Measurement Cell Development for nEDM (SNS)

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for presentation to

Neutron EDM Workshop
Oak Ridge National Laboratory
October 13, 2012
Outline

• Requirements
• Cell Construction
• Storage Time Measurements
• Conclusions and Future Work
There are four principal properties needed from the nEDM measurement cells:

• Ultra-cold neutron (UCN) production
  • Transverse size determined by cold neutron phase space and E field
  • Length balanced between UCN production and B-field uniformity (T$_2$, etc.)
  • Internal dimensions: 7.5 cm wide x 10 cm high x 40 cm long ~ 3 liters
• Convert the UV from $^3$He(n,p)t to blue light and be a good light guide
  • Build the cell from UVT acrylic (hydrogenated at present)
  • Coat the inner cell walls with dTPB (25-40%) in a dPS matrix: >1 $\mu$m
  • Blue light transmission loss < 15%
  • Optical quality glue joints
• Long depolarization time for the $^3$He
  • Verified to be ~25,000 s for dTPB in a dPS matrix when scaled to nEDM dimensions in experiments at Duke/NCSU and UIUC
• Long storage and depolarization times for the UCNs
  • Negligible losses in joints and valve holes
  • Coating thickness > 100 nm
  • Coating thickness < 4 $\mu$m to prevent crazing during thermal cycling
  • Desired average wall-loss per bounce $f$ ~ $10^{-5}$ at < 1 K to be negligible compared to decay and $^3$He absorption
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Swing Coating

Cell is built from 6 plates. Four are roughly 10 cm x 40 cm x 1.3 cm and two are roughly 4 cm x 4 cm x 0.6 cm. Eventually, the small ones will be deuterated.

- Technique developed during $^{3}$He wall depolarization studies (Gao, Golub, Ye)
- Plate is dipped into d-toluene+dPS/dTPB solution, swung out very slowly and smoothly
- Quality of results depends on the viscosity
- NCSU is also investigating using an automated applicator to drip the coating mixture onto the plate – excess liquid is then shaken off
Swing Coating
Coating Thickness

- Coating thickness is checked with a spectral reflectometer
- Coating observed with UV light for imperfections; transparent in room light
- TPB degradation may not allow these techniques in final cells
• Need to precisely position plates while minimizing handling and without touching inner surfaces
• Initial steps use external suction cups to hold plates
• Glue: deuterated MC-Bond
  – methylene chloride (81%), methyl methacrylate (14%), acetic acid (5%)
Edge Cleaning

- Have found that PS/TPB layer can cause bubbling in glue joint
- For consistent results, need to clean coating off of glued areas
- Coating removed by dipping in toluene to within 1 mm of inner surface of cell
Glue Joints

- Joints are optically clear, mostly bubble-free, have survived multiple temperature cycles without cracking
Cooling Jacket

- Spring loaded cooling plates are pressed against cell walls
- Jacket/frame also responsible for making tight contact with the UCN entrance valve
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LANL UCN Storage Time Tests

- Utilizes currently operating LANSCE UCN source
- Test wall coatings and cell construction for UCN storage

DIAGRAM:
- SD$_2$ UCN source
- Gate valve
- Monitor ion chamber
- Switcher and stored UCN ion chamber
- nEDM storage time
- Pre-polarizing magnet
• 1-cm diameter entrance hole in middle of a long face
  • same as eventual nEDM cells where it is used for $^3$He exchange
• Demonstrated $< 25 \, \mu m$ valve gap
  • 25 $\mu m$ gap gives 4000 s hole loss time in 3 liter cell
• 25 $\mu m$ Gortex (PTFE) filler between cell and valve box
  • Spring loaded
Measurement Cycle

1. 000 s – Wait 30 s beam gated off and cell open to UCN counter
2. 030 s – Fill the cell and guide – raise the switcher guide, remove the proton beam gate, open the gate valve
3. 130 s – Close the cell, lower the switcher guide to drain the UCN in the guide into the counter, gate the proton beam off, close the gate valve
4. 330 s – After an additional delay time, e.g. 200 s in this case, open the cell valve and count the UCN from the cell
5. 540 s – Go to 1 after done counting.
Expect storage time curves to change versus temperature, viz. Korobkina et al, PRB, 035409 (2004) for a Cu bottle. The up-scatterering from hydrogen is freezing out.
Rate Equations

