

Experimental report

16/07/2025

Proposal: 1-10-53

Council: 10/2022

Title: Depolarisation of Cu/Ti supermirrors

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples: Cu(N)/Ti(N) (99.995%) on borofloat substrate
Cu(N)/Ti(N) (99.6%) on borofloat substrate
Ni(Mo)/Ti on borofloat substrate

Instrument	Requested days	Allocated days	From	To
SUPERADAM He3 Spin Filter	3	3	29/05/2023	01/06/2023
PF1B He3 Spin Filter	21	21	26/06/2023 23/08/2023	05/07/2023 04/09/2023

Abstract:

Neutron decay experiments with the new instrument PERC currently under construction at FRM II will require a neutron guide with depolarisation on the order of 10^{-4} per bounce or less. To achieve this, we have developed neutron supermirrors based on Cu/Ti. With this proposal we aim to characterise these and obtain specular and off-specular information at SuperADAM, and high-precision specular information using the proven opaque ^3He test bench at PF1B. We intend to compare mirrors made using highest purity Ti and standard Ti targets, as well as conventional Ni(Mo)/Ti mirrors.

Report on the data analysis from experiment exp_1-10-53

The aim of this experiment was to calculate the depolarization of a fully polarized neutron beam after having been reflected by different low-depolarizing supermirror samples, namely Ni(Mo)/Ti, Cu/Ti (Ti 99.6%) and Cu/Ti (Ti 99.995%).

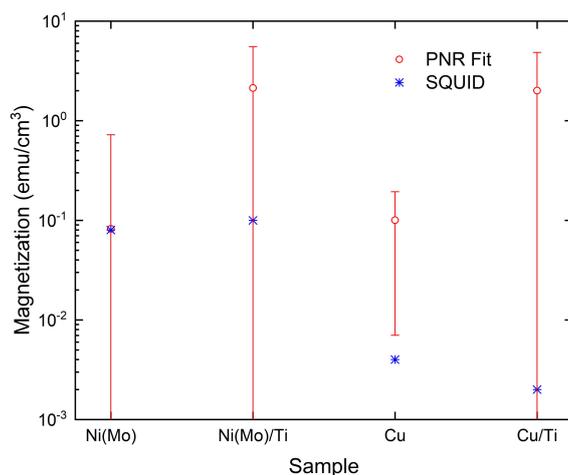
For this purpose, first of all the magnetic moment of the Cu, Ni(Mo), Ni(Mo)/Ti, Cu/Ti were extracted from data obtained in the reflectometer SuperADAM. Later, the different samples were installed inside a magnet with maximum field of around 0.7 T and analyzed using a fully polarized neutron beam. The polarization was given by the so-called "Opaque Test Bench", which consist on two identical magic boxes, each of them containing identical ^3He cells with high opacity, which is controlled by the ^3He pressure inside the cell.

1. SuperADAM results.

The SuperADAM instrument is able to measure specular and off-specular reflection off a sample for different incident angles and beam polarizations. It uses a solid state polarizer/wave-length filter providing a highly polarized (up to 99.7 %) monochromatic neutron beam with wavelength 5.183 Å, monochromatization $\Delta\lambda/\lambda = 0.5$ % (FWHM) and angular divergence $\Delta\alpha = 0.33$ mrad (FWHM). To measure the 4-states PNR curves (two spin-flip and two non-spin-flip) of the monolayers, we used the multi-mirror analyzer option with a polarization analysis efficiency of 99.3 %. For the measurement of the SM samples, we chose the ^3He analyzer option ($p_{\text{He}} = 1.35$ bar and $P_{\text{He}} = 78.2$ %). The flipping of the incident neutron polarization is performed using a 180° adiabatic gradient radio frequency flipper with an efficiency of up to 99.97 %. The samples were placed in a vertical 0.8T magnetic field parallel to the field of the polarizer. The analysis of the 4-states PNR curves was performed by a least square fit with the original software BoToFit, developed at ILL, which permits simultaneous fitting of up to four (two non-spin-flip and two spin-flip) reflectivity curves in each iteration cycle.

