Wide-angle polarization analysis using $^3$He spin filters on the LET spectrometer

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Outline

- The LET time-of-flight spectrometer
- Quick introduction to polarized neutrons
- The case for polarized neutrons on LET
- Technical implementation
- Polarized QENS: D$_2$O
- Powder magnetic scattering: Ho$_2$Ti$_2$O$_7$
The LET time-of-flight spectrometer

Direct geometry TOF spectrometer on coupled H$_2$ Moderator

- $E_i$ 1 - 25 meV
- Resolution 1 - 4 %
- $\phi$ (3 Å) $3 \times 10^5$ ncm$^{-2}$s$^{-1}$
- Beam size 2 x 4 cm$^2$
- Detectors $^3$He PSD
- Coverage π st.

Multi-chopper system: multiple $E_i$ in each time frame

Russina et. al. NIMA 604 624
Hexadecane (C\textsubscript{16}H\textsubscript{34})

Figure: R. Bewley
LET: QENS

Hexadecane (C_{16}H_{34})

IN6
5.1 Å, 70 µeV

Figure: R. Bewley
Hexadecane ($\text{C}_{16}\text{H}_{34}$)

$E_i = 9.6 \text{ meV}$, $\text{res} = 210 \text{ uev}$

$E_i = 3.2 \text{ meV}$, $\text{res} = 40 \text{ uev}$

$1.6 \text{ meV}$, $\text{res} = 15 \text{ uev}$

$0.9 \text{ meV}$, $\text{res} = 7 \text{ uev}$

$0.6 \text{ meV}$, $\text{res} = 4.4 \text{ uev}$

Figure: R. Bewley

IN6
5.1 Å, 70 µeV

$10^{-9}$ s
LET: QENS

Hexadecane ($\text{C}_{16}\text{H}_{34}$)

Figure: R. Bewley
Hexadecane ($\text{C}_{16}\text{H}_{34}$)

Let: QENS

Figure: R. Bewley
LET: current science

Magnetism 85%

QENS 15%

e.g. exotic phases in quantum magnets
Schmidiger et. al. PRL 115 147201

e.g. diffusion in ionic conductors
Voneshen et. al. PRL 118 145901
Polarized neutron beams

Neutrons possess an inherent spin-angular momentum $S = \frac{1}{2}$:

Single neutron

- $+\frac{1}{2}$: $z \parallel B$
- $-\frac{1}{2}$: $z \parallel B$

Beam of neutrons

$P = \frac{N_+ - N_-}{N_+ + N_-}$

where $N_+$ and $N_-$ are the number of neutrons with spin-up and spin-down, respectively.
Neutron polarization analysis

Samples also contain magnetic moments, either from nuclei or electrons (i.e. magnetism):

Some processes flip the neutron spin, others don’t - also depends on the relative orientations of the neutron moment and the moments in the sample.
Uniaxial polarization analysis

- **Polarizer**
- **Flipper**
- **Analyzer**

<table>
<thead>
<tr>
<th>Coherent</th>
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<td>1/3</td>
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\[
\frac{1}{2} \left[ 1 - (\hat{P} \cdot \hat{Q})^2 \right] \quad \hat{P} \cdot \left[ \hat{Q} \times (M(\hat{Q}) \times \hat{Q}) \right]
\]

\[
\frac{1}{2} \left[ 1 + (\hat{P} \cdot \hat{Q})^2 \right]
\]
Uniaxial polarization analysis

Polarizer | Flipper | Analyzer
---|---|---
\[ \uparrow \rightarrow p \rightarrow \downarrow \rightarrow f \rightarrow \uparrow \rightarrow a \rightarrow \downarrow \]

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LET with polarization analysis

Components of $S(Q,\omega)$: e.g. battery

Components of $S^{\alpha\beta}(Q,\omega)$: e.g. ladder

Longitudinal

Transverse

$H^+, D^+, Li^+, Na^+...$
Polarized LET: Concept

Supermirror polarizer, current-ramped Mezei (precession coil) flipper, \(^3\)He analyzer

Nilsen et. al. J. Phys.: Conf. Series 115 012019
Polarizer, flipper, and guide field give $P \sim 0.94$ at $\lambda > 3$ Å ($E_i < 9$ meV) with $T \sim 0.4$: 

Kosata et. al. Physica B 551 476
## Analyzer: $^3$He versus supermirrors

<table>
<thead>
<tr>
<th>Hyperpolarized $^3$He</th>
<th>Supermirrors</th>
</tr>
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<tbody>
<tr>
<td>Cheap(er) hardware</td>
<td>Expensive</td>
</tr>
<tr>
<td>Time-dependent, requires monitoring</td>
<td>Static</td>
</tr>
<tr>
<td>Large solid angle</td>
<td>Smaller solid angle</td>
</tr>
<tr>
<td>Sensitive to field gradients</td>
<td>No strict requirements</td>
</tr>
<tr>
<td>Easy corrections</td>
<td>Difficult corrections, systematic errors</td>
</tr>
</tbody>
</table>

