Spin Noise Spectroscopy of Rubidium

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Presentation Outline

- Review of Pertinent Quantum Mechanics
- Hyperfine Structure of Rubidium 85
- Faraday Rotation
- Spin Noise
- Future Goals
Transition rate is a ballpark for the rubidium levels reached by the 780nm laser
\( G_j \) is the lande G factor, \( \mu_B \) is the bohr magneton, \( m_j \) is the \( z \)-component of the total angular momentum, and \( B \) is the applied magnetic field. The magnetic field associated with the fine structure correction is \(~3000 \) Gauss.
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Fine structure results from spin-orbit coupling of the electron, while hyperfine structure results from spin of the nucleus interacting with the spin of the electron.
Hyperfine Structure of Rubidium 85
Hyperfine Structure of Rubidium 85

Probe Beam

![Graphical representation of hyperfine structure of Rubidium 85]
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Positive faraday constant means counter clockwise rotation when then direction of the magnetic field and laser are parallel, and clockwise when they are anti parallel.

- The faraday effect rotates the polarization of light by an angle $\beta$
- In matter, $\beta = vBd$ ($v$ is the verdet constant, units of rad/(mT))
- In rubidium vapor, $\beta$ depends on a difference between the index of refraction for right and left circularly polarized light
- Faraday rotation is the physics principal behind optical isolators

Illustration of the faraday effect
Positive Faraday constant means counter clockwise rotation when then direction of the magnetic field and laser are parallel, and clockwise when they are anti parallel.

In the linearly polarized light equation, the k’s are different because \( \lambda \) is frequency dependent.
\( n_e \) is the number density of atoms  
\( \sigma_0 \) is the integrated cross section of interaction  
\( \gamma_0/2\pi \) is the natural line width of the transition  
\( \nu_0 \) is the resonant frequency

- **Faraday Rotation**

  - The index of refraction depends on the frequency of light
    \[ n(v)=n_0+\frac{n_e\sigma_0}{(\gamma_0/2\pi)^2} \frac{(\nu_0-v)^2+(\gamma_0/2\pi)^2}{((\nu_0-v)^2+(\gamma_0/2\pi)^2)^2} \]

  - The Zeeman Effect
    - A weak magnetic field associates each \( m_i \) sublevels with a different energy
    - Right and left circularly polarized light cause different transitions within these sublevels
    - Right/left circular have different resonant energies, and therefore different indices of refraction

\( n_0 \) is the integrated cross section of interaction  
\( \gamma_0 \) is the natural line width of the transition  
\( \nu_0 \) is the resonant frequency
Faraday Rotation

Faraday Rotation Experimental Schematic
Faraday Rotation
Two distributions, but one with a small displacement

Subtraction yields
The peaks are both from Rb 85, f=2,3 to excited states
Larger Peak is Rb 85 while the smaller peak is Rb 87
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Spin Noise

Basic Experimental Schematic

Rb, K

Spectrum analyser

$\delta \theta_F(t)$
Spin Noise

Predicted Faraday Rotation

$$\langle \delta \theta_F^2 \rangle^{1/2} = \frac{e^2 f \beta}{4mc \Delta} \sqrt{\frac{N_0 L}{A}}$$

Example-Previously Published
Spin Noise

\[
\langle \delta \theta^2 \rangle^{1/2} = \frac{e^2 f \beta}{4mc\Delta} \sqrt{\frac{N_0 L}{A}}
\]

Variable Parameters:
- Homogeneity of the magnetic field
- \( \Delta \) (detuning from resonance)
- \( N_0 \) (density of atoms)
- \( L \) (interaction length)
- \( A \) (cross sectional area of laser beam)
Spin Noise

\[ \langle \delta \theta_F^2 \rangle^{1/2} = \frac{e^2 f \beta}{4mc\Delta} \sqrt{\frac{N_0 L}{A}} \]

- Magnetic field is 1.85 Gauss with no more than 10% variation over Rubidium cell
- Optimized the detuning of the laser based on previous results, \( \Delta \approx 20 \text{Ghz} \) from the \( D_2 \) transition
- 10 cm length of Rubidium cell is longer than previous experiments
- Heat tape increases density of rubidium to \( \sim 10^7 \text{ atoms/mm}^3 \)
- Circular aperture and lenses shrink beam area \( \sim 0.12 \text{ mm}^2 \)
Spin Noise

- Spin noise should be occurring at the larmor frequency, $g\mu_B B/h$
- Larmor frequency for $^{85}$Rb~0.87 Mhz, $^{87}$Rb~1.32 Mhz
- Currently, we see no difference between on the spectrum analyzer when the magnetic field is on vs. magnetic field off
- The last portion of the R.E.U. was dedicated to maximizing the parameters that govern spin noise, and trouble shooting the amplification circuit

$H=$planks constant, $\mu_B=$planks constant, $B$ is magnetic field, $g_f=$ground state g-factor.
Spin Noise

The Amplification circuit

Current Stage
\( I = R_i(\alpha \cdot P_2 - P_1) \)

Transimpedance Stage
\( V_{out} = -IR_i \)

Gain Stage
\( V_{out} = IR_i(R/R_i) \)
Spin Noise

R₁ determines the bandwidth and risetime of the photodiodes. R₁=1kΩ~4Mhz.

The gain, R₂/R₁, determines the bandwidth of the gain stage. For OPA228, R₂/R₁=3 means bandwidth~2.6 Mhz.

Total transimpedance gain ~ 3V/mA.

Previous groups had transimpedance gains of ~40V/mA.
Spin Noise

One possible solution is to use multiple gain stages, each with a lower amplification. A circuit with 3 gain stages attained ~100V/mA.
Spin Noise

With the 3 gain stage circuit, we attempted to find spin noise one last time.

In the spectrum analyzer around 1MHz:
- Noise floor was ~500µV with fluctuations of 250µV.
- Two peaks of 3.1mV and 7.7mV with fluctuations of 1.5mV and 2.5mV.
- Spin noise will be in the nanovolt region.
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Future Goals

Two main areas for future work

1. Refining the controllable parameters for spin noise
   • Creating a more static magnetic field, or using a smaller rubidium cell
   • More elaborate set of optics to shrink the beam area even further
   • Cell oven to increase max temperature
2. Engineering a low noise, high bandwidth, high gain circuit
   • Current is on the scale of picoamps or lower, and is oscillating around 1mhz
   • Commercially balanced, low noise detectors are available, but are pricey
   • Examining each circuit element in the spectrum analyzer to see its noise contribution, and selecting lower noise alternatives if necessary
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Works Cited


