SEOP Polarized ^{3}He for neutron polarization analysis at the JCNS

E. Babcock[1], S. Mattauch[1], V.Pipich[1], A.Radulescu[1], S.Staringer[1], A. Ioffe[1]

[1]JCNS: Jülich Centre for Neutron Science

2010 was an eventful year for the JCNS polarized ^{3}He program. We have been making steady progress towards our long term goals for the use of polarized ^{3}He techniques for polarized neutron instrumentation, and hosted an international workshop entitled "Modern Trends in Production and Applications of Polarized ^{3}He" [1]. The focus of our program is to develop polarized ^{3}He neutron spin analyzers based on the spin-exchange optical pumping (SEOP) method to provide unique and optimal solutions for each application. Wherever feasible we are focusing on in-stu polarizers because in-situ polarization will minimize technical support, simplify data treatment and maximize neutron performance. During this year we have made progress on two initial applications of in-situ ^{3}He polarizers. These applications include polarization analysis on reflectometry and SANS which we will describe in this report.

The system optimized for reflectometery is shown in Fig. 1. This in-situ polarizer is constructed around a mu-metal shielded magnetostatic cavity which has been measured to provide magnetic relaxation times for the ^{3}He cell on the order of 1000 hours at 1 bar ^{3}He pressure, even in the presence of stray magnetic fields from the sample magnet. The system features two grating spectrum-narrowed and stabilized diode laser arrays for optical pumping of up to a 15 cm diameter ^{3}He cell and has a high performance adiabatic fast passage system to reverse the direction of the ^{3}He polarization. This allows a reversible analysis direction and therefore a neutron flipper after the sample is not required.

In initial testing on the TREFF reflectometer this system achieved a high ^{3}He polarization using a high performance 6 cm diameter ^{3}He cell. After optimization of parameters, the system achieved a high level of stability and obtained a saturated ^{3}He polarization of over 80 % [2]. The ^{3}He polarization, monitored via the unpolarized neutron transmission of the cell, is shown in Fig. 2.

Additionally this in-situ polarizer has been used for its intended purpose, an analyzer for polarized GISANS and reflectometry on the new MARIA reflectometer [3]. During the last reactor cycle of 2010, the system was installed for polarization analysis (PA) on MARIA for the first polarized GISANS measurement. To obtain an angular coverage over a circle of 4.6°, we used a 9 cm I.D. cell. The system was fully operational and stable over the week-long experiment. The neutron analyzing efficiency at 4.5 Å was 95 % and the neutron transmission was high at > 40 % for the polarized beam due to the constantly maintained 73 % ^{3}He polarization. The use of the sample electromagnet at fields up to 1 T and routine AFP reversal of the ^{3}He polarization did not perturb the analyzer performance.

Further improvements to the MARIA system will include increasing angular coverage by further minimizing the sample to cell distance, and using a larger diameter cell which we are currently developing. The MARIA PA system will be available for user operation in 2011.

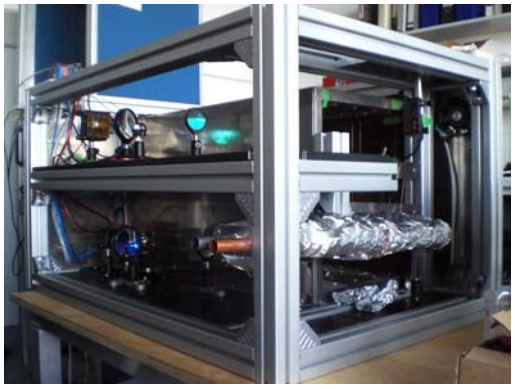

FIG. 1: Picture of in-situ SEOP polarizer.

Another application of polarized ^{3}He at the JCNS is PA for our SANS instrumentation [4]. Measuring the weak coherent scattering of protonated biological samples, or of biological samples in protonated solvents, is a fundamental limitation of standard SANS techniques for soft matter research. The incoherent scattering from the protons can make measurement of the coherent scattering, which gives the structure factors of the sample, very difficult to observe and lead to incorrect fit parameters in extreme cases [5].

Feasibility testing of polarization analysis using ^{3}He was performed on the KWS2 instrument (SANS) using off-line polarized gas. We polarized

the incident beam with a single super mirror in transmission geometry and obtained a polarization of 97 % at 4.5 Å. Two shielded end-compensated solenoids provided an appropriate magnetic environment and neutron beam polarization transport. In order to allow polarization analysis over a wide angle, the sample was placed close to the cell resulting in a solid angle coverage of 15° corresponding to Q < 0.35 $Å^{-1}$. A ^{3}He cell was polarized in the JCNS SEOP laboratory up to the starting polarization of 72 %, which gave a good polarization analyzing efficiency of 95 % for 4.5 Å at the beginning of the experiments and remained over 93 % after over 36 hours (the lifetime was 430 hours). This level of polarization lifetime would allow operation for 4 to 5 days on a single cell polarization with good neutron performance.

