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Continuously operating compact ^{3}He-based neutron spin filter

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Abstract

Polarized ^{3}He can be used as a spin filter to polarize a broad energy spectrum of neutrons. As a prototype for use on the single-crystal diffractometer (SCD) at the spallation neutron source (SNS), we have built a compact system to continuously polarize a ^{3}He spin filter by spin-exchange optical pumping. Polarizing in the neutron beam provides a constant neutron polarization and reduces the sensitivity to relaxation mechanisms. The capability to operate in the presence of non-optimal magnetic field homogeneity allowed us to employ a highly compact solenoid only 9.5 cm in diameter and 20 cm long. Using only 7 W of laser light we maintained 44% ^{3}He polarization in an 11 cm^3 cell, despite an overall cell relaxation time of $\approx$ 10 h. Results from a test on the SCD at IPNS are discussed.
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1. Introduction

The single-crystal diffractometer (SCD) [1] at the spallation neutron source (SNS) will have the capability to study magnetic materials with polarized neutrons. As a step toward developing a broadband ^{3}He spin filter for the SCD, a continuously operating polarizer was tested on the SCD at the intense pulsed neutron source (IPNS) [2].

The highly spin-dependent neutron capture cross section of polarized ^{3}He gas can be used to polarize a broad energy range of neutrons up to epithermal energies [3,4]. ^{3}He-based spin filters

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have a large angular acceptance and no effect on beam divergence, which make them ideal for neutron scattering experiments. Although the polarizing efficiency of a neutron spin filter is wavelength dependent, it can be determined solely from transmission measurements which are convenient at spallation sources. In this paper, we present a design for a simple, compact, polarizer, shielded from minor stray magnetic fields, that can provide a constant neutron polarization over long-time periods.

2. Neutron spin filters

The total cross section for neutrons on ^{3}He is almost entirely due to capture of neutrons whose spins are anti-aligned with the ^{3}He spins. A polarized sample of ^{3}He almost completely transmits aligned neutrons while strongly absorbing anti-aligned neutrons. The neutron polarization produced by a ^{3}He spin filter depends on its thickness. A thin polarizer has little attenuation for either state but provides a low neutron polarization. A thick polarizer has more overall attenuation, but one polarization state is very highly attenuated and therefore it provides a high neutron polarization. Since the ^{3}He capture cross section is directly proportional to wavelength, $\sigma(\lambda) \approx \sigma_0\lambda$, where $\sigma_0 = 29,662\,\mathrm{b/nm}$, and λ is the neutron wavelength in nanometers [5]. This energy dependence makes a typical polarizer look thin to fast neutrons and thick to slow neutrons. The neutron transmission T_n and polarization P_n are given as functions of λ by

$$T_\mathrm{n}(\lambda) = T_0(\lambda)\cosh(P_\mathrm{He} n\sigma_0\lambda l), \tag{1}$$

$$P_\mathrm{n}(\lambda) = \tanh(P_\mathrm{He} n\sigma_0\lambda l) = \left(1 - \frac{T_0^2(\lambda)}{T_\mathrm{n}^2(\lambda)}\right)^{1/2}, \tag{2}$$

where

$$T_0(\lambda) = T_\mathrm{E}\exp[-n\sigma_0\lambda l] \tag{3}$$

is the neutron transmission through unpolarized ^{3}He, T_E is the transmission of the empty ^{3}He cell, P_He is the ^{3}He polarization, l is the thickness of the ^{3}He cell, and n is the number density of the ^{3}He. We assume that T_E is wavelength independent as expected from the negligible neutron absorption in the glass. This was roughly confirmed in an auxiliary measurement on a piece of GE180 glass. In addition to showing the functional dependence of P_n on neutron energy, Eq. (2) shows that P_n can be determined solely from relative transmission measurements at each wavelength [6].

3. Apparatus

The compact polarizer is shown schematically in Fig. 1. The spin filter cell is continuously polarized by spin-exchange optical pumping [7,8] while in the neutron beam. The ^{3}He is contained in a sealed 1.7 cm diameter, 5 cm long blown GE180 [9] glass cell (named Oscar) filled with 2.6 bar of ^{3}He, 66 mbar of nitrogen, and ~ 0.05 g Rb. To increase the Rb vapor pressure in the cell, it is heated in an oven machined from a tube of high-temperature plastic [10] with an inner diameter of 4.75 cm. The central 10 cm length of the tube is closed off by double pane windows made from 1 mm thick fused silica glass. Hot air from a nearby heater enters at one end of the solenoid through a duct running longitudinally through the wall of the tube. The air escapes in holes around the windows.

The main solenoid is wound from 0.64 mm diameter (22 AWG) wire directly on the outside of the 8 cm diameter oven. At each end of the solenoid, a coil (18 turns) is wound in series with the main solenoid to compensate for end effects. An additional low current correction coil (50 turns) is wound on each end for fine tuning of the field. An 8.8 cm ID sleeve of 1.58 mm thick,

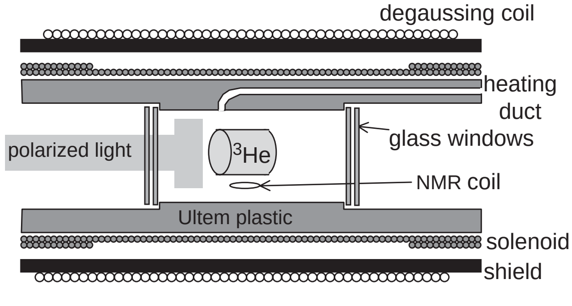

Fig. 1. Schematic diagram of the compact polarizer.

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