Constructing a Saturated Absorption Spectroscopy System for Laser Locking

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Motivation
Fine-Structure constant

• Fine-Structure constant
  • Fundamentally characterizes electromagnetic interactions of charged particles

• Advance interferometry measurements
  • Gravity gradients
  • Equivalence principle tests

• Test of Quantum Electrodynamics (QED) theory

• Best measurements
  • 0.25ppb Electron $g_e - 2$ [1]
  • 0.2ppb from cesium recoil [2]

• Our goals
  • 0.1ppb from recoil

Laser cooling

• Atomic beam
  • Oven with two holes

• Zeeman Slower
  • Doppler effect

• Magneto Optical Trap
  • In an ultrahigh vacuum

• Optical Dipole trap
  • Evaporative cooling
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Our way of measuring it

• Recoil frequency method - Rate of phase evolution
• Bose Einstein Condensate (BEC) for low velocity distribution
  • Coherence
• Contrast Interferometer (CI)
• Bragg pulses for acceleration
  • Standing waves
  • Make diffraction grating

\[ \alpha^2 = \frac{4 \pi R_{\infty}}{c} \frac{m}{m_e} \frac{\hbar}{m} \]
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Contrast Interferometer
Measuring the recoil frequency from phase

- Acceleration increases precision
- Recoil Frequency
  - What is this

\[ \Phi(2T) = \frac{1}{2} n^2 \omega_{\text{recoil}} T + \phi_{\text{offset}} \]

\[ \frac{\delta \omega_{\text{recoil}}}{\omega_{\text{recoil}}} = \frac{\delta \phi}{\frac{1}{2} n^2 \omega_{\text{recoil}} T \sqrt{M}} \]

- \( \Delta P = n\hbar k \)

\( T \) (ms) | Total Phase (rad)
---|---
0.990 | 28.0
0.995 | 31.0
1.000 | 34.0
1.005 | 37.0
1.010 | 40.0
1.015 | 43.0
1.020 | 46.0
1.025 | 49.0

Number of shots
Measuring the recoil frequency from phase

\( \omega_{\text{recoil}} = \frac{\hbar k_{\text{laser}}^2}{2m} \)

\( \alpha^2 = \frac{4\pi R_\infty}{c} \frac{m}{m_e} \frac{\hbar}{m} \)

\( \omega_{\text{recoil}} = \frac{\hbar k_{\text{laser}}^2}{2m} \)

\( \alpha^2 = \frac{4\pi R_\infty}{c} \frac{m}{m_e} \frac{\hbar}{m} \)
What I did

• Laser frequency stabilization

• Laser for cooling and diffraction beams

• Doppler effect

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What I did

- Laser frequency stabilization
  - Laser for cooling and diffraction beams
  - Doppler effect

\[ \omega_{\text{recoil}} = \frac{\hbar k_{\text{laser}}}{2m} \]

Need on the order of a MHz
Saturated absorption spectroscopy

- Fixing Doppler broadening
- Probe beam is the one detected
Saturated absorption spectroscopy

- Fixing Doppler broadening

- Probe beam is the one detected

Saturated absorption spectroscopy

- Acousto Optical Modulator (AOM)
  - Shift frequency
  - Modulates frequency
  - RF to sound waves
- Mix modulation signal with transmission
- Error signal
  - Lock to negative slope at 0
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Problems

• 60Hz noise
  • Heater tape
  • Correct grounding
It Works!

About 6.3MHz with 10:1 signal to noise
What is next

• Use this instead of the old beat node system to continue main experiment

• Mount spectroscopy in 3x1 foot breadboard
Thanks

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Other contributions

• Polarization optimization