Production

\[
dN_{UCN}(v) = P(v)dt - N_{UCN}(v) \sum \Gamma_i(v)dt
\]

\[
N_{UCN}(v) = P(v)\tau(v)\left(1 - e^{-\Gamma(v)t}\right) = P(v)\tau(v)\left(1 - e^{-t/\tau(v)}\right)
\]

Storage

\[
dN_{UCN}(v) = -N_{UCN}(v) \sum \Gamma_i(v)dt
\]

\[
N_{UCN}(v) = N_0(v)e^{-\Gamma(v)t} = N_0(v)e^{-t/\tau(v)}
\]

where \(P(v) \sim v^n\) is the UCN production rate for the source

In the LANSCE superthermal UCN source, \(n = 3\) from phase space and UCN self absorption in the solid deuterium

Equations are valid for each velocity
Storage Time $\tau$ in a Bottle

\[
\frac{1}{\tau(v)} = \frac{1}{\tau_n} + \frac{1}{\tau_w(v)} + \frac{1}{\tau_{\text{hole}}(v)} + \frac{1}{\tau_b(v)} + \frac{1}{\tau_3} + \ldots
\]

where

- $\tau_n$: neutron decay
- $\tau_w$: losses on the wall
- $\tau_{\text{hole}}$: losses through a hole
- $\tau_b$: barrier penetration
- $\tau_3$: $^3$He absorption

Integrating over velocity produces deviations from exponential storage time curves.
Wall Losses

\[
\frac{1}{\tau_{\text{wall}}(v)} = \frac{v}{\lambda} 2 f \left[ \frac{V}{E} \sin^{-1} \left( \frac{E}{V} \right)^2 - \left( \frac{V}{E} - 1 \right)^2 \right]
\]

where

- \( \nu \) neutron velocity
- \( \lambda \) mean free path
- \( f \) average loss per bounce = \( \frac{W}{V} \)
- \( V \) real nuclear potential
- \( W \) imaginary nuclear potential
- \( E \) neutron kinetic energy = \( \frac{1}{2} m \nu^2 \)

From Golub, Richardson, and Lamoreaux
LANL UCN Storage Time Tests

- Utilizes currently operating LANSCE UCN source
- Test wall coatings and cell construction for UCN storage

UCNA

SD$_2$ UCN source

Gate valve monitor ion chamber

Pre-polarizing magnet

Switcher and stored UCN ion chamber

nEDM storage time
Zr foil window separates the UCN source from the detector region.

Varying the field in the Pre-Polarizing Magnet (PPM) gives a variable low energy cutoff for UCNs transmitted through the window \((\frac{1}{2}mv^2 + \vec{\mu} \cdot \vec{B})_\perp\) due to modified magnetic energy and focusing or defocusing for the two polarization states.

Only the highest energy UCN enter the cell with the PPM off.

\[ \mu \cdot B = 100 \text{ neV at 20 Amps} \]

UCNA collaboration

No Foil

2 mil Zr Foil

4 mil Zr Foil

1 mil Zr Foil
PPM Scan

The graph shows the relationship between PPM potential (μ·B, neV) and the number of stored cts for three different conditions: 40 sec hold, $v^3$, and 100 sec, $v^3$. The data points are represented with error bars, indicating the variability in measurements.
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## Values for \( f \)

### Fits assume \( v^3 \) for source output phase space

<table>
<thead>
<tr>
<th>T (K)</th>
<th>( f(10^{-4}) )</th>
<th>( \Delta f(10^{-4}) )</th>
<th>( \chi^2/DOF )</th>
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<th>( \chi^2/DOF )</th>
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### Fits assume \( v^2 \) for source output phase space

<table>
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Source Production – $v^2$ or $v^3$

Cell drain time from exponential fit

- \( v^3 \ f = 1 \times 10^{-4} \)
- \( v^2 \ f = 2 \times 10^{-4} \)

| UCN <\( v\) (m/s) | 4.0 | 3.0 | 2.3 |
Conclusions and Future Work

- Have measured storage times with a cell sized for nEDM
- Consistency between storage time measurements, PPM sweeps, and cell drain times with $\nu^3$ source phase space
- Measured values of $f$ are larger than desired
- Work in progress

- Flushing with Ar and baking cell at 50 °C for ~2 weeks to explore low mass surface contaminations
- Looking into other loss mechanisms, e.g. rough surfaces or vibrations
- RGA shows a hint of d-methylene chloride from the glue
- Looking to make our modeling more sophisticated