constant of 30 mm. The 20 xy-sensors are distributed as regularly as possible in a distance of approximately 60 mm to each other. 20 reference magnetometers in three reference levels above the sensor are used to form electronically a first or second order gradiometer configuration. A detailed description of the used multi SQU[illegible] given in Ref. [4].

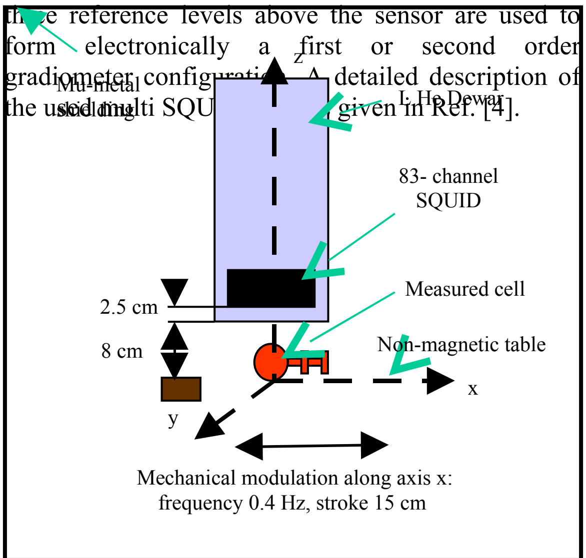

Fig. 1 Setup for the bio-magnetic measurements in the hospital used for detecting remanent magnetisation in magnetised ^3He spin filter cells.

3.Results

An example for a correlation field amplitude map with the approximate cell geometry in the xy-plane is presented in Fig. 2. The error of the cell positioning is about 5 mm. The fields from the magnetised cells can be fitted by a single magnetic dipole model with an error between 7% and 16%. The approximated magnetic moment in the fused silica cells, magnetised at 7 kG is about 160 nAm^2, which is slightly higher than the moment found when only taking a glass valve magnetised at 600 G. In the case of an exposition to 500 G, the cells show a magnetic moment of the same value as those exposed to 5 kG, suggesting that they became totally magnetised already at such low field strengths. Non-magnetised cells show magnetic moments more than 100 times smaller, which is comparable to or less than the electronic noise of the setup. The position of the dipole center was found to be in between the cell body and glass valve, much closer to the position of the inlet valve for all investigated cells. Subtracting the achieved magnetic dipole field of the stopcock from the field map of the whole glass cell should give an information about the magnetic contribution from the cell walls. This value is in the order of a few tenth of nAm² and cannot be fitted anymore as a single magnetic dipole (Fig. 3).

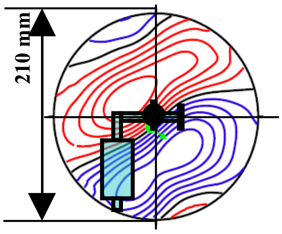

Fig. 2. Correlation field amplitude map measured for a Cs-coated cell (Cell No. 13, length = 30 mm, diameter = 50 mm) made of extremely pure synthetic quartz glass and magnetised at 5 kG. The T_1 measured in the cell after magnetisation is 0.86 h.

The cell is positioned with the glass stopcock in the centre of the field map. The distance between the equipotential lines is 500 fT. The measured map can be approximated by a single dipole with an error of 17.8%. The calculated magnetic moment of the dipole is 54 nAm². The position (xyz) of the dipole marked in the map is (-5, –11, 20), what in the frame of the precision of positioning is roughly in the position of the glass stopcock, only slightly shifted into the direction of the cell-body.

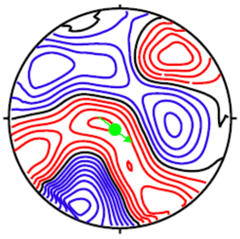

Fig. 3. Correlation field amplitude map resulting from subtraction of the single dipole field of the valve from the measured total field of cell No. 13. The distance between the equipotential lines is 100 fT

In order to find out why the magnetic moments of the cells are concentrated in the region around the valve and whether the vacuum grease is the reason, we performed a number of magnetisation measurements on vacuum glass stopcocks of the same type which we mostly used at our cells. It is a small type with 1.5 mm bore and with a threaded solid stem to fix it by means of a PVC nut. The O-ring and the plug were lubrificated with Apiezon H25 vacuum grease. All parts are shown in Fig. 4.

Fig. 4. Disassembled solid plug glass valve used for most of the cells. The valve body is made of quartz glass and the plug of Duran glass.

Table1

[illegible]	[illegible] moment Q [nAm²]	Error of single dipol model [%]	Contribution to the total moment [%]
Non-magnetised valve	**0.7**	15.5	-
Magnetised valve	**134.3**	8	-
Disassembled magnetized parts			
Valve body	5.6	8	4
Plug	19.6	10	14
Plastic nut and grove	32.8	5	23.5
Viton O-ring	81.6	5.5	58.5
Summ of magn. parts	**139.6**		100

In Table 1 the results of the measurements are presented. At first, the assembled, non–magnetised valve has been measured. A very weak moment of 0.7 nAm², not fittable as a single dipole, was detected. After exposing the valve to a magnetic field of 600 G, a much stronger magnetic moment of 134 nAm² has been measured. Afterwards the valve was disassembled and each part has been measured in order to find the origin of the strong moment. The results show that 82% of the total moment origins from the plastic parts and the O-ring. Moreover, the small O-ring is the most magnetic part of the whole valve, demonstrating a real magnetic dipole behaviour and contributing with about 60% of the total moment. The Apiezon grease showed only a rest magnetisation which contributes with about 2% to the total magnetic moment.

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