Optical Pumping of Rubidium Vapor

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Outline

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2. Landé g factor
3. Optical Pumping Setup
4. Procedure: RF sweep and varying of $\vec{B}$
5. Results for value of Earth's magnetic field, Landé g-factors
6. Conclusions

Introduction

- Exploration of radio-frequency region of atomic spectra useful for studying details of atomic structure.
- Kastler devised a new method of radio-wave spectroscopy.
- Optical pumping: technique of using visible light to raise individual atoms from lower to higher states of internal energy.
- Practical applications: the maser, the laser, magnetometers.

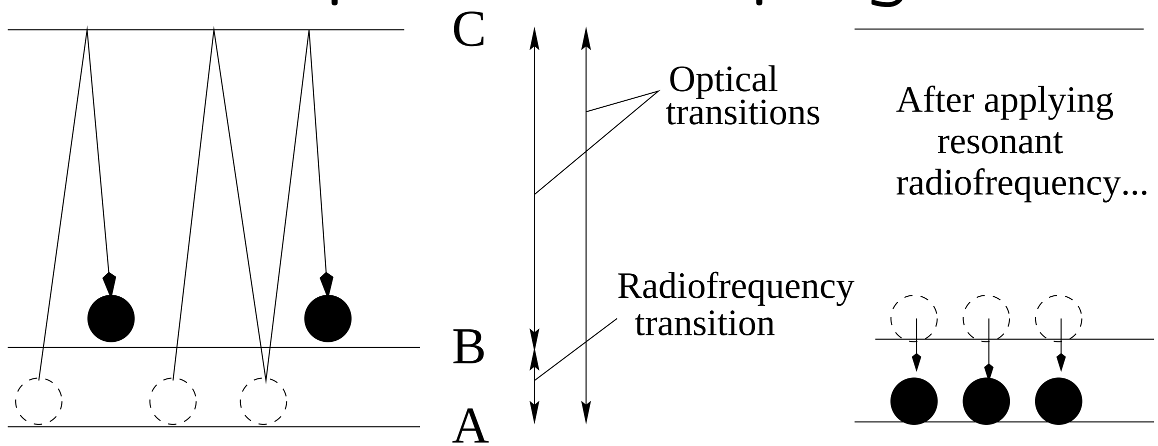
Motivation

- Observe resonant radiofrequencies in Rb-87 and Rb-85.

- Measure ambient magnetic field of Earth.

- Determine ratio and values of Lande g-factors for two isotopes of Rb.

Optical Pumping



- Rb pumping: due to circularly polarized light, every transmitted photon has an energy of $\pm\hbar$, transitions in the Rb atoms have $\Delta m_f = 1$.

- Spontaneous transitions can occur with $\Delta m_f = \pm 1, 0$.

- Atoms landing in $m_f = +1$ states remain there.

The Landé g-factor

- Geometric factor from magnetic interaction: $\vec{\mu} = g_f \frac{e}{2m} \vec{F}$.
- Landé g-factor g_J for fine structure interaction comes from spin-orbit coupling: $E_{fs} = \frac{e}{2m} \vec{B} < \vec{L} + 2\vec{S} >$.
- At small $\vec{B}$, fine structure dominates, use $|n, l, j, m_j >$ basis.
  - $\vec{L}$ and $\vec{S}$ precess rapidly about $\vec{J}$; project $\vec{S}$ on $\vec{J}$.
  - Obtain $< \vec{L} + 2\vec{S} >= g_J \vec{J}$.
- To obtain g_f, take into account magnetic moment of nucleus: $E_{hf} = \frac{e}{2m} \vec{B} < g_J \vec{J} + g_I \vec{I} >= g_f m_f \mu_B B$.

