Characterization of a Low-Pressure High-Capacity $^{129}$Xe Flow-Through Polarizer

Brian Saam
Department of Physics

DAMOP Session B4, Charlottesville, VA, 20 May 2009
Two Basic Ways to Implement SEOP

BATCH MODE ($^3$He): Slow spin-exchange rates (hours$^{-1}$), slow (He-Rb) alkali-metal spin-destruction rates.

FLOW-THROUGH MODE ($^{129}$Xe): Fast spin-exchange rates (minutes$^{-1}$), fast (Xe-Rb) alkali-metal spin-destruction rates.

Driehuys, et al. [Appl. Phys. Lett. 69, 1668 (1996)] introduces:

- Flow-through mode.
- Lean Xe gas mixture.
- Broadening of Rb absorption line by high-pressure He.
- Cryogenic separation of Xe from gas mixture.
What to do with More Photons?

\[ P_{Xe} \Phi_{Xe} \propto \langle P_{Rb} \rangle [Xe] V \gamma_{se} \propto \langle P_{Rb} \rangle [Xe] V [Rb] \xi_{se} \]

- Increasing volume instead of [Rb] avoids Rb-Rb spin destruction and makes it easier to handle heat load.

\[ \Phi_\gamma \text{ photon flux} \]

se physics
The Utah Flow-Through Polarizer

Diode-Laser Arrays offer increased power (tens to hundreds of watts) and can be spectrally narrowed.


- Long, narrow SEOP cell (≈ 2 m long by 4-5 cm diam)
- Low total gas pressure in addition to gas mixture lean in Xe.
- Xe polarization $P_{\text{Xe}} = 64\%$ at 0.3 L/h Xe flow rate with laser power = 90 W, $T = 160 \, ^\circ\text{C}$

- Our polarizer based on UNH design.
- $P_{\text{Xe}} = 25\%$ at 0.4 L/h Xe flow rate with laser power = 30 W, $T = 140 \, ^\circ\text{C}$.
- Can measure both $P_{\text{Xe}}$ and $P_{\text{Rb}}$. 
Diode-Laser Arrays offer increased power (tens to hundreds of watts) and can be spectrally narrowed.

Ruset, et al. [Phys. Rev. Lett. 96, 053002 (2006)] introduces:

- Long, narrow SEOP cell (≈ 2 m long by 4-5 cm diam)
- Low total gas pressure in addition to gas mixture lean in Xe.
- Xe polarization $P_{\text{Xe}} = 64\%$ at 0.3 L/h Xe flow rate with laser power = 90 W, $T = 160 \, ^\circ\text{C}$

- Our polarizer based on UNH design.
- $P_{\text{Xe}} = 25\%$ at 0.4 L/h Xe flow rate with laser power = 30 W, $T = 140 \, ^\circ\text{C}$.
- Can measure both $P_{\text{Xe}}$ and $P_{\text{Rb}}$. 
\[
\frac{\partial \psi(v, z)}{\partial z} = -[Rb] \sigma_s(v) \frac{\Gamma_{SD}(z)}{\gamma_{opt}(z) + \Gamma_{SD}(z)} \psi(v, z)
\]

with

\[
\gamma_{opt}(z) = \int_0^\infty \psi(v, z) \sigma_s(v) dv
\]

\[
P_{Rb}(z) = \rho_{+1/2} - \rho_{-1/2} = \frac{\gamma_{opt}(z)}{\gamma_{opt}(z) + \Gamma_{SD}(z)}
\]

\[
\frac{\partial P_{Xe}(z)}{\partial z} = \frac{1}{v_l} \left[ \gamma_{se}(z)(P_{Rb}(z) - P_{Xe}(z)) - \Gamma_{Xe}(z) P_{Xe}(z) \right]
\]

- Model also adapted from UNH work.
- Model yields predictions for: \(\gamma_{opt}(z), P_{Rb}(z), P_{Xe}(z)\); axial distributions, avg’d over transverse slice.
- We measure \(P_{Xe}\) and \(P_{Rb}(z)\)
**Optically Detected Electron Paramagnetic Resonance (ODEPR)**

- Angular momentum of Rb atoms in spin-temperature distribution:
  \[ P_{\text{Rb}} \propto e^{-\beta m_F} \]

- Low-level RF creates steady-state precession of \(^{85}\text{Rb}\) atoms at low angle to \(B_0\).

