Neutron lifetime measuring using magnetic trap

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Magnetic potential

\[ U = - \vec{\mu} \cdot \vec{B} \]

\[ F = -\nabla U = \nabla (\vec{\mu} \cdot \vec{B}) = \pm \mu \nabla |\vec{B}| \]

+ for \( \vec{\mu} \uparrow \uparrow \vec{B} \)

- for \( \vec{\mu} \uparrow \downarrow \vec{B} \)

For magnetic moment of neutron

Nuclear potential of Be

\[ U = 60 \text{neV} \cdot T^{-1} \]

250 neV

Magnetic field 1 T reflects neutrons up to 3.4 m/s, as Al.

Magnetic mirrors, channels and bottles neutrons.
Vladimirskii, V.V. Sov. Phys. JETP 12, 740-746, (1961)
Experimental setup
Trap filling

1. Fill lift volume
2. Close lift volume
3. Move lift down
4. Open lift and move lift up

\[ v_{\text{lift}} \ll v_{\text{R}} \]

UCN detector

Magnetic shutter OFF
Magnetic shutter ON

Monitor

Trapped UCNs
To control the depolarization (spin flip) of UCN we cover the inner trap walls with thin layer of fomblin that reflects depolarized UCN. After some collisions the depolarized UCN penetrate through the magnetic barrier of solenoid and are measured by the UCN detector installed below the solenoid. Hence this intensity may be used as monitor for depolarization losses during neutron storage.

- Monitor of trap filling
- Preliminary neutron spectrum preparation
- Absence of neutrons heating at the moment of magnetic shutter switching on.
\[ dN_{\text{trap}}(t) = \left( -\lambda_{\text{decay}} N_{\text{trap}}(t) - \lambda_{\text{dep}} N_{\text{trap}}(t) \right) dt \]

\[ dN_{\text{leak}}(t) = \varepsilon \lambda_{\text{dep}} N_{\text{trap}}(t) dt \]

\[ N_{\text{trap}}(0) = N_0 \]

\[ N_{\text{leak}}(0) = 0 \]

Model of magnetic storage with leakage

\[ N_{\text{trap}}(t) = N_0 e^{-(\lambda_{\text{decay}} + \lambda_{\text{leak}})t} \]

\[ N_{\text{leak}}(t) = \frac{\varepsilon \lambda_{\text{leak}} N_0}{\lambda_{\text{decay}} + \lambda_{\text{leak}}} \left( 1 - e^{-(\lambda_{\text{decay}} + \lambda_{\text{leak}})t} \right) \]

\[ \lambda_{\text{decay}} = \frac{\ln \left( \frac{N_{\text{trap}}(T)}{N_0} \right) (\varepsilon N_0 - \varepsilon N_{\text{trap}}(T) - N_{\text{leak}}(T))}{T \varepsilon \left( N_0 - N_{\text{trap}}(T) \right)} \]

\[ \lambda_{\text{dep}} = \frac{\ln \left( \frac{N_{\text{trap}}(T)}{N_0} \right) N_{\text{leak}}(T)}{T \varepsilon \left( N_0 - N_{\text{trap}}(T) \right)} \]
\[ N(400) = \sum_{t_i=401}^{2200} \frac{1}{\varepsilon} \cdot N(t_i) \cdot e^{\frac{t_i-400.5}{\tau_{\text{decay}}}} + \sum_{t_i=2201}^{2300} N_{2200}(t_i) \cdot e^{\frac{t_i-400.5}{\tau_{\text{decay}}}} \]

\[ N(400) = \sum_{t_i=401}^{1800} \frac{1}{\varepsilon} \cdot N(t_i) \cdot e^{\frac{t_i-400.5}{\tau_{\text{decay}}}} + \sum_{t_i=1801}^{1900} N_{1800}(t_i) \cdot e^{\frac{t_i-400.5}{\tau_{\text{decay}}}} \]

\[ N(400) = \sum_{t_i=401}^{500} N_{400}(t_i) \cdot e^{\frac{t_i-400.5}{\tau_{\text{decay}}}} \]
\[ N(400) = \sum_{t_i=401}^{2200} \frac{1}{\epsilon} \cdot N(t_i) \cdot e^{\tau_{\text{decay}}} + \sum_{t_i=2201}^{2300} N_{2200}(t_i) \cdot e^{\tau_{\text{decay}}} \]

\[ N(400) = \sum_{t_i=401}^{1800} \frac{1}{\epsilon} \cdot N(t_i) \cdot e^{\tau_{\text{decay}}} + \sum_{t_i=1801}^{1900} N_{1800}(t_i) \cdot e^{\tau_{\text{decay}}} \]

\[ N(400) = \sum_{t_i=401}^{500} N_{400}(t_i) \cdot e^{\tau_{\text{decay}}} \]
\[
\varepsilon = \frac{\sum_{t_i=301}^{300} (N_1(t_i) - N_2(t_i)) \cdot e^{-\frac{t_i-300.5}{\tau_{\text{decay}}}}}{\sum_{t_i=1001}^{1100} (N_2(t_i) - N_1(t_i)) \cdot e^{-\frac{t_i-300.5}{\tau_{\text{decay}}}}}
\]

\[\varepsilon = 0.90 \pm 0.02\]
Data analysis

\[ \varepsilon = \frac{\sum_{t_i = 301}^{1800} (N_1(t_i) - N_2(t_i)) \times e^{t_i \cdot \text{decay}}}{\sum_{t_i = 1801}^{1800} (N_2(t_i) - N_1(t_i)) \times e^{t_i \cdot \text{decay}}} \]
Cleaning of the neutron spectrum

Comparing cleaning time with depolarization and without (no normalized data)

Depolarization accelerates cleaning time
Vacuum dependence

\[ N(t) = N_0 \exp\left(-\lambda_{\text{decay}} - \lambda_p p t\right) \]

\[ \lambda_p = \frac{\ln\left(\frac{N_1(t)}{N_0}\right) - \ln\left(\frac{N(t)}{N_0}\right)}{t(p - p_1)} \]

\[ \lambda_p = 0.15 \pm 0.04 \ \text{1/s} \cdot \text{torr} \]

\[ \lambda_{\text{decay}} = \frac{1}{880} = 0.00113 \ \text{1/s} \]

\[ p \Rightarrow 10^{-6} \ \text{torr} \]
Fomblin vapor scattering

Fomblin spectrum under 98°C

Spectrum of the rest vapor in the trap
Choosing of empting time

- One can see that 50 s is enough for empting as intensity after 50 s is equal to background. We have checked this in each empting.
- It means that there are no any closed trajectories during empting.
PDG 2006/2007: \((885.7 \pm 0.85)\) s

\[\diamondsuit = 878.2 \pm 1.9\text{ s.}\]
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Our plans accuracy about 0.2-0.3 s.
Thank you