Theoretical Values of Landé g factors

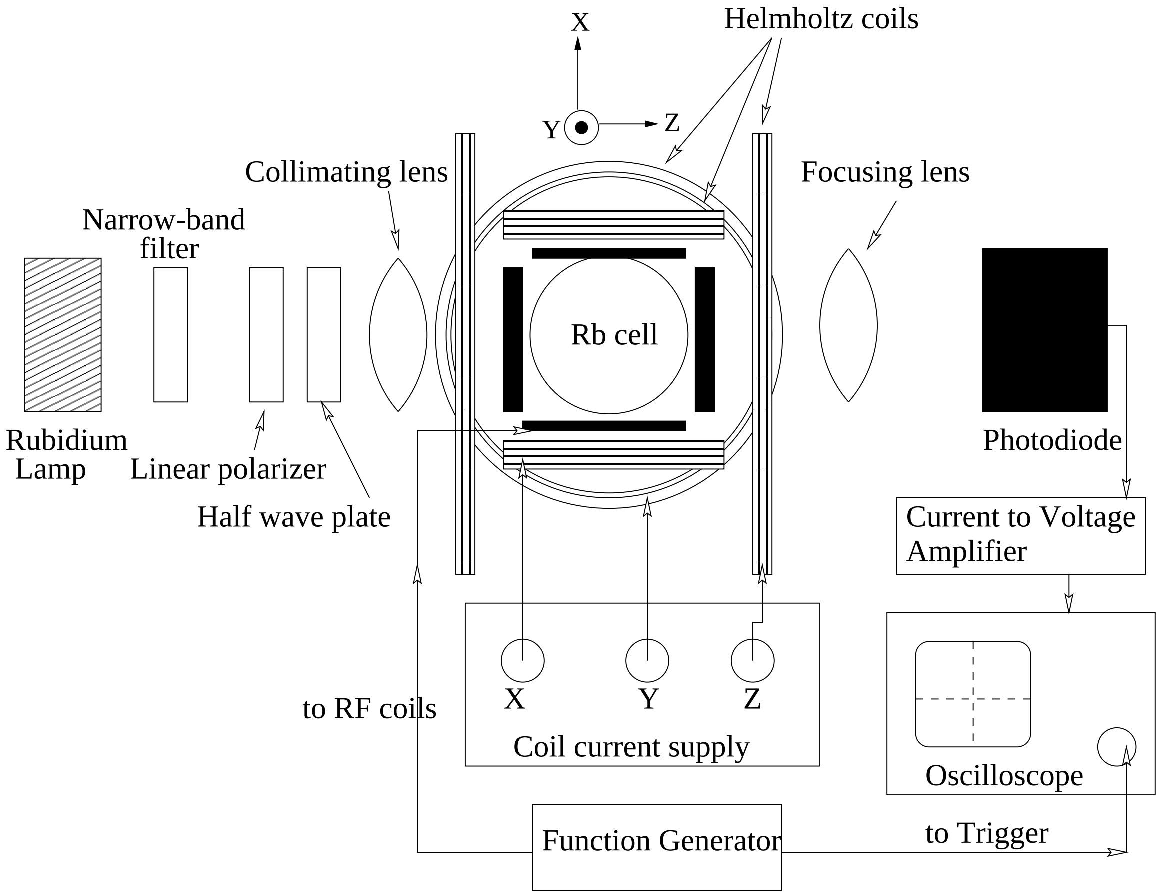
$$g_J = 1 + \frac{j(j+1)+s(s+1)-l(l+1)}{2j(j+1)}$$