In the case of the 800Å Ni(Mo) sample, the fitting yields an mSLD of $(0.24 \pm 1.82) \times 10^{-9} \text{Å}^{-2}$, which converts into a magnetization of $(0.08 \pm 0.64) \text{ emu/cm}^3$. However, the large uncertainty indicates a detection limit in the mSLD for the PNR technique. For the 1500Å Cu monolayer sample, the fitting yields an mSLD of $(0.29 \pm 0.27) \times 10^{-9} \text{Å}^{-2}$, which converts into a magnetization of $(0.10 \pm 0.09) \text{ emu/cm}^3$. The large uncertainty of the mSLD obtained for the Cu sample again indicates a detection limit in the mSLD for the PNR technique.

In the case of the supermirrors, a magnetization of $(2.1 \pm 3.4) \text{ emu/cm}^3$ for Ni(Mo)/Ti and $(2.0 \pm 2.8) \text{ emu/cm}^3$ for Cu/Ti was obtained. The figure below depicts the final magnetization results (in emu/cm^3) after converting the mSLD into units comparable with SQUID magnetometry. The values reported by [Gomez-Guzman et al.] are presented for reference.



2. PF1B results.

The Opaque Test Bench (OTB) is currently the only setup to test the depolarization of neutron mirrors down to the level of 10^{-4} due to the high polarizing power of the two cells filled with polarized ^3He used as polarizer (P) and analyzer (A). The cells are placed inside so-called magic boxes, which provide an homogeneous magnetic field for the polarized ^3He and shield from external magnetic fields using μ metal. Additionally, an adiabatic fast passage spin flipper is installed in each box, to flip the spin

of the ^3He as needed with negligible losses of the degree of ^3He polarization P_{He} on the order of 4×10^{-5} per flip, which translates to a reduction of the polarizing or analyzing power for 5 Å neutrons of 2×10^{-9} per flip.

Measurements were taken in two different cell configurations: the ^3He polarization in the cells are either parallel (count rate N_{\uparrow}) or anti-parallel (count rate N_{\downarrow}) alignment to the ^3He spin and are governed by two identical spin flippers. The measurements were taken with the following time structure to cancel possible drifts in the measurement conditions.

State	Status Spin Flippers		Duration [s]	
	SP1	SP2	He3xHe3_Tot_880s	He3xHe3_Tot_3520s
0	↑	↑	20	80
1	↓	↑	200	800
2	↓	↓	20	80
3	↑	↓	200	800
4	↑	↓	200	800
5	↓	↓	20	80
6	↓	↑	200	800
7	↑	↑	20	80

The count rate N was measured with a ^3He detector placed behind the analyzer for two cases: the ^3He polarization in the analyzing cell is parallel (white configuration) or anti-parallel (black configuration) to that of the polarizing cell. There were two possible spin combinations for both cases: $\uparrow \uparrow$ and $\downarrow \downarrow$ for white, and $\downarrow \uparrow$ and $\uparrow \downarrow$ for black. The product AP is then given by

$$AP = \frac{(N_w - N_w^{\text{bg}}) - (N_b - N_b^{\text{bg}})}{(N_w - N_w^{\text{bg}}) + (N_b - N_b^{\text{bg}})}$$

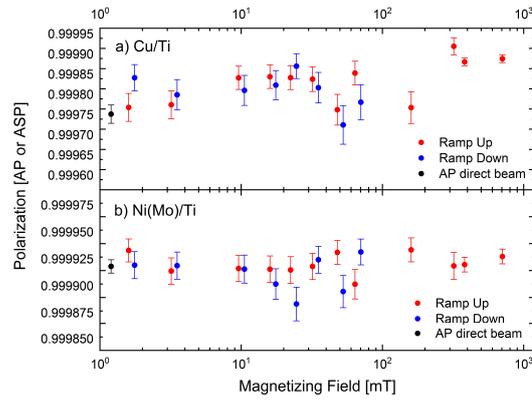
where N_w and N_b denote the uncorrected count rate in the white ($N_w = N_{\uparrow \uparrow} + N_{\downarrow \downarrow}$) and black ($N_b = N_{\downarrow \uparrow} + N_{\uparrow \downarrow}$) configurations, and the superscript **bg** refers to the same parameters for the background measurements, performed with the shutter closed.