- Absorption of probe-laser light (detuned from \(D_1\)) is modulated at \(^{85}\text{Rb}\) Larmor frequency (about 13 MHz at 27-28 G).

- Field-sweep generates hyperfine spectrum.

\( F = 3 \rightarrow -2 \)

\( F = 3 \)

\( m_F = -2 \rightarrow -1 \)

\( F = 2 \)

\( m_F = -2 \rightarrow -1 \)

\( 85\text{Rb spectrum at low Rb polarization.} \)

\( 85\text{Rb spectrum at high Rb polarization.} \)

\[
P_{\text{Rb}} = \frac{7r_{1/2,3} - 3}{7r_{1/2,3} + 3}
\]

\[
P_{\text{Rb}} = \frac{5r_{1/3} - 3}{5r_{1/3} + 3}
\]

\[
r_{1/2,3} = \frac{A_1}{A_2 + A_3}
\]

\[
r_{1/3} = \frac{A_1}{A_3}
\]
Nominal Optimal Operating Parameters

(unless varied):

- Temperature: 140 °C.
- He:N₂:Xe 1000:500:10 sccm flow rates.
- Total gas pressure: 840 mbar at room temperature.
$P_{\text{Rb}} = 85\text{-}90\%$ throughout optical pumping region at $T = 140 \text{ °C}$.

- Drop off is slower than predicted for higher temperatures. (Maybe actual [Rb] is smaller than vapor pressure curves predict.)

- In general $P_{\text{Xe}}$ is not limited by low $P_{\text{Rb}}$ for our optimal operating parameters.

- Anomalous region of depressed $P_{\text{Rb}}$ at 25 cm.
- Temp-dependence model gets trend right, but overestimates $P_{\text{Xe}}$ unless spin-exchange rate is reduced by 40%.
- Total flow dependence is modeled well only if we assume short $^{129}\text{Xe}$ wall-relaxation time (tens of seconds).
- Dependence on Xe partial pressure stronger than expected.
- Total pressure dependence is weak, as expected.
We have built and done initial tests on a flow-through Xe polarizer based on the UNH design.

- $P_{Xe} = 25\%$ at 0.4 L/h Xe flow rate with laser power = 30 W, $T = 140 \, ^\circ C$.

- We have modeled and measured: output $P_{Xe}$ AND $P_{Rb}$, the latter as a function of axial position in the cell.

- Modeling includes temp. dependence of spin-exchange rate, does a reasonable job of reproducing general shapes and trends.

- $P_{Xe}$ not apparently limited by $P_{Rb}$.
  - Yet $P_{Xe}$ not as large as predicted by model.
  - Anomalous regions where $P_{Rb}$ is depressed.
Hyperpolarized Gas Research Group

Faculty
Brian Saam
David Ailion
Gernot Laicher

Graduate Students
Geoff Schrank (graduating Summer 2009)
Eric Sorte
Zayd Ma

Undergraduates
Allison Schoeck
Laurel Hales
Oliver Jeong (HS student)
Rb Polarization: Total Pressure Dependence

- Pressure dependence is relatively slight (note scale change for $P_{\text{Rb}}$).
- Area of depressed $P_{\text{Rb}}$ more apparent.
- Lower total pressures have slightly lower $P_{\text{Rb}}$ (likely reflects lower laser absorption).
Results with Higher Laser Power

- Red curves show results with 100-Watt diode-laser array.