$$g_f = g_J[\frac{f(f+1)+j(j+1)-i(i+1)}{2f(f+1)}]$$

$$g_J(Rb^{85}) = 2, \qquad g_J(Rb^{87}) = 2$$

$$g_f(Rb^{85}) = -\frac{1}{2}, \qquad g_f(Rb^{87}) = -\frac{1}{3}$$

Optical Pumping Setup



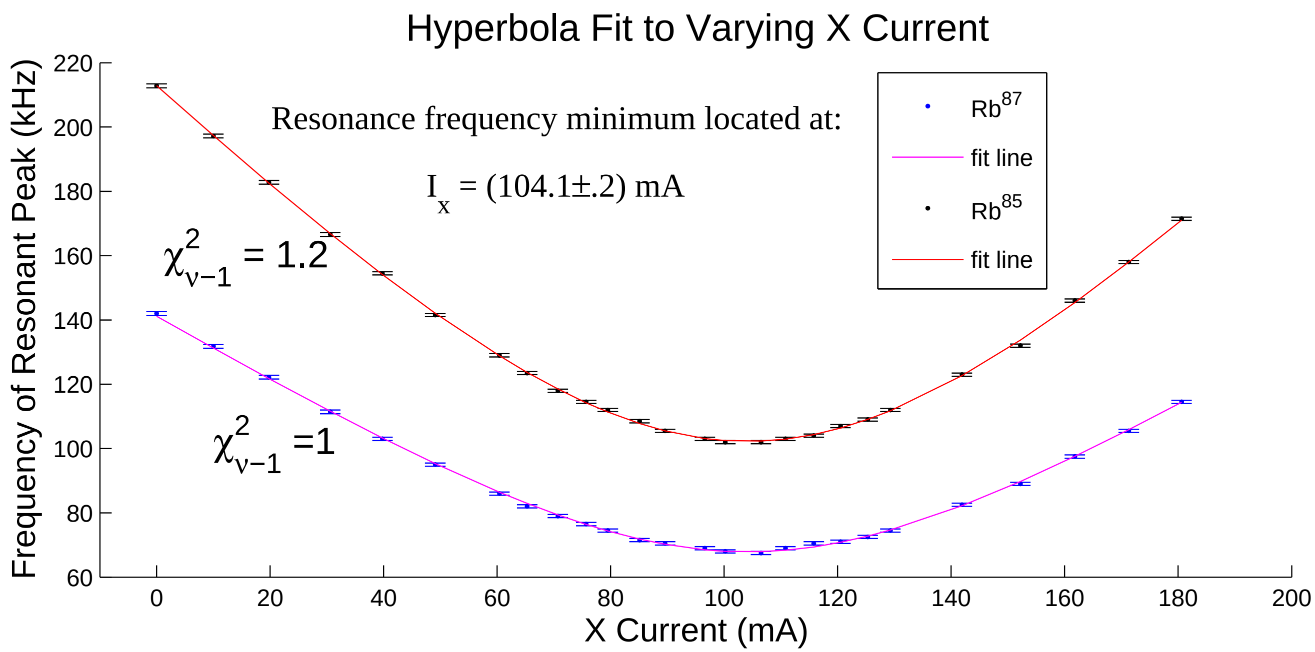
Relation between $\vec{B}$ and f

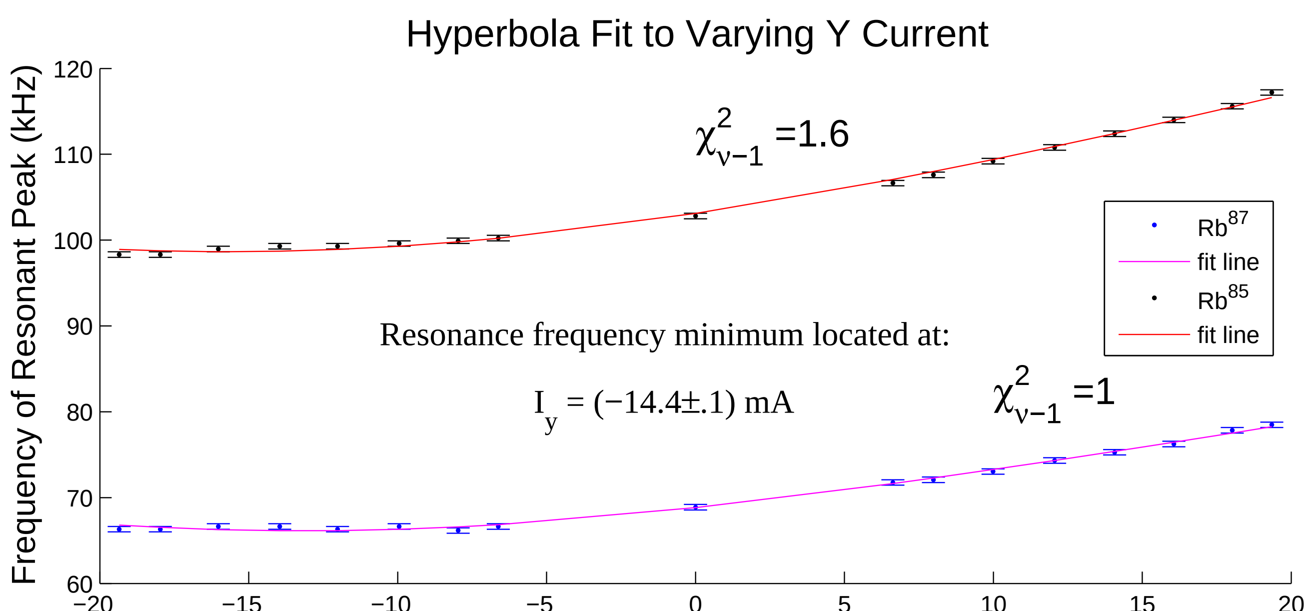
- $f = \frac{g_F \mu_B \vec{B}}{h}$ $\qquad |\vec{B}| = \sqrt{B_x^2 + B_y^2 + B_z^2}$