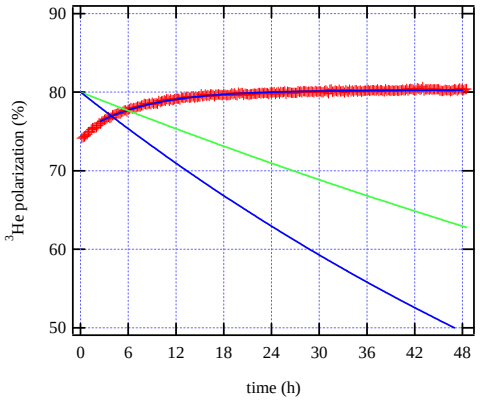

FIG. 2: ^{3}He polarization vs. time (red markers). For comparison the solid blue and solid green lines are the calculated polarizations vs. time with lifetimes of 100 hours and 200 hours respectively.

A sample of the data is shown in Fig. 3. Here grey/green circles are results of measurements with an unpolarized neutron beam of the sample in the solvent and the solvent alone respectively. After data treatment one obtains the black circles for the standard SANS; the blue dotted line is the presumed incoherent background level from the fit of this data. The red circles are results using a polarized incident beam with ^{3}He PA and clearly demonstrate the removal of the incoherent scattering. The red and black solid lines are Beaucage fits to unpolarized and polarized data respectively, where for the latter the background parameter is held to zero. One can see an increase in the ratio of coherent scattering to background/noise level on the order of 100 x. Further the data using PA can be unambiguously fit to a Q^{-4} structure factor in contrast to the unpolarized neutron data.

While we do not intend PA on SANS to replace currently successful means of obtaining the coherent scattering cross section of a sample (such as dueteration or contrast variation) we expect it to be useful in cases that are currently difficult without PA [6]. PA will therefore be an important addition to the capacity of our SANS instrumentation.

Thus based on this experience we are currently constructing another in-situ SEOP polarizer that has been optimized for the KWS instruments. Work is underway to construct a system to allow in-situ polarization, increase the available Q range to over 0.6 $Å^{-1}$ and use standard sample environment.

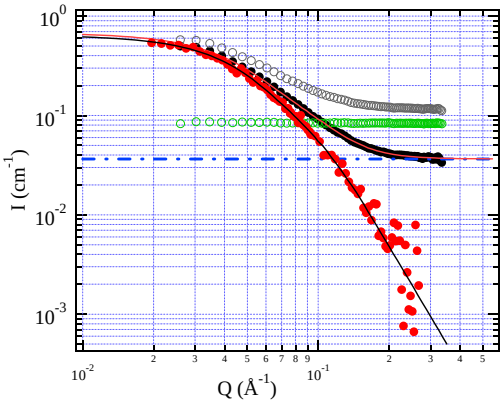

FIG. 3: A sample of the data obtained on a non-deuterated protein in a D_20 buffer solvent. Descriptions of the curves are in the text.

We would like to thank C. Sill for preparation of the sample used in the SANS tests and M-S. Appavou for help as a local contact during the experiment. We thank T.R. Gentile and W.C. Chen of NIST for fruitful collaborations. Finally we thank the technical staff of the JCNS for support, and the glass workshop in the ZAT for continued involvement in ^{3}He cell developments.

[1] Journal of Physics: Conference Series, workshop proceedings of "Modern Trends in Production and Applications of Polarized 3He," Ismaning Germany 2010, (to be published 2011)

[2] E. Babcock, S. Mattauch, A. Ioffe, *Nuclear Instruments and Methods in Physics Research A*, **625**, (2011), p. 43-46

[3] http://www.jcns.info/jcns_maria

[4] http://www.jcns.info/jcns_kws2
http://www.jcns.info/jcns_kws1

[5] K.A. Rubinson, C. Stanley, S. Krueger, *J. of Appl. Cryst*, **41**, 456-465, (2008).

[6] A.M. Gaspar, S. Busch, M.S. Appavou, W. Haeussler, R. Georgii, Y.X. Su, W. Doster, *Biochimica et Biophysica ACTA-Proteins and Proteomics*, **1804**, 76-82, (2010).