Compact ^{3}He-based Polarizer for In-situ Neutron Polarization

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Abstract

Polarized ^{3}He can be used as a neutron 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 the ^{3}He in the neutron beam provides a constant neutron polarization and reduces the sensitivity to relaxation mechanisms. The compact polarizer, 28 cm in diameter and 31 cm long, includes NMR coils to quickly flip the ^{3}He polarization with 0.01% loss. The achieved 67% ^{3}He polarization corresponds to P_n = 91% with T_n = 20%, at 0.3 nm, confirmed with the CoFe crystal analyzer.

Introduction

The Single Crystal Diffractometer (SCD) at the Spallation Neutron Source will have the capability to study magnetic materials with polarized neutrons. We constructed a continuously operating polarizer to test and develop the use of a ^{3}He spin filter for this goal. The polarizer was tested at the Intense Pulsed Neutron Source (IPNS) Single Crystal Diffractometer (SCD) at Argonne National Labs (ANL) in Chicago.

Advantages of ^{3}He Spin Filter

- polarizes broad energy range of neutrons (cold – epithermal)
- minimal effect on beam divergence
- wide angular acceptance

Neutron Spin Filters

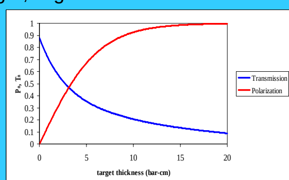
- the absorption cross-section for polarized ^{3}He is highly spin dependent
- anti-aligned neutrons see a thick absorption target, aligned neutrons see a thin target

$$T_0(\lambda) = T_e e^{-n\sigma_0\lambda l} \qquad T_n = T_0\cosh(P_{He} n\sigma_0\lambda l)$$

$$\lambda l) = \sqrt{1-\frac{T_0^2}{T_n^2}}$$

T_n = transmission
P_n = neutron polarization
P_{He} = ^{3}He polarization
l = cell length
λ = neutron wavelength
n = number density of ^{3}He

λ : the 1/v neutron capture cross-section is given by $\sigma(\lambda) \approx \sigma_0 \lambda$

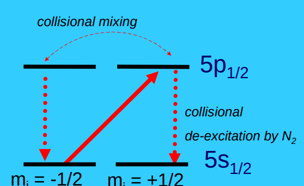


P_n and T_n, vs. ^{3}He cell length with 65% polarization, (λ = 0.3 nm, T_E = 88%).

Spin-Exchange Optical Pumping

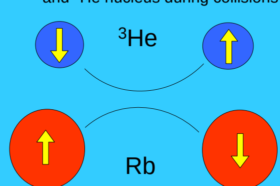
Optical Pumping

- pump Rb D1 line with circularly polarized light (795 nm)



Spin-Exchange

- spin is transferred between Rb electron and ^{3}He nucleus during collisions



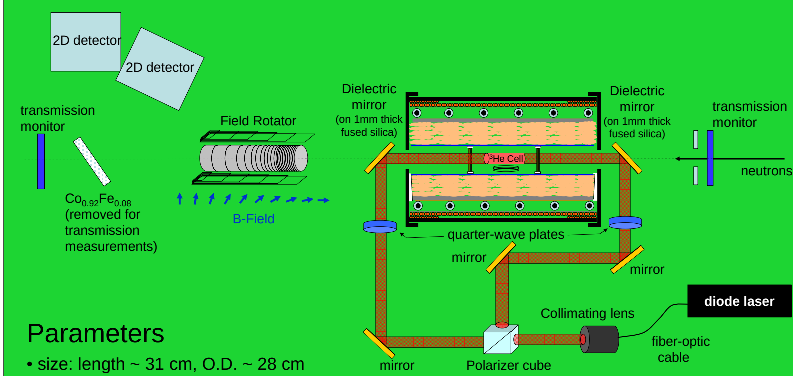
^{3}He Polarization

- slow process requires very slow spin relaxation rate

$$P_{He}(t) = \frac{\gamma_{SE} P_{Rb}}{\gamma_{SE}+\Gamma}\left[1 - e^{-(\gamma_{SE}+\Gamma)t}\right]$$

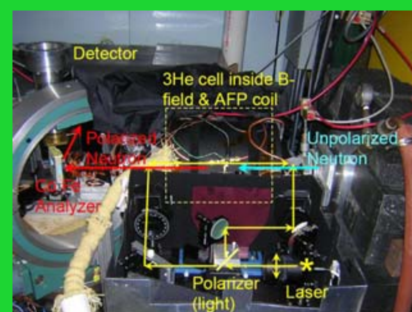
P_{He} – ^{3}He polarization
P_{Rb} – Rubidium polarization
γ_{SE} – spin-exchange rate
Γ – ^{3}He relaxation rate

Apparatus



Parameters

- size: length ~ 31 cm, O.D. ~ 28 cm
- beam size = 9mm
- T_e = approx. 88%
  - 2 double paned fused silica windows ~ 4mm total
  - 2 dielectric mirrors on fused silica ~ 2mm total
  - Cell windows ~ 3mm total



^{3}He Cell

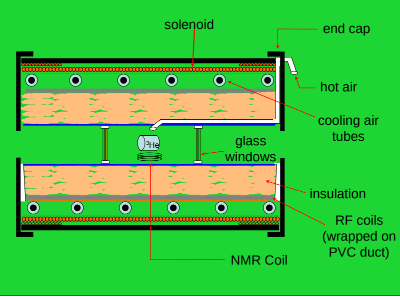
- produced at NIST
- size: 5.25cm long, 4cm OD
- nσl = 4.19 at 0.496nm
- 2.2 bar of ^{3}He, 60 mbar of N_2, drop of Rb
- $T_{1\ cell}$ ≈ 370 h, X=0.44

Optical Pumping

- temperature = 166˚C
- 30W fiber coupled diode laser array (not narrowed)

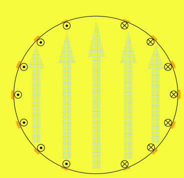
NMR system

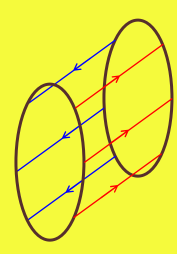
- single coil FID relative P_{He} monitor
- AFP coil for fipping polarization



AFP Spin-Flipping

- Adiabatic Fast Passage (AFP) NMR flips ^{3}He Polarization and reverses Neutron Polarization
- NMR loss = 0.01% per flip
- Flipped every 10 minutes without noticeable loss in polarization





Sine Coil:

produces uniform transverse RF field 50-150 kHz