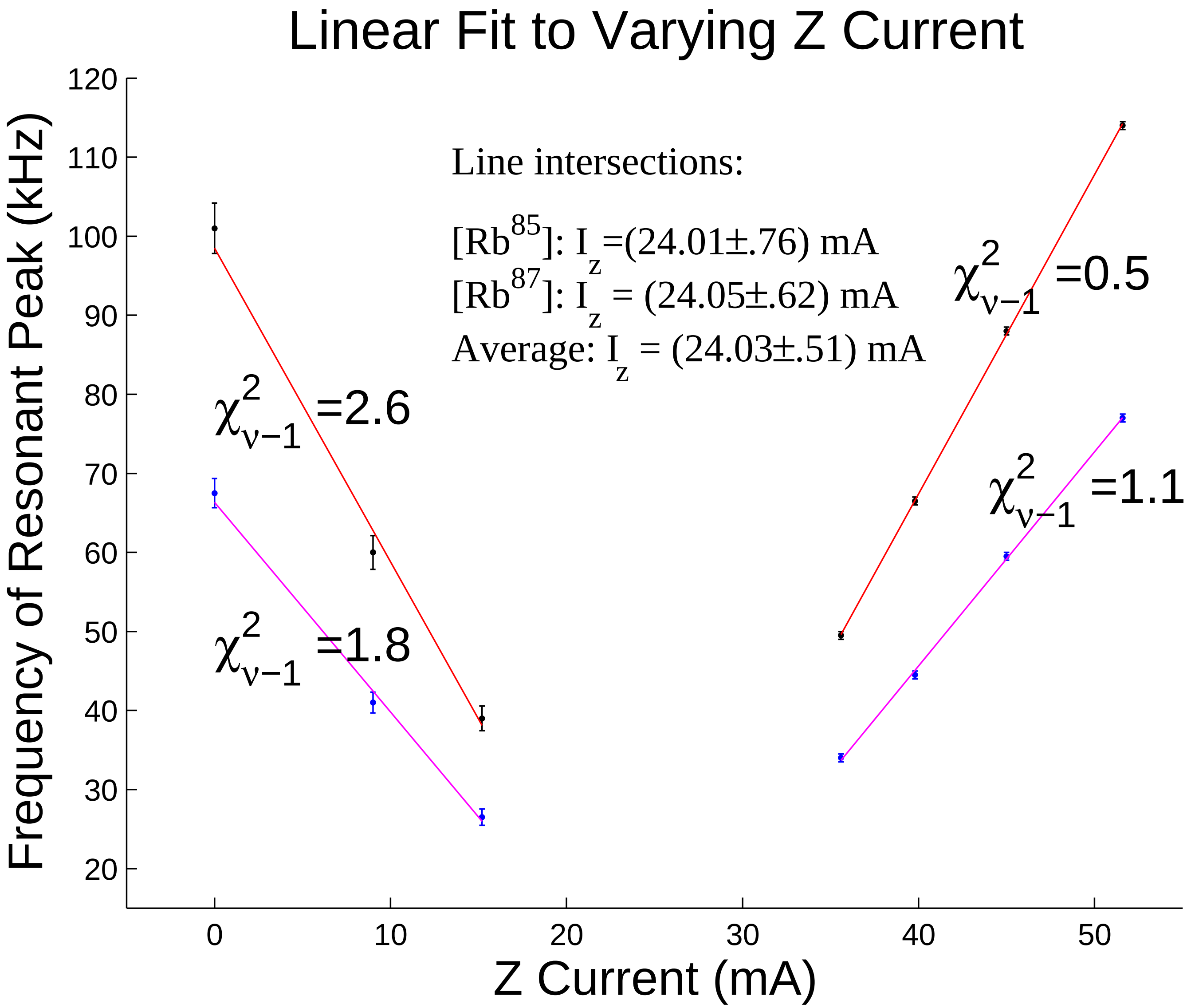
- Varied $\vec{B}_{HC} = \frac{8\mu_0 N \vec{I}}{\sqrt{125}R}$