To determine the degree of depolarization after reflecting off a sample, a supermirror is placed between the analyzer and the polarizer, so that the neutron beam is reflected at an angle below $\theta_{\text{crit,SM}}$. The sample is placed inside an electromagnet that generates a magnetizing field parallel to the mirror surface and perpendicular to the beam direction. Analogous to AP , the product ASP can be determined with the equation above by measuring the count rate for the two cell configurations.

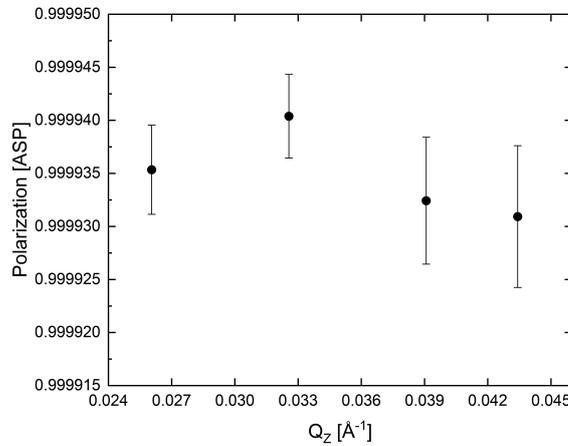
With AP and ASP , the depolarization of the neutron beam induced by the SM sample is determined as $D = 1 - (ASP/AP)$.

Polarization measurements of the neutron beam after reflection off the Cu/Ti(4N5) sample were taken at three different nominal cell pressures (1.4 bar, 1.6 bar and 1.8 bar) and at least at two different selector speeds. The chosen selector speeds correspond to neutron wavelengths 4.5 Å, 5 Å, and 5.5 Å. The incident angle of the incoming neutron beam was set to $\theta = 0.73^\circ$ to be within the range of total reflection for $m = 2.0$ SMs for 5 Å neutrons. From the collected data it was found that a pressure of 1.6 bar and a selected wavelength of 5 Å are ideal for the depolarization measurements, showing both a very high polarization and a reasonable transmission of the polarized neutron beam. Therefore, all results shown in the following are taken with cells of that pressure and a selector speed corresponding to 5 Å.

The field was gradually increased from 1.6 mT to 660 mT and decreased again. The results, depicted below, show that the polarization of the neutron beam after reflection off either sample is independent of the magnetizing field, indicating that both samples are already fully magnetized at the minimum field.



To measure the depolarization dependence of the Cu/Ti(4N5) sample on the momentum transfer $q = 4\pi\lambda\sin\theta$, the polarization ASP of the neutron beam after reflection was compared for four different θ angles (0.58° , 0.73° , 0.88° and 0.97°), all within the range of high reflectivity for 5 \AA neutrons, as $\theta_{\text{crit},5\text{\AA}} = 0.99^\circ$ for an $m = 2$ SM. The figure below shows no dependence of the polarization of the reflected beam while changing its momentum transfer q , as all values agree within the error bars.



During the experiment, it was found that the direct beam had a significant contribution from neutrons with short wavelengths around 1 \AA after the velocity selector. These short wavelength neutrons are not sufficiently polarized but well transmitted by the ^3He cells. In order to suppress the short wavelengths in the direct beam, a Be-filter was installed in the collimation in front of the first magic box. A 4 cm thick beryllium filter at room temperature was found not to be thick enough and still let through a significant amount of short wavelength neutrons. Therefore, measurements using a second 15 cm thick beryllium filter cooled to 77 K with a Peltier-cooled cryostat, which was installed in front of the polarizing cell, were done.

With the second Be Filter installed, the polarization of the direct beam AP considerably improved at $\lambda = 5 \text{ \AA}$. The figure below shows the measured AP with (black dot) and without (open black dot) the second Be Filter installed over the time after the installation of the ^3He cells. The depolarization D of the beam after reflection off either sample was calculated to be $D_{\text{Cu/Ti}(4\text{N}5)} = (1.1 \pm 0.7) \times 10^{-5}$ and $D_{\text{Ni(Mo)/Ti}} = (2.0 \pm 0.7) \times 10^{-5}$.