### Hyperpolarized $^3$He Analyzer
- HZB/FZJ (E. Babcock)

### Supermirrors
- HYSPEC, ORNL

![Image of $^3$He analyzer, HZB/FZJ (E. Babcock)](image1)

![Image of Supermirror, HYSPEC, ORNL](image2)
Analyzer: concept

Sectional View of Sample Vessel and Analyser Assembly

- Field Coils (Upper)
- \(^3\)He monitor
- Radial oscillating collimator
- Field Coils (Lower)
- Collimator Mounting Plate

Figure: P. Galsworthy

Cassella et. al. J. Phys.: Conf. Series, in press
Analyzer: implementation

Two cells constructed ($T_{1}^{\text{cell}1} = 55$ hours $T_{1}^{\text{cell}2} = 18$ hours), initial $^3$He polarization $P_{0} \sim 60\%$, rapid (20 s) changeover:

## Polarized LET: Overall performance

<table>
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<tr>
<th></th>
<th>3.84 meV</th>
<th>1.05 meV</th>
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<tr>
<td>$T_p$</td>
<td>0.4</td>
<td>0.35</td>
</tr>
<tr>
<td>$f_p$</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>$T_a$</td>
<td>0.32</td>
<td>0.16</td>
</tr>
<tr>
<td>$a$</td>
<td>0.72</td>
<td>0.94</td>
</tr>
<tr>
<td>FR</td>
<td>5.2</td>
<td>15.7</td>
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### Graph

- **Transmission ($T$)**
- **Neutron polarization ($P$)**
- **Quality factor ($P^2T$)**

$P_{He} = 0.6$

$P_{He} = 0.75$ bar

Slide: R. Stewart
QENS: D$_2$O

Arantxa Arbe, Juan Colmenero, Fernando Alvarez
University of the Basque Country
Victoria Garcia-Sakai, Ross Stewart
ISIS
First experiment: context

Intermediate-length scale diffusion in water and glass formers almost unexplored

Unpolarized QENS
(IN5, ILL)

- D$_2$O “coherent”
- H$_2$O “incoherent”

Polarized diffraction
(D7, ILL)

- Ratio coherent to incoherent, energy integr.

Arbe et. al. Phys. Rev. Lett. 117 185501
First experiment: context

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Arbe et. al. Phys. Rev. Lett. 117 185501
$D_2O$: incoherent-coherent separation

\[ S(Q, \nu)_{\text{inc}} = \frac{3}{2} S(Q, \nu)_{\text{sf}} \]

self motions

\[ S(Q, \nu)_{\text{coh}} = S(Q, \nu)_{\text{nsf}} - \frac{1}{2} S(Q, \nu)_{\text{sf}} \]

collective and self motions

D$_2$O: separation of timescales at low Q

D$_2$O: separation of timescales at low Q

D$_2$O: reconciling results with model

Three contributions to coherent dynamics, consistent with state-of-the art model:

- 3-component model from MD simulation
- effective local (1.81 meV and 3.84 meV)
- vibrational (1.81 meV and 3.84 meV)
- diffusive (1.81 meV and 3.84 meV)
- diffusive (1.05 meV, 1.81, and 3.84 meV)
- overall coherent 295 K (1.05 meV, 1.81, and 3.84 meV)
- overall coherent 280 K (1.05 meV, 1.81, and 3.84 meV)
- overall coherent 350 K (1.05 meV, 1.81, and 3.84 meV)
- effective coherent relaxation time from MD simulation
- T-dependence of neutron coherent relaxation time
- T-dependence of IXS coherent relaxation time

Paramagnetic scattering: Ho$_2$Ti$_2$O$_7$
Polarization analysis on a 2D detector

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LET detector, ~100000 pixels
Paramagnetic powder: $\text{Ho}_2\text{Ti}_2\text{O}_7$

$\text{Ho}_2\text{Ti}_2\text{O}_7$, 2 K, $E_i = 4.0 \text{ meV}$, energy integrated:
Z+: using PSD for separation

$\text{Ho}_2\text{Ti}_2\text{O}_7$, 2 K, $E_i = 4.0$ meV, energy integrated:
Conclusion

- A uniaxial polarisation mode has been constructed for the LET spectrometer.
- Overall performance is excellent, although some improvements remain to be made for the $^3$He analyser.
- The potential of the polarised mode for QENS is demonstrated by the first user experiment on D$_2$O.
- Magnetic scattering on a spectromter with large out-of-plane coverage is new territory - new approaches required.
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ISIS/UCL
Robin Perry