- $f = \frac{g_F \mu_B}{h} \frac{8\mu_0}{\sqrt{125}} \sqrt{B_x^2 + B_y^2 + B_z^2}$

- Fit line used for I_x and I_y: $y = \frac{b}{a}\sqrt{c^2 + x^2} + d$


Hyperbola Fit to Varying X Current
Resonance frequency minimum located at:
I_x = (104.1±.2) mA
χ²_ν−1 = 1.2
χ²_ν−1 =1
Rb87
fit line
Rb85
fit line
Frequency of Resonant Peak (kHz)
X Current (mA)


Hyperbola Fit to Varying Y Current
χ²_ν−1 =1.6
Resonance frequency minimum located at:
I_y = (−14.4±.1) mA
χ²_ν−1 =1
Rb87
fit line
Rb85
fit line
Frequency of Resonant Peak (kHz)



Linear Fit to Varying Z Current
Line intersections:
[Rb85]: Iz =(24.01±.76) mA
[Rb87]: Iz = (24.05±.62) mA
Average: Iz = (24.03±.51) mA
χ2ν−1 =2.6
χ2ν−1 =1.8
χ2ν−1 =0.5
χ2ν−1 =1.1
Frequency of Resonant Peak (kHz)
Z Current (mA)
120
110
100
90
80
70
60
50
40
30
20
0
10
20
30
40
50

Data Analysis

- For x- and y- directions, obtained value for current that resulted in a minimum resonant frequency.
- For z-direction, obtained intercept of two lines.
- Used equation for $\vec{B}$ created by Helmholtz coils to calculate value necessary to cancel out Earth's $\vec{B}$:

$$\vec{B}_{HC} = \frac{8\mu_0 N\vec{I}}{\sqrt{125}R} \tag{1}$$

Error Analysis

- $I_z = \frac{a_{r1} - a_{l1}}{a_{l2} - a_{r2}}$

- Error in I_z: $\sigma = \sqrt{I_z [\frac{\sigma_{r1}^2 + \sigma_{l1}^2}{(a_{r1} - a_{l1})^2} + \frac{\sigma_{l2}^2 + \sigma_{r2}^2}{(a_{l2} - a_{r2})^2}]}$

- Error in B components: $\sigma_B = \sqrt{B^2 (\frac{\sigma_I^2}{I^2} + \frac{\sigma^2}{R^2})}$

- Random Error: fluctuations in values on oscilloscope, errors in fit parameters.

- Additional unaccounted systematic error?

Results

- Calculated ratio between the g_fs of Rb^{87} and Rb^{85}, using location of two resonant peaks: 1.49 ± 0.01.

- Calculated $g_f = \frac{hf}{B_z \mu_B}$ for both Rb isotopes, compared to theoretical calculation.
  - Expt.: $g_f(Rb^{85}) = .319 \pm .001$, $g_f(Rb^{87}) = .520 \pm .001$
  - Theory: $g_f(Rb^{85}) = \frac{1}{3}$, $g_f(Rb^{87}) = \frac{1}{2}$

- Calculated $|\vec{B}|$ of the Earth: (294.1$\pm$21.1) mgauss, measured to be $\approx$ 300 mgauss, actual value $\approx$ 600 mgauss.

Conclusions

- Observed good agreement between experiment and theory in ratio and values of g_f for Rb^{87} and Rb^{85}; $.520 \pm .001$ and $.319 \pm .001$ respectively, compared to $\frac{1}{2}$ and $\frac{1}{3}$.

- Correct order of magnitude for $|\vec{B}|$ of Earth.

- Improvement: to measure Earth's field more accurately, need less interference.